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Does Industry-University-Research Cooperation Matter? An Analysis of Its Coupling Effect on Regional Innovation and Economic Development

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Abstract: The dislocation between regional innovation and economic development directly influences the economic effect of regional innovation. However, no in-depth researches have been made on how to solve this problem. Using data from Henan Province, China, employing geographical detector technology, this paper focuses on testing whether the industry-university-research cooperation can contribute to coordinating the relation between regional innovation and economic development. It is shown that: 1) the industry-university-research cooperation in Henan Province is increasing gradually, and the network presents a core-edge structure, and the coupling degree between regional innovation and economic development is spatially unbalanced, which is similar to the spatial distribution of the intensity of industry-university-research cooperation; 2) as an important approach to effectively connect scientific researches with market demands, the industry-university-research cooperation can help form an interactive, interconnected, coupled and coordinated virtuous relation between regional innovation and economic development. Compared with the cooperation between organizations of the same type and the separate innovation of organizations, the improvement of the industry-university-research cooperation level can better coordinate the relation between regional innovation and economic development; 3) the cooperative innovation model between enterprises and universities can better promote the coupling between regional innovation and economic development, compared with many industry-university-research cooperation models. For underdeveloped areas lacking local knowledge base, industry-university-research cooperation should be considered as a long-term development strategy, especially using the knowledge sources of external universities and scientific research institutions to enhance innovation capability and achieve economic growth.

Keywords: industry-university-research cooperation; regional innovation capability; economic development level; coupling relation; model difference; Henan Province, China

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1 Introduction

The relation between regional innovation and economic development has always been a topic to which the academic circles pay much attention (Solow, 1956; Romer, 1986; 1990; Aghion and Howitt, 1997; Antonelli, 2015; Fan et al., 2020). Many scholars believe that innovation can promote economic development (Crepon et al., 1998; Bettencourt et al., 2007; Kumbhakar et al., 2012; Petrariu et al., 2013; Dai and Cheng, 2018; Aldieri et al., 2021). In theory, regional innovation and economic development will form a coupling relation with mutual promotion and harmonious coexistence (Porter, 1990; Taalbi, 2017; Li and Cui, 2018). However, in practice, not all regional innovation and breakthroughs can bring sufficient economic benefits and not all regional economic development can promote innovation. That is, there is a dislocation between regional innovation and economic development, which directly affects the economic effect of regional innovation. For example, though China has made tremendous economic achievements in the over 40 yr after 1978 and the annual average GDP growth rate from 1979 to 2018 is as high as 9.4%, much higher than the global annual average GDP growth rate of 2.9% (Li et al., 2015), China's innovative achievement transformation rate and China's scientific and technological progress contribution rate are still low (Li and Cui, 2018). There are serious dislocation phenomena between innovation and economy, such as the development speed is not synchronized, the development fields are not matched, and the development links are not coupled. Why is there a dislocation between innovation and economy? How to promote the high coupling relationship between regional innovation and economic development?

Studies have shown that under the situation that the knowledge production mode has changed from mode 1 (knowledge production in a single discipline background) to mode 2 (knowledge production in the interdisciplinary or cross-organization background), the cross-organizational-boundary communication and cooperation are the key to constantly enhancing the national innovation capability and realizing economic growth and social values (Yoon and Park, 2017). Some empirical researches have provided strong evidence to show that the industry-university-research cooperation can enhance the economic efficiency of innovation (Fritsch and Schwirten, 1999; Veugelers and Cassiman, 2005; D'Este and Patel, 2007; Ryan et al., 2018; Suh et al., 2019). Producing new technology is important, but commercializing it is even more important (Furman et al., 2002). If any invention or creation fails to be commercialized, no economic returns can be gained from innovative achievements (Tijssen and Wijk, 1999). So, as an important bridge connecting technology and market (Calcagnini et al., 2016), is the close industry-university-research cooperation the main reason for solving the dislocation between innovation and economic development? Which model of industry-university-research cooperation is more efficient? Solving these problems will have great significance for enhancing the economic efficiency of regional innovation and strengthening the innovative promotion of economic growth.

The research on the dislocation between regional innovation and economic development is more qualitative, but few studies are quantitative. The existing research on cooperation in industry-university-research also pays more attention to its forms, motives, operation modes, facilitating factors, adverse factors and results (Ankrah and Al-Tabbaa, 2015; Mascarenhas et al., 2018; Rybnicek and Königsgruber, 2019). Although the research not only agrees that industry-university-research cooperation can promote regional innovation (D'Este and Patel, 2007), but also agrees that it can promote economic performance (Power and Malmberg, 2008), it has not paid enough attention to the important effect of the industry-university-research on solving the dislocation problem between regional innovation and economic development. Therefore, the scientific question of this paper is whether industry-university-research cooperation plays an important role in the coupling of regional innovation and economic development (hereinafter referred to as the innovation-economy coupling). The paper will also explore the effective mode of the industry-university-research cooperation in both the theoretical analysis and the empirical test, aiming to find an effective way to solve the 'two skin' problem of technology and economy through the industry-university-research cooperation and provide some references for regional development policy making.

2 Theory and Hypothesis

Theoretically, enterprises, universities and research in-

stitutions are the three major basic entities involved in the innovation process. According to the different types and quantities of the entities participating in innovation, different innovation-economic organization models are formed. For example, separate innovation of organizations, collaborative innovation between organizations of the same type and industry-university-research collaborative innovation (i.e., cooperative innovation between entities of different types). In the separate innovation of organizations, these entities with heterogeneous resources are relatively independent, and external resources are difficult to integrate effectively (Wirsich et al., 2016). With the increasing complexity of technology, it has become impossible to undertake all innovation tasks by relying on the strength of only one organization, especially for knowledge-intensive and technology-intensive industries such as biological industry, new energy and information technology (Phene et al., 2006; Soh and Subramanian, 2014). In this way, it is easy to cause the industrial community and the academic community to behave separately and lead to a development dislocation situation, and it is very difficult to achieve coupling and interaction between regional innovation and economic development through such an innovation process (Guan and Zhao, 2013). Collaborative innovation between organizations of the same type makes the functional mutual supplement degree between limited due to their similar nature and homogeneity of behavior. Therefore, the industrial activities and the academic activities are not synchronized. For example, the common cooperation forms of the same type include cooperation between enterprises, cooperation between universities and cooperation between research institutions. Among these forms, cooperation between enterprises includes channel cooperation and strategic cooperation besides technology cooperation. The cooperation of the enterprises is usually profit-oriented and they pursue value maximization (He, 2012). Therefore, the enterprises may achieve some innovative results, but may not achieve subversive scientific breakthroughs. And their cooperation mainly promotes economic development and it may not promote regional innovation. Cooperation between universities and cooperation between research institutions mainly promote advanced knowledge exchange and high-end talent cultivation. The two kinds of cooperation are usually academy-oriented and they pursue scientific research value maximization. Therefore, innovative results may not be recognized and accepted by the market and these two kinds of cooperation mainly promote regional innovation and they may not promote economic development (Casper, 2013).

According to resource-based view, the more complementary and diversified resources are, the more valuable they will become (Das and Teng, 2000). As an organizational relationship network in which different types of stakeholders participate in innovation economic behavior, industry-university-research cooperative innovation can effectively combine the two complementary resources of basic research in universities or scientific research institutions and applied research in enterprises (Cunningham and Link, 2015; Abbas et al., 2019), so as to realize benefit sharing and risk sharing (Bonaccorsi and Piccaluga, 1994; Szücs, 2018). In the industry-university-research cooperation, innovation and economic development are organized through the cooperative relation between public research institutions and enterprises, the academic community and the industrial community are no longer isolated and separated from each other, a distance is no longer kept between them and an open and interactive network relation between the academic community and the industrial community appears (Chai and Shih, 2016). Industry-university-research cooperation is conducive to the transformation of scientific achievements into actual productivity and can really promote economic construction so as to achieve the coordinated development of the scientific and technological system and the economic system. Therefore, as an important approach to connect basic research with market demand, the industry-university-research cooperation promotes deep integration of innovation and economy and helps form a coupled and coordinated virtuous cycle relation with mutual support between innovation and economy (Fig. 1). So we put forward hypothesis 1: different innovation economic organization models have different effects on the coupling relation between regional innovation and economic development, and the improvement of industry-university-research cooperation can better coordinate the relation between regional innovation and economic development.

Furthermore, different types of basic entities have different functional attributes because of their different research fields. According to the research attributes of the basic entities participating in the industry-university-research collaborative innovation, theoretically different

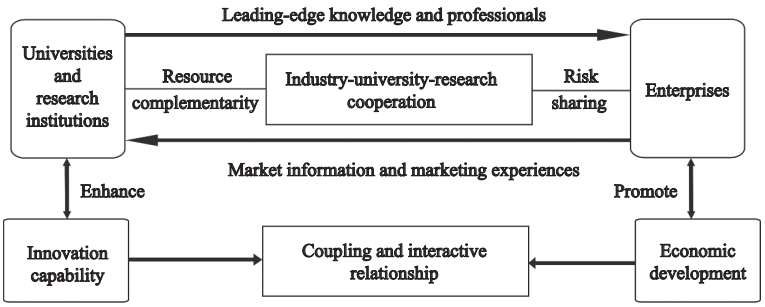

Fig. 1 Theoretical analysis framework of industry-university-research cooperation affecting coupling relationship between regional innovation and economic development

modes of industry-university-research cooperative innovation can be formed. The three main cooperative innovation models are the enterprise-university cooperation, the enterprise-research institution cooperation and the enterprise-university-research institution cooperation. Universities and research institutions have abundant scientific and technological knowledge and technological achievements, they are good at fundamental and strategic research of knowledge and technology and they pay much attention to knowledge supply, but little attention to knowledge and technology transfer and application. Enterprises have abundant market information and innovation requirements, they are good at commercialization and industrialization of knowledge and technology and they are poor in supplying leading edge property and creativity of knowledge and technology (Poyago-Theotoky et al., 2002; Fontana et al., 2006; Ivascu et al., 2016). These major players in the enterprise-university-research institution cooperation can mutually supplement each other in both the resources aspect and the expertise aspect. On the one hand, enterprises provide abundant market information and practice information for universities and research institutions, and the information can reduce the market entry risks of universities and research institutions and help realize quick commercialization and industrialization of their research achievements. On the other hand, universities and research institutions bring leading-edge knowledge and talents of the basic theories to enterprises, and the knowledge and talents can be used to reduce the basic innovation risks of enterprises and realize smooth breakthrough of the core technology (Mansfield, 1991; Etzkowitz et al., 2000; Camagni and Capello, 2013). Therefore, industry-university-research cooperation among enterprises, universities and research institutions facilitates the full utilization and commercialization of the knowledge created by universities and research institutions, thus enabling both scientific innovation and industrial development to be promoted (Perkmann et al., 2013). On these grounds, we put forward hypothesis 2: the mode of cooperative innovation among enterprises, universities and research institutions could better promote the coupling between regional innovation and economic development.

3 Data and Methods

3.1 Research regions and time periods

This study chooses Henan Province, China as the research area, mainly for the following reasons: 1) The dislocation between innovation capability and economic development in Henan Province is relatively more prominent. The comprehensive science and technology innovation level of Henan Province ranked 21st among the 31 provinces and autonomous regions in China (excluding Hong Kong, Macao and Taiwan of China) in 2017, but its GDP in the same year ranked 5th among the 31 provinces and autonomous regions in China (Chinese Academy of Science and Technology for Development, 2019). The regional innovation and economic development of Henan Province are not coordinated, so it is more typical to select Henan Province as the research area. 2) The characteristics of Henan Province in terms of population, economy and social structure are similar to the overall situation of China, so it is more representative to select Henan Province as the research area. 3) People usually believe that innovation is mainly in regions with relatively developed economies and they pay very much attention to the regions. They pay less attention to how to innovate in environments with relatively poor economy (Rodríguez-Pose and Wilkie, 2019). Then, how to better stimulate innovation in a less

developed region, and how to transform innovation into growth, is a more significant thing to do.

Henan Province is located in the central China, with a geographical range between 31°23′N–36°22′N and 110°21′E–116°39′E (Fig. 2). It has jurisdiction over 17 prefecture-level cities, 1 county-level city directly under the central government, 21 county-level cities, 83 counties and 53 municipal districts, with a total area of 167 000 km^2. At the end of 2017, the permanent resident population was 95.59 million and the regional GDP was 4455.283 billion yuan (RMB) (Statistics Bureau of Henan Province and Henan Survey Team of National Bureau of Statistics, 2018). The prefecture-level cities of Henan Province were taken as the basic spatial analysis units. Though Jiyuan City is a county-level administrative unit, it has been promoted and become a city directly under the provincial government. Therefore, it was included in the list of prefecture-level cities. Finally, the research regions included 18 cities and they were Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Shangqiu, Zhoukou, Zhumadian, Nanyang, Xinyang and Jiyuan. The whole research period for the industry-university-research cooperation characteristic analysis is from 1985 to 2017, mainly because the data collection of the National Patent Retrieval and Analysis System started in 1985, and the information disclosed by 2017 was relatively complete. The research period of coupling characteristics analysis is from 2010 to 2017. On the one hand, the number of industry-university-research cooperation patents in Henan Province before 2010 is relatively small; on the other hand, in order to avoid the impact of the international financial crisis in 2008, it starts from the time when economy basically recovered from the impact.

3.2 Data sources and processing

The industry-university-research cooperation is a selectively incomplete concept. Not all industry-university-research cooperation must include enterprises, universities and research institutes. If a cooperation is between an enterprise and a university or between an enterprise and a research institution, it can also be called industry-university-research cooperation (Chen, 2012). In the paper, the joint patent application data were taken as the samples to research the industry-university-research cooperation situation. It has been specified that a patent can be identified as a patent of the industry-university-research cooperation if the applicants of a patent include enterprises and universities or research institutions. All patent data from 1985 to 2017 used in this study were from the Patent Retrial and Analysis Service Platform of China National Intellectual Property Administration. Web crawlers were used to collect data. After the data were cleaned, processed and classified, the collected data showed that there were 233 255 patents solely applied for by enterprises, 64 531 patents solely applied for by universities, 10 843 patents solely applied for by research institutions, 3246 patents of the industry-university-research cooperation and 2410 pat-

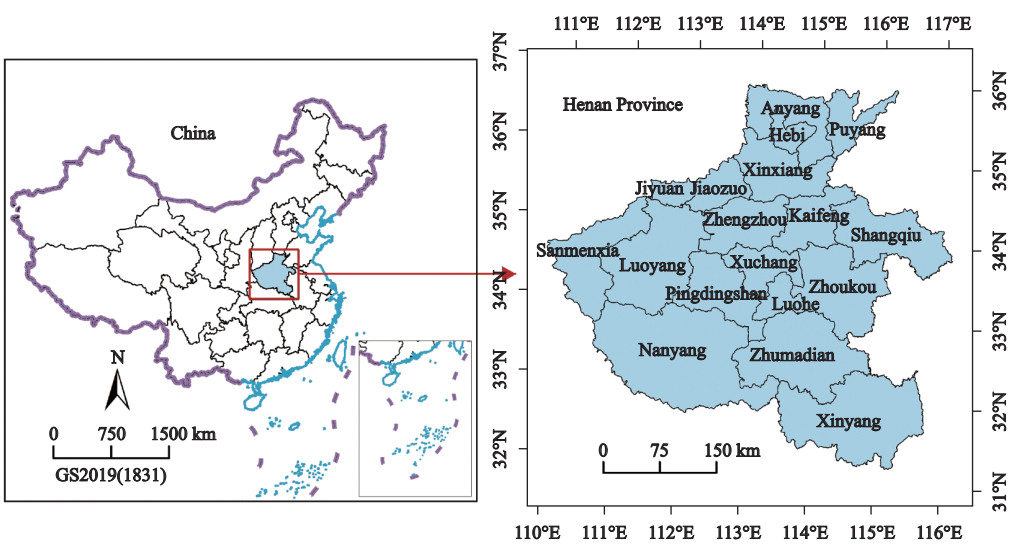

Fig. 2 Location of Henan Province in China

ents jointly applied for by organizations of the same type (mainly patents jointly applied for by enterprises, patents jointly applied for by universities and patents jointly applied for by research institutions). In addition, a comprehensive evaluation index system was established to measure the regional innovation capabilities and economic development levels of all the above-listed cities of Henan Province so as to measure and calculate the coupling degree between the regional innovation capability and the economic development level. All the index data needed in the research were from Henan Statistical Yearbook (Statistics Bureau of Henan Province and Henan survey team of National Bureau of Statistics, 2011–2018) and China City Statistical Yearbook (Department of Urban Surveys National Bureau of Statistics of China, 2011–2018).

3.3 Index system and methodology

3.3.1 Establishment of the evaluation index system

Considering the existing research achievements (Li and Cui, 2018) and according to the principles of scientific, representative, systematic and operable, 17 indexes were selected by considering the index selection in the three dimensions—innovation input, innovation output and innovation environment—so as to establish a comprehensive evaluation system of innovation capability. And 18 indexes were selected by considering the index selection in the four dimensions—economic scale, economic benefits, economic growth and economic structure—so as to establish a comprehensive evaluation system of economic development (Table 1).

3.3.2 Introduction to the main analysis methods

(1) Coupling degree analysis. Coupling refers to interaction between two or more systems. Its connotation originated in the physical concept 'capacitive coupling'. The coupling model derived from the initial concept can be used to measure interaction intensity between systems. Based on this, the model introduced in the paper is used to analyze the interaction relation between the two systems: the regional innovation capability and the economic development level. The specific formula is shown as follows:

$$C = \left[\frac{U_1 \times U_2}{\left(\frac{U_1 + U_2}{2} \right)^2} \right]^{\frac{1}{2}} \tag{1}$$

where C denotes the coupling degree, i.e., the coupling degree between regional innovation and economic development. Its value is between 0 and 1. According to the formula, the greater the coupling degree is, the higher the coupling level between the regional innovation and the economic development is, and otherwise the lower the coupling level is. U_1 and U_2 are respectively the comprehensive level of innovation capability and the comprehensive level of economic development.

(2) Geographical detection analysis. Geographic detector is a statistical method to detect spatial differentiation, it has no linear assumption, elegant form and clear physical meaning and can be used to detect the explanatory degree of influence factors on dependent vari-

Table 1 The comprehensive evaluation index system of innovation capability and economic development

Target layer	Criterion layer	Index layer
Innovation capability	Innovation input	Internal expense of R&D expenditure; Input intensity of R&D expenditure; Full-time equivalent of R&D personnel; Percentage of scientific and educational expenditure in total fiscal expenditure; University student enrollment per 10^4 people; Internal expenditure of R&D expenditure in enterprises above designated size; Number of persons for science and technology; Number of R&D institutions
	Innovation output	Number of patent applications per 10^4 people; Number of valid patents for invention per 1000 people; Number of scientific papers per 10^4 people; Output value of new products in enterprises above designated size; Sales revenue of new products in enterprises above designated size; Transaction volume of technology market
	Innovation environment	Popularization rate of internet; Popularization rate of mobile telephone; Number of public library books per 10^4 people
Economic development level	Economic scale	GDP Regional fiscal revenue; Total investment in fixed assets; Total retail sales of consumer goods; Total deposit balances of financial institutions; Total amount of post and telecommunication services
	Economic benefit	Per capita GDP; Regional per capita fiscal revenue; Per capita investment in social fixed assets; Per capita total retail sales of consumer goods; Per capita total deposit balance of financial institutions
	Economic growth	GDP growth rate; Secondary industry growth rate; Tertiary industry growth rate
	Economic structure	Percentage of secondary industry output value; Percentage of tertiary industry output value; Percentage of employed population of secondary and tertiary industries; Urban-rural resident income ratio

ables (Wang and Xu, 2017). The paper hereby used the method to detect the degree of the effect of different organization models on the innovation-economy coupling relation. The specific formula is shown as follows:

$$q = 1 - \frac{1}{n\sigma^2}\sum_{h=1}^{L} n_h \sigma_h^2 \tag{2}$$

where q is the explanatory power of an influence factor on the innovation-economy coupling degree, that is, the independent variable explains $100q\%$ of the dependent variable; n is the number of the samples in the whole region; σ^2 is the dispersion variance of the whole region; L is the number of the classifications of some influence factor; n_h and σ_h^2 are respectively the number of type h samples and dispersion variance. The value q is between 0 and 1. The greater the value of q is, the higher the degree of the effect of some factor on the innovation-economy coupling level is.

4 Results and Analyses

4.1 Network characteristics of urban industry-university-research cooperation

According to the city and contact information of the patent applicants, the industry-university-research cooperation network with the city as the node is drawn by using Origin software (Fig. 3). From 1985 to 1995, the network scale was small, and only 28 cities participated in industry-university-research cooperation. The network density was 0.1020, and the average network path length was 2.3688. With the passage of time, the number of participants in the industry-university-research cooperation network has gradually increased and their average partners also have gradually increased. From 2007 to 2017, the network scale developed rapidly, and more and more cities participated in the industry-university-research cooperation. The number of cities involved increased to 98, the network density was 0.0660, and the average path length of the network was 2.3785. Although the number of cities participating in industry-university-research collaboration is growing strongly, the overall level of linkages between cities is still not high. With the network scale increasing year by year, the network density decreases to a certain extent, and the average network path length increases to a certain extent. This indicates that the industry-university-research cooperation network in Henan Province is still at the primary level of development, which has not yet formed a long-term and stable cooperative connection.

By analyzing the characteristics of individual networks (using Pajek software to calculate node centrality, see Table S1 for the specific results), the cities in Henan Province have different positions in the industry-university-research cooperation network, and the cities with strong scientific and technological innovation and knowledge production have higher node centrality. Although the cities at the core are constantly changing with the evolution of the network, it is always the cities with strong comprehensive development strength that play an important role in the industry-university-research cooperation network. On the whole, there is a serious polarization in the value of centrality index. Most cities have fewer connections and weak transmission, and only a few cities have a high degree of contri-

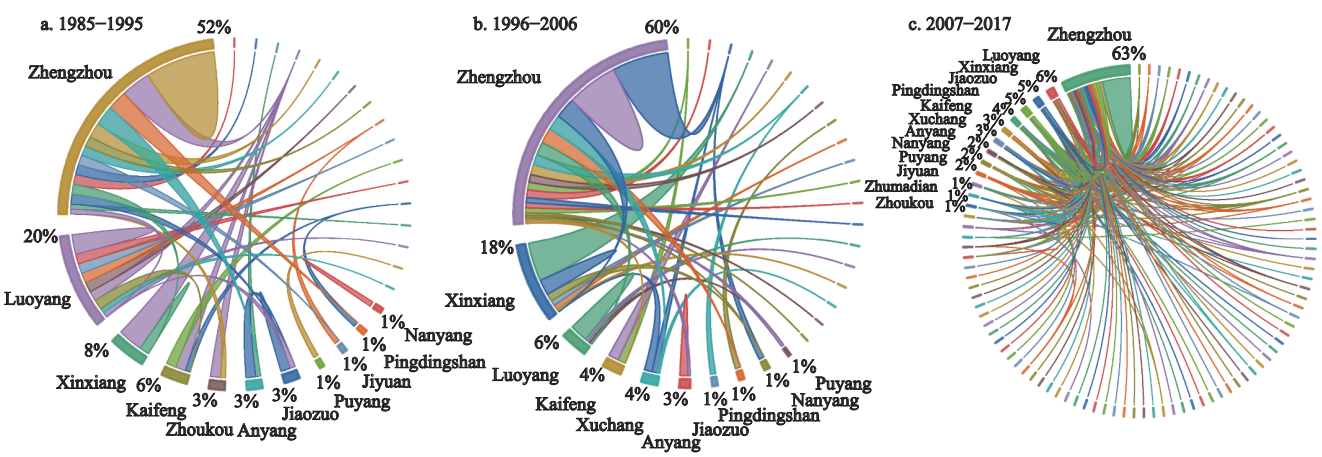

Fig. 3 Evolution of the industry-university-research cooperation network of Henan Province from 1985 to 2017. The percentage represents the contact strength, where the color block label only identifies the cities whose contact ratio is greater than or equal to 1%

bution and control in the industry-university-research cooperation network. The industry-university-research cooperation network presents the cored-edge structure.

4.2 Comparison and connection of spatial distribution

4.2.1 Spatial differential characteristics of the industry-university-research cooperation

In this paper, the cooperation of which all patent applicants belong to the same city is defined as the local cooperation and the cooperation of which patent applicants belong to different cities is defined as the cross-border cooperation. It can be found from our analyses on the local cooperation characteristics in the three periods (the period from 1985 to 1995, the period from 1996 to 2006 and the period from 2007 to 2017; the local connection intensity was classified into five grades by using the natural breaks classification method in Fig. 4) that the overall spatial differentiation and local agglomeration characteristics of the industry-university-research local cooperation intensity of Henan Province were distinct. The local knowledge production capabilities in northern, western and central regions of Henan Province were strong while the local knowledge production capabilities of the southern region and the eastern region were weak. It can be found from our analyses on the cross-border cooperation characteristics in the three periods the period from 1985 to 1995, the period from 1996 to 2006 and the period from 2007 to 2017 (the cross-border connection intensity was classified into five grades by using the natural breaks classification method in Fig. 5) that the spatial structure of the industry-university-research cross-border cooperation network of Henan Province was complex. With Henan Province as the core, the network extended and expanded to the northwest, southwest, northeast and southeast directions, and presented hierarchical characteristics. The main cross-border cooperation regions outside the province were Beijing, Wuhan, Xuzhou, Xi'an, Chongqing, Nanjing, Hefei and Shanghai. Beijing was the first choice of most cities of Henan Province for gaining knowledge from outside Henan Province. Beijing participated in nearly 20% of the trans-municipal and trans-provincial industry-university-research cooperation of Henan Province and this was undoubtedly related to numerous universities and research institutions with strong research and development strength of Beijing. Except Beijing, the other regions with close cooperation outside Henan Province were mostly provincial capital cities, which indicated that the geographical distance was no longer the most important influence factor when a region selected its industry-university-research trans-provincial cooperation objects and the cities with talent, cash and technology advantages were more liable to be selected.

4.2.2 Spatial differential characteristics of the innovation-economy coupling level

To directly reflect the innovation-economy coupling interaction situation, the coupling degrees of all the prefecture-level cities of Henan Province were classified into different grades. Considering that it was not an appropriate classification method to subjectively set critical values, an objective quintile classification method was selected and the coupling degree was classified in-

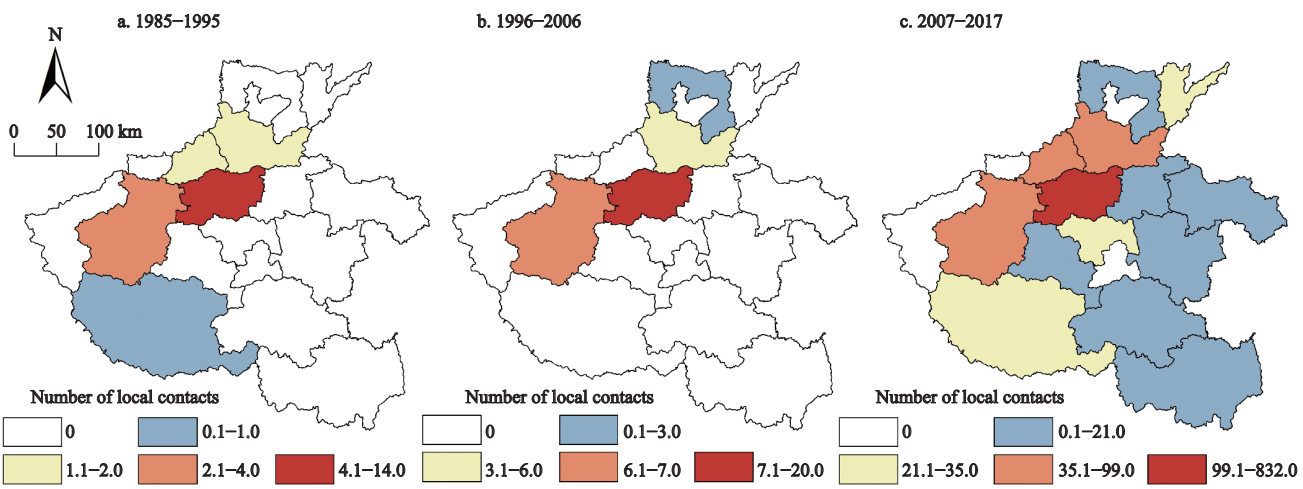

Fig. 4 The spatial pattern of the local cooperation network of industry-university-research in Henan Province from 1985 to 2017

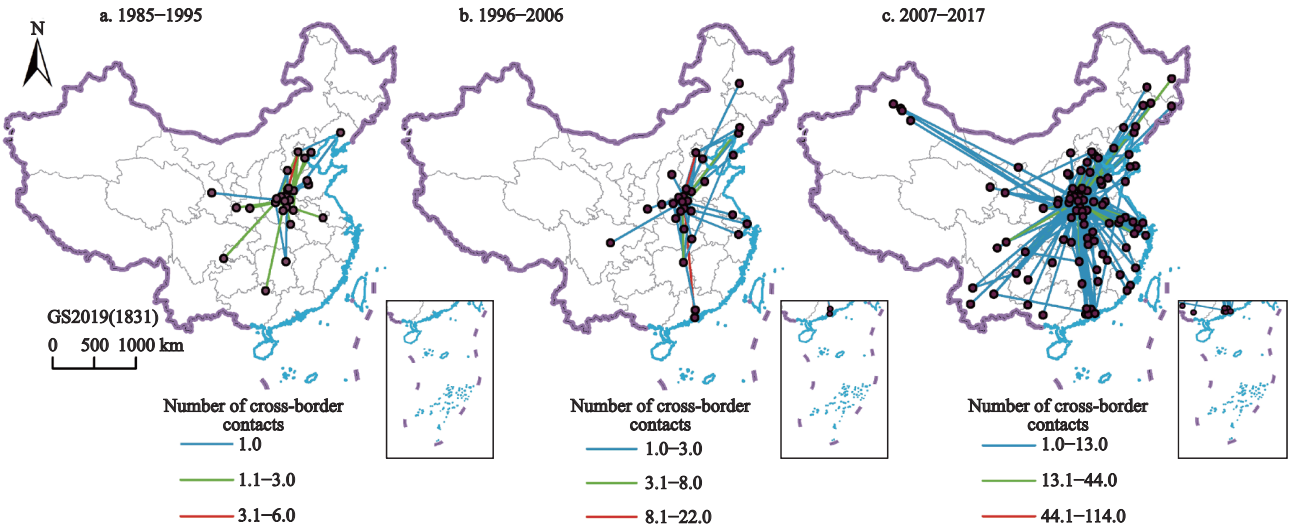

Fig. 5 The spatial pattern of the cross-border cooperation network of industry-university-research in Henan Province from 1985 to 2017

to five stages: the low level, the medium-low level, the medium level, the medium-high level and the high level (Jiang et al., 2017). ArcGIS Software was used to spatially visualize the innovation-economy coupling degrees of all the prefecture-level cities of Henan Province at the three time points: 2010, 2014 and 2017. The following information was obtained by analyzing the innovation-economy coupling degrees of all the prefecture-level cities (Fig. 6): 1) The coupling degree values of all the prefecture-level cities in the period from 2010 to 2017 were between 0.7346 and 1.0000, and the percentages of the low level coupling cities, the medium-low level coupling cities, the medium level coupling cities, the medium-high level coupling cities and the high level coupling cities in all the prefecture-level cities were respectively 11%, 11%, 17%, 33% and 28% in 2010. Among the percentages, the percentage of the medium-high level coupling cities was the highest. The percentages of the low level coupling cities, the medium-low level coupling cities, the medium level coupling cities, the medium-high level coupling cities and the high level coupling cities in all the prefecture-level cities were respectively 17%, 22%, 11%, 17% and 33% in 2017. Among the percentages, the percentage of the high level coupling cities was the highest. It could be found from the above information that the innovation-economy coupling degrees of all the prefecture-level cities of Henan Province were generally high, and as time went by, the absolute differences and relative differences would become greater. 2) Though the coupling degrees of all the prefecture-level cities were generally high, the spatial unbalance was very obvious. The medium-high level and high level coupling cities were mainly in the central, western and northern regions of Henan Province while the medium-low level and low level coupling cities were mainly in the eastern and southern regions of Henan Province. 3) As time went by, the spatial popularization trend of the coupling degrees became more obvious. The coupling degrees of most prefecture-level cities in the eastern and southern regions of Henan Province were at the low level, and the range of the medium-low level and low level coupling cities expanded to some extent, which further deepened the 'strong west and north and weak east and south' pattern.

4.2.3 Similarity of cooperation intensity and coupling level in spatial distribution

The spatial distribution of the industry-university-research cooperation intensity was very uneven. The high cooperation intensity areas of Henan Province were mainly in the northern region, the western region and the central region of Henan Province. Meanwhile, the spatial unbalance of the innovation-economy coupling level was very obvious. The high coupling areas of Henan Province were also in the northern region, the western region and the central region of Henan Province. The industry-university-research cooperation intensity and the innovation-economy coupling level were similar in the spatial distribution. The area with better industry-university-research cooperation was usually also the area with the high coupling relation between regional innovation and economic development. We can obtain at least one intuitive understanding from the simil-

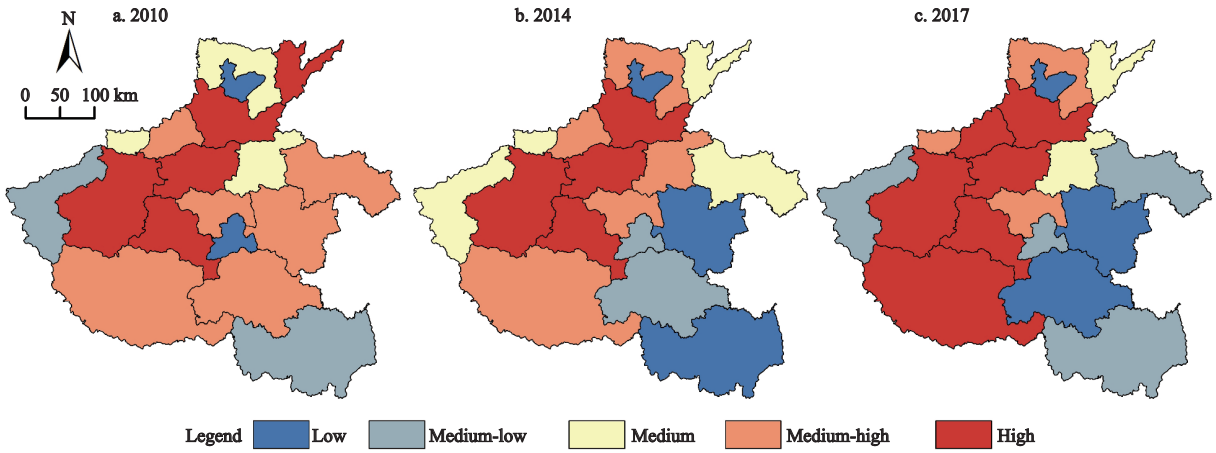

Fig. 6 Spatial disparity of coupling degree in prefecture-level cities of Henan Province in 2010, 2014 and 2017

arity of the cooperation intensity and the coupling level in spatial distribution—the industry-university-research cooperation facilitated the formation of the coupling interaction relation between regional innovation and economic development.

4.3 Exploration on factor influence difference

4.3.1 Difference between influences of different innovative economy organization models

The geographic detector model was used to detect the effects of the industry-university-research cooperation level, the cooperation level of organizations of the same type and the separate innovation level of organizations on the innovation-economy coupling degree. The industry-university-research cooperation level, the cooperation level of the organizations of the same type and the separate innovation level of organizations were respectively measured with the percentage of the industry-university-research cooperation patent applications in the total of the patent applications, the percentage of the cooperative patent applications of the organizations of the same type in the total of the patent applications and the percentage of the separate patent applications of organizations in the total of the patent applications in each prefecture-level city (Descriptive statistics of key variables are shown in Table 2). Because the independent variables must be type variables in the geographic detector, the paper transformed the driving factor indexes into sequence data by using the natural breaks classification method. The specific detection results are shown in Table 2. Viewing from the detection results, the explanatory power of the industry-university-research cooperation level (0.3755) on the innovation-economy coupling degree was the highest. In the industry-university-research cooperation model, the interpenetration of the borders of all the relevant entities could integrate superior resources and maximize the sharing and utilization of resources, and promote the transformation of scientific and technological achievements into real productive forces. Which not only promotes both regional innovation and economic development, but also effectively coordinates the relation between regional innovation and economic development. The influence of the separate innovation level of organizations (0.3555) was also high. It was mainly because the then separated innovation level of organizations of Henan Province was still in the high stage. In 2017, the number of separated patent applications was 73 759 in Henan Province and the percentage of separated patent applications in the total of the patent applications of Henan Province was 98%. The separate innovation of organizations also promoted the regional innovation and economic development to some extent. Therefore, the effect of the separate innovation of organizations on the innovation-economy coupling relation was also strong. However, the separate innovation of organizations cannot closely combine academia and industry, and its promotion effect on regional innovation and economic development is not synchronous with industry-university-research cooperation, so its influence on coupling degree of regional innovation and economic development is weaker than that of industry-university-research cooperation. The explanatory power of the cooperation level of organizations of the same type on the innovation-economy coupling degree was weak, compared with other explanatory power. The cooperation between similar institutions is

Table 2 Descriptive statistics and geodetector results of different innovative economy organization models of Henan Province in 2017

Variables	Descriptive statistics		Geodetector results
	Mean	SD	q
Industry-university-research cooperation level	0.0004	0.0007	0.3755
Cooperation level of organizations of the same type	0.0005	0.0010	0.2400
Separate innovation level of organizations	0.0494	0.0841	0.3555

the communication between homogeneous subjects, with limited complementary functions and unsynchronized industrial activities and academic activities, so it has little influence on the coupling of regional innovation and economic development. The detection results basically agreed with the theoretical expectation, which verified the above-mentioned research hypothesis. As a whole, the effects of different innovative economy organization models on the innovation-economy coupling relation were different and the industry-university-research cooperation model could better promote the coupling between innovation and economy.

4.3.2 Difference between influences of different industry-university-research cooperation models

It can be found from the above-mentioned results that the effect of the industry-university-research cooperation on coordination of the innovation-economy relation was relatively strong. Then, what industry-university-research cooperation model could better promote the coupling between regional innovation and economic development? The geographic detector was hereby used to further analyze the difference between the effects of different industry-university-research cooperation models on the innovation-economy coupling intensity. The participation intensity of the three main industry-university-research cooperative innovation models (that is, the enterprise-university cooperation, the enterprise-research institution cooperation and the enterprise-university-research institution cooperation) were used as the influence factors to carry out the geographic detection, and the percentage of the enterprise-university cooperation patent applications in the total of the patent applications, the percentage of the enterprise-research institution cooperation patent applications in the total of the patent applications and the percentage of the enterprise-university-research institution cooperation patent applications in the total of the patent applications were respectively used for the measurements (Descriptive statistics of key variables are shown in Table 3). According to the above-mentioned processing mode, similarly, the natural breaks classification method was used to transform the continuous variables into type variables, then the calculation was carried out according to Formula (2), and finally, the q values of the effects of the enterprise-university cooperation intensity, the enterprise-research institution cooperation intensity and the enterprise-university-research institution cooperation intensity on the innovation-economy coupling level were obtained (Table 3). The descending order of the effects on the innovation-economy coupling level is: the enterprise-university cooperation (0.3755), the enterprise-research institution cooperation (0.2190) and the enterprise-university-research institution cooperation (0.0199). The differences among all the factors were significant. Among them, the explanatory power of the enterprise-university cooperation intensity factor was the strongest, and the explanatory power of the enterprise-research institution cooperation intensity factor and the explanatory power of the industry-university-research institution cooperation intensity factor on the innovation-economy coupling level were obviously weaker. The results have shown that the enterprise-university cooperation as an industry-university-research cooperation model can better promote the coupling relation between regional innovation and economic development. This is possibly because the samples of cooperation among three types of organizations—enterprises, universities and scientific research institutions—are not as many as needed. In 2017, 527 industry-university-research cooperation patents were applied for in Henan Province. However, the patents jointly applied for by three types of organizations were only three patents. Generally, an enterprise only tries to cooperate with one organization, i.e., a university or a scientific research institution. In addition, high-level scientific research institutions are mainly distributed in developed areas such as Beijing and Shanghai and only a few scientific research institutions are distributed in Henan Province—an underdeveloped province. In Henan, most enterprises only try to cooperate with local universities

Table 3 Descriptive statistics and geodetector results of different industry-university-research cooperation forms in Henan Province

Variables	Descriptive statistics		Geodetector results
	Mean	SD	q
Enterprise-university cooperation intensity	0.0003	0.0007	0.3755
Enterprise-research institution cooperation intensity	0.0001	0.0001	0.2190
Enterprise-university-research institution cooperation intensity	0.0000	0.0000	0.0199

such as Henan University, Henan Agricultural University and Henan University of Science and Technology. At the same time, when enterprises choose cooperation partners, in addition to adopting cooperation modes such as joint development and technology transfer, they also prefer cooperation modes with high interaction degree such as talent cultivation. Compared with scientific research institutions, colleges and universities have more advantages in personnel training and multidisciplinary integration. Compared with the connection between enterprises and scientific research institutions, the connection between enterprises and universities has a deeper interactive cooperation mode, so it can more effectively acquire and make full use of each other's resources and capabilities, thus promoting both growth and innovation. Therefore, the empirical results of the paper have shown that the enterprise-university cooperative innovation model as an industry-university-research cooperation model can better promote the coupling relation between regional innovation and economic development.

5 Discussion

The research has more deeply explored the effect of the industry-university-research cooperation on the innovation-economy coupling and made some achievements. The results of the paper have shown that the industry-university-research cooperation is important and regional organizations—universities, public research organizations, relevant industries and their commercial services—are all the key factors that promote regional economic growth (Anselin et al., 2000). Policy makers should introduce a series of measures such as financial support, tax preference and other industry-university-research cooperation promotion policies to create effective institutional arrangements, build good interactive platforms and promote interaction among universities, industries and research institutions in the national innovation system (Zhang et al., 2019). Western developed countries generally pay high attention to the industry-university-research cooperation and have developed complete systems and mechanisms. China and the other developing countries should clearly regard the industry-university-research cooperation as a development strategy, constantly strengthen the technology transfer and personnel exchange between universities, research institutions and enterprises, and constantly promote the transformation of scientific research achievements into productivity. The research results of the paper have also shown that it is important to establish relations between enterprises and universities. Universities are important sources of new knowledge, especially in scientific and technological field (Agrawal, 2001). Therefore, policy makers should actively encourage universities to surpass the traditional teaching and research activities, undertake 'the third mission', i.e., produce, use, apply and develop knowledge, and strengthen knowledge transfer, commercialization and innovation with external stakeholders and the whole society, more directly interact with industries and make contributions to them (Giuliani and Arza, 2009; Secundo et al., 2017; Nsanzumuhire and Groot, 2020).

Another implication of this research is that it is more necessary for the areas without strong local knowledge support to promote the industry-university-research cooperation, especially to further strengthen the cooperation with scientific research institutions in other places, so as to promote regional wealth growth. Viewing from the long-term angle, the industry-university-research cooperation relation is in essence a knowledge spillover mechanism. The knowledge spillover of the industry-university-research cooperation can promote knowledge flow, enable new knowledge to be transformed into new products, new flows and new organizations, and realize commercialization (Mueller, 2006). As an important channel of knowledge spillover, industry-university-research cooperation can make the knowledge created by universities and scientific research institutions be fully utilized and completely commercialized,

further enabling areas with less intensive knowledge to successfully utilize the innovation and achieve higher economic performance. Therefore, strengthening the industry-university-research cooperation in underdeveloped areas can be regarded as an effective approach to compensate for the local insufficient knowledge. Besides, some researches have shown that geographic distance is not necessarily a limiting factor when an enterprise selects a university or a scientific research institution for innovative cooperation (Laursen et al., 2011). Areas with less strong internal knowledge creation ability can use the knowledge sources of universities and scientific research institutions in other areas to develop their innovation and achieve greater economic growth (Capello and Lenzi, 2014; Braunerhjelm and Henrekson, 2015). Of course, this is far from enough. Underdeveloped areas should gradually solve the rare local scientific research resource problem and the insufficient 'original innovation' ability problem. To do this, it is necessary for underdeveloped areas to attract various high-level scientific research institutions from developed areas and encourage them to establish their branches or R&D centers in underdeveloped areas so as to cultivate the innovation with self-development ability.

Though the paper has made some conclusions with reference significance to coordinate the interactive relation between regional innovation and economic development, there are some shortcomings in the research of the paper. First, restricted by difficulties to collect joint patent application data, the paper only selected Henan Province as the research unit. In the future, more samples need to be collected and some quantitative researches need to be carried out to verify the effect of the industry-university-research cooperation on the innovation-economy coupling relation. Second, the paper has not completely opened the black box that conceals the action mechanism of the industry-university-research cooperation on the innovation-economy coupling relation and the operation mode of the industry-university-research cooperation. In the future, some quantitative research that needs more profound theories needs to be carried out to explore how the industry-university-research cooperation influences the innovation-economy coupling relation. Third, the implementation situation of the industry-university-research cooperation is both complex and multidimensional and it is difficult to accurately measure it with the data of one patent. Because the effect of the industry-university-research cooperation on the innovation-economy coupling relation is both complex and profound, it is difficult to accurately express it with one regression model. In the future, comprehensive data and methods need to be applied to more clearly research the effect of the industry-university-research cooperation on the innovation-economy coupling relation.

6 Conclutions

Based on the data obtained by crawling the websites related to patents and the data of the relevant statistical yearbooks, this paper verifies the theoretical viewpoint that industry-university-research cooperation plays an important role in promoting the coupling relationship between regional innovation and economic development by using spatial analysis, geographic detection and other tools. Firstly, in the industry-university-research cooperation, enterprises can cause innovative achievements of universities and research institutions to closely follow the market demands while universities and research institutions can cause practices and production of enterprises to closely follow the scientific and technological leading edges. The industry-university-research cooperation promotes both regional innovation and economic development so as to form an interactive, interconnected, coupled and coordinated virtuous relation between regional innovation and economic development. Secondly, the different innovative economy organization models have different effects on the innovation-economy coupling relation. Compared with the cooperation of organizations of the same type and the separate innovation of organizations, improvement of the industry-university-research cooperation level can better coordinate the relation between regional innovation and economic development. Thirdly, among the three main industry-university-research cooperation models, the enterprise-university cooperation as an industry-university-research cooperation form can better promote the coupling between innovation and economy. This is more or less related to the rare cooperation between enterprises in underdeveloped areas and scientific research institutions that are mainly distributed in developed areas.

Appendix

Table S1 Calculation results of node centrality

Time phasing	Rank	City	Degree centrality	City	Closeness centrality	City	Betweenness centrality
1985–1995	1	Zhengzhou	19	Zhengzhou	0.6122	Zhengzhou	0.5075
	2	Luoyang	12	Luoyang	0.5495	Luoyang	0.3685
	3	Jiaozuo	5	Jiaozuo	0.4559	Kaifeng	0.0762
	4	Xinxiang	5	Xinxiang	0.3968	Anyang	0.0655
	5	Kaifeng	4	Kaifeng	0.3968	Jiyuan	0.0153
1996–2006	1	Zhengzhou	27	Zhengzhou	0.7436	Zhengzhou	0.8539
	2	Xinxiang	9	Xinxiang	0.5179	Xinxiang	0.2623
	3	Luoyang	7	Xuchang	0.4915	Luoyang	0.1355
	4	Xuchang	5	Nanyang	0.4754	Xuchang	0.0739
	5	Kaifeng	3	Luoyang	0.4677	Kaifeng	0.0690
2007–2017	1	Zhengzhou	118	Zhengzhou	0.7760	Zhengzhou	0.7281
	2	Luoyang	33	Jiaozuo	0.5480	Jiaozuo	0.1468
	3	Xinxiang	30	Luoyang	0.5419	Xinxiang	0.0903
	4	Jiaozuo	28	Xinxiang	0.5215	Luoyang	0.0898
	5	Xuchang	26	Xuchang	0.5215	Pingdingshan	0.0664

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