Transport development, intellectual property rights protection and innovation: The case of the Yangtze River Delta Region, China

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Abstract

The links between transport development and economic growth have been widely discussed in the field of transport governance and economics. However, the existing studies have not included an institutional variable when exploring the role of transport development in innovation disparities within a region. In order to fill the research gap, this paper examines whether transport development and the institution of intellectual property rights (IPRs) can assist in understanding disparities between cities in terms of innovation, using the Yangtze River Delta Region (YRDR) as a case study. The impact mechanism is twofold. Firstly, transport development can affect institutions, including IPRs protection, which in turn has an influence on innovation. Secondly, evidence from existing economic literature suggests a link between transport development and innovation through economic agglomeration, production factors and industrial flows. We first employ ordinary least squares (OLS) regression to test the basic associations between transport development and innovation. We then apply two-stage least squares (2SLS) regression analysis to address endogeneity and add a spatial model to examine neighbour effects. The findings show that IPRs protection has a positive effect on patenting and research and development (R&D), while the roles played by transport development stock and density in patenting and R&D are more mixed. Moreover, our findings on neighbour effects show that agglomeration economies exist in the YRDR. These findings have important policy implications regarding urban agglomeration for both the YRDR specifically and China overall.

Keywords

Transport development and innovation; Transport governance; Transport management; Intellectual property rights protection; Economic agglomeration; Yangtze River Delta region

Highlights

- The impacts of different types of transport on innovation disparities within a region are explored.
- Transport development is a determinant of innovative activity in a cross-city context.
- We allow for the possibility of endogeneity and spatial heterogeneity with regard to transport development, IPRs and urban innovation.
- The effects of transport development and IPRs protection on urban innovation are examined.

1 Introduction

Economists have long emphasised the effects of transport development on regional economic growth (Weinhold and Nair-Reichert, 2009; Ding, 2013; Spurling et al., 2019), and transport development has been viewed as an effective governance instrument in the fields of accessibility, employment and sustainability (Banister and Button, 2015; Veeneman, 2018). This suggests that the development of transport systems could be an important factor in boosting economic growth over the long run, through its influence on institutional change (policy change)[1] (e.g. Köhler et al., 2008; Kemmerling and Stephan, 2015; Legacy, 2018). Meanwhile, previous studies conducted in developed countries, such as Italy, the US and France have also suggested that transport could play a direct role in the agglomeration of the regional economy and the evolution of innovation (Faini et al., 1993; Glaeser, 1997; Combes and Lafourcade, 2001). Theoretically, 'new economic geography' integrates transport costs into economic activities at a spatial dimension to gain insight into when, why and how economic agglomeration or innovation occurs in a given geographical area (Tabuchi, 1998; Behrens and Murata, 2007; Fujita and Thisse, 2009). The objective of this study is to explore whether transport development could help to explain innovation and economic agglomeration across cities. In particular, this paper primarily focuses on the relationship between transport development, intellectual property rights (IPRs) protection and urban innovation.

Most previous studies investigating the impacts of transport development on innovation or economic growth have focused on spatial labour mobility caused by transport development (Krugman, 1991a, b), transport costs (Acs and Varga, 2002; Thisse, 2009), and transport investment (Clayton et al., 2011; OECD and ITF, 2013; Caroline and Greg, 2015). Moreover, some of the aforementioned studies were conducted at a regional or urban level, and it is argued that transport development is a more efficient way to promote regional economic development due to the flow of production factors (Bråthen and Halpern, 2012). For example, using data on China's prefectures, Ding (2013) tested the relationships between transport development and economic concentration. Similarly, Banister and Berechman (2001) discussed the effects of transport investment on the promotion of economic growth at the regional and urban level. Regarding transport development's effect on institutional evolution, the existing studies have concentrated on budgetary institutions, project planning institutions (Nieto-Parra et al., 2013), electoral and voting institutions (Kemmerling and Stephan, 2015), and social welfare institutions (Jussila Hammes and Nilsson, 2016). In

[1] Transport development not only promotes economic growth, but also reflects the policy orientation in a region or country. First, spatial distance can be shortened, while traffic congestion can be reduced due to transport development. This helps to facilitate policy dissemination. Second, transport development is conducive to centralisation and local government control, because in the event of any violation of the central government, the latter can reach the local government in the shortest possible time through the well-developed transport system. Third, a good transport network is conducive to the government's ability to respond in a timely way to various emergencies, so as to maintain regional and national safety. Fourth, changes in transport planning and development have knock-on effects for economic and social policies, which will also be adjusted accordingly.

addition, some studies view a country's main political institution as a measure of the quality of the institutional background against which to test the relationships between transport development and economic growth or innovation (Honeychurch, 1996; Di Foggia and Arrigo, 2016).

In terms of the institutional dimension, IPRs protection has significant impacts on innovation and economic growth. For example, Schneider (2005) concluded that IPRs protection is positively related to innovation in developed countries but has negative impacts in developing countries. However, Allred and Park (2007) questioned this conclusion, because they found there were no statistically significant effects of IPRs protection on innovation in the developing countries of Argentina, Brazil, Mexico, and India. In addition to the relationships between IPRs protection and innovation, some studies have explored direct relationships between IPRs protection and national economic growth. For instance, Chen and Puttitanun (2005) used 64 developing countries to outline a nonlinear relationship between IPRs protection and GDP growth. Some studies have tested the relations between IPRs protection and economic growth under conditions whereby no distinctions were made between the type of countries examined, and confirmed the positive correlation (Gould and Gruben, 1996; Thompson and Rushing, 1996).

Overall, transport development promotes regional growth, and the institution of IPRs plays an important role in national economic growth and innovation. In addition, government institutions have a significant effect on innovation through their impact on regional or trans-local production systems (Zhu and Pickles, 2016). However, the existing studies have overlooked the following: first, there are no studies that view IPRs protection as an institutional variable with which to test the effect of transport development on innovation; second, the notion of spatial heterogeneity at the urban level, and the neighbour effects of transport development, institutional IPRs and innovation, are absent from the related literature. In particular, relatively few studies discuss IPRs protection at sub-national levels. This dimension is important, as there are significant differences between the intensity of IPRs protection at different administrative levels or regions in China. For example, Shanghai, as one of the most developed cities in China, may need stronger IPRs protection with regard to the international market, whereas Suqian, a developing city, needs a lower level of IPRs protection to promote more rapid growth; third, there are limited studies which have examined the endogeneity between transport development and innovation, and between IPRs protection and innovation.

The aim of this study is to examine the impacts of transport development and IPRs protection on urban innovation. Using official data (national and urban statistical yearbooks), we first employed the OLS model to test the primary influence of transport development and IPRs protection on urban innovation. However, we found that support from the OLS estimation results is relatively weak, and thus we then used 2SLS to tackle endogeneity issues in the model. Finally, the spatial effects were added to 2SLS to understand the spatial disparities with regard to innovation. In sum, many studies suggest that transport development could be an important determinant of innovation, and these two factors may be jointly influenced by institutions and growth. This paper contributes to existing knowledge in the following ways: first, we regard transport development as a determinant of urban innovation. More specifically, this study systematically explores how transport development affects innovation; second, we introduce a new institutional variable, IPRs protection, into the framework of how transport development affects innovation; third, we empirically examine the impact of transport development and IPRs protection on urban innovation at a sub-national level and simultaneously address the endogeneity issues; finally, this study focuses on whether there is any evidence of spatial autocorrelation in the mechanisms, and thus we also examine neighbour effects. Although Ding (2013) explored the endogeneity between transport development and economic concentration, only the GDP indicator was used as a dependent variable in his study, which means that it may not fully reflect sustainable economic development, while institutional factors were not taken into account either. Therefore, in order to fill the aforementioned research gaps, this study aims to examine whether transport development and the institution of IPRs could help us to understand why there are innovation disparities across cities.

The rest of the paper is organised as follows. Section 2 provides a literature review discussing how transport development affects innovation and what role the institution plays. Section 3 describes the case study, data and methods. Section 4 presents the modelling results and findings. The final section draws conclusions and suggests policy implications.

2 Literature review

The aim of this section is to understand the impacts of transport development on innovation, as well as explaining why we introduced the IPRs institution into the mechanism. Researchers have indicated that transport development has significant impacts on innovation. Although new communication technologies, such as 4G/5G networks and Wi-Fi, are reshaping the working environment, physical communication supported by a developed transport network still plays a fundamental role in sharing ideas, enhancing cooperation and trust, and promoting innovation (Graham and Marvin, 2001). Thus, physical transport still plays an important role in innovation and growth. Moreover, because cities are willing to invest in themselves in order to remain at the forefront of information exchange and innovation (Simmie, 2001), it is likely that face-to-face communication will continue to grow (Iain et al., 2009).This could explain why cities are keen to integrate transport investment with new business locations and the construction of innovation centres, such as economic and technological development zones, industrial parks, etc. (Iain et al., 2009). Overall, the existing studies have indicated that improved transport development has significant impacts on urban innovation.

In this section, we clarify the impact of transport development on innovation from the perspectives of economic agglomeration, production factor flows and industrial spatial flows. By reviewing the related literature, we also found that transport development is closely related to institutional change. This connects with the aim of our study, as we focus on the role played by the IPRs institution in terms of how transport development affects innovation. Figure 1 shows the theoretical framework used to assess the impact of transport development and IPRs protection on innovation. In addition, the existing literature also demonstrates that the mechanism through which transport development and IPRs influence innovation is an endogenous mechanism.

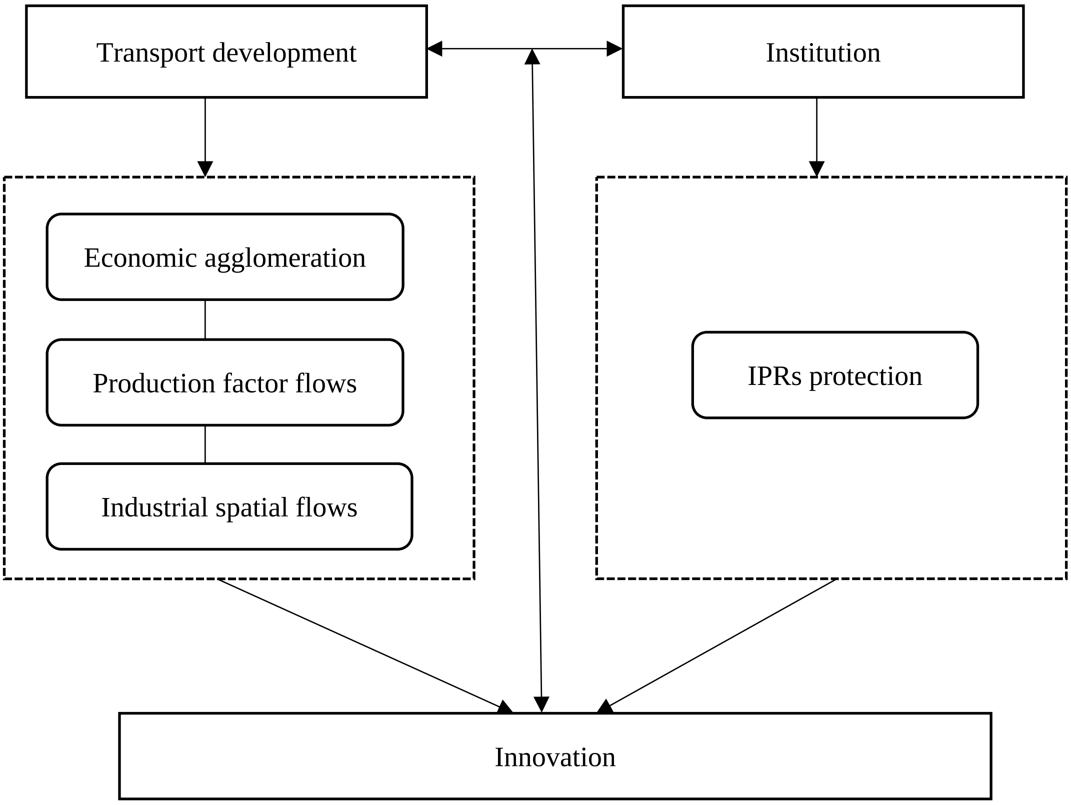

Fig. 1 A theoretical framework of the impact of transport development and IPRs protection on innovation

2.1 Transport development and innovation

The literature on economic agglomeration has widely discussed the effects of transport development on innovation. Studies have shown that innovation can be stimulated by standardisation and economic agglomeration (Zweimuller, 2000; Ni et al., 2016), because R&D expenditures, the distribution of human capital endowments and industrial diversity can all have significant impacts on promoting innovation (Mukim, 2012). Thisse (2009) concluded that the relationship between transport costs and regional economic concentration can be represented by an inverted U-shaped curve, meaning that higher transport costs can lead to innovation in the early stages of economic development due to the low cost of communication[2]. However, Ding (2013) argued that, if transport costs are sufficiently high, the standardised manufacturing of goods is discouraged, and production is still dispersed in proximity to goods markets. This indicates that higher transport costs may not result in innovation because decentralised production and non-standardised manufacturing of goods does not lead to economic agglomeration. In addition, transport development may be positively related to innovation through high market participation and economic density caused by economic agglomeration. Cheaper transport development costs decrease the costs of market participation (Weinhold and Nair-Reichert, 2009), which can increase the opportunities for innovation. This is because innovative activities are widely dispersed across the regions or populations with a high level of market participation (Sokoloff and Khan, 2000; Khan and Sokoloff, 2001). In terms of economic density, a high economic density implies a short transport distance between agents, and this short transport distance, in turn, drives agglomeration economies (Roberts and Goh, 2011), which increases the opportunities for innovation.

Another strand of literature focuses on production factor flows being beneficial from a transport development and innovation perspective (CfIT, 2002; Florida, 2005; Ding, 2013). This section discusses two types of production factors: skilled labour, and investment and inventors. First, regional transport development is conducive to attracting more skilled labour, and free labour mobility can lead to growth and innovation (Biswas, 2015). Florida (2005) indicated that jobs tend to move to areas favoured by creative people. Thus, transport development accelerates the flow and promotes the gathering of creative people, which contributes to regional capacity for innovation. Similarly, with the falling costs of and increasing returns on transport development, capital and labour are concentrated in core regions where market sizes are larger and thus economic agglomeration occurs, thereby increasing the potential for regional innovation (Ding, 2013). With regards to investment and inventors, as well as providing sufficient capital to support innovation, this also produces spillover effects, especially in terms of technology, which the surrounding regions can benefit from (Nanda and Rhodes-Kropf, 2013). A report by The Commission for Integrated Transport (CfIT) (2002) showed that, in addition to speed and capacity, modern transport systems have to offer more interactions between different areas of a city in order to attract more investment. These interactions are conducive to the formation of a new economic growth pole, and can drive the growth of surrounding areas. Therefore, the interaction between transport development and investment promotes growth and regional innovation. Surveys by the CfIT (2002) have indicated that transport and its effects in terms of noise, journey barriers and local air pollution are the biggest impediments to the quality of life from investors' perspective. Investors play a vital role

[2] According to the study conducted by Thisse (2009), due to differences in communication costs, a fall or increase in transport costs would result in contrasting production patterns. When communication costs are high, decreasing transport costs can lead to a growth in agglomeration. However, if communication costs are low, high transport costs will mean that most plants will still be located within the core regions. Once transport costs fall below a certain threshold, however, the relocation of industrial activities will involve a smaller range of transport costs.

in innovation, because they are viewed as active monitors who provide insurance against innovation failures, and contribute to knowledge spillovers from highly innovative economies (Luong et al., 2017). Furthermore, investment, especially from developed countries and regions, can promote innovation in the host area (Piperopoulos et al., 2018), demonstrating that transport development, especially marine or water traffic, plays a critical role in innovation.

In addition, some studies have discussed the links between transport development and innovation from the perspective of industrial spatial flows. For example, Puga (1999) and Krugman and Venables (1995) argued that decreasing transport costs may encourage enterprises to migrate from core regions into peripheral regions in order to reduce the costs of innovation and development, which in turn promotes transport development due to the connections between peripheral regions and core regions. The spatial flow of industry refers to the flow, dissemination and diffusion of knowledge within a geographical location, which promotes the formation of a regional innovation network (Sammarra and Biggiero, 2008). Moreover, the industrial spatial flows caused by transport development will accelerate the establishment of industrial clusters in peripheral regions, which not only creates new sites of innovation, but also promotes further innovation flows (Brachert, Brautzsch and Titze, 2016).

2.2 The role of the institution

Studies have suggested that transport development is closely related to the evolution of institutions, which in turn plays an important role in transport development (Kenworthy and Laube, 2001, 2002; Nieto-Parra et al., 2013; Stone and Legacy, 2013; Stone, 2014; Kemmerling and Stephan, 2015). For instance, Stone and Legacy (2013) and Stone (2014) clarified the key role of transport outcomes in the behaviour of political actors and local institutional conditions. The centrality of local politics is regarded as an important factor in explaining urban transport policy trajectories, while institutions, local politics and the behaviour of actors in different regions play different roles in transport planning and development. Moreover, new geo-economic institutions and the establishment of Free Trade Zones, such as the ‘One Belt One Road’ and the ‘Go West’ strategy, are currently reshaping China’s transport development, particularly in terms of the container seaport system (Notteboom and Yang, 2017). One of the aims of these political and institutional strategies is to promote regional innovation and growth, and to form innovation and growth networks by improving transport development. Some studies have focused on the differences in transport development that have occurred as a result of institutions. For example, Kenworthy and Laube (2001, 2002) argued that, due to varying local institutional conditions and economic development strategies, transport development differs significantly even between cities with many physical similarities. Evidence from Canada and Europe has also shown the effects of political factors on differences in transport development (Bratzel, 1999; Kennedy et al., 2005), in terms of organisational structure, democracy, and investment policy, etc. Meanwhile, a growing number of studies have explored the various aspects of transport governance and their effects in promoting development and growth, such as the relationships between the authority and operator performance, trusted partnerships and free market models, etc. (Roy and Yvrande-Billon, 2007; Boitani, Nicolini and Scarpa, 2013; Van de Velde and Preston, 2013). These studies suggest that transport development is closely related to regional and/or local institutions whose aim is to boost innovation and growth.

While the studies cited above focus on the impact of a policy or institutional quality, we extend this research to explore the association between transport development and another potentially important aspect of institutional quality: IPRs protection, as this institution has been shown to interact strongly with innovation in the existing studies. Regarding the literature on the impact of IPRs on innovation, both at a theoretical level and in terms of empirical evidence, Greenhalgh and Dixon (2002) conducted a useful review at the level of firms, industries and countries, and a considerable amount of literature has already clarified this point.

Transport development also helps to promote innovation through its effect on the evolution of institutions. Enoch (1997), Page (2006), Stone (2014) and Legacy (2018) pointed out that mass economic and political participation facilitated by transport development results in institutional change, because transport development has the effect of changing a location’s original spatial geographical structure and geographical range. In order to achieve regional growth and innovation, the regional coordination of institutions as a result of transport development is an inevitable trend (MacKinnon et al., 2008). Sokoloff and Khan (1990, 2000) and Khan and Sokoloff (2001) and Khan (2002) even claimed that such economic and political participation served to make early American IPRs institutions different from the prevailing European institutions. In the United States, patent applications are less expensive, much simpler and available to a much broader spectrum of technologies and scientific fields (Weinhold and Nair-Reichert, 2009). Therefore, the combination of advanced transport development and stronger IPRs protection played a significant role in the innovation that took place during the early period of American industrialisation. Similarly, in China, due to the promotion of institutions, transport development and its related patent protection are currently going through a stage of rapid development, increasing China’s ability to innovate (Qiu and Qi, 2012).

Consequently, the theory suggests that transport development could have an impact on innovation (and thus growth) via its influence on economic agglomeration, the flow of production factors and industrial spatial flows, as well as through its effect on institutions, especially IPRs protection. Although the basic hypothesis to be examined is that either transport development or strong IPRs protection (or both) may affect innovation, a key caveat to the story is that endogeneity might be an issue. For instance, a significant ability to innovate may, in turn, demand stronger IPRs protection (Sutton, 1998). Fernald (1999) and Tatom (1993) argued that endogeneity exists with regard to the correlation between transport stocks and economic growth or output. In addition, the endogeneity of institutions and economic growth has been an important focus in the fields of IPRs and the literature on institutions. Although there are possibilities for reverse causality between innovation and IPRs protection, we have not found a convincing empirical treatment of this issue in a cross-city context, nor one which takes transport development into account. Therefore, this study also tests the potentially endogenous nature of transport development, innovation and IPRs protection by using a 2SLS estimation strategy. We attempt to resolve the issue of spatial effects between these variables. In sum, the contribution of the study is twofold. First, we introduce transport development as a determinant of innovation in a cross-city context; and second, the study explicitly addresses the endogeneity of innovation, IPRs protection and transport development, as well as adding spatial effects into our empirical specification.

3 Case study, data and methodology

In this study, we explore whether transport development and IPRs protection can help understand differential innovation capabilities across cities in the Yangtze River Delta Region from 2000 to 2016. The aforementioned theoretical framework (see Fig. 1) that informs this study is based on the effects of transport development and IPRs protection on innovation, and thus we look for empirical evidence of these impacts in the present. The theoretical linkages between transport development and institutional evolution develop over the long term; however, transport development has evolved rapidly in China. Therefore, we can expect to observe evidence of the relationships between transport development and IPRs protection from 2000 to 2016. In addition, as long as the institutions that protect IPRs and/or transport facilities remain in existence, they will continue to play a role in the future. Therefore, the study examines their cumulative influence.

3.1 Case study

The Yangtze River Delta Region (YRDR) was selected as a case study (Fig. 2): as a vital part of China's national economy, the YRDR is viewed as one of the world's six largest emerging megalopolises (Gottmann, 1976; Li and Phelps, 2018). According to the Yangtze River Delta Urban Planning document published by China's State Council in 2016, the YRDR is composed of Shanghai and two provinces, which contain a total of 25 cities. In 2014, the YRDR's gross domestic product (GDP) and population accounted for 18.5% and 11% of China's total, respectively. Despite the aforementioned rapid growth, cities in the YRDR are characterised by spatial disparities. For example, in 2016, Research and Development (R&D) investment and the number of patents authorised in Shanghai, the YRDR's most prosperous city, exceeded that of Quzhou, its poorest, by a ratio of 203:1 and 49.18:1, respectively, which illustrates the huge spatial disparities in innovation within the YRDR.

In addition, the YRDR has a high-quality transport development system, typical of those found in modern day China. It also has a strong integrated transport service capacity. There is a passenger service every 1 to 1.5 hours between the central cities in the region. The Shanghai metropolitan area, as well as Nanjing, Hangzhou, Hefei, Suzhou, and the Ningbo metropolitan area benefit from an hourly commuter service. Moreover, the YRDR's *Integrated development plan for higher quality transport*, which was jointly issued by The China National Development and Reform Commission and the Ministry of Transport, sets out a comprehensive plan for various types of traffic and transport networks, including railways, highways, airports, ports, etc. However, there are still disparities in terms of transport development between cities in the YRDR. According to the results of research conducted by Shanghai Jiaotong University (https://www.cenews.com.cn/opinion/jczs/201910/t20191022_913548.html), the development of the urban transport infrastructure has proceeded at an uneven rate across cities, and the connectivity between cities is very weak in the YRDR. Thus, production factors, such as talent, capital and technology, make it difficult to achieve efficient flows and an equitable allocation of resources between cities, which has resulted in a widening gap and hampered the development of high-quality integration. In particular, the coverage rate of the high-speed rail network in the YRDR is still low, there is an imbalance in the spatial distribution between cities, and the distribution of rail transit in cities is still relatively scattered. Thus, although the YRDR is widely regarded as a regional economic growth pole, there are still significant spatial disparities between cities in the region.

Therefore, in this paper, we chose to explore the effects of transport development and the institution of IPRs on urban innovation for cities within the YRDR. In addition, using longitudinal data from 2000 to 2016, the study tests to what extent transport development and IPRs protection can explain existing spatial disparities in innovation between cities in the YRDR. Furthermore, we also distinguish between the intensity of IPRs protection for different cities.

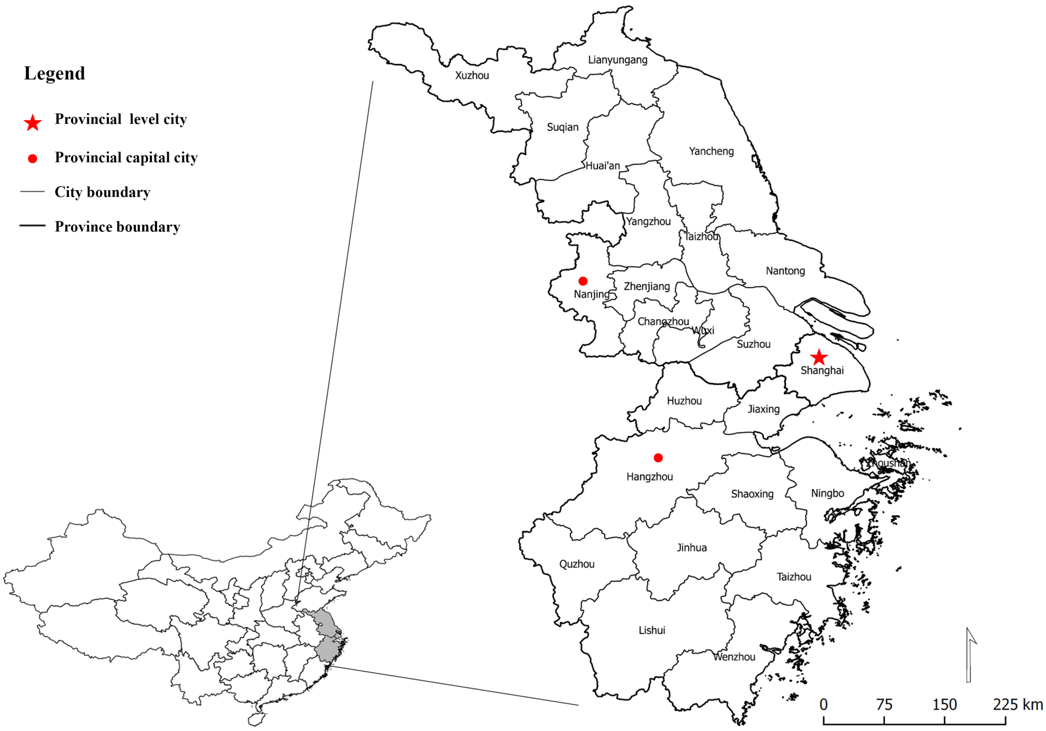

Fig. 2. Case study of the Yangtze River Delta Region (YRDR)

3.2 Data

3.2.1 Dependent variable (innovation)

As the measures of innovation, we chose data on patents granted (PATENT) and local R&D investment (R&D) from 2000 to 2016 across a sample of 25 cities, which provides us with a measurement of innovation investment and inventions that covers many cities over the sample period in question (Weinhold and Nair-Reichert, 2009). In addition, PATENT and local R&D investment are the measures of innovation output and innovation input, respectively (Chen and Puttitanun, 2005).

A number of previous studies have selected patent counts as the proxy of aggregate innovation (Bottazzi and Peri, 2005; Chen and Puttitanun, 2005; Mancusi, 2008). However, some researchers have questioned the ability of patent count data to evaluate innovation. Firstly, although patent count data can reveal information about innovation output, it may not measure the innovation process precisely enough. For instance, stronger IPRs protection increases the number of patents granted; however, it does not necessarily promote innovation. This is because it is only a static measure of innovation at particular time points in the process of innovation (Weinhold and Nair-Reichert, 2009). Therefore, in this study, we added the input measure of innovation in order to represent the innovation process. In addition, only if the benefits of patent protection are greater than the costs, will patent application and the granting of patents occur. Meanwhile, patent protection cannot cover all types of innovation output, because some inventions may be protected by trade secrets and copyright. Thus, it is possible that the measure of innovation is downwardly biased (Weinhold and Nair-Reichert, 2009).

Levin et al. (1987) and Cohen et al. (2003) indicated that there is considerable heterogeneity in patenting behaviour within different industries. However, Weinhold and Nair-Reichert (2009) pointed out that, although these issues may be significant at the firm and industry levels (disaggregated level), they are not likely to be significant at an aggregated level. This is because patenting is closely linked to inventive activities overall and can, therefore, reflect innovative ability at an aggregated level (e.g. regional or nationwide), and our research focuses mainly on the latter.. Moreover, Griliches (1995) also observed that patents are a good indicator of inventive activities at aggregated levels. Our study does not involve any data collected at the firm or industry level. Consequently, regarding our aim and research questions, the patent count is a good proxy of innovation output.

The reasons for choosing local R&D investment as a measure of innovation input are as follows: 1) it can redress the patent count shortcomings and reflect the innovation process more fully; 2) R&D can reflect a city's motives for innovation; and 3) higher R&D investment means a greater probability of innovation returns (Cohen et al., 2003). Also, some studies have chosen R&D output as a proxy of innovation ability (Lee and Roh, 2020; Minguillo and Thelwall, 2015). However, double counting of R&D output and patent counts can occur. We therefore chose patent counts as the measure of innovation output due to the advantages discussed in the preceding paragraph. Moreover, our study is designed to cover the whole process of innovation through input (R&D investment) and output (patent counts). However, compared with patents, it is difficult to convert other forms of R&D output into real productivity over a short period, and many of them do not have a very strong market potential. Therefore, obtaining an accurate measure of actual innovation ability is problematic. In addition, it is rare to find reliable measures of R&D output for developing countries, such as China (Weinhold and Nair-Reichert, 2009), which would significantly limit our data collections and calculations. Thus, ultimately we decided to select local R&D investment as a measure of innovation input.

3.2.2 Independent variables

The index of IPRs protection (IPP) is adapted from Han and Li (2005). They used law enforcement efforts to revise the indicators developed by Ginarte and Park (1997). Ginarte and Park (1997) (G-P) designed five indicators whose scores ranged between 0 and 5, with the higher values indicating stronger IPRs protection. Maskus and Penubarti (1995) argued that these indicators capture broader characteristics of the variability of patent protection more effectively than a simpler dummy variable method. However, China's IPRs protection measured by the G-P method is stronger than actual levels of protection (Han and Li, 2005). For example, in 1993, IPRs protection based on the G-P method in China outweighed that of some developed countries. Weinhold and Nair-Reichert (2009) also argued that the gap between actual and measured levels of protection obtained by the G-P method could result from ineffective law enforcement. Therefore, Han and Li (2005) commented that the G-P method is not suitable for measuring China's IPRs protection, due to flaws in the country’s current judicial system. Consequently, they introduced law enforcement efforts into the G-P method, and the revised IPRs protection measure that we developed is as follows:

$$P^A(t) = F(t) * P^G(t) \quad (1)$$

Where
$P^A(t)$ is IPRs protection intensity at t time.
$F(t)$ refers to law enforcement efforts.
$P^G(t)$ is IPRs protection intensity measured by the G-P method.

Maskus and Penubarti (1995) used business survey data from the US Chamber of Commerce to measure policy enforcement. However, these data may not reflect Chinese law enforcement objectively, because they come from an American source and therefore could be susceptible to potential bias. Thus, Han and Li (2005) quantified four indicators to measure China’s law enforcement efforts, namely: the legalisation of society; the effectiveness of the legal system; economic development; and the supervision and balance of international society[3]. The final scores for law enforcement efforts are the arithmetic means of the aforementioned four indicators. Moreover, due to China’s decentralisation and differing regional policies on IPRs protection, we can examine the difference in regional IPRs protection through law enforcement efforts. In our study, the measure of IPRs protection intensity is based on data at the urban level.

Generally, IPRs is a national phenomenon and hence is implemented nationally. However, in China, the central government policy is vague. As long as they do not violate central government policy, local governments can formulate and implement policies that are appropriate to the specific local conditions, and thus there are regional differences in the intensity of IPRs protection. Moreover, due to China’s economic decentralisation, the responsibility for economic growth is becoming increasingly complex and diversified, which has led to competition and inequality between various regions and cities (Wu, 2016). With regard to IPRs, different regions have different incentives and preferential policies for patent technology, while penalties for infringement also differ. Overall, IPRs protection and economic growth tend to be stronger in eastern China and weaker in the west. Nevertheless, few studies have examined regional or urban IPRs protection in China. Chu and Gao (2019) calculated a measure of IPRs protection at the provincial level and found a significantly negative impact of IPRs protection on the investment efficiency of China’s creative enterprises. However, they only used the rate of patents not being infringed to measure the intensity of IPRs protection, which is not comprehensive. Although patent rate is an output measure of economic growth (Weinhold and Nair-Reichert, 2009), it cannot reflect the legal enforcement of IPRs, and neither can it cover all different kinds of IPRs, such as

[3] The extent to which international society monitors and provides checks and balances on the mechanisms for IPRs protection and innovation.

trademarks, trade secrets, etc. Thus, Han and Li's (2005) method is most suitable for our study.

As for transport development, this study measures it in relation to stock and density. Ding (2013) tested the effect of transport development variables for the aforementioned two dimensions on economic growth at city-proper and non-city-proper levels. In our study, the transport development stock variables comprised: the total length of railway transportation lines in a city (Rail_Stock); the total length of roads in a city (Road_Stock); and the total route length of a city's waterways (Water_Stock). In addition, Ding (2013) chose four variables with which to measure airport and port transport development. In this research, we also chose the same four variables to assess airport and port transport development, namely: whether there is at least one airport in a city (Air_D); whether there has been major airport expansion in a city (AirG_D); whether there is at least one port in a city (Port_D); and whether there has been major port expansion in a city (PortG_D). Additionally, we based our choice of variables on the following literature. Huang et al. (2015) indicated that whether a city is coastal could play an important role in economic growth. This is because it reflects the extent to which a city participates in the global economy. In addition, the development of airports and ports can accelerate the flow of production factors, including technology, knowledge and skilled labour, which promote international trade and globalisation (Lee and Cho, 2017). Furthermore, trade and globalisation are significantly related to patenting and R&D (Santos, 2017; Jorgenson, 2018). Therefore, based on the aforementioned literature, we selected these four transport development stock variables.

In terms of transport development density variables, in Ding's study design (2013), density variables are used to deal with the heteroscedasticity issue, because he distinguished city-proper transport from non-city-proper transport. However, in this study, we do not distinguish between city-proper and non-city-proper transport. With the development of urbanisation in China, the emergence of a large number of rural-urban fringe zones has increasingly blurred the boundaries between rural areas and urban areas. Moreover, in order to promote local economic growth, local governments tend to attract investment through land finance, and a large number of economic development zones have begun to appear in rural areas, which generally promote innovation and economic growth (Huang et al., 2015). Thus, we chose to measure the overall transport density of cities. In addition, density indicators can help us to understand the role played by transport development in economic activities. Some studies have suggested that transport has a significant effect on high-density economies (Brueckner et al., 1992). For example, for a given shipping route, the number of ships increases when there is an increase in transport density. If we compare the shipping routes from Jakarta to Japan and Singapore to Japan, it becomes clear that although the two routes cover a similar distance, they differ in terms of traffic density (Japan Logistic System Association, 1996). Thus, transport density can compensate for the shortcomings of the stock measure. Moreover, transport density is a key source of industrial agglomeration and can contribute to the self-integration of transport routes

(Mori and Nishikimi, 2002). Therefore, transport density can be regarded as an appropriate measure of economic activities. In addition, regarding density, we chose employment density, calculated by the number of workers per square km of transport. The existing studies have indicated that labour density has a positive impact on productivity and agglomeration (Zheng et al., 2009; He and Pan, 2010; Roberts and Goh, 2011). Thus, we explore the relationships between employment density and transport and innovation agglomeration. There are five transport density variables in our study, namely Rail_Densi, Road_Densi, Water_Densi, Air_Densi and Port_Densi. Table 1 summarises all the variables used in the study.

Table 1

Summary of variables.

	Variables	Definitions
Intellectual property rights protection	IPP	IPRs protection measure at city level based on the method used by Han and Li (2005)
Transport development	Rail_Stock	Total length of railway transportation lines in a city (square km)
	Road_Stock	Total length of roads in a city (square km)
	Water_Stock	Total route length of a city's waterways (square km)
	Air_D	Whether there is at least one airport in a city
	AirG_D	Whether there has been major airport expansion in a city
	Port_D	Whether there is at least one port in a city
	PortG_D	Whether there has been major port expansion in a city
	Rail_Densi	The length of railway transport lines to employment counts in a city as a percentage
	Road_Densi	The route length of a city’s road transport network to employment counts in a city as a percentage
	Water_Densi	The route length of a city's waterways to employment counts as a percentage
	Air_Densi	The number of airport counts to employment counts in a city as a percentage
	Port_Densi	The number of port counts to employment counts in a city as a percentage
Innovation	PATENT	The amount of patent authorised in a city
	R&D	Research and development expenditure in a city (millions; unit: Chinese yuan)

Data used in our study came from three different sources: firstly, China’s city statistics yearbooks, which publish economic development data on IPP, transport-employment data, urban R&D and patents data, as well as transport data; secondly, the Chinese legal statistics yearbook and Peking University’s magic weapon database, which helped us to measure IPRs protection; and lastly, the study chose the consumer price index (CPI) for the year 2000 as a measure by which to adjust all economic data in order to make them comparable. Our research question is whether exogenous differences in primary conditions across cities can explain the impacts of differential urban innovation abilities on IPRs and transport development. Therefore, cross-sectional data are more suitable for addressing this question than panel and time series data. Moreover, the instruments used in the study are related to exogenous geographical features of cities that do not change over time. Therefore, the data type makes it possible to discern the deeper underlying differences in IPRs institutional quality across cities; however, it cannot shed light on variations in annual changes within a given region or city (Weinhold and Nair-Reichert, 2009). For these reasons, cross-sectional data are adequate for the purposes of this study. Meanwhile, the variables in our study are calculated based on time-averaged data, which can solve potential problems of temporary measurement errors linked to the employment density measure in particular (Roberts and Goh, 2011).

3.3 Methods

Thus, drawing on the data and literature discussed above, the basic OLS model specification of a cross-sectional regression is as follows:

$$Innovation_i = \alpha + \beta_1 IPP_i + \sum_k \beta_k TransportDevelopment_{ki} + \varepsilon_i \quad (2)$$

where innovation is the natural log of the patents and R&D investment of *i* city over the period from 2000 to 2016. Transport development denotes a set of 12 stock and density transport variables. The natural logs of the variables Rail_Stock, Road_Stock and Water_Stock were used.

In our study, we use city fixed effects, because Hausman tests reject the hypothesis that there is no correlation between explanatory variables and a city at a 1% significance level. When we conducted the OLS regression, we used Moran's *I* statistic in order to test whether spatial effects exist. If spatial autocorrelation was found to exists, the study ran spatial regression. In addition, the existing studies have indicated that there is an endogeneity issue concerning the relationship between transport development and economic output (Tatom, 1993; Gramlich, 1994; Fernald, 1999). Therefore, the study employed two-stage least squares (2SLS) analysis, following Ciccone (2002), by choosing the natural log of a city's land area as an instrument.

4. Results

4.1. OLS estimation

Table 2 shows the OLS estimation results based on time-averaged data from 2000 to 2016. Before running the OLS regression analysis, we first calculated the correlation coefficients of all explanatory variables in order to test for multicollinearity. The correlation results demonstrate that there is a weak correlation between all the coefficients of the independent variables, and thus the independent variables are independent from each other, indicating that multicollinearity is not a problem in our

OLS estimations. Models (1) and (2) report the results from testing for a relationship between PATENT and transport stock, as well as between PATENT and transport density, respectively. Models (3) and (4) report the effects of stock and density on R&D, respectively. Table 2 indicates that the smallest R^2 and adjusted R^2 values in all the models are 0.612 and 0.499, respectively, revealing that transport development and IPRs protection can explain innovation in cities within the Yangtze River Delta particularly well.

According to Table 2, IPP, representing the intensity of IPRs protection, has a significantly positive relationship with innovation (although it could be endogenous), indicating that stronger IPRs protection can promote urban R&D investment and patent output. Weinhold and Nair-Reichert (2009) argued that positive relationships between IPRs and innovation are reflected by the fact that increasing IPRs protection by one standard deviation means a corresponding increase of about a quarter standard deviation in innovation. In terms of transport stock, Rail_Stock has a significantly positive impact on innovation. With the development of railway communication networks and information technology, railway informatisation has become a goal of rail transport in China, and advanced railway transport can promote continuing innovation (Zhou, et al., 2012). Furthermore, larger rail networks or more railways tend to lead to greater economic growth because of increased trade and deeper economic integration (Caruana-Galizia and Martí-Henneberg, 2013). The positive effect of railway development on R&D is greater than that of PATENT. This could be because economic growth resulting from railway development leads firms to invest more in R&D; however, the patent value of technologies does not always outweigh their market value. In such cases, it is therefore not worth spending money on applying for a patent to obtain the copyright for using the new technologies, as there is no benefit to be gained. Road is positively related to PATENT, while there is no statistically significant association between Road and R&D. An advanced urban road network means a highly urbanised population, who would have a stronger capacity for patent invention than a rural population (Weinhold and Nair-Reichert, 2009). Water_Stock does not show a statistically significant effect on PATENT and R&D, indicating that waterways are not a particularly important means of transport for cities in the Yangtze River Delta. In addition, Air_D and AirG_D have a significantly positive impact on innovation. Zhang (2014) indicated that urban development is the strongest driving force behind the airport economy and developed airport transport can promote technologies and R&D. The OLS analysis revealed that the effects of Port_D and PortG_D on innovation are not significant. Overall, transport stock produces a positive effect on urban innovation in the Yangtze River Delta.

Regarding transport density, Rail_Densi is positively related to PATENT, whereas there is no statistically significant correlation between Rail_Densi and R&D, indicating that a higher railway density results in patent agglomeration (innovation agglomeration) for cities in the Yangtze River Delta. The positive effects of Road_Densi on PATENT and R&D are significant. Henderson (2004) suggested that a higher density of urban roads can lead to urban agglomerations based on technological externalities, which results in the close spatial proximity of economic agents which, in turn, promotes innovation. Meanwhile, urban agglomeration and technological innovation promote economic growth (Henderson, 2004), and thus endogeneity may exist between transport density and innovation. Although Water_Densi does not show a statistically significant effect on innovation, Port_Densi has a significantly positive impact on innovation. In the Yangtze River Delta, many inland waterways have been abandoned, whereas trade in coastal cities is very developed, resulting in trade agglomeration (Abe and Wilson, 2011). The spillover effects of capital and technology caused by trade promote innovation in these coastal cities (Song et al., 2015). Air_Densi has a negative effect on innovation in the Yangtze River Delta. This may be because the flow of production factors between Chinese cities depends heavily on railways and highways; there are relatively few international flights within the Yangtze River Delta region, and their distribution is extremely uneven (Zhang, 2014). Thus, Air_Densi cannot promote innovation agglomeration.

Table 2

OLS results.

Variable	Log(PATENT) (Innovation output)		Log(R&D) (Innovation input)	
	Model (1) Stock	Model (2) Density	Model (3) Stock	Model (4) Density
Constant	-2.163* (-0.12)	2.398 (49.41)	4.103 (46.81)	3.895* (33.60)
IPP	0.117** (1.90)	0.500 (66.19)	0.036* (4.45)	0.137** (4.92)
Log (Rail_Stock)	0.054** (10.09)		0.084** (2.85)	
Log (Road_Stock)	0.021** (0.09)		-0.140 (-4.98)	
Log (Water_Stock)	-0.569 (-2.17)		-0.093 (-13.30)	
Air_D	0.480** (6.27)		0.003*** (2.90)	
AirG_D	1.010** (27.60)		0.039* (5.91)	
Port_D	-0.003 (-0.30)		-0.034* (-4.33)	
PortG_D	-0.001 (-0.03)		-0.075 (-2.49)	
Rail_Densi		0.360** (27.65)		-0.467 (-10.60)
Road_Densi		0.553** (4.79)		0.450*** (1.88)
Water_Densi		-0.140 (-1.08)		0.206 (0.76)
Air_Densi		-0.103* (-16.53)		-0.263* (-0.28)
Port_Densi		0.038* (5.76)		0.347** (2.06)
R^2	0.792	0.612	0.704	0.622
R^2 (adj)	0.685	0.500	0.592	0.499
Joint significance of fixed effects	0.069*	0.052*	0.082**	0.071**
Moran's I	0.149**	0.031	0.076**	0.105*
LM-LAG	0.231*	0.108*	0.129	0.021**
LM-ERR	0.610	0.013	0.127*	0.139
Robust LM-LAG	0.053**	0.067*	0.182	0.084**
Robust LM-ERR	0.161	0.043*	0.093*	0.056*

Notes: ***Significant at 1% level, **at 5% level and *at 10% level.

4.2 Controlling for endogeneity

The OLS estimation results provide relatively weak support for the effect of transport development and IPRs protection on innovation. However, the study highlighted earlier that the potential for endogeneity issues exists. First, a highly innovative community may, in turn, need stronger IPRs protection (Sutton, 1998), and the endogeneity between IPRs protection and innovation has been a major focus in the theoretical IPRs literature (Gould et al., 1997; Chen and Puttitanun, 2005). Second, there is endogeneity between transport stocks and innovation output (Gramlich, 1994; Fernald, 1999). OLS analysis indicates that Rail_Stock and Road_Stock are related to innovation, and thus the two variables are treated as endogenous. Meanwhile, the Durbin-Wu-Hausman test rejects the null hypothesis that estimates of the two variables produced by OLS analysis are unbiased and consistent. Lastly, the relationship between transport density and innovation may be endogenous. Cities with a higher level of innovation are likely to attract more migrants, which will cause the estimated OLS transport density coefficient to be upwardly biased (Roberts and Goh, 2011). Moreover, although the type of data used in the study mitigates temporary measurement errors, using time-averaged data could cause more permanent measurement error problems, which may, in turn, lead to an errors-in-variables issue, resulting in downward bias (Wooldridge, 2013). Therefore, the following discussion is based on the estimated results of the 2SLS model.

Table 3 presents the 2SLS results based on the instrumenting urban land area (Log area). The geographical instrument is more objective and is therefore seldom affected by other factors (Weinhold and Nair-Reichert, 2009). Ciccone (2002) and Roberts and Goh (2011) argued that it is reasonable to use the instrument variable in economic studies. Similarly to the OLS results, IPP has a positive and significant impact on innovation. In Models (2) and (4), compared to OLS estimation, choosing log urban land area as an instrument causes the estimated coefficients of innovation to rise with respect to transport density. Therefore, we can now reject the hypothesis of no innovation agglomeration, at least at the 10% significance level, according to all the transport density coefficients in Models (2) and (4). Meanwhile, Models (1) and (3), produce a similar result to that of the OLS analysis and this continues to hold when the measure of transport stocks is controlled. In all models, the instruments are also strongly significant in first-stage estimates. Furthermore, the values of the Wu–Hausmann test show that we can reject the consistency of OLS and 2SLS in all models. Overall, the 2SLS results are much more supportive of the impact of IPRs and transport development on innovation. However, it is important to note that 2SLS can produce substantial bias in small samples like that of our 26 cities (Wooldridge, 2013). Consequently, although the OLS estimate is preferred on asymptotic grounds, the results obtained from 2SLS should be treated with some caution.

Table 3

2SLS results.

Variable	Log (PATENT) (Innovation output)		Log (R&D) (Innovation input)	
	Model (1) Stock	Model (2) Density	Model (3) Stock	Model (4) Density
Constant	-0.207 (-3.88)	-4.159* (-16.68)	-2.467** (-12.81)	-3.362 (-3.24)
IPP	0.010** (8.38)	0.058*** (10.36)	0.036*** (2.69)	0.039** (4.22)
Log (Rail_Stock)	0.111*** (4.90)		0.507** (3.11)	
Log (Road_Stock)	0.115** (20.24)		-0.501* (-3.32)	
Log (Water_Stock)	-0.019* (-5.64)		-0.077 (-2.16)	
Air_D	0.058*** (8.02)		0.800*** (2.84)	
AirG_D	0.742* (5.87)		0.006** (0.81)	
Port_D	0.764 (14.84)		0.076 (0.62)	
PortG_D	0.098* (5.27)		-0.004 (-0.008)	
Rail_Densi		0.742*** (6.84)		-0.263 (-2.74)
Road_Densi		0.764*** (14.14)		0.487*** (1.94)
Water_Densi		0.098 (6.62)		0.916* (2.85)
Air_Densi		0.035 (8.21)		0.031* (3.48)
Port_Densi		0.431** (5.82)		0.401 (2.14)
R^2	0.743	0.698	0.663	0.810
R^2 (adj)	0.638	0.576	0.542	0.764
Significance in first stage	0.021**	0.003*	0.012**	0.001***
Wu–Hausmann test	0.013*	0.005**	0.010**	0.004**
Anselin–Kelejian test	0.981	0.932	0.918	0.951

Notes: ***Significant at 1% level, **at 5% level and *at 10% level.

4.3 Spatial neighbour effects

According to Table 2, the OLS results indicate the existence of spatial autocorrelation, that is, errors are linked to the strength of pair-wise correlations relying on the distance separating two cities, which is based on some common tests for spatial autocorrelation reported in Table 2. In light of this, Table 4 shows the results of adding spatial effects to the baseline specification. In the study, we added three types of weights, namely: innovation (W Log (Innovation)); IPRs protection (W IPP); and transport development (W TD). In Models (1) and (2), the W Log (Innovation) is the measure based on innovation output, while those in Models (3) and (4) are based on innovation input. In Models (1) and (3), W TD is a measure which is dependent on transport stock. The study chose the mean of Log (Rail_Stock), Log (Road_Stock) and Log (Water_Stock) as the transport stock weight basis. Similarly, in Models (2) and (4), the weight is based on the mean measure of the transport density variables. In the aforementioned two cases, the weights depend on the inverse square of the distance between two cities (Roberts and Goh, 2011). In Table 4, all results are based on 2SLS estimation.

Table 4 indicates that there are no neighbour effects on the previously reported results. IPRs protection is positively related to innovation. Although IPP has a negative effect on R&D in Model (3), the coefficient is not statistically significant. As for the neighbour effects of IPP, IPRs protection in surrounding cities has a significant effect on a city's own urban innovation at the conventional level. Therefore, we can reject the null hypothesis based on the 2SLS results at 10% significance level, indicating that there is a strong distance-related spillover effect in relation to IPRs protection. When the study specifies spatial neighbour effects as arising from innovation levels in surrounding cities, the evidence of spatial spillover is more significant; in the density models in particular, the spillover effects become very strong. Not only are the estimated coefficients of W(Innovation) significant at least at the 5% level, but the density coefficients are also larger than those for W(IPP) and W(TD). In this respect, if innovation doubles in a city's neighbours, this causes the city's own innovation level to rise by at least 15% in terms of patenting and 17% in terms of R&D. In addition, there are also spillover effects associated with transport infrastructure stock. The role played by transport in terms of spatial development is to connect different cities, and a high level of stock increases the potential for greater connectivity. The spillover effects of stock may be caused by the connectivity of the transport infrastructure both at the national and the regional level. The YRDR is committed to regional transport and economic integration, which explains why spillover effects were found for the transport infrastructure stock and reflects the level of connectivity. This conclusion is consistent with the findings of Yu et al. (2013). These results are similar to those observed for the spatial agglomeration of innovation in our data set. In addition, transport development in surrounding cities has significantly positive effects on a city's own urban innovation, indicating that transport agglomeration can promote innovation clustering. Therefore, overall, this evidence of spatial neighbour effects demonstrates a more general role for IPRs protection and transport development in understanding the spatial innovation disparities between cities in the YRDR. In particular, it indicates that the effects of IPRs protection are very strong.

Table 4

Results of 2SLS including spatial effects.

Variable	Log (PATENT) (Innovation output)		Log (R&D) (Innovation input)	
	Model (1) Stock	Model (2) Density	Model (3) Stock	Model (4) Density
Constant	-5.745 (-1.48)	-2.257* (-2.58)	-2.505* (-3.55)	-3.344 (-2.08)
IPP	0.347** (8.62)	0.620** (1.73)	-0.010 (-3.34)	0.806** (1.24)
Log (Rail_Stock)	0.082** (1.60)		0.262* (4.18)	
Log (Road_Stock)	0.116** (1.01)		-0.002* (-4.04)	
Log (Water_Stock)	-0.001 (-1.10)		0.095** (21.73)	
Air_D	0.046 (5.16)		0.765** (24.50)	
AirG_D	0.104* (1.64)		-0.234 (-4.47)	
Port_D	-0.398 (-3.68)		0.233* (6.70)	
PortG_D	-0.042 (-0.65)		-0.039 (-3.83)	
Rail_Densi		0.142** (2.99)		-0.185 (-2.20)

Road_Densi		0.300** (2.41)		0.389* (1.86)
Water_Densi		-0.002 (-2.48)		-0.003 (-1.90)
Air_Densi		0.119 (5.67)		0.154** (2.50)
Port_Densi		0.757* (3.50)		0.985 (1.96)
W Log(Innovation)	0.147** (2.54)	0.510*** (4.94)	0.174*** (4.27)	0.664*** (3.35)
W IPP	0.393** (0.21)	0.004** (0.05)	0.184* (0.40)	0.231** (0.27)
W TD	0.095** (2.67)	0.175* (1.79)	0.174* (5.14)	0.228*** (1.33)
R^2	0.604	0.619	0.672	0.770
R^2 (adj)	0.512	0.531	0.551	0.638
Significance in first stage	0.001	0.000	0.003	0.000
Wu–Hausmann test	0.014**	0.009*	0.012**	0.011***

Notes: ***Significant at 1% level, **at 5% level and *at 10% level.

5 Discussion and conclusions

The study examined whether the presence of well-developed transport systems and effective IPRs protection can promote innovation across cities in the YRDR. Overall, our results show that transport development and IPRs protection can help to explain the differences in urban innovation between cities in the YRDR. By applying the 2SLS method, we were able to address the endogeneity issue, as we focused on whether the positive relationships between strong IPRs protection and innovation, as well as transport development and innovation, were due to endogeneity or omitted variable bias. Moreover, we considered neighbour effects within the mechanism because of the evidence of spatial autocorrelation, and tested the empirical relevance of IPRs protection and transport development in explaining spatial innovation disparities within the YRDR by adding spatial weights. Our study expanded the literature on transport governance by introducing the IPRs institution into the equation, and showed that this makes a difference in terms of promoting regional growth through transport governance and institutional change.

Overall, our results show clear roles for IPRs protection and transport development in determining innovation disparities between cities. More specifically, the study comes to the following conclusions: first, in terms of IPRs protection, stronger IPRs protection is beneficial to patenting and R&D. This finding is consistent with those discussed in the existing studies (Greenhalgh and Dixon, 2002; Weinhold and Nair-Reichert, 2009); second, regarding transport stock, with the exception of water traffic (Water_Stock, Port_D, PortG_D), other types of transport development stock have a positive effect on innovation. This finding is consistent with the previous discussion which suggested that developed transport networks can promote innovation, because they offer cheaper transport and institutional costs to markets (Weinhold and Nair-Reichert, 2009); third, in terms of transport density, railway density is positively related to patent output, whereas it has no significant effect on R&D input. The impact of water traffic density on innovation is not significant. The effect of airport density on innovation input and output is significantly negative, while road density and port density are significantly positive.

In addition, through 2SLS analysis, the study finds some evidence that exogenous variation in transport development and IPRs protection has predictive power for urban innovation ability. That is, the causality in their relationship runs from transport development to innovation and from IPRs protection to innovation._More generally, there is also strong evidence of significant spatial innovation spillover effects. Therefore, cities can benefit from proximity to more innovative cities, according to the spatial effects analysis. Meanwhile, all the results indicate that agglomeration economies exist, including transport development agglomeration, IPRs protection agglomeration and innovation agglomeration. These findings also validate Ding's (2013) arguments, claiming that spillover effects exist for transport development and that different types of transport have differing influences on innovation.

Our results have potentially important policy implications. The current planning strategy of urban agglomeration in the YRDR is explicitly based on continuing technological innovation and improvement. It is hoped that the economic growth generated by technological advances and industrial agglomeration can then be used to promote the development of urban agglomeration in the middle reaches of the Yangtze River and Chengyu regions. However, the long-term success of this planning strategy relies crucially on the positive returns of IPRs protection and transport development. Meanwhile, the official planning strategy of urban agglomeration in the YRDR specifically mentions strengthening innovation, upgrading technology and building an integrated transport system. Given the YRDR's leading position within China, whether this planning strategy is successful has significance for China's overall Go West development strategy because Chengyu's urban agglomeration comes within western China. In this regard, future studies should increase the number, and refine the administrative dimensions, of cities, in order to obtain more data sets and more precise empirical insights so as to test the validity of 2SLS analysis on the existence of spatial spillover and agglomeration. Moreover, we are aware that using small samples may cause bias in the results obtained by the 2SLS method (Wooldridge, 2013). Although we decided that it was preferable to use the OLS method to generate the estimate on asymptotic grounds, and used 6,800 observations in the statistical model, the results derived from the 2SLS analysis should be interpreted with caution in relation to other contexts, given the limited dataset of 25 cities. Thus, future studies examining the role played by transport development in urban innovation should expand the sample size and regional scale. In addition, our study tested the impact of transport development and the IPRs institution on urban innovation at the macro-economic level. However, it does not distinguish the different functions of different transport modes in the context of the IPRs institution. Therefore, based on our analysis, future research could focus on a specific transport mode or compare different modes. Finally, regarding the implications for transport development and IPRs protection, although not all transport development is positively related to innovation, this does not negate the overall usefulness of transport development in understanding disparities between cities in terms of innovation.

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