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운송 파급효과가 항공네트워크와 지역경제에 미치는 영향*

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Transport Spillover Effect on Airport Networks and Its Impact on Regional Economy

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Abstract

Air transport is at the core of global economic growth. There is a close relationship between the flow of regional elements and the growth of the regional economy. It is easy to misestimate the impact of airports on the regional economy without considering spatial spillover effects. This study attempted to establish an asymmetric economic geographical weight matrix by applying the Spatial Durbin Model with cargo volume and passenger numbers as indicators. The influence of spillover effects on the regional economy, including direct spillover effects and indirect spillover effects are studied. The results revealed that passenger numbers and cargo volume have significant positive spillover effects on the regional economy. The driving effect of the airport on the regional economy was considered from a wider space scope. This study contributes to the scientific evaluation of the aviation economy.

Keywords: Economy of air transport, Spatial Durbin Model (SDM), Spatial spillover effect, Regional economic growth
JEL Classifications: C21,L93,R12,R58

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Ⅰ. Introduction

The good transport infrastructure and services have a positive impact on economic development is recognized by most scholars worldwide (Button and Lall, 1999; Button and Taylor, 2000; Ozbay et al., 2003; Lakshmanan, 2011). China's transportation infrastructure shows obvious spatial gradient, economic agglomeration, and obvious spatial dependence and heterogeneity (Yu et al., 2013; Qi et al., 2020).

Airports are considered strategic infrastructure (Percoco, 2010). According to data from the Air Transport Action Group (ATAG, 2019) , before the arrival of COVID-19, across the world, nearly generated more than 18.8 billion US dollars of economic and trade volume every day by air. Aviation provides over 65 million jobs around the world. In China, 6 million jobs were supported by air transport and tourists arriving by air. The economy created by these jobs has contributed US $78 billion to the GDP of China (International Air Transport Association (IATA) , 2019). At the same time, GDP development with steady growth has been observed in China: from $5.1 trillion in 2009 to $14.72 trillion in 2020 (National Bureau of Statistics, 2021). Driven by the economy, there were 241 civil aviation airports in China, with a passenger throughput of more than 41777.82 ten thousand and 676.61 ten thousand tons of cargo and mail throughput (Civil Aviation Administration of China (CAAC), 2021). The future development space is huge. It is, thus, very important to evaluate the efficiency of the airport scientifically to achieve the harmonization and common development of the regional economy and airport economy.

Any movement of transport facilities between regions carries an economic cost; that is, the transport cost of factors of production between regions cannot be zero. Therefore, there is no doubt about the spatial spillover of transportation facilities. The transportation points of the transportation network between different highways form the direct airports connecting the airports by air routes, so as to realize the transportation channels. Considering that the space spillover benefit between air networks is key to not overestimate or underestimate the effect of airport economic benefits, it is a pity that similar research in China is rare.

The present study aims to explore the following questions: 1. Is there a spatial spillover effect between China's airport networks? 2. If there is, what are the distribution characteristics of this spatial spillover effect? 3. Do spatial spillover characteristics match the current situation of airport distribution in China? 4. What is the guiding significance of the spatial spillover effect on the competitive and cooperative relationships between Chinese airports?

The structure of this paper is as follows: In the next chapter, we review similar research literature in China and abroad. In chapter 3, we review the theoretical background and architecture of the spatial economic and the selection of the spatial panel model. In chapter 4, we describe the data used, and the source of the variables then determines the final model. In chapter 5, the empirical data are discussed, along with the meanings of estimation results in econometric issues. Chapter 6 is a summary of the study and recommendations for the future development of aviation.

Ⅱ. Literature review

In general, convenient transportation networks have potential effects on regional economic development. Rosenstein-Rodan (1943) mentioned that the lack of transportation facilities is an obvious obstacle to economic progress. Transport infrastructure services may have an economic impact on the region in which they are located, and could also have an impact on other regions (Arbues et al., 2015). There are regional externalities in transport infrastructure, and the impact should not be limited to where the transport infrastructure is located but should also include other adjacent areas. The economic spatial spillovers from transport infrastructure have been extensively examined in practical studies (Zhou and Sun, 2016; Doerr et al., 2020). In China, from a regional point of view, the positive spillover effect of transportation infrastructure exists across the board, but at the national level, there are considerable differences across different periods (Jiang et al., 2017).

Air transportation is timely, rapid, and safe, and can quickly transfer individuals, goods, and services from one place to another. In recent years, due to the increasing cargo volume which are shipped by air around the world, the economic value and research value is also increasing. A long tradition of research has led to the economic impact of airports being divided into four main categories: primary effects, secondary effects, tertiary effects, and perpetuity effects (Button and Taylor, 2000; Percoco, 2010). From a short-term perspective, direct construction and operation of airports can create new service categories for suppliers of goods and services, create new jobs in the region (Brueckner, 2003; Blonigen and Cristea, 2015), and promote tourism and related services (Cohen and Paul, 2003; Wu et al., 2020). From a long-term perspective, airports, as the driving force of productivity growth, generate economic costs and benefits in international trade services, improve economic efficiency, provide new stimulus to the economy, and generate new investments (Debbage, 1999). Creating new government taxes could also improve economic well-being (Fu et al., 2018). Therefore, airport development is an important component of regional development (Kasarda and Green, 2005; Allroggen and Malina, 2014).

The relationship between aviation logistics and economic development is often proved causally by Granger causality test (Green, 2007; Baker et al., 2015; Fu et al., 2018). For the realization of the Granger causality test, it must be under the premise that the time series is stationary, and at the same time, it is easy to be affected by the results of predicting variables by interfering variables. However, spatial interdependence does not necessarily involve shared geographical boundaries, and airports are linked from the point of view of spatial transport networks (Cohen and Paul, 2003). The overlap between air transport and other transport infrastructure and networks, as well as factors such as the population in these areas, has interfered with this relationship (Breidenbach, 2020). Since, Granger causality test cannot be used as a real and effective judgment basis for testing causality because it is only applicable to the prediction of variables in econometrics.In this causal relationship, the most important thing is to ignore the spillover effect of the airport in spatial distribution. Because of the strong interdependence, it is difficult to estimate the economic benefits of the aviation (Blonigen and Cristea, 2015). Unfortunately, because of the small amount of air transport, many studies have overlooked it (Ozbay et al., 2003; Li and Qi, 2016). Although some studies include aviation, because of China's vast territory, the study area is often divided into three (Jiang et al., 2017; Qi et al., 2020) or four macro-regions (Yu et al., 2013). The linkage of the studied area is too extensive and empty to be representative. There is a great difference between the spatial network connection between specific cities and the relationship between the key macro-regions. From the point of view of the spatial spillover effect, there is little research on the influence of route networks on the regional economy. Therefore, it is necessary and meaningful to study and understand the competition and cooperation between airports in a spatial manner to support regional economies.

Ⅲ. Theoretical background

1. Spatial econometric model

The rapid development of geographic information technology has prompted many scholars to pay attention to the spatial location factors in the field of regional development. Anselin (1988) proposed spatial interaction as a construct, spatial structure of economic activities were brought into the consideration through the lens of econometrics, and the spatial econometric model was established. Due to the spatial correlation and spatial heterogeneity, the spatial measurement model was divided into Spatial error model (SEM), Spatial lag model (SLM), and Spatial Durbin Model (SDM). Because SLM is similar to autoregressive models in time series, it is also called Spatial autoregressive model (SAR).

SAR is primarily used to measure the spatial spillover effect of dependent variables.

$$Y_{it} = p^* \sum_{j=1}^{N} W_{ij} Y_{it} + X_{it} \phi_i + \psi_i + \eta_i + \theta + \epsilon_{it} \quad (1)$$

Note: Yit were observations of dependent variables in i area during the t period (i=1,2,..., N; t=1,2,..., T;); Weight matrix: Wij was N × N orders; $\sum W_{ij} Y_{it}$ measured the spatial spillover effect of dependent variables; p was the coefficient; Xit represented each explanatory variables; ϕi was the variable regression coefficient; ψi & ηi was the regional fixed effect and the time fixed effect respectively; θ was a constant term; ϵit was error term.

SEM : Spatial dependence of reaction error terms:

$$Y_{it} = X_{it}\phi_i + \psi_i + \eta_i + \theta + \tau_{it}$$
$$\tau_{it} = \lambda^* \sum_{j=1}^{N} W_{ij}\tau_{it} + \epsilon_{it} \quad (2)$$

Note: τit was the error term; $\sum W_{ij}\tau_{it}$ was error impact; λ was the coefficient.

Refer to Eq. (1) for the meaning of the other indicators.

SDM contained the spatial lag term of the dependent variable and the spatial lag term of explanatory variable.

$$Y_{it} = p^* \sum_{j=1}^{N} W_{ij} Y_{ijt} + X_{it} \phi_i + \delta^* \sum_{j=1}^{N} W_{it} X_{ijt} + \theta + \phi_i + \eta_i + \epsilon_{it} \quad (3)$$

Note: Wit was the N*N order spatial weight matrix; $\sum W_{ij} Y_{ijt}$ measured the impact of air passenger throughput and cargo volume in one region on the economies of other regions. Refer to Eq. (1) for the meaning of the other indicators.

The reasonable setting of the spatial model is the basis of spatial measurement analysis and reflects the economic spatial relationship comprehensively. SDM is better able to explain the relationship between spatial variables. At the same time, it can better reduce the deviation of parameter estimation of endogenous and exogenous interaction effects, can eliminate or lead to omitted related variable problems, and does not impose prior restrictions on the influence of spatial spillover (LeSage and Pace, 2010). Therefore, SDM is often considered the best model available in this study.

2. Spatial weight matrices

When conducting spatial analysis, it is required to select the appropriate weight matrix to reflect the intensity of the geographical relationship between observations. This is different from the selection of general spatial matrix in other research (Yang and Wong, 2012; Qi et al., 2020). The asymmetric economic geographical weight matrix was used to measure the scale of the spillover effect under the distance between geography and economy in this study.

According to the first law of geography, everything is interrelated, but the relationship between adjacent things is closer than that between distant things (Tobler, 1970). Therefore, the first spatial weight matrix W1 used the distance weight matrix (Pace & Barry, 1997) to define the adjacency in the relationship of spatial objects. The diagonal element is 0, and the other matrix elements are the square of the reciprocal of the straight-line distance between the two cities' latitude and longitude. Taking into account the effects of geographic extent between transport networks by different means of transport, the threshold distance was set in advance. There is a competitive impact of high-speed rail on the aviation network. Chen (2017) proposed that, in China, after covering high-speed rail services in the 500-800 km range connecting to the main hub, the capacity of passengers and flights and seats has been significantly reduced. The effect of high-speed rail on aviation substitution is obvious. Considering that this study uses data from 2009 to 2019, the distance is set at 800 km for the consideration of time change. Perform further matrix transformation processing on the previously set matrix, where the diagonal elements are still 0.

$$W_1 = W_{ij} = \begin{cases} 1, & d_{ij} > 800 \\ 0, & d_{ij} \le 800 \end{cases} \tag{4}$$

Note: dij was the distance between two airports; Wij referred to the spatial connection between regional i and regional j.

The final spatial weight matrix was the asymmetric economic geographical weight matrix with regional differences. Economic spatial weight matrices also be set in this matrix, as they are used with respect to social and economic factors. This approach was more complex to set, depending on GDP, traffic, capital flows, and even social networks. The matrix of the principal diagonal element E was 0, the other was the ratio between the average GDP per capita in the two regions. The spatial weight matrix with economic distance was closer to the reality of the regional economy. In reality, economically developed cities usually had greater spatial spillover effects ($W_{ij} \neq W_{ji}$). As a result, the economic geographical weight matrix with regional differences W2 was constructed.

$$W_2=W_1*diag(\frac{GDP_i}{GDP_a}) \quad (5)$$

Note: diag $(\frac{GDP_i}{GDP_a})$was the diagonal matrix; GDPi was the GDP of the city i, where the airport was located; GDPa represented the average GDP of all cities.

Ⅳ. Variables Described and Econometric Model

Gao (2020) showed that, with respect to the Variance Inflation Factor (VIF) of the test variables, the collinearity between air cargo volume and air passenger volume was strong. Therefore, in the analysis model, the explanatory variables and their spatial spillover effects are analyzed separately to ensure accuracy and objectivity of the results. The two changes showed a new attempt. All the data were analyzed using Stata 16.

According to the above analysis, the empirical model of this study was

$$\begin{aligned} InY_{it} &= \alpha WInY_{it} + \delta_1 WInpassenger \\ &+ \delta_2 WInjob + \delta_3 WInti \\ &+ \delta_4 WInsecond + \delta_5 WInthird \\ &+ \beta_1 Inpassenger + \beta_2 Injob \\ &+ \beta_3 Inti + \beta_4 In second \\ &+ \beta_5 Inthird + \theta + \epsilon_{it} \end{aligned} \quad (6)$$

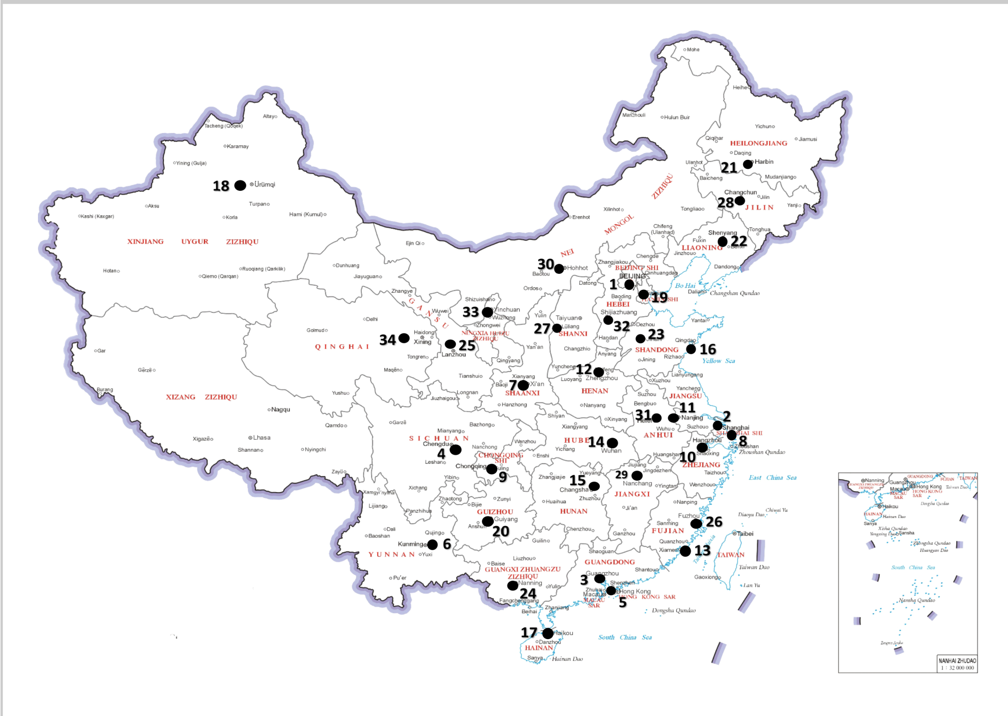
$$\begin{aligned} InY_{it} &= \alpha WInY_{it} + \delta_1 WIncargo \\ &+ \delta_2 WInjob + \delta_3 WInti \\ &+ \delta_4 WInsecond + \delta_5 WInthird \\ &+ \beta_1 Incargo + \beta_2 Injob \\ &+ \beta_3 Inti + \beta_4 In second \\ &+ \beta_5 Inthird + \theta + \epsilon_{it} \end{aligned} \quad (7)$$

Note: W was the spatial weight matrix; α, δ, β was the coefficient. θ was a constant term; ϵit was error term. InY was the regional GDP indicator; Incargo represents the airport air cargo, postal throughput; Inpassenger represents the air passenger throughput; Injob represents number of employees in transport, warehousing, and postal services, Inti represents tourism income; Insecond represents the proportion of secondary industry increment in GDP; Inthird represents the proportion of tertiary industry increment in GDP.

1. Data

China has a vast territory of 34 provincial administrative regions. This includes 23 provinces, five autonomous regions, four municipalities directly under the central government, and two special administrative regions. Based on the availability and integrity of the data, this research intercepted provincial capital cities of 30 provinces (provincial capitals, municipalities directly under the central government, and autonomous regions). We also considered that some provinces may have two large airports due to economic development, and that the proportion of total transport volume of both airports' cargo and passenger throughput was large, and its economic impact cannot be ignored. According to the CAAC report "Civil Aviation Airport Production Statistics Bulletin in 2019," based on the passenger-cargo throughput ranking of the top 20 in the country, four analysis

Fig. 1. Map of airports distribution in China



Note: Refer to the Appendix for the airports and regions represented by the serial numbers

objects were added.

There are 34-panel cross-section objects, as described in Figure 1. Statistical descriptions of the variables are given in Table 1. Considering the financial crisis in 2008 and the COVID-19 in 2020, the huge impact of the external environment on the economic and aviation development, the data is not stable, so the time series will be set as 2009-2019. Based on the time series panel data of 11 years, the InGDP represented economic development (Yu et al., 2013), and air cargo, postal throughput (Incargo) and air passenger throughput (Inpassenger) (Ozcan, 2013; Chen et al., 2021) represented the development of China's Airports. The novelty of this study lies in its innovations in the selection of control variables, which include the following: (1) Number of employees in transport, warehousing, and postal services (Injob): This indicator includes all employees in air transport activities. It is the best representative index of aviation-related practitioners in a city, which can show the influence of space transportation spillover on urban employment. (2) Tourism income (Inti): Unlike the simple use of the number of tourists (Chen et al., 2021) and hotel visitors (Button and Yuan, 2013), considering that international tourists are more likely to travel by plane, this research uses the foreign exchange income from international tourism in each province/the number of international tourists received by each province as an indicator to measure the city's attractiveness. (3) The proportion of secondary industry

Table 1. Descriptive statistics of each variable (2009-2019)

Variables	Definition	Unit	Max	Min	Mean	S.D.
InGDP	City GDP	Billion RMB	4.580	2.690	3.728	0.398
Inpassenger	Airport passenger throughput	10,000 people	8.004	6.121	7.175	0.364
Incargo	Airport cargo, and postal throughput	10,000 tons	6.582	3.873	5.204	0.535
Injob	Number of employees in transport, warehousing, and postal services	10,000 people	5.128	0.320	1.351	0.316
Inti	Tourism income (City attraction)	Dollars/ Person	3.677	2.287	2.777	0.218
Insecond	The proportion of secondary industry increment in GDP	Billion RMB	4.021	2.078	3.329	0.39
Inthird	The proportion of tertiary industry increment in GDP	Billion RMB	4.474	2.367	3.460	0.428

Source: National Bureau of Statistics, Civil Aviation Administration of China (2009-2019)

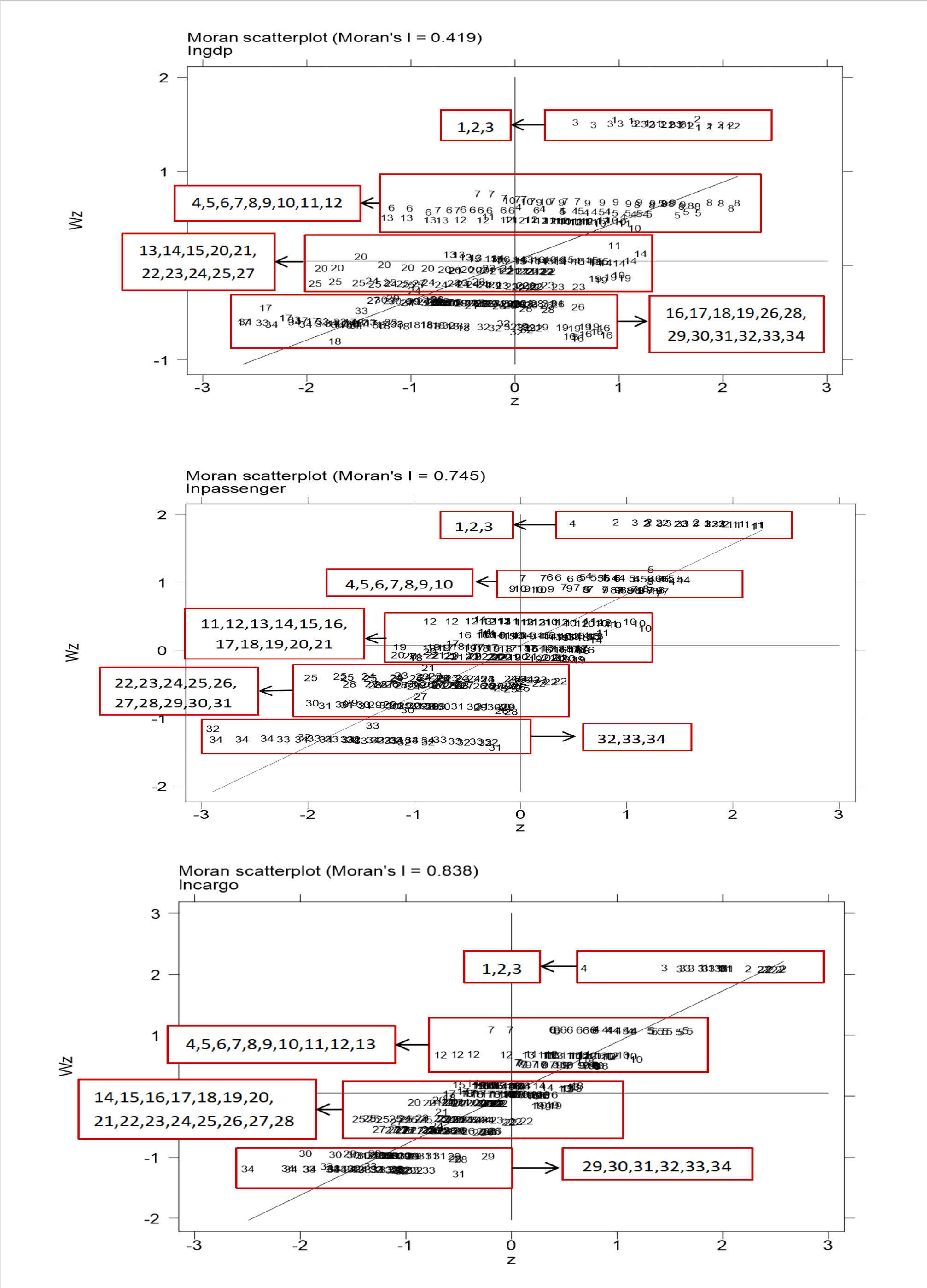
increment in GDP (Insecond): In China, the aviation industry belongs to the secondary industry. This research uses the added value of the secondary industry to reflect the impact of the aviation industry economy. (4) The proportion of tertiary industry increment in GDP (Inthird): Aviation has a link between the value-added of the tertiary industry (Yang and Cui, 2018). By using the value-added of the tertiary industry, this research indicates the value-added change of the service industry in an area.

Data used was from the National Bureau of Statistics, CAAC Publication of the Civil Aviation Airport Production Statistics Bulletin. Due to insufficient official statistics and unguaranteed data consistency, a linear complement in Stata is used to complement the missing value in the data within a reasonable range. To eliminate the difference caused by the different units of statistical variables, the natural logarithm is carried out in Stata to ensure the maximum unification of the data and reduce heteroscedasticity.

2. Model test

Moran's I was first used to test whether the object had a spatial correlation. In the construction of the Moran index model, this study does not use the traditional Moran index test method. Instead, a panel model was added to the Moran test, which takes into account the spatial relationship between variables. The results (see Table 2) showed that the Moran index was positive, passed the 1% significance test, and had high aggregation. Also, as shown in Figure 2, the Moran space plot of the three variables showed a huge positive spatial agglomeration, especially concentrated in the first quadrant (low-low agglomeration) and the fourth quadrant (high-high agglomeration). Cities clustered in the fourth quadrant tend to develop faster and have higher economic maturity than cities clustered in the first quadrant. Therefore, we can think that this phenomenon is basically in line with the development status of the selected airport cities.

Fig. 2. Moran scatter plots (lnGDP, lnpassenger and lncargo, 2009-2019)



Note: Refer to the Appendix for the airports and regions represented by the serial numbers

Table 2. Model test results

Variables			Moran's I test	Incargo	Inpassenger
Moran's I test	-	Moran's I	0.419 (0.000)***	0.838 (0.000)***	0.745 (0.000)***
	-	Geary's c	0.530 (0.000)***	0.135 (0.000)***	0.295 (0.000)***
LM Test	Spatial Error	Moran's I	-	9.099 (0.000)***	11.087 (0.000)***
		LM	-	43.687 (0.000)***	84.864 (0.000)***
		RLM	-	44.006 (0.000)***	87.676 (0.000)***
	Spatial Lag	LM	-	0.013 (0.088)*	2.078 (0.049)**
		RLM	-	0.332 (0.074)*	4.891 (0.027)**
Hausman Test	-		-	23.62 (0.003)***	20.59 (0.001)***
LR Test	Time/Ind/Both		-	36.55 (0.000)***	31.71 (0.000)***
	SDM vs SAR		-	104.57 (0.000)***	110.01 (0.000)***
	SDM vs SEM		-	73.87 (0.000)***	79.91 (0.000)***
Wald Test	Spatial Error		-	117.58 (0.000)***	123.81 (0.000)***
	Spatial Lag		-	32.63 (0.000)***	29.34 (0.000)***

Note: The P-value are in parentheses; *p<0.1, **p<0.05, ***p<0.001.

Burridge (1980) proposed the Lagrange Multiplier (LM) model to determine whether there is a spatial lag dependency or spatial error dependency. The results (see Table 2) showed that on the whole, SEM and SAR effects exist in the model effect, so the SDM model can be considered. Mutl and Pfaffermayr (2011) proposed the fixed and random effect spatial lag term of the panel data model and tested it with the Hausman test. Table 2 showed the assumption that the fixed coefficient was greater than the random coefficient. The results all passed the significance test. Therefore, the fixed effect model was considered the best choice. Likelihood Ratio (LR) test, the joint significance of spatial and temporal periodic effects based on ordinary least squares (OLS) regression test without considering spatial interaction effects is applied. The LR test here detects whether the model should be time-fixed, individual-fixed, or both-fixed. The results are shown in Table 2 that the SDM model cannot be simplified to SAR or SEM model. On the other hand, the hypothesis of the both-fixed model was rejected, and the individual fixed values were significant. Therefore, in the final model, the individual fixed model was more suitable. Finally, the Wald test needs to be done to test the model whether can be simplified to SAR or SEM. The test results (see Table 2) showed that both the SAR and SEM effects passed the significance test. Therefore, the SDM fixed model was the most suitable model for this research.

Because the spatial econometric model contains two matrices to explain the spatial correlation between the dependent variable and the independent variable, the total effect coefficient of an explanatory variable to the explained variable is not equal. To explain the coefficients of the spatial econometric model and illustrate the effects of spillover effects carefully, LeSage and Pace (2010) proposed the decomposition of the influence coefficient by using the spatial regression model partial differential method to calculate the direct, indirect, and total impacts. This research adopts the same analytic method.

Ⅴ. Empirical Results and Analysis

The coefficient of WX refers to the spatial correlation of variables between regions after weighting, which specifically shows the spatial spillover effect. From the results in Table 3, it can be seen that the passenger throughput (0.394) and cargo throughput (0.341) both passed the 1% significance test, which had a significant positive spatial effect on regional economic development. Except for the statistical results of the secondary industry are not significant, the rest of the variables have passed the 5% and 10% significance tests. The number of employees in air transport had a strong negative spatial correlation, the rest of the index indices showed positive effects. The R-Squared values of the two models were 0.933 and 0.941. In other words, the models fit well, and the explanatory variables can fully reflect the changes in the degree of explanatory variables. This result fully confirmed that there was a spatial spillover effect between airport transportation networks, the air transportation network produces scale benefits through external connections. The air transport network eliminates the boundaries of urban transport geographic boundaries, interconnects transport markets, reduces costs, and promotes inter-regional economic development.

As mentioned above, the relationship coefficient in the spatial effect relationship is difficult to interpret because of the weights given to the spatial model. In order to explore the reasons for this result, we analyze the results more carefully. First, the direct effect is produced by the average value of the diagonal elements of the matrix, which is the effect of the change of the explanatory variable in this region on the explained variable. In addition, the direct effect not only includes the influence of the independent variable in the region on the dependent variable, but also includes the feedback effect, that is, other regions are affected by the variables in the region, which in turn have an impact on the region (Chen et al., 2021). This is also the main reason why the coefficients of the models are different. As shown in the results in Table 3, except for aircraft passenger throughput and city attractiveness, which failed the significance test, the rest of the explanatory variables passed the significance test, which had a significant positive effect on the development of the regional economy. On the basis of the continuous expansion of air cargo throughput in the region, the continuous increase in the number of employment in the aviation industry and the

Table 3. Results about air cargo and postal / passenger throughput in SDM

	WX	Direct	Indirect	Total
lnpassenger	0.394(0.000)***	−0.008(0.657)	0.293(0.000)***	0.285(0.000)***
lnjob	−0.406(0.000)***	0.043(0.001)***	−0.309(0.000)***	−0.266(0.000)***
lnti	0.408(0.000)***	0.009(0.284)	0.296(0.000)***	0.306(0.000)***
lnsecond	0.226(0.879)	0.605(0.000)***	−0.153(0.000)***	0.452(0.000)***
lnthird	0.406(0.024)*	0.070(0.000)***	0.271(0.000) ***	0.342 (0.000)***
rho		−0.388(0.059)*		
R-Squared		0.933		
lncargo	0.341 (0.000)***	0.032 (0.018)**	0.305 (0.001)***	0.337 (0.001)***
lnjob	−0.273 (0.003)**	0.042 (0.001)***	−0.247(0.004)***	−0.204(0.018)**
lnti	0.266 (0.005)***	0.007 (0.400)	0.235 (0.008)***	0.242 (0.007)***
lnsecond	−0.161 (0.181)	0.597 (0.000)***	−0.215(0.000)***	0.382 (0.000)***
lnthird	0.429 (0.008)***	0.072 (0.000)***	0.366 (0.000)***	0.438 (0.000)***
rho		−0.137 (0.056)*		
R-Squared		0.941		
Observations		374		
No.groups		34		

Note: The P-value are in parentheses; *p<0.1, **p<0.05, ***p<0.001.

continuous development of the secondary industry and the tertiary industry will not only have a positive effect on the economic development of the region, but also have a positive impact on neighboring regions. The economic development of the region plays a driving role. Due to the feedback effect, the economic development of the region will be stimulated by the economic development of the neighboring region and further develop.

The indirect effect (also known as the spatial spillover effect) results from the row average of the off-diagonal elements of the matrix specified earlier. It pays more attention to measuring the influence of the change of a variable in the adjacent area on the economic development of the airport area, which is also the main purpose of this research. It can be seen from the results all the variables passed the 1% significance test, the development of cities adjacent to the airport has a very significant effect on the economic promotion of the airport area. Indirect effects outperformed direct effects, indicating that the spatial role of aviation cannot be ignored.

There was a negative spatial relationship between the secondary industry and the aviation industry personnel, the competition for talents and resources between the two regions. This is in accord with the present situation of China. The development of the secondary industry had a negative spatial spillover effect, while the tertiary industry had a positive promotion effect, which is considered for the following reasons. The resource flow and consumption brought about by the aviation may cause some resource competition and economic diversion between the region and the adjacent areas.

It leads to differences and imbalances in economic development among different regions. Different from the positive correlation effect shown by other variables, the negative effect here is more inclined to the difference caused by time. The positive economic stimulus brought by the development of the aviation industry to the regional economy may be more inclined to long-term cyclical performance, so negative spillover effects are observed in the short term. A city can reap significant benefits if it can attract high-level employment. The airport is a highly attractive technology infrastructure and an important catalyst for high-tech growth (Button and Lall, 1999). In most cases, people in the area adjacent to the airport may travel to the area for professional services (Cidell, 2015). The spillover of human capital to the economic development of the surrounding areas is gradually enhanced because of the “causal cycle” of economic development and talent reserve and the “siphon effect” of regional economic distribution of human resources. A variety of factors, thus, lead to the movement of aviation workers and regional distribution imbalance. How to promote the rational distribution of employment resources in local and adjacent areas has become an important issue.

The total effect is the sum of the direct effect and the indirect effect, which mainly explains the average impact of the variation of the explanatory variable in a certain region on the explained variable in all regions. Air passenger throughput (0.285) and cargo and mail throughput (0.337) passed the 1% significance test, the impact on economic development was actively promoted, and the rest of the variables also passed the significance test. As with the other results, aviation workers here also show a competitive relationship in the region. Infrastructure was a fundamental determinant of national tourism flows (Doerr et al., 2020). Rich commodity reserves have attracted increased levels of infrastructure building and services, which increases urban attractiveness. The expenses that tourists must occur in the process of tourism and the consumption expenditure that may occur in during this process bring huge trade profits. The effect of tourism flows has contributed to the flow of goods, which has increased regional sales. Regional tourism expenditure has a multiplier effect on other industries, which promotes the rapid development of the regional economy. In cities with a high share of the tourism market, it is also possible for neighboring cities to gain access to the market, improve and promote the agglomeration and diffusion of economic activities, affect the industrial distribution, and produce positive spillover effects. The interaction of the explanatory variables creates a good cycle with regional economic development.

Ⅵ. Conclusion and discussion

An asymmetric economic geographical weight matrix was constructed in this research and the 34 main airports in China from 2009 to 2019 were analyzed in an SDM model. The goal was to explore the spillover effects of airport connectivity on the regional economy. The development of China's major airport network, including the development of air passenger throughput and air cargo and mail throughput, had obvious positive spatial spillover effects. The development of the airport had an important role in promoting the economic development of the airport area or the adjacent area. The development of airport services can cross the economic restrictions on size, scope, density, and a wide range of aviation networks to provide more direct and excellent services.

Overall, air cargo and mail throughput had a more significant impact on regional economic development than air passenger throughput. This showed that developing network connectivity in the air cargo market was more important than expanding air passenger throughput. The results were different from other studies (Chen, 2021). This may be due to the symbiosis between variables. At the same time, indirect effects (spillover effects) are stronger than direct effects. It is considered that, compared with the promotion effect of the airport development in the airport area itself, the stimulating effect brought by the development of the airport in the adjacent area is greater. In fact, through the connection of the airline route networks, the operation cost of economic factor input between cities was reduced, which can promote the resource flow and resource allocation across regions in a wider range and stimulate the development of the GDP.

The aviation industry's requirements for high-quality talents can easily lead to the competition of aviation talents between regions and the emergence of regional economic development competition. Aviation brings about economic growth at the expense of other regions (Yu et al., 2013). The government should take into account the employment competition relationship between airports, formulate more realistic employment policies, ensure the employment rate of aviation professionals, and invest in airports reasonably. When the government evaluates airport benefits, the spatial relation and spillover effects should be fully taken into account to exert the overall scale effect of air transportation. Airlines should also maintain and develop more tourist or commercial routes. Joint efforts by all the various industries in the region should ensure rational and scientific cross-regional flows of resources, reduce regional economic differences, and increase the sustainable development of resources.

The complete data is missing due to force majeure in this research. The data collected only covers a limited period of time; the long-term cycle is not well-reflected. Some other influencing factors that may affect regional economic development, such as airport routes, investment levels, population size, and national policies, were not taken into consideration in the analysis. These have been identified as factors associated with regional economies and airports (Cheung et al., 2020). With the development of continuous research and the collection of statistical updates, there is hope that we can do a deeper analysis in the future.

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Appendix. Basic information about the airport

Id	Airports	Region
1	Beijing Capital International Airport	Beijing
2	Shanghai Pudong International Airport	Shanghai
3	Guangzhou Baiyun International Airport	Guangzhou
4	Chengdu Shuangliu International Airport	Sichuan
5	Shenzhen Bao'an International Airport	Guangzhou
6	Kunming Changshui International Airport	Yunnan
7	Xi'an Xianyang International Airport	Shannxi
8	Shanghai Hongqiao International Airport	Shanghai
9	Chongqing Jiangbei International Airport	Chongqing
10	Hangzhou International Airport	Zhejiang
11	Nanjing Lukou International Airport	Jiangsu
12	Zhengzhou Xinzheng International Airport	Henan
13	Xiamen Gaoqi International Airport	Fujian
14	Wuhan Tianhe International Airport	Hubei
15	Changsha Huanghua International Airport	Hunan
16	Qingdao Liuting International Airport	Shandong
17	Haikou Meilan International Airport	Hainan
18	Urumchi Diwopu International Airport	Xinjiang Uygur
19	Tianjin Binhai International Airport	Tianjin
20	Guiyang Longdongbao International Airport	Guizhou
21	Harbin Taiping International Airport	Heilong Jiang
22	Shenyang Taoxian International Airport	Liaoning
23	Jinan Yaoqiang International Airport	Shandong
24	Nanning Wuxu International Airport	Guangxi
25	Lanzhou Zhongchuan International Airport	Gansu
26	Fuzhou Changle International Airport	Fujian
27	Taiyuan Wusu International Airport	Shanxi
28	Changchun Longjia International Airport	Jilin
29	Nanchang Changbei International Airport	Jiangxi
30	Hohhot Baita International Airport	Inner Mongolia
31	Hefei Xinqiao International Airport	Anhui
32	Shijiazhuang Zhengding International Airport	Heibei
33	Yinchuan Hedong International Airport	Ningxia
34	Xining Caojiapu international airport	Qinghai