Industrial Engineering and Innovation Management (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/ieim.2022.050801
ISSN 2522-6924 Vol. 5 Num. 8

Research on Spillover Effect of Airport on Urban Economy Based on Spatial Durbin Model

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Keywords: Hub Airport, Urban economy, Spillover effect, Spatial Durbin Model

Abstract: Airport plays an important role in urban economic development. With the rapid development of China's air industry and the accelerating process of hub airport construction, more and more attention has been paid to the relationship between airport and urban economy. Considering the spatial factor, this paper constructs a Spatial Durbin model based on the mixed spatial weighting matrix to study the spatial spillover effects of airports on urban economic development and 38 hub airports in China from 2001 to 2019 have been selected for research. The influence of airport has been further divided into direct, indirect and total effect. The results show that the airport not only has a positive direct impact on the local economy, but also has a significant positive spillover effect on neighboring cities connected by the air network. The total effect of the airport on urban economy would be underestimated when the spatial spillover effect is not taken into account.

1. Introduction

In recent years, China's civil aviation industry has developed rapidly and gradually formed an air passenger travel network with the hub airport as the core. While providing passenger travel services, air transport, as a strategic and leading industry, plays a more and more important role in promoting local economic development. A convenient air transport network can reduce transport time costs, improve transport efficiency, and expand the service market on a larger scale. As the gateway for the city to enter the air transport, airport can meet the travel needs of passengers, increase urban employment, promote the development of related industries which further promote the economic development.

The development of air transport not only greatly shortens the space-time distance between cities, but also strengthens the social and economic ties between cities. The first Law of Geography proposed by Tobler (1970) holds that " Everything is related to everything else, but near things are more related than distant things". Nooteboom (1970) believes that convenient transportation can minimize spatial, cognitive and cultural distance, thus becoming the key to knowledge exchange. As the gateway node of the air transport network, the contribution of the airport to the economy is not limited to the promotion of the local economy. Air transport has changed the accessibility between cities, means of production such as labor, capital and technology can achieve a wider and more efficient flow by air network. Li (2017) believe that the airport, as a network node, has a spillover effect on urban economic development to a certain extent, and urban economic development shows a significant spatial dependence.

The relationship between airport and economic development has been studied by many researchers. Sun S (2011) demonstrated that airport had a great impact on economic growth by analyzing the relationship between airport transportation development and economic growth. Brueckner (2003) studied the relationship between air passenger traffic and service industry’s employment in American metropolitan area by establishing a cross-sectional data model. Vijve (2016) studied the Granger causality between European air industry and regional economy and found that there is a strong correlation between them. However, most of studies before are still based on traditional econometric models and focus on the relationship between air transport and urban internal factors of production. There are less attention to the impact of spatial factors in urban economic development and absence of research on spillover effects. In facts, cities are related to each other, and no one can be independent during development which makes the results estimated by the traditional econometric model deviate. Few studies considered the spatial spillover effect and most of them did not take into account the impact of air transport on urban spatio-temporal distance. Considering the spatial spillover effects of airports, this paper establishes a spatial Durbin model to measure the direct, indirect and total effects of hub airports on urban economic development

2. Methods

2.1. Data

In the "Thirteenth five-year Plan for the Development of China's Civil Aviation", it is clearly proposed to build ten international air hubs, including Beijing, Shanghai and Guangzhou, and 29 regional hub airports. Hub airport is a key node in air transport network. Considering the integrity and representativeness of data, 38 hub airports above except Lhasa was selects for research from 2001 to 2019. As shown in the Fig.1, the hub airports have a great representativeness which is account for a large proportion (more than 86%) in the whole airports.

The prices indices are adjusted based on the year 2000. And for the case that there is more than one airport in a city, the air traffic data are merged.

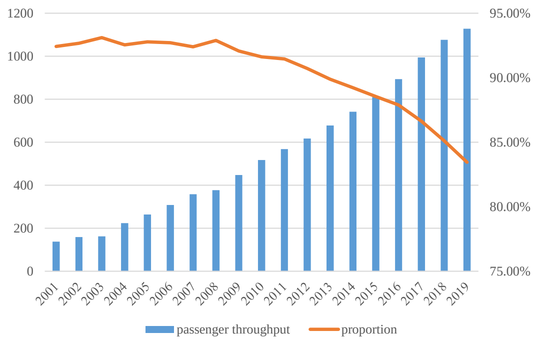

Figure 1: Passenger traffic of 38 hub airports

For dependent variable, GDP was selected to show the level of economic development, and the airport passenger traffic as the independent variable. There are also many factors affecting urban economic development. Based on the previous studies, we selected following control variables: export was used to represent urban openness; meanwhile we also control consumption, fiscal expenditure and employment.

2.2. Spatial Auto-correlation

Before using spatial analysis method, it is necessary to examine whether the data are spatially dependent. The results obtained by the classical linear regression model would have a deviation when the variables are spatially dependent. Spatial econometric model can effectively eliminate the deviation caused by spatial factors and better measure the spatial effects between variables.

Spatial auto-correlation test is often used to determine whether there is a spatially dependent among the variables. If there is, a spatial econometric model is constructed to research. In this paper, Moran's I index (Moran, 1950) was used to test the spatial dependence as follows:

$$\text{Moran I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{1}$$

Where x_i, x_j are variables of sample i and j in research, $\bar{x} = \frac{1}{n}\sum_{j=1}^{n} x_i$ was the average of all variables, $S^2 = \frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n}$ was the variance, and w_{ij} was the element of the spatial weight matrix W, which is used to measure the distance between i and j. $\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$ is the sum of all the spatial weights elements.

The range of $Moran\ I$ is between -1 and 1. When $Moran\ I$ is greater than 0, there is a positive correlation between variables. When $Moran\ I$ is less than 0, there is a negative correlation between variables. The greater the absolute value of $Moran\ I$, the higher the degree of spatial correlation. When $Moran\ I$ equals 0, it indicates that the spatial distribution between variables is random, and there is no spatial auto-correlation among the variables.

2.3. Spatial Weighting Matrix

It is the premise of spatial econometric analysis to measuring the spatial "distance" between cities. $\{x_i\}_{i=1}^{n}$ was the spatial data from n cities, where i was represented city. w_{ij} pictured the distance between city i and city j, and then the spatial weighting matrix W was defined as follows.

$$W = \begin{pmatrix} w_{11} & \cdots & w_{1j} \\ \vdots & \ddots & \vdots \\ w_{i1} & \cdots & w_{ij} \end{pmatrix} \tag{2}$$

The element on the main diagonal in matrix W are all equal to 0, that is $w_{11} = \cdots = w_{ij} = 0$.

The spatial weight matrix is usually constructed in the form of distance function such as 0-1 binary adjacency matrix or inverse distance space matrix. The 0-1 matrix is built up according to whether the nodes are adjacent, that is, if there are common edges. If node i and j are adjacent, $w_{ij} = 1$, if not, $w_{ij} = 0$. The inverse distance spatial weight matrix reflects the influence of the distance between nodes on the spatial correlation. The spatial weight matrix element $w_{ij} = 0$ when $i = j$ and $w_{ij} = 1/d_{ij}$ when $i \neq j$.

Zhang (2014) proposed that the composite space matrix can better reflect the effectiveness of model estimation than a single distance or adjacency matrix. In this paper, the compound spatial weight matrix W is constructed by using the combination of passenger traffic and distance, as follows.

$$W = V \times P$$
$$= \begin{pmatrix} v_{11} & \cdots & v_{1j} \\ \vdots & \ddots & \vdots \\ v_{i1} & \cdots & v_{ij} \end{pmatrix} \times \begin{pmatrix} p_{11} & \cdots & p_{1j} \\ \vdots & \ddots & \vdots \\ p_{i1} & \cdots & p_{ij} \end{pmatrix} \quad (3)$$

Where V is the distance weight matrix and P is the matrix based on airport passenger traffic. Considering the competition from high-speed rail for air transportation, the 800km is used as the distance threshold to construct the distance weight matrix, and the matrix element v_{ij} are as follows:

$$v_{ij} = \begin{cases} 0, if\ d_{ij} > 800 \\ 1, if\ d_{ij} \leq 800 \end{cases} \quad (4)$$

Where d_{ij} is the distance of the great circle of the earth between i and j. Suppose that the latitudes of city i and j are θ_1 and θ_2 respectively, the longitude difference is φ, then $d_{ij} = R \cdot \arccos(cos\theta_1\ cos\theta_2 cos\varphi + sin\theta_1 sin\theta_2)$, where the radius of the earth is R=6371km.

P is the airport passenger traffic matrix, and the values of the matrix element p_{ij} are as follows:

$$p_{ij} = \begin{cases} \frac{\overline{p_j}}{\overline{p_i}}, if\ i \neq j \\ 0, if\ i = j \end{cases} \quad (5)$$

Where $\overline{p_i}$, $\overline{p_j}$ were represented the average passenger traffic of airports in city i and j, respectively. The matrix P is a non-pair matrix, which reflects the difference of the interaction between airports in i and j. The higher the $\overline{p_j}/\overline{p_i}$ is, the greater the impact of airport in j on the airport in i is.

2.4. Spatial Durbin Model

Considering the influence of spatial correlation, a spatial Durbin model was constructed for empirical analysis, and its general form is as follows:

$$y = \alpha t_n + \lambda Wy + X\beta + WX\delta + \varepsilon, \varepsilon \sim N(0, \sigma^2 I_n) \quad (6)$$

Where α is a constant term, t_n is the unit vector. W is the spatial weight matrix; X is the independent variable matrix, $WX\delta$ represents the influence from the neighbor independent variable; Wy is the spatial lag dependent variable, and λWy represents the influence of the interpreted variable from neighbor. λ, β and δ are the corresponding coefficient vectors, and $\varepsilon \sim N(0, \sigma^2 I_n)$ is the random error term.

The spatial econometric model pays more attention to the spatial effect of variables. Formula (6) can be converted into:

$$y = (I - \lambda W)^{-1}\alpha t_n + ((I - \lambda W)^{-1}(X\beta + WX\delta) + (I - \lambda W)^{-1}\varepsilon \quad (7)$$

From (7) we know that:

$$(I - \lambda W)^{-1} = I + \lambda W + \lambda^2 W^2 + \lambda^3 W^3 \cdots (8)$$

Suppose the $x_n = (x_{1n}, x_{2n} \cdots x_{nn})$ in X,

$$(X\beta + WX\delta) = (x_1, x_2 \cdots x_n)(\beta_1 + W\delta_1, \cdots, \beta_n + W\delta_n) = \sum_{n=1}^{N}(\beta_n + W\delta_n)x_n \quad (9)$$

Thus, Formula (7) can be written as follows:

$$y = \sum_{n=1}^{N}(\beta_n + W\delta_n)x_n(I - \lambda W)^{-1} + (I - \lambda W)^{-1}\alpha t_n + (I - \lambda W)^{-1}\varepsilon = \sum_{n=1}^{N} S_\gamma(W)x_n + (I - \lambda W)^{-1}\alpha t_n + (I - \lambda W)^{-1}\varepsilon \quad (10)$$

Where $S_\gamma(W) = (\beta_n + W\delta_n)(I - \lambda W)^{-1}$. It can be seen from (10) as follows:

$$\begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix} = \begin{pmatrix} s_\gamma(W)_{11} & \cdots & s_\gamma(W)_{1m} \\ \vdots & \ddots & \vdots \\ s_\gamma(W)_{n1} & \cdots & s_\gamma(W)_{nm} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix} + (I - \lambda W)^{-1}\alpha t_n + (I - \lambda W)^{-1}\varepsilon \quad (11)$$

From (11), $S_\gamma(W)_{ij} = \frac{y_i}{x_{jn}}$. The variable of city j may have an influence on the explained variable of any city i. From this, we can further calculate the direct, indirect and total effect of x_n, which are as follows:

The direct effect of the variable x_γ equals to the average value of the sum of the elements on the principal diagonal of the matrix $S_\gamma(W)$. The indirect effect of the variable x_γ equals to the average value of the sum of the elements other than the principal diagonal of the matrix $S_\gamma(W)$. And the total effect equals to the sum of the elements in row i of the matrix $S_\gamma(W)$, that is $\sum_{j=1}^{n} S_\gamma(W)_{ij}$.

3. Results

3.1. Spatial Correlation

According to the spatial dependence test of the logarithm of urban economic development index in table 1, the $Moran\ I$ index equals to 0.138 in 2019, and through the 10% significance test. It shows that there is a positive correlation and spatial dependence in the economic development of hub cities in China. From the results of spatial dependence test, there are spatial effects in the economic development of hub cities. Therefore, a spatial econometric model should be constructed to consider the influence of spatial effects.

Table 1: Result of moran i test

Moran I	**E(I)**	**sd(I)**	**z**	**p-value***
0.138	-0.027	0.085	1.944	0.052

3.2. Empirical Analysis

In order to reduce the heteroscedasticity of the data and enhance the stationarity, the logarithmic processing of the main variables is taken in this paper, and the spatial Durbin model (SDM) is obtained as follows:

$$lny = \alpha t_n + \lambda W lny + lnX\beta + WlnX\delta + \varepsilon, \quad \varepsilon \sim N(0, \sigma^2 I_n) \quad (12)$$

$$lnGDP = \alpha t_n + \lambda W lnGDP + WlnX\delta + \beta_1 \ln Air + \beta_2 \ln open + \beta_3\, ln\, expenditure \ +$$

$$\beta_4 \ln consumption + \beta_5 \ln employment + \varepsilon,\ \ \varepsilon \sim N(0, \sigma^2 I_n) (13)$$

Where GDP represents the level of urban economic development, W is the spatial weight matrix, $\lambda WlnGDP$ represents the influence from the explained variables of neighbors, that is, the interaction of urban economic development, and $WlnX\delta$ indicates that the urban economic development is affected by neighbor explanatory variables, indicating that the urban economic development is affected not only by local variables, but also by neighboring cities. Air is the passenger throughput of hub airport, $open$ is the degree of openness of the city, $expenditure$ represents financial expenditure, $consumption$ represents urban consumption level, $employment$ represents employment level, λ, δ and β are the regression coefficients of spatial lag terms, and ε is the random error term.

Meanwhile, this paper constructs OLS model, spatial Autoregression (SAR) and spatial error model (SEM) to test the robustness of the results.

- OLS examines the linear relationship between variables. The model is as follows.

$$lnGDP = \alpha + \beta_1\, ln\, Air + \beta_2\, ln\, open + \beta_3\, ln\, expenditure\ \ + \beta_4\, ln\, consumption + \beta_5\, ln\, employment + \varepsilon,\ \ \varepsilon \sim N(0, \sigma^2 I_n)\ (14)$$

- SAR examines whether there are spillover effects of explanatory variables in neighboring cities. The model is as follows.

$$lnGDP = \alpha t_n + \beta_1 ln\, Air + \beta_2 ln\, open + \beta_3\, ln\, expenditure\ \ + \beta_4\, ln\, consumption + \beta_5\, ln\, employment + \lambda WlnGDP + \varepsilon,\ \ \varepsilon \sim N(0, \sigma^2 I_n) \qquad (15)$$

- SEM studies the spatial autocorrelation in the random error term ε. The model is as follows:

$$lnGDP = \alpha t_n + \beta_1\, ln\, Air + \beta_2\, ln\, open + \beta_3\, ln\, expenditure\ \ + \beta_4\, ln\, consumption + \beta_5\, ln\, employment + \varepsilon, \varepsilon = \lambda W \varepsilon + \mu\ (16)$$

The meaning of variables is the same as that of SDM model. The empirical test results are shown in TABLE 2.

According to the results of the SDM, the coefficient of $lnAir$ $\beta_1 = 0.189$ and passed the significance test at 1% level, that means the airport passenger traffic has a significant positive impact on the urban economic. In addition, the coefficient of $WlnAir$ is $\delta = 0.179$, which is significant at 5% level. It means that the airport has a significant positive spatial spillover effect on urban economic development. In other words, airport not only has a significant positive correlation with the local economic development, but also has a great impact on the economic development of neighboring cities. The results of OLS, SAR and SEM further verify that there is a significant positive correlation between airport and urban economic development, and all passed the significance test at 1% level.

The influence of airport could be further divided into direct, indirect and total effect. The direct effect indicates the effect of airport on local economy. And the indirect effect is the spillover effect of airport network, which indicates the impact of the airport on the economic development of neighboring cities. The total effect is the sum of direct and indirect effects, indicating the overall impact of the airport on economic development. According to the previous decomposition of the spatial Durbin model, the following empirical results are obtained in TABLE 3.

Table 2: Estimation results of spatial measurement model

Variables	OLS	SDM	SEM	SAR
Main				
ln Air	0.22*** (13.00)	0.189*** (9.81)	0.196*** (10.70)	0.158*** (9.17)
lnopen	0.064*** (5.73)	0.073*** (6.75)	0.073*** (7.04)	0.078*** (7.83)
lnexpenditure	0.159*** (9.83)	0.173*** (10.64)	0.156*** (10.15)	0.180*** (11.77)
lnconsumption	0.199*** (11.45)	0.170*** (8.99)	0.180*** (9.35)	0.170*** (9.75)
lnemployment	0.199*** (8.15)	0.190*** (7.95)	0.206*** (8.55)	0.172*** (7.66)
Cons	5.56*** (51.98)	-	-	-
Wx				
lnAir	-	0.179** (2.92)	-	-
lnopen		0.048 (1.62)		
lnexpenditure		-0.028 (-0.47)		
lnconsumption		-0.160* (-2.47)		
lnemployment		0.079 (1.43)		
Spatial				
Rho/ Lambda	-	-0.145 (-0.82)	-0.421*** (-5.32)	-0.366*** (-6.76)
Variance				
sigma2 e	-	0.010*** (18.88)	0.011*** (18.87)	0.009*** (22.54)

Note: t statistics or z statistics with coefficients in parentheses. ***, **,*means p < 0.01, 0.05, 0.1, respectively.

Table 3: Spatial effect decomposition results

Variables	Direct	Indirect	Total
lnAir	0.188*** (9.31)	0.138** (2.20)	0.326*** (4.45)
lnopen	0.073*** (6.79)	0.036 (0.96)	0.109*** (2.91)
lnexpenditure	0.176*** (11.11)	-0.053 (-1.30)	0.123*** (11.05)
lnconsumption	0.173*** (9.77)	-0.159*** (-2.75)	0.014 (0.23)
lnemployment	0.190*** (8.06)	0.049 (0.88)	0.238*** (3.84)

From the table above we can know that:

• The total effect of airport on urban economic development will be underestimated without considering the spatial spillover effect. According to the results of SDM model, there is a significant positive relationship between airport and urban economy, and the total effect coefficient of airport on GDP is 0.326, which is significant at 1% level. In the classical linear regression, the coefficient of airport to GDP is 0.22, which obviously underestimates the positive impact of airport on economic development without considering spatial factors.

• The airport has a network spillover effect on the economic development. The airport not only has a positive impact on the local economy, but also has a spillover effect on the development of neighboring cities connected by the air network. The impact coefficient of the airport on the local economy is 0.188, that is, for every 1% increase in airport passenger traffic, the GDP of local city will increase by 0.188%. At the same time, airports also have network spillover effects on neighboring cities, with an impact coefficient of 0.138 and pass the significance test at 5% level, that is to say, the greater the airport passenger traffic, the stronger the spatial spillover effect on neighboring cities.

When evaluating the overall contribution of airports to social and economic development, the network spillover effects of airports should be fully taken into account. The network spillover effect of the airport is two-way, that means the airport can not only have a spatial impact on the economic development of other nodes in the network, but also the economy of the city where it is located will also be affected by other nodes in air network.

4. Conclusion

As a strategic industry, air industry is playing a more and more important role in the development of urban economy. Fully considering the influence of spatial factors, we construct a spatial Durbin model to empirically analysis the network spillover effect of airport on urban economy. The results show that there is a significant positive correlation between airport passenger traffic and urban economy. In the results of the spatial Durbin model, the total effect coefficient of the airport on economic development is 0.326, while in the traditional panel econometric model, it is 0.22. The effect of airport on urban economic development will be underestimated if not considering the space factors.

The airport has a significant spatial spillover effect, which not only affects the local economy, but also has an indirect impact on the economy of other cities. Its spatial spillover effect should not be ignored when measuring the economic contribution of the airport. The larger the scale of the airport network is, the greater the spillover effect on economic development will be. It is of great practical significance to speed up the construction of the air transport network with the aviation hub as the core for promoting economic development. For the hub airport, it is important to improve the hub service capacity and give full play to the spillover effect of hub network. And for non-hub airports, it is also an effective way to promote the economic development of non-hub cities by increase connectivity by improving connectivity with hub airport.

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