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Research on the Influence Mechanism of Air Transport on Industrial Upgrading in Beijing-Tianjin-Hebei Region

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Abstract: In order to explore the influence mechanism of air transport on industrial upgrading in Beijing-Tianjin-Hebei region, this study combines existing literature and takes capital flow, technological innovation, and population flow as intermediary variables. Based on data from 2010 to 2023, an intermediary benefit model is constructed for empirical analysis. The study found that air transport has a significant positive effect on the industrial upgrading of Beijing-Tianjin-Hebei, and among the mediating variables, capital flow did not play a mediating role, while technological innovation and population flow played a mediating role, accounting for 12.317% and 61.098% of the total effect respectively. The research conclusions provide an empirical basis for optimizing the air transport network and strengthening the policy of technological synergy and talent flow under the Beijing-Tianjin-Hebei collaborative development strategy.

Keywords: air transport; industrial upgrading; the mediating effect model; capital flows; technological innovation; population flow

1. Introduction

Since the launch of the Beijing-Tianjin-Hebei regional development strategy, the region has undergone profound adjustments in the institutional framework and operational mechanism. After ten years of development, the process of cross-domain collaboration has been significantly accelerated, the mode of industrial linkage and project cooperation has shown a diversified trend, and the implementation of the strategy has achieved remarkable results. As a major national regional development strategy, the plan covers multi-dimensional economic and social reforms, in which industrial upgrading has become the core driving force for regional economic transformation. In this process, the air transport system provides basic support for regional economic growth by strengthening the efficiency of factor circulation and optimizing the resource allocation network, and plays a significant role in promoting the optimization and upgrading of industrial structure.

At present, in the study of the impact of air transport on regional industrial upgrading, air transport has played a positive role in attracting population flow, connecting enterprises in different regions, promoting knowledge transfer, and promoting technological innovation. The investment and construction of aviation infrastructure construction directly stimulated the local fixed asset investment [1]. Under the influence of the investment multiplier, the circulation, turnover and reproduction in the circulation and production fields were continuously carried out, and the scale of investment was multiplied several times, so as to promote its value-added and drive capital flows. Zhao et al. based on the panel data of 237 prefecture-level cities in China from 2011 to 2019, empirical research shows that capital flow has a significant driving effect on the upgrading of industrial structure [2]. It pointed out that in the process of economic development, when capital withdraws from backward production capacity and flows to industries and enterprises with high added value and high technological content, the process of transformation and upgrading of traditional industries has been started [3].

Wang et al. pointed out that air transport has greatly promoted the frequent flow of talents by virtue of its fast and convenient advantages, and these talents are the fresh carriers of knowledge and technology [4]. Wang et al. found that technological innovation can promote industrial upgrading [5]. Zhao et al. pointed out that technological innovation not only promotes the generation of new products, but also attracts more industrial entities to participate in technological innovation, further stimulates market demand, spawn's new products and new markets, changes investment structure, consumption structure, export structure, and affects the urban industrial structure [6]. Zou et al. used the LASSIS model to find that technological innovation promotes industrial upgrading through the introduction of new technologies and integrated innovation [7]. Yan et al. found that technological innovation affects industrial upgrading by using fixed effect model and threshold effect model [8].

Xi et al. found that the most intuitive role of air transport is reflected in its significant shortening of the travel time between cities, which greatly improves the traffic efficiency and reshapes people's perception of space and distance [9]. Shi et al. found that compared with other traditional modes of transportation, air transport can quickly cross long geographical distances with several times or even dozens of times the speed advantage, allowing people to reach all corners of the world in just a few hours [10]. Wang found that developed regions can accelerate the development of the tertiary industry and high-tech industries by attracting foreign population, forming an industrial agglomeration effect [11]. The less developed areas are forced to adjust their industrial structure, eliminate backward production capacity, and develop characteristic industries and emerging industries adapted to local conditions through population outflow, so as to achieve industrial upgrading.

From the above theoretical research, it can be seen that air transport can have a positive impact on the industrial upgrading of regions and cities. Therefore, this paper analyzes the impact mechanism of air transport on industrial upgrading in the Beijing-Tianjin-Hebei region. Taking industrial upgrading as the core explanatory variable, it successively incorporates three intermediary variables: capital flow, technological innovation and population flow, constructs an intermediary effect model, and systematically tests the intermediary effect of intermediary variables in the air transport-industrial upgrading chain.

2. Model Setting and Variable Selection

2.1. Construction of Mediating Effect Model

The mediating effect is widely used in the fields of sociology, psychology and economics. It can analyze the process and mechanism of the influence of independent variables on dependent variables, so as to obtain deeper results. If there is a certain correlation between the two variables before the study, the mediating effect can be established to verify the internal mechanism between the two. In the empirical analysis, if the independent variable X affects the dependent variable Y through the intermediary variable M, there is considered to be an intermediary effect, and M is the intermediary variable.

The relationship between the mediating effect is shown by Figure 1 and the following regression equation:

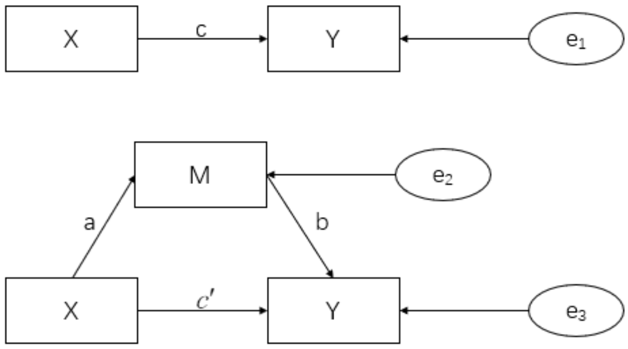

Figure 1. Mediation Effect Diagram.

$Y = cX + e_1$ (1)

$M = aX + e_2$ (2)

$Y = c'X + bM + e_3$ (3)

In the above equation, the coefficient is the total effect of the independent variable on the dependent variable; the coefficient is the effect of the independent variable on the mediating variable; the coefficient is the effect of the mediating variable on the dependent variable after controlling the independent variable; the product of the coefficient and the coefficient is the indirect effect of the independent variable. The coefficient is the direct effect of the independent variable on the dependent variable after controlling the intermediary variable, and is the regression residual.

In the analysis of mediating effect, there are usually two main methods: one is stepwise regression test, the other is product coefficient test. The stepwise regression test method explores the mediating effect through hierarchical regression analysis, which is popular because of its simplicity and clarity. The second method is the product coefficient test method, which can be implemented by Sobel test or Bootstrap sampling technique. Sobel test requires the data to be normal distribution, which is suitable for large samples, and the product of a and b is also required to be normal distribution. These conditions limit its application range. In contrast, Bootstrap sampling technology is gradually becoming the mainstream intermediary effect analysis method because of its high-test power and unlimited distribution. This study uses Bootstrap sampling method for empirical analysis.

This paper tests the mechanism of air transport on industrial upgrading through the mediating effect model, that is, air transport has an impact on industrial upgrading through three paths: capital flow, technological innovation and population flow. The following regression model is constructed as follows:

$Y_{it} = \alpha_i + \lambda_t + c_0 X_{it} + \in_{it}$ (4)

Formula (4) is the first step in the test of the mediating effect. It represents the industrial upgrading index and tests the impact of air transport on industrial upgrading without considering the mediating variables.

$M_{it} = \alpha_i + \lambda_t + a_1 X_{it} + \in_{it}$ (5)

Formula (5) is the second step of the mediation effect test. M_{it} represents capital flow, technological innovation and population flow respectively, which is used to test the impact of air transport on intermediary variables such as capital flow, technological innovation and population flow.

$Y_{it} = \alpha_i + \lambda_t + c_1 X_{it} + bM_{it} + \in_{it}$ (6)

Equation (6) is the third step of the mediating effect test. If the coefficients c_0, a_1, b are significant, and c_1 is significantly lower or numerically lower than c_0, then the mediating effect exists.

2.2. Variable Selection and Measurement

2.2.1. Explained Variables

The industrial upgrading index is the explained variable. The existing literature on the measurement of industrial upgrading presents diverse approaches. For example, Chen et al quantified the process of industrial upgrading at the provincial level with the proportion of the added value of the tertiary industry in the gross regional product as the core indicator; Xu et al. constructed a two-dimensional framework, which was evaluated from two aspects: industrial structure optimization and coordination [12,13]. McCallie et al. assigned weights according to the proportion of each industry in the gross domestic product (GDP), and used the industrial structure upgrading as a measure of industrial upgrading [14]. Adler et al. put forward the rationalization index of industrial structure to measure industrial upgrading [15].

Although these measurement methods have different emphases, the common goal is to evaluate and understand industrial upgrading more accurately. In order to reflect the level of industrial upgrading more comprehensively, this paper builds upon previous calculation methods and synthesizes the research results of Xu Min and Gan Chunhui. Through the comprehensive application of the advanced and rationalization indices of industrial structure, the measurement system of industrial upgrading level is constructed. In order to obtain a comprehensive industrial upgrading index, we use the entropy method to weight the above two indexes to obtain a comprehensive index that can fully reflect the level of industrial upgrading.

The formula of industrial structure upgrading index (TS) is as follows:

$$TS = \sum_{i=1}^{3} x_i \times i, 1 \leq TS \leq 3 \tag{7}$$

x_i represents the proportion of the output value of the i-th industry to the total output value.

The formula of industrial structure rationalization index (TL) is as follows:

$$TL = \sum_{i=1}^{n} (Y_i \ / \ \mathrm{Y}) \ln({}^{Y_i \ / \ L_i}/_{Y \ / \ L}) \tag{8}$$

Y represents the output value, L represents the number of employed people, i represents the industry, and n represents the number of industrial sectors.

The formula of industrial upgrading index (TT) is as follows:

$$TT = \sum_{j=1}^{s} W_{ij} x'_{ij}, \sum_{j=1}^{s} W_{ij} = 1 \tag{9}$$

W_{ij} represents the weight, x'_{ij} represents the sum TS and TL after standardization.

2.2.2. Explanatory Variables

The civil aviation traffic volume is selected as the explanatory variable. The civil aviation traffic volume refers to the calculation method of the annual workload of the International Airport Association, and the passenger throughput and cargo throughput indicators are summarized. Civil aviation traffic volume = passenger throughput + cargo throughput × 10.

2.2.3. Mediating Variables

Capital flow: At present, the methods of evaluating capital flow are mainly divided into two types: absolute scale index and relative scale index. Absolute scale indicators usually include social fixed asset investment, government budget funds and deposit and loan balances of national banks. Although these indicators can show the scale of capital to a certain extent, they may not fully reveal the real situation of capital flows. The relative scale index provides a more reasonable measure. However, due to the availability of data at the city level, the use of government budget funds and national bank deposit and loan balances to assess urban capital flows may bring some deviations. To reflect capital flows more accurately, this paper uses the growth rate of total fixed capital formation as a measure of capital liquidity.

Technological innovation: In evaluating urban technological innovation, we focus on two aspects: innovation input and innovation output. Although innovation input is the basis of innovation output, its effects accumulate over a long period of time and are often difficult to measure due to a lack of R&D data. Innovation output can directly reflect the technological innovation achievements of a city. The common indicators of innovation output are the sales revenue of new products and the number of patents. Although new product sales revenue can reflect market acceptance, it may ignore the role of technological innovation in knowledge creation. In contrast, the number of patents not only directly reflects the results of technological innovation but also represents the level of technological innovation in a city due to its objectivity and comparability. Therefore, the number of patents granted is used to measure technological innovation.

Population flow: This study provides an intuitive reflection of the trend of population flow by comparing the ratio of the number of permanent residents to the number of registered populations at the end of the year. When this ratio is less than 1, it indicates that the city is experiencing a net outflow of population, that is, the number of people leaving the city exceeds the number of people moving in. On the contrary, if the ratio exceeds 1, it means that the city is attracting more people to move in, showing a net inflow of population. By using this indicator, we can more accurately assess the impact of air transport on population flow, and then analyze its long-term impact on urban development and regional economy.

2.3. Data Source

In this study, the original data of industrial upgrading and air transport come from the official statistical yearbook, civil aviation statistical bulletin and official press conference. Capital flow and population flow data are derived from the 2010-2024 China City Statistical Yearbook, local statistical yearbooks, and economic and social statistical bulletins. Data related to technological innovation are obtained through the CNRDS China Research Data Platform.

3. Empirical Analysis

3.1. Test Results and Analysis of the Mediating Effect of Capital Flows

Taking capital flow as the mediating variable, the mediating effect model is used to test whether capital flow plays a mediating role between air transport and industrial upgrading of Beijing-Tianjin-Hebei urban agglomeration. The test results are shown in Table 1:

Table 1. Mediation Effect Model Test Results of Capital Flow.

Variable	Industrial upgrading (1)	Capital flow (2)	Industrial upgrading (3)
constant	0.232** (6.544)	0.462** (11.045)	0.269** (3.728)
air transport	0.874** (11.506)	0.014 (0.151)	0.875** (11.420)
capital flow			-0.078 (-0.580)
R^2	0.768	0.001	0.770
adjusted R^2	0.762	-0.024	0.758
F ratio	132.378	0.023	6260

Note: *, ** denotes $p < 0.05$, $p < 0.01$, the value in parentheses is t statistic.

According to Table 1, the results of model (2) show that the influence coefficient is not significant, indicating that civil aviation traffic has no significant impact on capital flows. In other words, the growth of civil aviation traffic neither promotes nor inhibits capital flows. The model (3) takes industrial upgrading as the explanatory variable, and incorporates civil aviation transportation volume and capital flow into the regression equation. The results show that civil aviation transportation has a significant impact on industrial upgrading; however, the regression of capital flow to industrial upgrading is not significant, which indicates that capital flow cannot affect the industrial upgrading of Beijing-Tianjin-Hebei urban agglomeration. The results of the mediating effect model show that there is no mediating effect of capital flow on the relationship between civil aviation transportation and industrial upgrading.

3.2. Test Results and Analysis of the Mediating Effect of Technological Innovation

Taking technological innovation as the mediating variable, the mediating effect model is used to test whether technological innovation plays a mediating role between air transport and industrial upgrading of Beijing-Tianjin-Hebei urban agglomeration. The results of the mediating effect model test and analysis are shown in Table 2 and Table 3.

Table 2. Mediation Effect Model Test Results of Technological Innovation.

Variable	Industrial upgrading (1)	Technological innovation (2)	Industrial upgrading (3)
constant	0.232**	0.423**	0.116
	(6.544)	(8.436)	(2.099)
air transport	0.874**	0.391**	0.767**
	(11.506)	(3.645)	(9.368)
technological innovation			0.275**
			(2.635)
R^2	0.768	0.250	0.803
adjusted R^2	0.762	0.231	0.793
F ratio	132.378	13.284	79.500

Note: *, ** denotes $p < 0.05$, $p < 0.01$, the value in parentheses is t statistic.

Table 3. Mediation Effect Analysis of Technological Innovation.

Model effect	Effect size	Bootstrap 95% CI		Standard error SE value	*z* value / *t* value	Proportion of effect
		Lower limit	Upper limit			
gross effect	0.874	0.725	1.023	0.076	11.506	100%
direct effect	0.767	0.606	0.927	0.082	9.368	87.683%
indirect effect	0.107	0.002	0.248	0.063	1.722	12.317%

According to Table 2, he results of model (2) show that the regression coefficient of air transport scale to technological innovation in Beijing-Tianjin-Hebei region is 0.391 ($p < 0.01$), indicating that air transport has a significant role in promoting regional technological innovation. Further testing with model (3) reveals that after adding the variable of technological innovation, the direct effect of air transport on industrial upgrading is 0.767 ($p < 0.01$), while the effect of technological innovation itself on industrial upgrading is 0.275 ($p < 0.01$). Compared to when the intermediary role of technological innovation is not considered, the coefficient of civil aviation transportation volume on industrial upgrading is reduced when the intermediary role of technological innovation is taken into account. The above results show that civil aviation transportation promotes industrial upgrading in the Beijing-Tianjin-Hebei urban agglomeration through technological innovation.

From Table 3, it can be seen that technological innovation is an intermediary variable, and its test results on the relationship between air transport and industrial upgrading of the Beijing-Tianjin-Hebei urban agglomeration show that air transport has a positive impact on industrial upgrading through the path of technological innovation. The indirect effect is 0.107, accounting for 12.317 % of the total effect, indicating that although technological innovation is not the dominant factor, it still has an auxiliary role in promoting industrial upgrading. The total effect of air transport on industrial upgrading (0.874) is composed of direct effect (0.767) and indirect effect, which further verifies the complementary role of technological innovation. These data show that although the mediating effect of technological innovation is not large, it is still an important way for air transport to affect industrial upgrading.

3.3. Test Results and Analysis of the Mediating Effect of Population Flow

Taking population flow as a mediating variable, the mediating effect model is used to test whether population flow plays a mediating role between air transport and industrial upgrading of Beijing-Tianjin-Hebei urban agglomeration. The results of the mediating effect model test and analysis are shown in Table 4 and Table 5:

Table 4. Mediation Effect Model Test Results of Population Flow.

Variable	Industrial upgrading (1)	Population flow (2)	Industrial upgrading (3)
constant	0.232**	0.223**	0.097**
	(6.544)	(4.810)	(3.522)
air transport	0.874**	0.880**	0.340**
	(11.506)	(8.869)	(4.209)
population flow			0.607**
			(8.119)
R^2	0.768	0.663	0.914
adjusted R^2	0.762	0.654	0.909
F ratio	132.378	78.659	206.562

Note: *, ** denotes p < 0.05, p < 0.01, the value in parentheses is t statistic.

Table 5. Mediation Effect Analysis of Population Flow.

Model effect	Effect size	Bootstrap 95% CI		Standard error SE value	*z* value / *t* value	Proportion of effect
		lower limit	upper limit			
gross effect	0.874	0.725	1.023	0.076	11.506	100%
direct effect	0.340	0.182	0.499	0.081	4.209	38.902%
indirect effect	0.534	0.393	0.733	0.089	6.020	61.098%

According to Table 4, the results of model (2) show that the regression coefficient of civil aviation transportation is 0.880, which also shows a significant level of 0.01, indicating that civil aviation transportation significantly promotes population mobility. Model (3) takes industrial upgrading as the explained variable, and includes civil aviation transportation volume and population flow into the regression equation. The results show that the regression coefficient of air transportation to industrial upgrading is 0.340 ($p < 0.01$), indicating that it has a significant positive impact. The effect coefficient of population flow on industrial upgrading is 0.607 ($p < 0.01$), and the result is significantly positive. Compared to when the intermediary role of population flow is not considered, the coefficient of civil aviation transportation volume on industrial upgrading is reduced when population flow is considered as an intermediary variable. The above results show that population mobility, as an intermediary variable, plays a mediating role between civil aviation transportation and industrial upgrading.

The results of the mediating effect of population flow in Table 5 show that after adding the mediating variable of population flow, air transport can still significantly promote the industrial upgrading of Beijing, Tianjin and Hebei. The mediating effect of population flow is 0.534, accounting for 61.098 % of the total effect, indicating that population flow plays an important role in the process of air transport affecting industrial upgrading.

4. Conclusion

Through this study, it is found that capital flow does not play a mediating role between air transport and industrial upgrading, while technological innovation and population flow play a mediating role between air transport and industrial upgrading. The indirect effect of technological innovation accounts for 12.317 % of the overall impact. Although the contribution is lower than the direct effect, its auxiliary function to industrial upgrading still needs to be paid attention to. In contrast, the mediating effect of population flow accounts for 61.098 %, which significantly confirms the path of air transport indirectly driving industrial transformation by accelerating population migration. This conclusion provides a key basis for regional policy design and emphasizes the supporting role of optimizing the allocation of population resources in industrial upgrading.

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