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Analysis of the coupling coordination between transportation infrastructure investment and economic development in Hubei province

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ABSTRACT: The relationship between transportation infrastructure investment and regional economic growth has been the focus of domestic and foreign academic research. Using the models of coupling degree and coupling coordination degree, this paper calculated the coupling degree and coupling coordination degree between the comprehensive level of transportation infrastructure investment and economic development in Hubei province and its 17 cities, and analyzed its temporal and spatial characteristics. The result showed that, from 2001 to 2013, the coupling and coupling coordination between transportation infrastructure investment and economic development in Hubei province were on a steady rise in the time sequence characteristics. It experienced the upgrade from the uncoordinated - nearly uncoordinated - barely coordinated - intermediately coordinated stages. In the year of 2013, the coupling and coupling coordination of transportation infrastructure investment and economic development in the 17 prefecture-level cities of Hubei Province showed a very uneven spatial difference. Good coordination, primary coordination, barely coordinate, and barely in-coordination are distributed in the province. The average coordination degree of the 17 prefecture-level cities in Hubei is relatively low, and there is a negative tend to expand the difference. This study has confirmed the relationship between transportation infrastructure investment and the economic development to be in an interactive coupling and coordination, but in different regions and different stages, the degree of coordination has obvious spatial and temporal differences.

Keywords: transportation infrastructure investment; economic development; entropy-weight method; coupling coordination degree; Hubei province.

1 INTRODUCTION

The development of transportation infrastructure and economic growth interact with each other; the investment in infrastructure will promote economic growth, while economic growth will have a greater demand and supply capacity for the investment in infrastructure. There is interactive coupling relationship and interactive effect between the development of transportation infrastructure and economic growth. However, in different countries, regions, economic development stages and investment patterns, there are obvious differences in the degree of coupling coordination, while the interaction between them is not constant positive or has positive effect, and even in some regions, there are some in-coordinating problems in some periods of time, which greatly restricts the sustainable development of regional and social economy. Hubei province is located in central China, known as the “thoroughfare of nine provinces”, which is the strategic center zone of the “rise of central China”. In recent years, Hubei province has vigorously developed transportation infrastructure, and promoted the rapid development of social economy. However, is transportation infrastructure investment continuing to promote economic development? Is that in coupling coordination with economic development? How is the degree of coupling coordination? What is the characteristic of the space-time dimension? In Hubei province, the coupling coordination development between transportation infrastructure investment and economic growth has a direct impact on the social and economic sustainable development, the central provinces and even the country, while the research on the coupling coordination development relationship between them

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should become an important issue for all levels of government and academia.

2 RESEARCH METHODS AND DATA SOURCES

2.1 *Research methods*

(1) *Construction of index system*: Transportation infrastructure investment and economic growth constitute a multi-level and multi-factor interactive symbiosis, and resonance coupling social and economic development system. Transportation infrastructure investment and economic growth are the subsystems of this system, which shows significant complexity, integrity and dynamic nature. In this study, the construction of the evaluation index system has comprehensively reflected the structure and function of the two subsystems of transportation infrastructure investment and economic growth. By combining the regional characteristics of Hubei province, on the basis of the following principles of integrity, comprehensiveness, hierarchy, systematicness and operability, the study conducted frequency statistics and theoretical analysis of the comprehensive measurement index of transportation infrastructure investment and economic development in recent years, selected the index frequently used by scholars, and took the availability of data into account; from the scale, level and development of the investment subsystem of transportation infrastructure, freight volume, passenger volume, freight turnover, passenger turnover, railway construction investment, highway construction investment and waterway construction investment and other 7 indexes were selected to construct the comprehensive evaluation index system of transportation infrastructure investment in Hubei province; from the scale, structure and benefit of economic development subsystem, total population, the total social fixed assets investment, gross regional production, the proportion of the second industry in GDP, the proportion of the third industry in GDP, the proportion of transportation in GDP, per capita GDP, growth rate of GDP and other 8 indexes were selected to construct the comprehensive evaluation index system of economic development (see Table 1).

(2) *Standardization of index data*: In order to eliminate the influence of the index dimension, it is needed to standardize the indexes. In this paper, the original index data are processed with range standardization, the following formulas are adopted:

Positive index standardization:

$$X_{ij} = \frac{x_{ij} - \min X_j}{\max X_j - \min X_j} \tag{1}$$

Negative index standardization:

$$X_{ij} = \frac{\max X_j - x_{ij}}{\max X_j - \min X_j} \tag{2}$$

Wherein, x_{ij} indicates the original value of the j^{th} evaluation index of the i^{th} sample; X_{ij} indicates the standardization value of the j^{th} evaluation index of the i^{th} sample. The range of standardized values is [0, 1], $\min X_j$ indicates the minimum of the j^{th} evaluation index in all samples, and $\max X_j$ indicates the maximum of the j^{th} evaluation index in all samples.

(3) *Determination of index weight*: Information entropy can be used to indicate not only the uncoordinated degree of the system, but also the effective information of the relevant data in the system, so as to determine the weight of the data, which is the entropy weight method. In this paper, the entropy weight is used to calculate the weights of each index (see Table 1), and the mainly steps are as follows:

Calculate the proportion of the evaluation index:

Table 1. The evaluation index system and its weights of comprehensive level of transportation infrastructure investment and economic development in Hubei province

Target layer	Criterion layer	Index layer	Units	Time sequence weight	Spatial sequence weight
The evaluation index system of comprehensive level	Transportation infrastructure investment /X	Freight volume /x_1	10^4 Tons	0.0699	0.2337
		Passenger volume /x_2	10^4 People	0.0300	0.1284
		Freight turnover /x_3	10^8 Tons km	0.0951	0.2542
		Passenger turnover /x_4	10^8 People km	0.0492	0.1270
		Railway construction investment /x_5	10^8 Yuan	0.2283	
		Highway construction investment /x_6	10^8 Yuan	0.1922	0.2567*
		Waterway construction investment /x_7	10^8 Yuan	0.3353	
	Economic development /Y	Total population /y_1	10^4 People	0.0004	0.1000
		The total social fixed assets investment /y_2	10^8 Yuan	0.3687	0.1101
		Gross regional production /y_3	10^8 Yuan	0.1759	0.1303
		The proportion of the second industry in GDP /y_4	%	0.0034	0.1108
		The proportion of the third industry in GDP /y_5	%	0.0012	0.1228
		The proportion of transportation in GDP /y_6	%	0.2547	0.1817
		Per capita GDP /y_7	Yuan/Person	0.1801	0.1303
		Growth rate of GDP /y_8	%	0.0156	0.1139

Notes: * is the weight of total investment in transport infrastructure.

$$Q_{ij} = \frac{P_{ij}}{\sum_{i=1}^{m} P_{ij}} \quad (3)$$

Calculate the information entropy of the evaluation index:

$$e_j = -k\sum_{i=1}^{m}(Q_{ij} \times \ln Q_{ij}) \quad (4)$$

Calculate the entropy redundancy of the evaluation index:

$$d_j = 1 - e_j \quad (5)$$

Calculate the weight of the evaluation index:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

Wherein, $k = \frac{1}{\ln m}$, i=1,2,3,…,m, m indicates the sample number of evaluation index; j=1,2,3,…,n, n indicates the number of evaluation index.

(4) *Calculation of comprehensive level index*: Assuming X_{ij} and Y_{ij} are respectively the standard values of the index of transportation infrastructure investment and economic development, v_j and w_j are respectively the corresponding weight of that, and then the calculation formulas of the comprehensive level index of the i^{th} transportation infrastructure investment $f_i(x)$, and those of the comprehensive level index of economic development $g_i(y)$ are as follows:

$$f_i(x) = \sum_{j=1}^{n} v_j X_{ij} \quad (7)$$

$$g_i(y) = \sum_{j=1}^{n} w_j Y_{ij} \quad (8)$$

(5) *Coupling model*: Coupling is a concept in physics, which means the phenomenon of interaction by two (or more) systems or motion forms, and the coupling degree is a parameter describing the interaction degree between system and elements. The two subsystems of transportation infrastructure investment and economic development are involved in this study, and the coupling degree model is as follows:

$$C_i = \left\{ f_i(x) \times g_i(y) / [f_i(x)/2 + g_i(y)/2]^2 \right\}^k \quad (9)$$

Wherein, k is the adjustment factor, and $k \geq 2$. In this study, 2 is adopted, C_i indicates the coupling value of the two subsystems, and the value range is [0, 1]. It can be seen that when C_i=1, the coupling is maximum, indicating that the elements between the systems or within the system are in a positive coupling, and the system will tend to be a new order structure; when C_i=0, the coupling is minimum.

(6) *Model of coupling coordination*: Coupling is difficult to fully and accurately reflect the overall efficacy and coordination effect of the two subsystems, which is not accurate enough and merely relies on the coupling discrimination. In order to reflect the interactive coupling coordination between transportation infrastructure investment and economic development, the coupling coordination model is introduced, and the coupling coordination degree can effectively judge the coupling coordination of the two subsystems. The calculation formula is as follows:

$$D_i = \sqrt{C_i \times T_i} \quad (10)$$

$$T_i = \alpha f_i(x) + \beta g_i(y) \quad (11)$$

Wherein, D_i is the coordination degree; C_i is the coupling; T_i is the comprehensive coordination index, reflecting the synergistic effect. In order to guarantee $D_i \in (0, 1)$, in reality, it is better to make $T_i \in (0, 1)$. $f_i(x)$ and $g_i(y)$ are respectively the comprehensive level indexes of the two subsystems of transportation infrastructure investment and economic development. α and β are undetermined coefficients, which are both 0.5 in this study, because transportation infrastructure investment and economic development are equally important. With reference to the research achievements of some scholars, the coupling coordination degree can be divided into seven types (see Table 2).

Table 2. Criteria for classification of the coupling coordination degree

Codomain of the coupling coordination degree	Type	Grade
[1.00-0.90]	Quality coordination	I
(0.90-0.80]	Good coordination	II
(0.80-0.70]	Intermediate coordination	III
(0.70-0.60]	Primary coordination	IV
(0.60-0.50]	Barely coordinate	V
(0.50-0.40]	The verge of imbalance	VI
(0.40-0.00]	Imbalance	VII

2.2 *Data sources*

The data in this study are mainly from the statistical yearbooks of Hubei province from 2001 to 2013, the statistical bulletins of Hubei province national economic and social development from 2001 to 2013 (hereinafter referred to as statistical bulletins), the transportation yearbook of Hubei Province in 2013, and the statistical yearbook and statistical bulletins in 17 prefecture-level cities of Hubei province in 2013.

3 TEMPORAL AND SPATIAL CHARACTERISTICS OF COUPLING COORDINATION DEGREE

3.1 *Time sequential characteristics*

The relevant research data of the statistical yearbooks and statistical bulletins of Hubei Province from

Table 3. The comprehensive level index, coupling degree and coupling coordination degree of transportation infrastructure investment and economic development in Hubei province (2001-2013)

	Comprehensive level index of transportation infrastructure investments /$F(X)$	Comprehensive level index of economic development /$G(Y)$	Coupling degree/C	Coordination index/T	Coupling coordination degree	
					/D	Grade
2001	0.0034	0.0010	0.4853	0.0022	0.0325	VII
2002	0.0113	0.0067	0.8747	0.0090	0.0889	VII
2003	0.0345	0.0142	0.6822	0.0244	0.1290	VII
2004	0.0832	0.0311	0.6266	0.0571	0.1892	VII
2005	0.1883	0.0428	0.3641	0.1155	0.2051	VII
2006	0.3057	0.0667	0.3461	0.1862	0.2539	VII
2007	0.3958	0.0998	0.4138	0.2478	0.3202	VII
2008	0.4233	0.1424	0.5679	0.2828	0.4008	VI
2009	0.5643	0.2038	0.6079	0.3840	0.4832	VI
2010	0.6536	0.2804	0.7062	0.4670	0.5743	V
2011	0.7071	0.3538	0.7905	0.5305	0.6476	IV
2012	0.6990	0.4455	0.9043	0.5722	0.7193	III
2013	0.8269	0.5482	0.9196	0.6876	0.7951	III

2001-2013 are adopted. According to the research methods and relevant calculation formulas mentioned above, (1) the weights of the two subsystems of transportation infrastructure investment and economic development of Hubei province from 2001-2013 are obtained (see the time sequence weight in Table 1); (2) the comprehensive level indexes of transportation infrastructure investment and economic development of Hubei province in each year are calculated; (3) the coupling and coupling coordination of the two subsystems of transportation infrastructure investment and economic development of Hubei Privince form 2001-2013 are calculated using coupling and coupling coordination model (see Table 3).

It can be known from Table 3 that the coupling and coupling coordination degree of transportation infrastructure investment and economic development of Hubei Province from 2001-2013 show a steadily rise in the time sequence characteristics.

The coupling coordination value between the two subsystems continues to increase year by year, from a minimum of 0.0325 in 2001 to a maximum of 0.7951 in 2013, with a growth of 0.7626, and an annual increase of 0.0636. The annual average value is 0.3722, and the standard deviation is 0.2520. In these 13 years, the coordination development degree of the two subsystems of transportation infrastructure investment and economic development in Hubei province continues to increase, which has vigorously developed transportation infrastructure, and promoted economic growth rapidly.

The type of uncoordinated (Type VII) in 2001 is gradually optimized to intermediate coordination (Type III) in 2013. In the last 13 years, it experienced the upgrade from the uncoordinated (2001-2007) - nearly uncoordinated (2008-2009) - barely coordinated (2010) - Primary coordinated (2011) - intermediately coordinated stages (2012-2013), which mainly depended on the coordinated development of transportation infrastructure investment and economic development in Hubei province. The structure of the two systems was optimized, the function was fully played, and it also laid the foundation for the sustainable development of future social economy, so it has a good development prospect.

3.2 *Spatial differences*

In order to further analyze the spatial differences in the coupling and coupling coordination degree of the two subsystems of transportation infrastructure investment and economic development in Hubei province, the statistical yearbooks and statistical bulletins of 17 prefecture-level cities of Hubei province in 2013 and the related data of statistical yearbooks of the transportation in Hubei province were selected in this study. The above research methods and calculation formulas were adopted so that the weight of each index of the two subsystems of transportation infrastructure investment and economic development in 17 prefecture-level cities of Hubei province could be obtained (see the spatial sequence weight in Table 1), the comprehensive level index of that was calculated, and then the coupling and coupling coordination degree was calculated using the coupling and coupling coordination degree model (see Table 4).

As can be seen from Table 4, the coupling and coupling coordination degree of transportation infrastructure investment and economic development in Hubei province has showed a very unequal spatial diversity: (1) the gap of the coupling coordination value between the two subsystems in 17 prefecture-level cities is very huge, the standard deviation of the coupling coordination in the 17 prefecture-level cities of Hubei Province is 0.2047. Wuhan has the highest coupling coordination degree, whose value is as high as 0.8829, belonging to good coordination (Type II); Xiangyang, Yichang and Shiyan belong to primary coordination (Type IV); Huanggang, Jingzhou, Huangshi, and Jingmen are barely coordinated (Type V); Xiaogan City, Enshi, Xianning and Suizhou are barely coordinated (VI); Qianjiang, Tianmen, Ezhou, Xiantao,

Table 4. The comprehensive level index, coupling degree and coupling coordination degree of transportation infrastructure investment and economic development in 17 prefectures, cities and states of Hubei province (2013)

Region	Comprehensive level index of transportation infrastructure investments /$F(X)$	Comprehensive level index of economic development /$G(Y)$	Coupling degree /C	Coordination index /T	Coupling coordination degree		
					/D	Sequencing	Grade
Wuhan	1.0000	0.6792	0.9283	0.8396	0.8829	1	II
Xiangyang	0.5876	0.3979	0.9273	0.4928	0.6760	2	IV
Yichang	0.5311	0.3922	0.9553	0.4616	0.6641	3	IV
Shiyan	0.3582	0.3666	0.9997	0.3624	0.6019	4	IV
Huanggang	0.3645	0.2778	0.9639	0.3211	0.5564	5	V
Jingzhou	0.3461	0.2594	0.9594	0.3027	0.5389	6	V
Huangshi	0.2633	0.2719	0.9995	0.2676	0.5172	7	V
Jingmen	0.3622	0.2284	0.8999	0.2953	0.5155	8	V
Xiaogan	0.2115	0.2562	0.9818	0.2339	0.4792	9	VI
Enshi	0.1981	0.2922	0.9277	0.2451	0.4769	10	VI
Xianning	0.1997	0.2354	0.9866	0.2175	0.4633	11	VI
Suizhou	0.1498	0.2021	0.9564	0.1759	0.4102	12	VI
Qianjiang	0.0745	0.2034	0.6164	0.1389	0.2926	13	VII
Tianmen	0.0656	0.1728	0.6361	0.1192	0.2753	14	VII
Ezhou	0.0609	0.2104	0.4845	0.1356	0.2564	15	VII
Xiantao	0.0589	0.2337	0.4133	0.1463	0.2459	16	VII
Shennongjia	0.0006	0.3285	0.0001	0.1645	0.0032	17	VII

Shennongjia forest region are coordinated (Type VII), wherein the coupling coordination of Shennongjia is the lowest, and its value is only 0.0032, which is 0.8797 less than that of Wuhan. (2) The average coupling coordination degree of the 17 prefecture-level cities in Hubei province is 0.4621, with a relatively low coupling coordination. The regions with higher degree of coupling coordination in Hubei province are mainly located in the big cities, the prefecture-level cities with large city scale and high quality, the regions with key transportation infrastructure construction, some regions with poor natural conditions, the slow economic development, and some county-level cities with low coupling coordination degree.

4 CONCLUSIONS AND SUGGESTIONS

Transportation infrastructure is an important symbol and the prerequisite of modern economic development and its construction can promote economic development, which is the guarantee to expand its investment. Transportation infrastructure investment and economic development are two interdependent and complementary subsystems in the social and economic development. Their development should be coupled and coordinated. In this study, transportation infrastructure investment and economic development are taken as two mutual coupling subsystems in the social economic development so as to construct the comprehensive level evaluation index system. By using the entropy weight method to determine the index weight, the comprehensive level index of transportation infrastructure investment and economic development of Hubei province from 2001-2013 and the 17 prefecture-level cities in 2013 are calculated; the coupling and coupling coordination degree of transportation infrastructure investment and economic development of prefecture-level cities in Hubei province are calculated by introducing the coupling and coupling coordination mode; coupling relationship of the two subsystems of transportation infrastructure investment and economic development in Hubei province and the time-space characteristics of coordination degree and coupling coordination are analyzed. The conclusions are reached as follows:

From 2001 to 2013, the coupling and coupling coordination of the two subsystems of transportation infrastructure investment and economic development in Hubei province showed a steady rise in the time sequence characteristics. The coupling coordination value of the two subsystems increased steadily, and the coordinated development degree is constantly improved; coupling coordination degree is gradually optimized from the in-coordination (Type VII) in 2001, to intermediate coordination (Type Ⅲ) in 2013, which experienced the upgrade from the uncoordinated - nearly uncoordinated - barely coordinated - intermediately coordinated stages.

In 2013, the coupling and coupling coordination of transportation infrastructure investment and economic development in the 17 prefecture-level cities of Hubei province showed a very uneven spatial difference. Good coordination (Type II), primary coordination (Type IV), barely coordination (Type V), and barely in-coordination (Type VI) are distributed in the province. The average coordination degree of the 17 prefecture-level cities in the province is relatively low, and there is a negative tend to expand the difference.

From the empirical point of view, this study has confirmed the relationship between transportation infrastructure investment and economic development to be in an interactive coupling and coordination, but in different regions and stages, the degree of coordination has obvious spatial and temporal differences.

Governments at all levels should adjust measures to local conditions and the different time and constantly adjust transportation infrastructure investment and economic growth system, give full play to the promotion effect between two systems so as to make the sustainable development of transportation infrastructure investment and economic growth system achieve the overall optimal effect.

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