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Evaluating the Coordinated Development of Economic, Social and Environmental Benefits of Urban Public Transportation Infrastructure: The Case of Four Chinese Autonomous Municipalities

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Abstract: The economic, social and environmental benefits generated by the use of urban public transportation infrastructure constitute a complex dynamic urban public transportation infrastructure utilization benefit system. This paper evaluates the coupling coordination among these three benefits taking four Chinese autonomous municipalities as an example. These four cities have large-scale urban public transportation infrastructures but their utilization has many serious problems. The basic function of urban public transportation infrastructure has not been fully played in these cities. Whether the different benefits of urban public transportation infrastructure have been developed in harmony or not is unclear. We analyzed the coordinated development among three benefits by constructing coupling coordination degree model and used Gini coefficient to study the difference of coordinated development among three benefits of four cities. The result shows that the levels of coordinated development among three benefits of urban public transportation infrastructure were lower in these four cities and have positive correlation with it of urban public transportation infrastructure utilization benefit. Raising the level of urban public transportation infrastructure utilization benefit is the most crucial solution of promoting the coordinated development among three benefits.

Keywords: urban public transportation infrastructure; utilization benefits; coupling coordination degree model; Gini coefficient

1. Introduction

In recent years, with the acceleration of urbanization in China, many Chinese cities have initially established an integrated urban internal public transportation infrastructure system in which many transportation infrastructures such as urban bus and metro are interconnected. This system provides the basic substance guarantee to the development of urban economy. At the same time, the construction of urban public transportation infrastructure changes the living condition of a city which is beneficial to quicken the flow of population, raise the urbanization rate and the level of living and promote the development and progress of society. In addition, urban public transportation infrastructure facilitates the travel of dwellers which is helpful to reduce the use of private transport and has positive influence to the protection of urban ecological environment. Therefore, the use of urban public transportation infrastructure has important impact on the urban economic, social and environmental systems. The economic, social and environmental benefit of urban public transportation infrastructure generated by the use of it should be emphasized equally.

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The coordinated development of these three utilization benefits is conducive to increase the whole level of urban public transportation infrastructure utilization benefit.

The impact of transportation infrastructure on economy has been discussed many times in the past. The scholars mainly paid attention to the relationship between transportation infrastructure and economic growth and applied different econometric methods to analyze it. Hong et al. [1] estimated the linkage between transportation infrastructure and regional economic growth using panel data of 31 Chinese provinces from 1998 to 2007. Yu et al. [2] analyzed the causal linkages between transportation infrastructure and economic growth in China at national and regional levels. Pradhan and Bagchi [3] used Vector Error Correction model to examine the effect of transportation infrastructure on economic growth in India over the period from 1970 to 2010. Beyzatlar et al. [4] investigated the Granger-causality relationship between transportation infrastructure and GDP of 15 European countries using a panel data set. Agbelie [5] applied three econometric frameworks to analyze the economic impacts of transportation infrastructure expenditures across 40 countries. The results of them indicated that there was an endogenous relationship between transportation infrastructure and GDP. Transportation infrastructure not only has the impact on economic growth but also affect the value of property. Many studies used econometric methods to analyze the impact of urban transportation on house value. Among these, Mathur and Ferrell [6] applied hedonic regression model to measure the effect of urban transportation infrastructure on housing prices. Seo et al. [7] studied the impact of highways and light rail transit on residential property values using spatial hedonic regression. Efthymiou and Antoniou [8] analyzed the influence of transport infrastructure and its policies of Athens to the house prices and rents using spatial econometric methods. All of these researches showed that proximity to transport infrastructure was associated significantly and positively with house values. Several scholars studied the influence of transportation infrastructure to the land value. Woudsma et al. [9] estimated the land value impacted by transportation infrastructure in Canada by dividing the country into three geographic categories based on the urban development level. Lavee [10] established an economic model to analyze the relationship between the elasticity of land price and estimating the future value of land used for transport projects. The result of it indicated that taking the land value during the feasibility analysis of transportation projects into account may prevent the excessive use of land. There were some professors who analyzed the spatial economic impact of transportation infrastructure. Hensher et al. [11] advanced an approach which combines the behavioural richness and its output to a spatial computable general equilibrium model to analyze the economy impacts of transport infrastructure. Beyazit [12] used the method of ex-post analysis to assess the impacts of the Istanbul Metro on urban spatio-economic inequalities. In addition, Kato et al. [13] evaluated the economic benefit of urban rail projects by improving travel-time reliability using scheduling approach.

Transportation infrastructure also has significant impact on urban development, especially urbanization. Many scholars studied the relationship between transportation infrastructure and the expansion of urban region. Priemus et al. [14] pointed out that the development of transportation infrastructure has impact on urban expansion and population growth. Ma and Xu [15] studied urban expansion of the built-up area of Guangzhou City in different periods by means of specific extraction and supervised classification of remote sensing information and found that transportation infrastructure is one of the main factors of urban growth. Feng et al. [16] put forward an improved cellular automata model based on particle swarm optimization approach to simulate the spatio-temporal process of urban growth using accessibility to transport infrastructure as a main driver of urban change. Aljoufie et al. [17] explored the relationship between transport infrastructure and urban growth of Jeddah city using many spatial statistical tools. The results of them indicated that transport infrastructure is a constant and strong spatial influencing factor of urban growth. Some professors explored the problem of service quality of transportation infrastructure. Yang et al. [18] analyzed the satisfaction level of Metro commuters and its main factors using binary logit model. Joewono et al. [19] carried out a series of structural equation modeling estimations to study the factors of service quality of road-based public transportation in urban areas of Indonesia.

With the expansion of urban area, the problem of urban environment has been gradually discussed. Urban public transportation infrastructure has important influence to urban natural environment. Some experts used life cycle assessment method to study the environmental impact of urban transportation infrastructure. Chester et al. [20] developed near-term and long-term life cycle assessment method to assess the environmental impact of urban transportation infrastructure in Los Angeles. Lajunen and Lipman [21] compared the lifecycle costs and carbon dioxide emissions of different types of city buses. Other experts applied different methods to analyze the environmental benefit of urban transportation. Mulley et al. [22] compared the impact of greenhouse gases emissions from urban bus and rail in Australia on environment. Nanaki et al. [23] compared the environmental benefits of urban public bus transportation system in nine European cities in term of air pollution emissions reductions. Matute and Chester [24] employed the cost-benefit methodology to analyze the effectiveness of reductions in greenhouse gas emissions from urban transportation infrastructure in California. Xue et al. [25] developed a Public Health and GHGs Emission model to estimate the impact of urban road transportation on both GHGs emission and public health damage in Xiamen City. Cheng et al. [26] explored the design and operation modes of urban transit system for reductions in greenhouse gas emissions. Peng et al. [27] used bottom-up model to predict the energy saving and emission reduction potential of urban passenger transportation in Tianjin. Ercan et al. [28] applied a system dynamics approach to investigate the carbon emission reduction potential of public transportation in United States. Doll and Balaban [29] studied the environmental co-benefits of the Delhi metro from the perspective of carbon emissions. Wang et al. [30] estimated and analyzed carbon emission from urban passenger transportation in Beijing by establishing a city level emission model. Fan and Lei [31] built Fisher index decomposition model to measure the potential factors of energy-related carbon emissions from the transportation sector in Beijing. Chen and Lei [32] used the path analysis model to analyze the influences of driving factors on transportation CO_2 in Beijing and investigate the relationship between them. Dirgahayani [33] took the bus system in Yogyakarta of Indonesia as an example to analyze the opportunities and challenges of raising the environmental co-benefits of public transportation. Geng et al. [34] employed a case study in Shenyang of China to analyze the co-benefit of urban public transportation sector. Muñoz-Villamizar et al. [35] put forward an approach using mathematical modeling with multiple objectives to explore how to reduce environmental impacts of the electric vehicles in urban transport networks while maintain the efficiency of service.

In summary, the use of urban public transportation infrastructure has obvious positive impact on the development of urban economy, society and environment. Many scholars have used plenty of methods to study the relationship between urban public transportation infrastructure and economic, social and environmental systems. Nevertheless, the research on the comprehensive evaluation of urban public transportation infrastructure utilization benefit is relatively scarce. Fewer scholars studied the relationship among three utilization benefits of urban public transportation infrastructure. In reality, different utilization benefits of urban public transportation infrastructure can affect each other. Increasing the economic benefit of urban public transportation infrastructure promotes the raise of urban income level and attracts the inflow of external population which is helpful to raise the level of social benefit of it. The increase of urban economic and social development level is beneficial to add the investment on urban public transportation infrastructure and improves the technology level of it which has positive impact on the protection of urban natural environment. The raise of environmental benefit of urban public transportation infrastructure is conducive to attract the investment and raise the level of urbanization which promotes the improvement of economic and social benefits of it. Thus, as a whole, all of these three utilization benefits of urban public transportation infrastructure should be raise simultaneously and develop in harmony. The level of urban public transportation infrastructure utilization benefit will be raise only if all of these three utilization benefits of urban public transportation infrastructure are well coordinated. This paper takes four autonomous municipalities of China, which are Beijing, Tianjin, Shanghai and Chongqing, as an example to analyze the coordinated development among different utilization benefits of urban public transportation infrastructure using panel data. They are the highest development level regions in China at the aspect of economy. The investment and construction scale of urban public transportation infrastructure in these four cities are giant and increasing quickly year by year. But the basic function of urban public transportation infrastructure has not been fully played in these cities. Whether the different utilization benefits of urban public transportation infrastructure have been developed in harmony or not is unclear. Therefore, this paper tries to study the coordinated development among different utilization benefits of urban public transportation infrastructure in these four cities and reveals the difference of the coordinated development among them of these four cities. A comprehensive approach of evaluating the coordinated development among three utilization benefits of urban public transportation infrastructure was put forward in this study. As one of the approaches for measuring interactive effects, coupling coordination degree model was applied to fully and objectively evaluate the coordinated development level among three utilization benefits of urban public transportation infrastructure. Then the difference of the coupling coordination degrees among them of these four cities was studied using the Gini coefficient which was used to analyze the divergence level of different individuality. The purposes of this paper are to reveal the coordinated development level of three utilization benefits of urban public transportation infrastructure and to identify the distinction of it of four cities and then to provide references for more coordinated development of three utilization benefits of urban public transportation infrastructure.

The rest of this paper is organized as follows. Section 2 constructs the urban public transportation infrastructure utilization benefit indicator system and introduces the empirical research methods used in this paper. The result of empirical analysis is revealed in section 3. Section 4 discusses the result of empirical analysis. And section 5 summarizes the main conclusions and provides the policy implications.

2. Methodology

2.1. Content of three utilization benefits of urban public transportation infrastructure

The economic benefit of urban public transportation infrastructure is the positive influence of it to the development of urban economy via external effect and spillover effect. The construction of urban public transportation infrastructure promotes the development of transport industry and increases the regional GDP which is helpful to raise the level of fiscal revenue of urban government and consumption expenditure of urban resident. The well-conditioned urban public transportation infrastructure attracts the investment by reducing the transport cost which is beneficial to increase the profit of enterprise and raise the productivity. In addition, the urban public transportation infrastructure facilitates the circulation of commodity and raises its sale amount.

The social benefit of urban public transportation infrastructure is the function of it in the process of promoting the progress of urban society. Developing the transport industry promotes the development of other related industries through the interaction among different industries. The development of plenty of industries is beneficial to recruit new workers and raises the employed rate. The increase of labour demand raises the wage level of employed persons which is helpful to add the disposable income of urban population. Moreover, urban public transportation infrastructure provides convenience for the flow of population which results in the immigration of population from rural region. It is favorable to raise the urbanization rate of one city.

The environmental benefit of urban public transportation infrastructure is the impact of it on protecting urban natural ecological environment by decreasing the use of private transport. Reducing the use of private transport not only relieves the pressure of urban transport system but also decreases the emission of pollution and harmful gas which is conducive to improve the quality of urban air. Furthermore, the decreased use of private transport is helpful to reduce the emergence of traffic noise which protects the regional living and work environment.

These three benefits are interconnected and interactive which constitute the dynamic and complex urban public transportation infrastructure utilization benefit system. The stability of this system depends on whether these three benefits are in the situation of coordinated development or not. The coordinated development degree of these three benefits reflects the situation of the balance development of different variables of urban public transportation infrastructure utilization benefit system. Thus, the coordinated development of these three benefits is a fine base to the well-conditioned urban public transportation infrastructure utilization benefit system.

2.2. Construction of indicator system

In this study, building urban public transportation infrastructure utilization benefit indicator system should be confirmed by the following criteria. First, the indicators should be measurable, comprehensive, and independent each other [36]. Second, the indicators must play an important role in measuring the urban public transportation infrastructure utilization benefit. Third, the chosen indicators are directly influenced by urban public transportation infrastructures, which have obvious changes when urban public transportation infrastructures have been built. Fourth, the data of these indicators should be obtained easily.

Based on these principles, this paper designed an indicator system which comprised 18

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indicators to evaluate the urban public transportation infrastructure utilization benefit of four cities. This study analyzed the relationship among three benefits of urban public transportation infrastructure. Therefore, these indicators should comprehensively reveal these three benefits which are brought about by urban public transportation infrastructure (Table 1). The content of table 1 illustrates the three level hierarchical arrangements which comprise three levels. The first one is the attribute level, second is dimensional level and third indicator level. The fourth column shows the calculation method of the value of these indicators. As the amount of urban public transportation infrastructure changes, the utilization benefit will be also undergo changes. The value of indicator should show its change degree along with the change of urban public transportation infrastructures. It will reflect how significantly urban public transportation infrastructure impacts each indicator. Consequently, according to the elastic calculation formula in economics, the calculating method of each indicator is shown in Table1. It indicates how much the change percentage of each indicator is when the urban public transportation infrastructure changes 1%. In other words, it means the impact of urban public transportation infrastructure on each indicator.

Table 1. An evaluation indicator system for urban public transportation infrastructure utilization benefit.

Level 1	Level 2	Level 3	Calculation method
Urban public transportation infrastructure benefit (U)	Economic benefit (U_1)	GDP (U_{11})	(change rate of GDP/change rate of urban public transportation infrastructure level)*100%
		Fiscal revenue (U_{12})	(change rate of fiscal revenue /change rate of urban public transportation infrastructure level)*100%
		Average consumption expenditure of urban dwellers (U_{13})	(change rate of average consumption expenditure of urban dwellers /change rate of urban public transportation infrastructure level)*100%
		Amount of fixed asset investment (U_{14})	(change rate of amount of fixed asset investment /change rate of urban public transportation infrastructure

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		level)*100%
	Society labour productivity (U_{15})	(change rate of society labour productivity /change rate of urban public transportation infrastructure level)*100%
	Total retail amount of commodity (U_{16})	(change rate of total retail amount of commodity /change rate of urban public transportation infrastructure level)*100%
	Total profit of industry enterprise (U_{17})	(change rate of total profit of industry enterprise /change rate of urban public transportation infrastructure level)*100%
	Actual utilized foreign investment (U_{18})	(change rate of actual utilized foreign investment /change rate of urban public transportation infrastructure level)*100%
Social benefit (U_2)	Employed population (U_{21})	(change rate of employed population /change rate of urban public transportation infrastructure level)*100%
	Average wage of employed personnel (U_{22})	(change rate of average wage of employed personnel /change rate of urban public transportation infrastructure level)*100%
	Disposable income per capita (U_{23})	(change rate of disposable income per capita /change rate of

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		urban public transportation infrastructure level)*100%
	Rural net income per capita (U_{24})	(change rate of rural net income per capita /change rate of urban public transportation infrastructure level)*100%
	Urbanization rate (U_{25})	(change rate of urbanization rate /change rate of urban public transportation infrastructure level)*100%
Environmental benefit (U_3)	Average value of traffic noise (U_{31})	(change rate of average value of traffic noise /change rate of urban public transportation infrastructure level)*100%
	Average daily NO_2 (U_{32})	(change rate of average daily NO_2/change rate of urban public transportation infrastructure level)*100%
	Average daily SO_2 (U_{33})	(change rate of average daily SO_2/change rate of urban public transportation infrastructure level)*100%
	Excellent rate of air ambient quality (U_{34})	(change rate of excellent rate of air ambient quality /change rate of urban public transportation infrastructure level)*100%

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	Average daily particulate matter (U_{35})	(change rate of average daily particulate matter/change rate of urban public transportation infrastructure level)*100%

2.3. Calculation of urban public transportation infrastructure utilization benefit index

The required data came mainly from China Statistics Yearbook 2004-2015 and the Yearbook 2004-2015 of every city. Here this paper takes the data of year 2003 as the base when calculating the change rate of each variable. Doing like this makes the index value of each year calculated under the same standard. It also can avoid the severe fluctuation of the indicator's value owing to the different base period data.

The important issue in calculating the urban public transportation infrastructure utilization benefit index concerns the contribution of each indicator to the utilization benefit index at each hierarchy level. To incorporate this into the assessment involves the use of weightings. This paper adopts the entropy method to calculate the weight of each indicator. Generally speaking, the entropy which is used in the field of economy and management refers to the information entropy and is the measure of the system's disorder state. Its mathematical implication equals to the thermodynamics entropy in physics. It is commonly believed that the value of information entropy which means the variation degree of each indicator is proportional to the equilibrium degree of the system structure. The higher the variation degree is, the greater the weight of the indicator is. Therefore, the weight of each indicator is calculated according to the value of entropy. The detailed step is showed as follow.

Step1: standardize the indicators by the standardized method. Different data has different measurement and magnitude. In order to eliminate the influence of dimension and magnitude, the raw data need to be standardized using formulas (1) and (2).

$$Y_{ij} = \frac{X_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}}. \quad (1)$$

$$Y_{ij} = \frac{\max\{X_j\} - X_{ij}}{\max\{X_j\} - \min\{X_j\}}. \quad (2)$$

Where X_{ij} is the observed value of the j th indicator in year i; $\max\{X_j\}$ is the maximum observed value; $\min\{X_j\}$ is the minimum observed value, Y_{ij} is the normalized value. When the increasing value of indicator raised the level of urban public transportation infrastructure utilization benefit, the formula (1) is applied. When the decreasing value of indicator raised the level of urban public transportation infrastructure utilization benefit, the formula (2) is applied. In this paper, the values of U_{31}, U_{32}, U_{33} and U_{35} are calculated by formula (2) and the values of

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other indicators by formula (1).

step2: calculate the proportion of the j th indicator value in year i.

$$\varpi_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}}. \tag{3}$$

step3: calculate the information entropy of each indictor and the redundancy degree of the information entropy.

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\left(\varpi_{ij} \times \ln \varpi_{ij}\right). \tag{4}$$

$$d_j = 1 - e_j. \tag{5}$$

Where e_j is defined as the information entropy of the j th indicator, $0 \le e_j \le 1$, d_j is the redundancy degree of the information entropy.

step4: calculate the weight.

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}. \tag{6}$$

Where w_j is the weight of the j th indicator.

step5: calculate the urban public transportation infrastructure utilization benefit index.

$$S_{benefit,i} = \sum_{j=1}^{n} w_j Y_{ij}. \tag{7}$$

Where $S_{benefit,i}$ is the urban public transportation infrastructure utilization benefit in year i, $S_{benefit,i} \in [0,1]$.

2.4. Coupling coordination degree model

This paper introduces the concept of coupling in physics to calculate the coupling degree of four cities′ three utilization benefits of urban public transportation infrastructure [36, 37]. Coupling refers to the dynamic relationship which is mutual influenced between two or more systems. Coupling degree reflects the correlation degree between the systems. But in some cases it does not tell the synergies between the systems. Therefore, this paper will construct a coupling coordination degree model to analyze the coordinated development degree among three utilization benefits of urban public transportation infrastructure. The coupling coordination degree model is given in the following formulas:

$$H = \sqrt{C \times S_{benefit}}. \tag{8}$$

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$$C=\left[\frac{U_1\times U_2\times U_3}{(U_1+U_2+U_3)^3}\right]^{1/3}. \quad (9)$$

Where H represents the coupling coordination degree, and $H\in(0,1)$; C represents the coupling degree among three utilization benefits; U_1, U_2 and U_3 represent the economic benefit, social benefit and environmental benefit respectively.

According to the value of coupling coordination degree, the coordinated development of three utilization benefits of urban public transportation infrastructure was divided into ten classes (Table2). It reflects the overall coordination result of three utilization benefits.

Table 2. Discriminating standard of the class of coupling coordination development.

H	class
0.000-0.100	Extremely unbalanced development
0.101-0.200	Seriously unbalanced development
0.201-0.300	Moderately unbalanced development
0.301-0.400	Slightly unbalanced development
0.401-0.500	Barely unbalanced development
0.501-0.600	Barely balanced development
0.601-0.700	Slightly balanced development
0.701-0.800	Moderately balanced development
0.801-0.900	Favorably balanced development
0.901-1.000	Superiorly balanced development

2.5. Measuring the difference of coupling coordination degrees among four cities: Gini coefficient

In order to compare the coupling coordination degrees among three benefits of urban public transportation infrastructure of four cities, this paper applied Gini coefficient to measure the difference of them. Gini coefficient is an important index which is used to judge the divergence degree of income allocation in the theory of economics. It has been widely used as a major statistical analysis index which is applied to measure the difference degree of different individuals because of convenience of its calculation. Although all of these four cities have the higher level of economy development, whether the distinction of the coupling coordination degrees among three benefits of urban public transportation infrastructure of them is smaller or not was unclear. It is worthy of calculating the difference level of the coupling coordination degrees among three benefits of urban public transportation infrastructure of these four cities to compare them among cities with approximate economy development level.

Here, we suppose G_k is the Gini coefficient value of the k th indicator, n is the total number of sampling, Y_{ki} is the value of the i th data of the k th indicator, e_k is the expected value of the k th indicator. The calculation formulas of the value of Gini coefficient are shown as below:

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$$G_k = \sum_{i=1}^{n}\sum_{j=1}^{n}\left|Y_{ki} - Y_{kj}\right| / \left(n^2 - n\right) \tag{10}$$

$$G_k = \sum_{i=1}^{n}\sum_{j=1}^{n}\left|Y_{ki} - Y_{kj}\right| / 2n^2 e_k \tag{11}$$

When the average value of indicators is zero, the formula (10) is applied. When the average value of indicators is not zero, the formula (11) is applied.

3. Results

3.1. Changes in the utilization benefit value

This paper calculated the weight of each indicator using the entropy method. The weight of each benefit is calculated by adding up the weights of its indicators at the next lower level. The results were displayed in Table 3 and 4. As shown in Table 3, the weight values of these indicators have no obvious difference in different city except for a few of indicators. The values in Table 4 indicated that the weights of three benefits of each city were different. The weight of economic benefit of these cities was the largest except for that of Tianjin whose environmental benefit weight value was the highest. The benefit with smallest weight of these cities was social benefit except for that of Shanghai whose environmental benefit weight value was the lowest. The highest weight values among three benefits of four cities were all between 0.4 and 0.5 and the lowest ones between 0.2 and 0.3. The results revealed that the difference among the weights of three benefits in these four cities was relatively smaller.

The levels of urban public transportation infrastructure utilization benefit of four cities were calculated by formula (7). As illustrated in Figure 1, four cities have obvious different levels of urban public transportation infrastructure utilization benefit from 2004 to 2014. The benefit level of Beijing was at a lower level during this period except for 2008. Chongqing experienced some volatility of the level of urban public transportation infrastructure utilization benefit and wholly displayed a decrease trend. In contrast, Tianjin and Shanghai showed an obvious increase trend of the level of urban public transportation infrastructure utilization benefit from 2004 to 2014. The benefit levels of these two cities were obviously higher than them of the other two cities. But the benefit levels of Tianjin and Shanghai could be further raised. The results indicated that all of them still need to be improved in the future.

In addition, Figure 1 revealed the change trends of three benefits of urban public transportation infrastructure in these four cities from 2004 to 2014. The value of each benefit is the weighted sum of the indicators at the next lower level of it. There were several interesting findings could be found according to the trends shown in Figure 1. Firstly, every benefit has not always shown the same change trend as it of urban public transportation infrastructure. When three benefits have the same change trends, the change trend of urban public transportation infrastructure utilization benefit was the same as them of three benefits. When the change trends of three benefits were various, the change trend of urban public transportation infrastructure utilization benefit was always the same as it of one benefit. Among these four cities, the change trend of urban public transportation infrastructure utilization benefit in Tianjin was always the

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same as it of environmental benefit, that in Shanghai was always the same as it of economic benefit and that in Chongqing was always the same as it of social benefit. The change trend of urban public transportation infrastructure utilization benefit in Beijing was the same as it of economic and social benefit when three benefits appeared different change trend for the first time and it was the same as it of environmental benefit for the next two times from 2004 to 2014. Secondly, three benefits of each city have not appeared the same change trend at all time. For example, the economic and social benefits of Tianjin increased in 2005 but its environmental benefit decreased. Its economic and social benefits constantly raised from 2005 to 2013 during which its environmental benefit showed obvious volatility. In contrast, the economic and social benefits of Shanghai decreased in 2005 but its environmental benefit increased. Three benefits of Shanghai appeared different change trends in many years such as 2009, 2012 and 2014. And three benefits of Chongqing showed different change trends in 2005 for the first time and then showed from 2007 to 2009 and in 2014. Thirdly, three benefits of each city have experienced several severe changes from 2004 to 2014. Beijing underwent severe increase of three benefits in 2008 and seriously decreased in 2009. The economic and social benefits of Tianjin raised severely in 2005. The social and environmental benefits of Shanghai displayed obvious large fluctuation in 2005 and its economic and social benefits displayed in 2007. And the environmental benefit of Chongqing appeared larger change in 2005 and the other two benefits of it appeared in 2010. Fourthly, the level of each benefit has significant difference among these four cities. The values of three benefits of Beijing were significantly lower than them of the other three cities in most years.

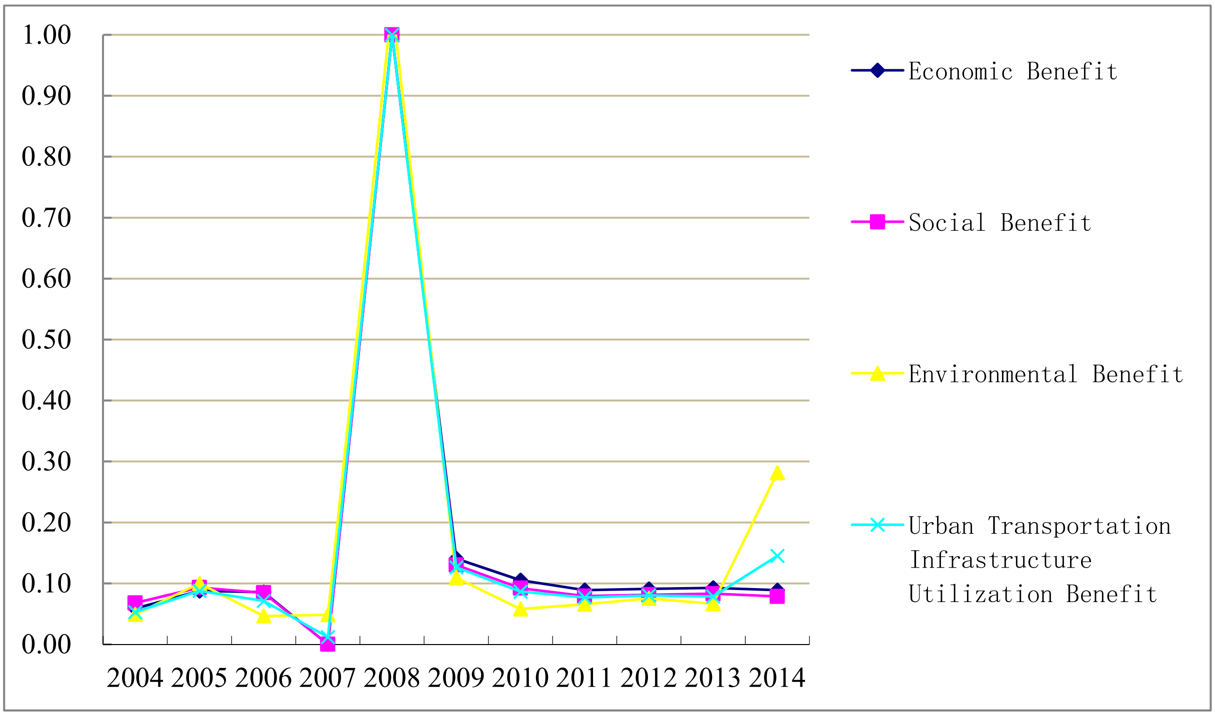
Table 3. Weights of urban public transportation infrastructure utilization benefit indicators of four cities (2004-2014).

Indicator	Beijing	Tianjin	Shanghai	Chongqing
GDP (U_{11})	0.0538	0.0420	0.0548	0.0566
Fiscal revenue (U_{12})	0.0533	0.0452	0.0602	0.0376
Average consumption expenditure of urban dwellers (U_{13})	0.0511	0.0415	0.0586	0.0649
Amount of fixed asset investment (U_{14})	0.0432	0.0459	0.0585	0.0511
Society labour productivity (U_{15})	0.0556	0.0414	0.0519	0.0555
Total retail amount of commodity (U_{16})	0.0573	0.0429	0.0544	0.0510
Total profit of industry enterprise (U_{17})	0.0346	0.0415	0.0551	0.0508
Actual utilized foreign investment (U_{18})	0.0586	0.0416	0.0631	0.0857
Employed population (U_{21})	0.0520	0.0418	0.0570	0.0225

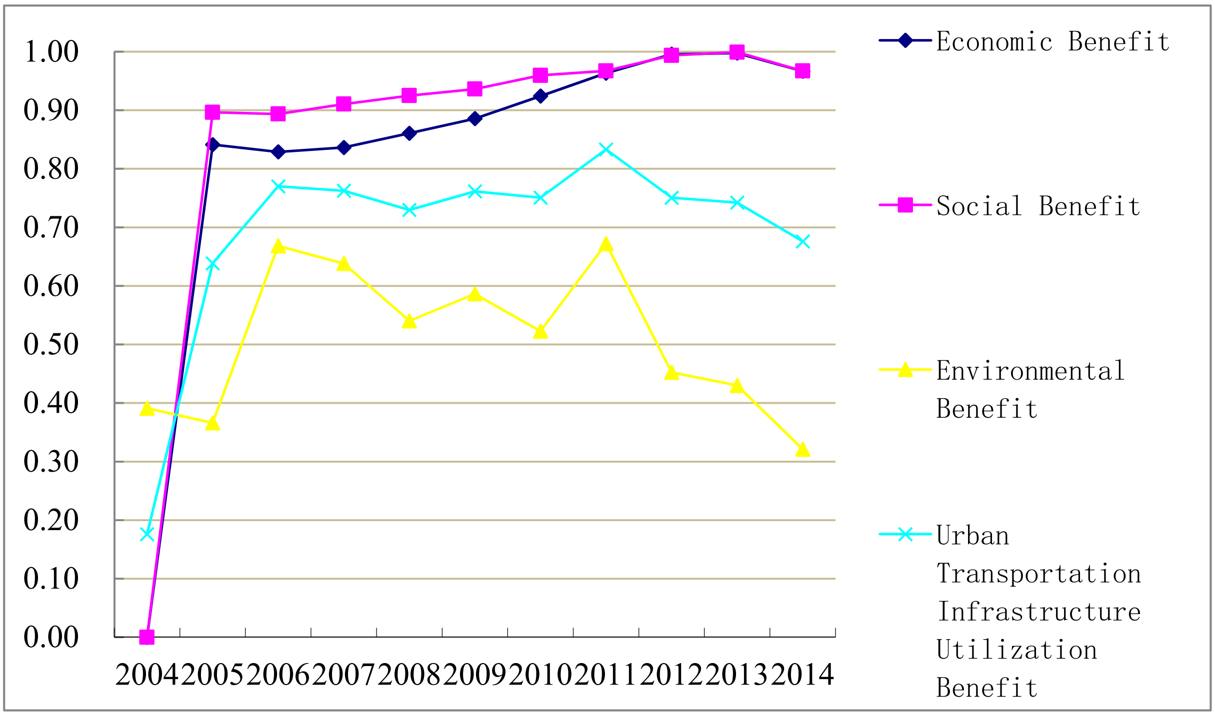
Average wage of employed personnel (U_{22})	0.0570	0.0416	0.0551	0.0574
Disposable income per capita (U_{23})	0.0548	0.0417	0.0550	0.0671
Rural net income per capita (U_{24})	0.0544	0.0414	0.0551	0.0597
Urbanization rate (U_{25})	0.0533	0.0413	0.0638	0.0627
Average value of traffic noise (U_{31})	0.0337	0.1257	0.0393	0.0163
Average daily NO_2 (U_{32})	0.0937	0.1583	0.0523	0.0154
Average daily SO_2 (U_{33})	0.0662	0.0543	0.0497	0.1091
Excellent rate of air ambient quality (U_{34})	0.0729	0.0707	0.0513	0.0501
Average daily particulate matter (U_{35})	0.0546	0.0413	0.0646	0.0864

Table 4. Weights of three benefits of urban public transportation infrastructure of four cities (2004-2014).

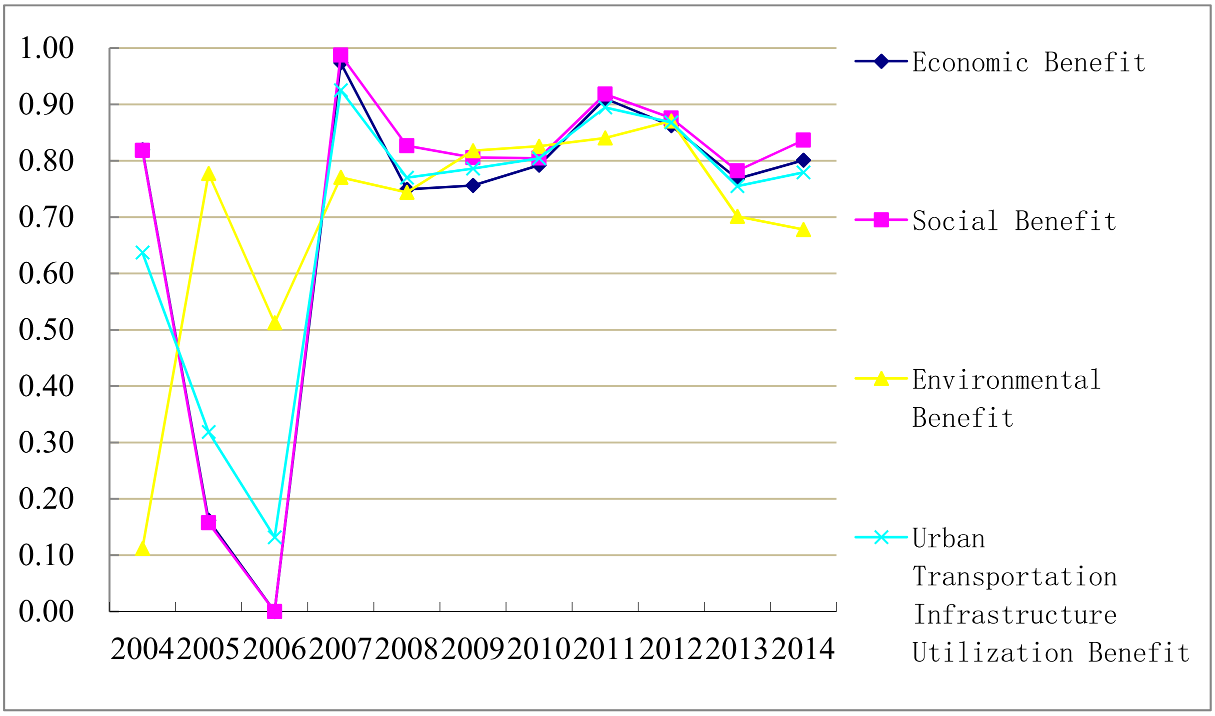
Indicator	Beijing	Tianjin	Shanghai	Chongqing
Economic Benefit	0.4074	0.3419	0.4568	0.4532
Social Benefit	0.2715	0.2077	0.2860	0.2695
Environmental Benefit	0.3211	0.4503	0.2572	0.2773



(a) Beijing



(b) Tianjin



(c) Shanghai

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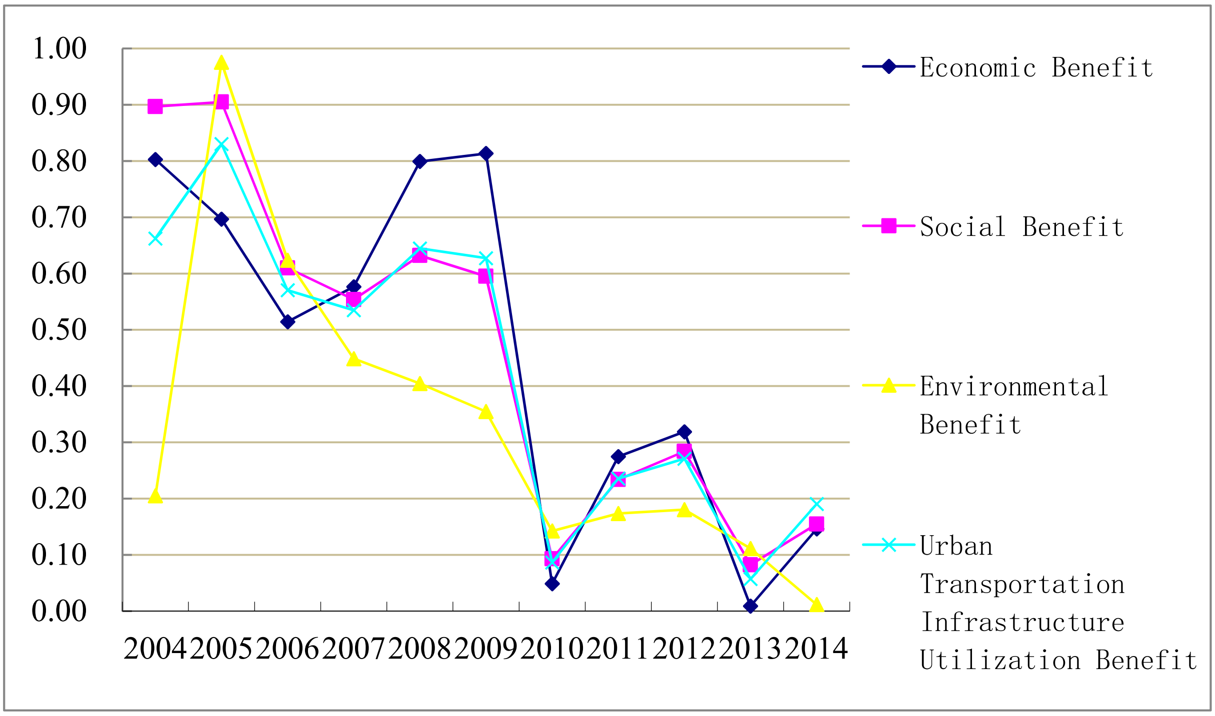

(d) Chongqing

Figure 1. Urban public transportation infrastructure utilization benefits of four cities.

3.2. Coupling coordination degree among three benefits of four cities

As revealed in Figure 2, the coupling coordination degrees among three benefits of urban public transportation infrastructure of four cities displayed different change trends from 2004 to 2014. The values of coupling coordination degrees among three benefits of urban public transportation infrastructure of four cities were lower than 0.6. According to the discriminating standard of the class of coupling coordination development in Table 2, the coordinated development among three benefits of Shanghai was at the level of barely balanced development after 2007 and that of the other three cities were all at the level of unbalanced development in most years. This result showed that the levels of coordinated development among three benefits were all lower. In addition, the change trends of coupling coordination degrees among three benefits were the same as them of urban public transportation infrastructure utilization benefit in four cities. Therefore, the raise of urban public transportation infrastructure utilization benefit was helpful to improve the coordinated development level of three benefits.

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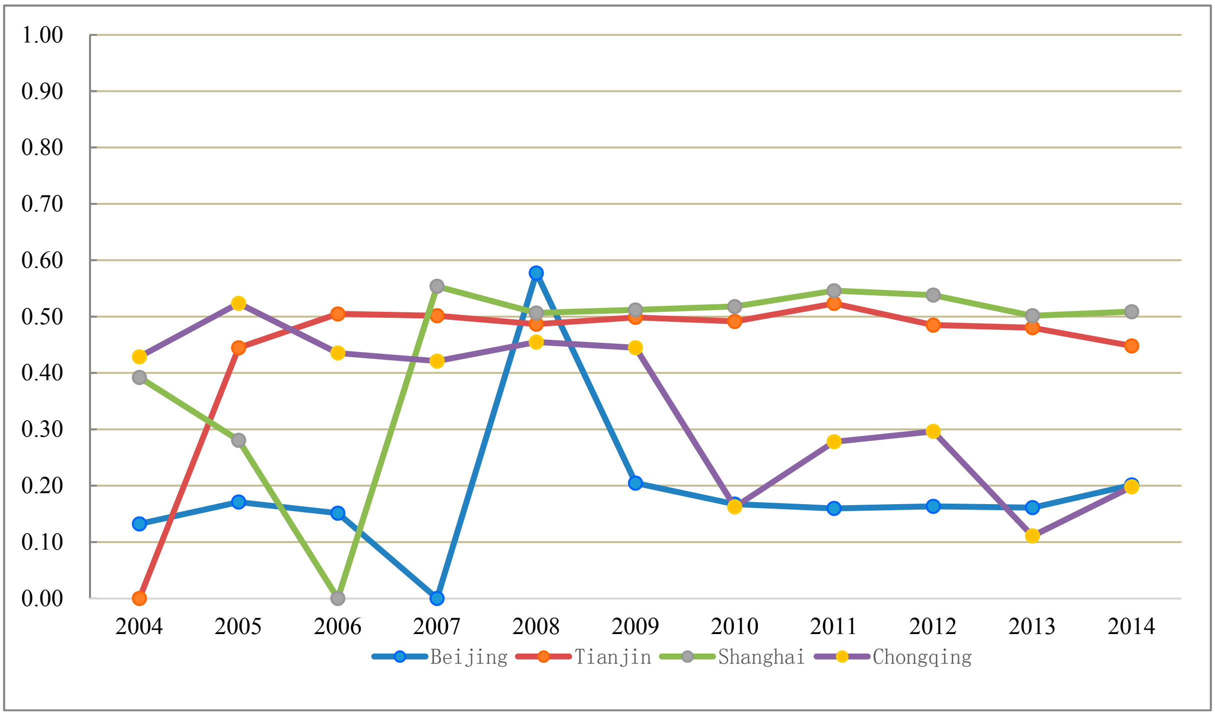

Figure 2. Coupling coordination degree of three utilization benefits of urban public transportation infrastructure of four cities.

3.3. Result of the calculation of Gini coefficient

Figure 3 revealed the result of the calculation of Gini coefficient. This paper used formula (11) to calculate it because all of the average values of coupling coordination degrees of four cities were not zero. The result showed that the values of Gini coefficient almost were not above 0.2. It illustrated that the distinction of coupling coordination degrees of four cities was smaller. Nevertheless, the levels of coordinated development of three benefits were not high from 2004 to 2014. Therefore, the calculation result indicated that all of these four cities faced the problem of raising the level of coordinated development of three benefits of urban public transportation infrastructure again.

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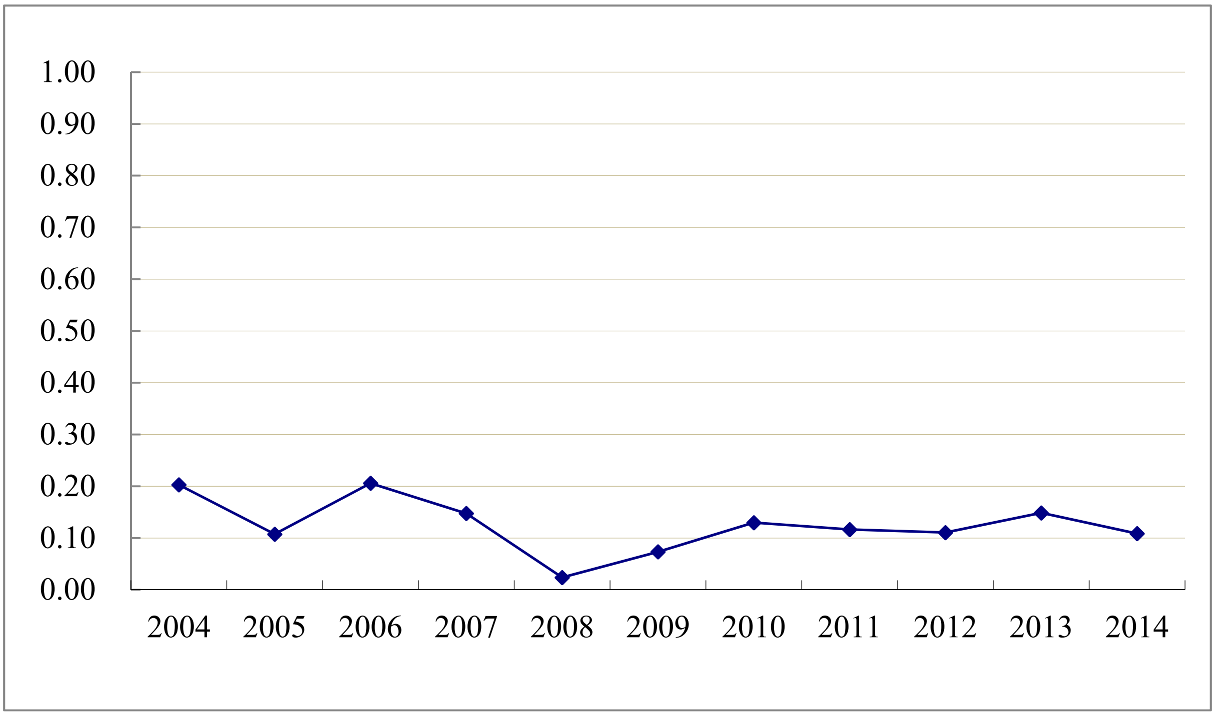

Figure 3. Gini coefficient of coupling coordination degree of three urban public transportation infrastructure utilization benefits in four cities.

4. Discussion

This paper analyzed the relationship among three benefits of urban public transportation infrastructure in four Chinese autonomous municipalities and compared them. Moreover, the difference of coordinated development levels among three benefits of these four cities was studied in this paper. The research results showed that the coordinated development of three benefits of urban public transportation infrastructure of these four cities has some problems and need to be improved.

Generally speaking, this paper has three main findings. The first finding was that the coordinated developments among three benefits of urban public transportation infrastructure of four cities were relatively lower. Among these four cities, Shanghai has the highest value of coupling coordination degree among three benefits in many years but its value was still below 0.6. The other three cities were almost at the level of unbalanced development from 2004 to 2014. The result indicated that the impacts of urban public transportation infrastructure on economy, society and environment were obviously different. Three benefits of urban public transportation infrastructure often appeared relatively bigger distinction. It coincided with the fact that the change trends of three benefits were different in these four cities.

The second one was that the change trends of the coordinated developments among three benefits of urban public transportation infrastructure were consistent with them of urban public transportation infrastructure utilization benefit in four cities. Although the coordinated development degrees among these three benefits of four cities were all lower, the levels of it in Tianjin and Shanghai were relatively higher than them in Beijing and Chongqing. This result showed that the change of urban public transportation infrastructure utilization benefit has a positive influence to it of the coordinated development among three benefits of urban public transportation infrastructure. Therefore, raising the level of urban public transportation infrastructure utilization benefit is an important way of promoting the coordinated development among three benefits of urban public transportation infrastructure.

The last one was that the difference of the coordinated developments among three benefits of four cities was smaller. According the result of the calculation of Gini coefficient, the levels of coordinated development among three benefits were fairly close in these four cities. All of these four cities need to improve the coordinated development among three benefits of urban public transportation infrastructure.

5. Conclusions and Policy Implications

In conclusion, the results suggest that the levels of coordinated development among three benefits of urban public transportation infrastructure were lower in these four cities and have positive correlation with it of urban public transportation infrastructure utilization benefit. Therefore, raising the level of urban public transportation infrastructure utilization benefit is the most crucial solution of this problem.

This paper provides the following policy implications. First, four cities should strengthen the basic function of urban public transportation infrastructure in the process of economy development. On the one hand, four cities need to promote the market-oriented reform of urban public transportation infrastructure and the development of transport industry. On the other hand, the development of urban public transportation infrastructure should satisfy the demand of urban economy development. The urban transportation infrastructure has obvious spillover effect which has strong interaction with other industrial sectors. Four cities should raise the urban transport capacity by developing public transportation infrastructure which accelerates the circulation of commodity. The well-conditioned urban public transportation infrastructure is helpful to increase the profit of enterprise and the development of investment and consumption which results in the raise of urban economy development level.

Second, four cities should raise the urban development level and improve the living condition of urban dwellers by building public transportation infrastructure. As important public goods, urban public transportation infrastructure has obvious external effect whose social benefit considerably exceeds economic benefit. Four cities should develop urban public transportation infrastructure to drive the development of other industries which leads to the increase of labour demand. It is beneficial to raise the level of employment and average wage which further promotes the improvement of urban living quality and social progress. In addition, the perfect urban public transportation infrastructure system facilitates the flow of population and promotes the expansion of urban built-up district. Four cities should form the structure of urban and rural balance development by developing urban public transportation infrastructure. It is conducive to raise the level of urbanization.

Third, environmental benefit of urban public transportation infrastructure also should be valued highly. Protecting the urban natural environment is one main aim of developing public transportation infrastructure. Four cities should set up the strict standard of pollutant emission from public transportation infrastructure. The governments of four cities should intensify the environmental management of urban public transportation infrastructure through different approaches such as taxation and enacting regulation. The related agencies should establish the reasonable prices of urban public transport to encourage the urban dwellers to choose public transport as primary travel mode. Meanwhile, four cities should speed up the research and development of new energy vehicle and raise the technology level of urban public transportation infrastructure to reduce its energy consumption which is helpful to raise the environmental protection level of public transportation infrastructure.

Last, four cities should attach importance to the proportion among different benefits of urban public transportation infrastructure. Economic, social and environmental benefits organically constituted the whole structure of urban public transportation infrastructure utilization benefit. The development level of them should close in general. And the performance of them must be controlled and regulated strictly. In addition, the development of urban public transportation infrastructure should fit the demand of urban development. In this way, the gap among different benefits of urban public transportation infrastructure can be narrowed.

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