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Research Article

An Empirical Analysis of the Coupling Coordination among Decomposed Effects of Urban Infrastructure Environment Benefit: Case Study of Four Chinese Autonomous Municipalities

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The environment benefit of urban public infrastructure is the positive influence on the natural ecological environment generated by the use of urban infrastructure. This paper decomposes urban infrastructure environment benefit into three effects which include treating waste effect, purifying air effect, and regulating climate effect for the first time and introduces a comprehensive approach to evaluate the coupling coordination among three effects taking four Chinese autonomous municipalities as an example. These four cities have large-scale urban infrastructures but their environment problems are more serious. The basic function of urban infrastructures, especially environment protection, has not been fully played in these cities. Whether the different decomposed effects of urban infrastructure environment benefit have been developed in harmony or not is unclear. We analyzed the coordinated development among three effects by constructing a coupling coordination degree model and studied the impacts of three effects on coupling coordination degree using the panel data regression model. The result showed that the coupling coordination degrees among three effects of urban infrastructure environment benefit of four cities were all at the level of moderately unbalanced development and the impacts of three effects on coupling coordination degree among them in four cities were fairly close.

1. Introduction

Urban public infrastructure includes energy infrastructure, water infrastructure, transportation infrastructure, sanitation infrastructure, telecommunication infrastructure, and disaster-preventing infrastructure. With rapid economic progress and urbanization, it has become a necessary condition which ensures the urban usual operation of production and life. The use of it not only promotes the development of economy and raises the urban residents' living level but also has important significance on the protection of urban ecological environment [1]. The environment benefit of urban public infrastructure is the positive influence on the natural ecological environment generated by the use of urban infrastructure. In recent years, China has been experiencing the process of rapid urbanization [2]. With the expansion of the urban scale, the environment problem of the city has become increasingly prominent which prevents the development and progress of urban society seriously although the construction of urban public infrastructure has been accelerating. Air pollution, greenhouse gas emission, traffic noise, degraded water quality, and so on are the main aspects of the urban environment problem [3–5]. The issues of how to cope with the urban environment problem and promote the harmonious development of economy and environment while playing the function of environment protection of urban public infrastructure have become important subjects for the Chinese government and scholars.

The environment benefit that emerged from the use of urban infrastructure contributes to the improvement of urban environment conditions and further indirectly boosts the development level of urban society. Therefore, how to improve urban infrastructure environment benefit has become a hot topic. Many authors in the literature have studied the environment influence of urban infrastructure. Some scholars held that the development of green infrastructure is a strategically important process for the creation of the ecologically friendly urban environment, as well as for the satisfaction of the socioeconomic needs of city dwellers without harming the nature [6]. Other scholars assessed the environment impacts of sanitation infrastructure such as sewer infrastructure and waste collection system as well as charging infrastructure through Life Cycle Assessment [7–9]. Urban green infrastructure can to a certain extent mitigate urban warming [10, 11] and reduce noise [12, 13]. Most importantly, urban green infrastructure has the function of providing ecosystem service [14–16]. Besides, some authors in the literature have considered other environment benefits of urban infrastructures. One of them is the process of local climate stabilization via air filtration [17, 18] or cooling [19, 20] which is particularly important for the mitigation of urban heat island effects. Another is to offset carbon emissions [21, 22] and increase carbon storage and sequestration [23–25]. Some scholars also analyzed and predicted the carbon footprint of the construction of urban infrastructure [26, 27] while others studied the cost of reducing carbon dioxide emissions of urban infrastructure using Life Cycle Assessment [28, 29]. Except for them, urban infrastructure can improve air quality by reducing the concentrations of nitrogen dioxide and particulate matter [30, 31] and produce positive influence such as saving energy [32].

In summary, the scholars mainly studied the environment influence of urban sanitation infrastructure which contains public green space, urban park, special vehicle for urban appearance and sanitation, household waste hazard-free treatment factory, polluted water treatment factory, and so on. Its environment benefit can be decomposed into three aspects. Firstly, it produces environment benefit through treating waste. Sanitation infrastructure such as sewage treatment plant and household waste hazard-free treatment plant has the function of controlling pollution. It collects urban daily waste and disposes it intensively which reduces the negative impact of waste on the urban natural environment. We can name this aspect as treating waste effect of urban infrastructure. Secondly, it can improve the air quality by absorbing the pollutants and hazardous substances in the sky. For example, urban public green space and park raise the city's green plant coverage ratio. The green plant is helpful to reduce the concentration of pollutants and hazardous substances in the urban air. This aspect can be named as purifying air effect. Thirdly, urban public green space and park can reduce the heat island effect and regulate the regional climate through decreasing temperature and humidity. We can name this aspect as regulating climate effect. These three decomposed effects organically combine and constitute the environment benefit of urban sanitation infrastructure. According to the above analysis, urban sanitation infrastructure plays an important role in protecting urban natural environment at many different aspects. It provides the basic function of environment protection. The environment benefit of urban public infrastructure is mainly produced by urban sanitation infrastructure. Therefore, this paper mainly studies the environment benefit generated by urban sanitation infrastructure.

Previous studies showed that the nice effect of urban infrastructure on the natural environment is more and more clear. Nevertheless, the research on the comprehensive evaluation of urban infrastructure environment benefit is relatively scarce. Fewer scholars studied the relationship among decomposed effects of urban infrastructure environment benefit. In reality, different decomposed effects of urban infrastructure environment benefit can affect each other. Disposing waste can decrease the amount of pollutants in the air to improve the air quality. Cutting down the amount of pollutants not only purifies the air but also maintains the ecological balance and prevents the occurrence of heat island effect for regulating local climate. Thus, as a whole, all of the decomposed effects of urban infrastructure environment benefit should be raise simultaneously and develop in harmony. The level of urban infrastructure environment benefit will be raised only if all of the decomposed effects of urban infrastructure environment benefit are well coordinated. This paper takes four autonomous municipalities of China, which are Beijing, Tianjin, Shanghai, and Chongqing, as an example to analyze the coupling coordination degree among different decomposed effects of urban infrastructure environment benefit 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 infrastructure in these four cities are giant and increasing quickly year by year. But the environment problem of four cities is serious. The basic function of urban infrastructures, especially environment protection, has not been fully played in these cities. Whether the different decomposed effects of urban infrastructure environment benefit have been developed in harmony or not is unclear. Therefore, this paper tries to study the coupling coordination degree among decomposed effects of urban infrastructure environment benefit in these four cities and reveals how the coupling coordination degree of them is influenced by decomposed effects of urban infrastructure environment benefit. A comprehensive approach of evaluating the coupling coordination among three effects of urban infrastructure environment benefit was put forward in this study. As one of the approaches for measuring interactive effects, coupling coordination model was applied to fully and objectively evaluate the coordinated development level among three decomposed effects of urban infrastructure environment benefit. Then the impact of each effect on the coupling coordination degree among three decomposed effects of urban infrastructure environment benefit was studied using the panel regression model. The purposes of this paper are to reveal the coordinated development level of three effects of urban infrastructure environment benefit and to identify the impact of each effect on the coupling coordination degree among three decomposed effects of urban infrastructure environment benefit and then to provide references for more coordinated development of urban infrastructure environment benefit.

The rest of this paper is organized as follows. Section 2 constructs the urban infrastructure environment benefit

Table 1: An evaluation indicator system for urban infrastructure environment benefit.

Level 1	Level 2	Level 3	Calculation method
Urban infrastructure environment benefit (U)	Treating waste effect (U_1)	Level of household waste hazard-free treatment (U_{11})	(Change rate of household waste hazard-free treatment rate/change rate of household waste hazard-free treatment factory amount) ∗ 100%
		Level of urban sewage treatment (U_{12})	(Change rate of urban sewage treatment rate/change rate of polluted water treatment factory amount) ∗ 100%
		Level of road sweeping and cleaning (U_{13})	(Change rate of area under cleaning program/change rate of special vehicle for urban appearance and sanitation amount) ∗ 100%
	Purifying air effect (U_2)	Excellent rate of air ambient quality (U_{21})	(Change rate of excellent rate of air ambient quality/change rate of area of garden green space in built-up area) ∗ 100%
		Average daily particulate matter (U_{22})	(Change rate of average daily particulate matter/change rate of area of garden green space in built-up area) ∗ 100%
		Average daily NO_2(U_{23})	(Change rate of average daily NO_2/change rate of area of garden green space in built-up area) ∗ 100%
		Average daily SO_2(U_{24})	(Change rate of average daily SO_2/change rate of area of garden green space in built-up area) ∗ 100%
	Regulating climate effect (U_3)	Average annual temperature (U_{31})	(Change rate of average annual temperature/change rate of area of garden green space in built-up area) ∗ 100%
		Average annual relative humidity (U_{32})	(Change rate of average annual relative humidity/change rate of area of garden green space in built-up area) ∗ 100%

indicator system and introduces the empirical research methods used in this paper. The result of empirical analysis is revealed in Section 3. Section 4 summarizes the main conclusions and provides the policy implications.

2. Methodology

2.1. Construction of Indicator System. In this study, building urban infrastructure environment benefit indicator system should be confirmed by the following criteria. First, the indicators should be measurable, comprehensive, and independent of each other [33]. Second, the indicators must play an important role in measuring the urban infrastructure environment benefit. Third, the chosen indicators are directly influenced by urban infrastructures, which have obvious changes when 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 9 indicators to evaluate the urban infrastructure environment benefit of four cities. This study decomposed urban infrastructure environment benefit into three effects. Therefore, these indicators should comprehensively reveal the environment benefit which is brought about by urban sanitation infrastructure and can reflect the three decomposed effects of urban infrastructure environment benefit (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 is indicator level. The fourth column shows the calculation method of the value of these indicators. As the amount of urban sanitation infrastructure changes, the environment benefit will also undergo changes. The value of indicator should show its change degree along with the change of urban infrastructures. It will reflect how significantly urban infrastructure impacts each indicator. Consequently, according to the elastic calculation formula in economics, the calculating method of each indicator is shown in Table 1. It indicates how much the change percentage of each indicator is when the urban sanitation infrastructure changes 1%. In other words, it means the impact of urban sanitation infrastructure on each indicator.

2.2. Calculation of Urban Infrastructure Environment 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 infrastructure environment benefit index concerns the contribution of each indicator to the 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 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 [34]. Therefore, the weight of each indicator is calculated according to the value of entropy. The detailed step is showed as follows.

Step 1. 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):

$$Y_{ij} = \frac{X_{ij} - \min\left\{X_j\right\}}{\max\left\{X_j\right\} - \min\left\{X_j\right\}}, \tag{1}$$

$$Y_{ij} = \frac{\max\left\{X_j\right\} - X_{ij}}{\max\left\{X_j\right\} - \min\left\{X_j\right\}}, \tag{2}$$

where X_{ij} is the observed value of the jth indicator in year i; $\max\{X_j\}$ is the maximum observed value; $\min\{X_j\}$ is the minimum observed value, and Y_{ij} is the normalized value. When the increasing value of indicator raised the level of urban infrastructure environment benefit, formula (1) is applied. When the decreasing value of indicator raised the level of urban infrastructure environment benefit, formula (2) is applied. In this paper, the values of U_{11}, U_{12}, U_{13}, and U_{21} are calculated by formula (1) and the values of U_{22}, U_{23}, U_{24}, U_{31}, and U_{32} by formula (2).

Step 2. Calculate the proportion of the jth indicator value in year i,

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

Step 3. Calculate the information entropy of each indictor and the redundancy degree of the information entropy,

$$\begin{aligned} e_j &= -\frac{1}{\ln m} \sum_{i=1}^{m} \left(\varpi_{ij} \times \ln \varpi_{ij}\right), \\ d_j &= 1 - e_j, \end{aligned} \tag{4}$$

where e_j is defined as the information entropy of the jth indicator, $0 \le e_j \le 1$, and d_j is the redundancy degree of the information entropy.

Step 4. Calculate the weight,

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, \tag{5}$$

where w_j is the weight of the jth indicator.

Step 5. Calculate the urban infrastructure environment benefit index,

$$S_{\text{benefit},i} = \sum_{j=1}^{n} w_j Y_{ij}, \tag{6}$$

where $S_{\text{benefit},i}$ is the urban infrastructure environment benefit in year i, $S_{\text{benefit},i} \in [0, 1]$.

2.3. Coupling Coordination Degree Model. This paper introduces the concept of coupling in physics to calculate the coupling degree of four cities' three decomposed effects of urban infrastructure environment benefit [33, 35]. Coupling refers to the dynamic relationship which is mutual influence 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 decomposed effects of urban infrastructure environment benefit. The coupling coordination degree model is given in the following formulas:

$$\begin{aligned} H &= \sqrt{C \times S_{\text{benefit}}}, \\ C &= \left[\frac{U_1 \times U_2 \times U_3}{\left(U_1 + U_2 + U_3\right)^3}\right]^{1/3}, \end{aligned} \tag{7}$$

where H represents the coupling coordination degree, and $H \in (0, 1)$; C represents the coupling degree among three decomposed effects; U_1, U_2, and U_3 represent the treating waste effect, purifying air effect, and regulating climate effect, respectively.

According to the value of coupling coordination degree, the coordinated development of three decomposed effects of urban infrastructure environment benefit was divided into ten classes (Table 2). It reflects the overall coordination result of three decomposed effects.

2.4. Panel Regression Model. The coupling coordination degree among three decomposed effects of urban infrastructure environment benefit shows the coordinated development level among three decomposed effects. Therefore, generally speaking, the coupling coordination degree is influenced by the level of these three effects. Once the level of one effect changes, the proportional relationship among these decomposed effects will be altered correspondingly. It will further affect the coordinated development level among these effects. In a word, the change of anyone of three decomposed effects will exert an impact on the coupling coordination degree, which results in the change of coordinated development level among three decomposed effects

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

of urban infrastructure environment benefit. So how much are these three decomposed effects impact on the coupling coordination degree is also an issue worthy of in-depth study.

In order to analyze the impact of three decomposed effects on their coupling coordination degree, an empirical model is established. Because the sample contains different cities at different years, so this paper uses panel data models to investigate the impact of three decomposed effects on their coupling coordination degree. Panel data models can control individual heterogeneity, reduce the effects of correlation among the variables, raise the degree of freedom, improve the estimation efficiency, and allow for more informative data [36]. Based on the above analysis, we establish the panel regression model as follows:

$$H_{i,t} = \alpha_0 + \alpha_1 U_{1i,t} + \alpha_2 U_{2i,t} + \alpha_3 U_{3i,t} + \varepsilon_{i,t}, \qquad (8)$$

where $H_{i,t}$ is the coupling coordination degree of city i at year t; $U_{1i,t}$, $U_{2i,t}$, and $U_{3i,t}$ represent treating waste effect, purifying air effect, and regulating climate effect of city i at year t, respectively; α_0 represents constant term and the parameters α_1, α_2, and α_3 represent the elasticity estimates of H with respect to U_1, U_2, and U_3, respectively.

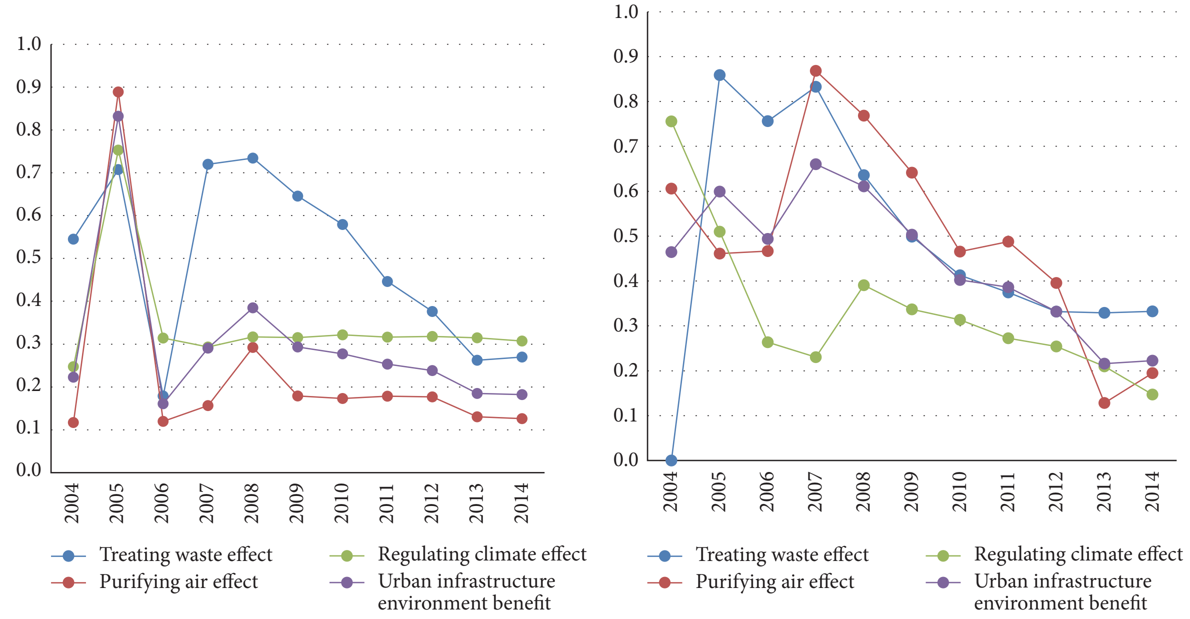
3. Results

3.1. Changes in the Environment Benefit Value. This paper calculated the weight of each indicator using the entropy method. The weight of each effect is calculated by adding up the weights of its indicators at the next lower level. The results were displayed in Tables 3 and 4. As shown in Table 3, the weight values of each indicator have obvious difference in different city. The values in Table 4 showed that the levels of gap among the weights of three effects of each city were different. The gap among the weights of Beijing was the most obvious. The weight of purifying air effect of Beijing was 0.6487, which was far more than other two effects. The city with the smallest gap was Tianjin whose weights of three effects were all between 0.3 and 0.4. The differential levels among the weights of Shanghai and Chongqing were in-between.

The levels of urban infrastructure environment benefit of four cities were calculated by formula (6). As illustrated in Figure 1, the level of urban infrastructure environment benefit showed a decreasing trend from 2004 to 2014 in four cities, although it displayed the increase trend in a few years. The urban infrastructure environment benefit values of four cities were generally below 0.6 except for some specific years. The difference of urban infrastructure environment benefit level of four cities was not large. The research result indicated that the urban infrastructure environment benefits of four cities were almost at the same level and had certain improvement space. All of them still need to be raised in the future.

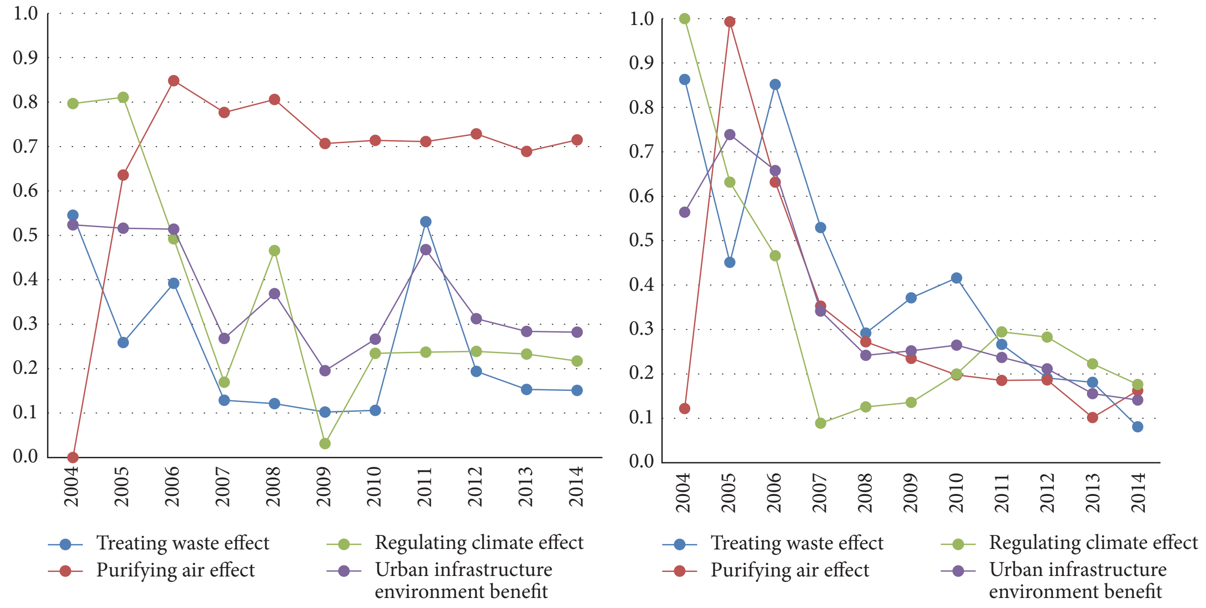
In addition, Figure 1 revealed the change trends of three decomposed effects of urban infrastructure environment benefit of four cities from 2004 to 2014. The value of each effect is the weighted sum of the indicators at the next lower level of it. According to the trends shown in Figure 1, three decomposed effects of four cities also presented the decreasing trend and were at a lower level except for the purifying air effect of urban infrastructure in Shanghai. The Shanghai city's purifying air effect of urban infrastructure has obviously increased and at a higher level since 2005. However, the weight of this effect in Shanghai city's urban infrastructure environment benefit index is the lowest. Thus, the high level of this effect did not raise the level of Shanghai city's urban infrastructure environment benefit. Although three decomposed effects of four cities performed decreasing trends as a whole, the change trends of every effect were not exactly the same in different cities. The treating waste effect experienced severe increase and decrease in four cities from 2004 to 2014, which showed obvious volatility. The purifying air effect also experienced a severe increase in four cities. After a severe increase, the purifying air effect of Shanghai has remained at a higher level and that of other cities has decreased quickly again. The regulating climate effect of four cities has been decreasing from 2004 to 2014 except for one obvious increase and decrease in Beijing and Shanghai.

3.2. Coupling Coordination Degree among Three Decomposed Effects of Four Cities. As illustrated in Figure 2, the coupling coordination degrees among three decomposed effects of urban infrastructure environment benefit of four cities initially increased, then decreased, again increased, and finally decreased from 2004 to 2014. The coupling coordination degrees among three decomposed effects of four cities all increased in 2005 and decreased in 2006 except that of Shanghai. The coupling coordination degree among three decomposed effects of Shanghai firstly decreased in 2007. The second increase of coupling coordination degree among three decomposed effects of Beijing emerged in 2007 and that of Tianjin also in 2007, that of Shanghai occurred in 2008, and that of Chongqing appeared in 2009. The coupling coordination degree of Shanghai increased for the third time in 2010. It indicated that the trend of coupling coordination degree among three decomposed effects of Shanghai changed most frequently from 2004 to 2014. All of the city's coupling



(a) Beijing

(b) Tianjin



(c) Shanghai

(d) Chongqing

FIGURE 1: Urban infrastructure environment benefits of four cities.

coordination degrees among three decomposed effects have decreased since 2011. The highest value of coupling coordination degree among three decomposed effects of four cities occurred in 2005, 2008, 2006, and 2005, respectively. The values of coupling coordination degree among three decomposed effects of four cities were lower than 0.5 from 2004 to 2014 beside that of Beijing in 2005.

The result demonstrated that the degrees of coordinated development among three decomposed effects of four cities were all in low level from 2004 to 2014. In 2014 the values of coupling coordination degree among three decomposed effects of four cities were all between 0.2 and 0.3. According to the discriminating standard of the class of coupling coordination development in Table 2, the coordinated developments among three decomposed effects of four cities were all at the level of moderately unbalanced development. Four cities all have the problem of uncoordinated development among three decomposed effects of urban infrastructure environment benefit. It was unfavorable to the increase of urban infrastructure environment benefit.

Table 3: Weights of urban infrastructure environment benefit indicators of four cities (2004–2014).

Indicator	Beijing	Tianjin	Shanghai	Chongqing
Level of household waste hazard-free treatment (U_{11})	0.0744	0.0554	0.2064	0.1283
Level of urban sewage treatment (U_{12})	0.0360	0.1922	0.0426	0.1345
Level of road sweeping and cleaning (U_{13})	0.0908	0.0624	0.2235	0.0417
Excellent rate of air ambient quality (U_{21})	0.1783	0.0910	0.0346	0.0781
Average daily particulate matter (U_{22})	0.0759	0.1226	0.0657	0.1915
Average daily NO_2(U_{23})	0.2479	0.1010	0.0404	0.0308
Average daily SO_2(U_{24})	0.1466	0.0666	0.0532	0.1487
Average annual temperature (U_{31})	0.0371	0.0755	0.0729	0.1187
Average annual relative humidity (U_{32})	0.1130	0.2334	0.2609	0.1278

Table 4: Weights of three effects of urban infrastructure environment benefit of four cities (2004–2014).

Indicator	Beijing	Tianjin	Shanghai	Chongqing
Treating waste effect	0.2012	0.3100	0.4724	0.3045
Purifying air effect	0.6487	0.3812	0.1939	0.4490
Regulating climate effect	0.1501	0.3088	0.3337	0.2465

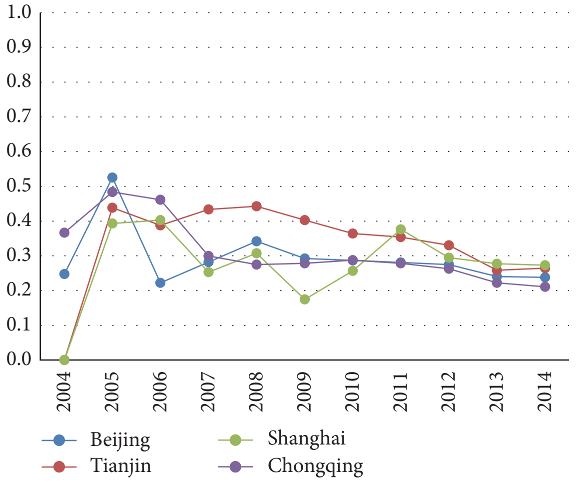


Figure 2: Coupling coordination degree of three decomposed effects of urban infrastructure environment benefit of four cities.

3.3. Result of Panel Regression Model. This section consists of the following sequential estimations which are descriptive statistics of the variables, panel unit root test, panel cointegration tests, panel model selection, and panel model regression for analyzing the impact of three decomposed effects on the coupling coordination degree in four cities. Table 5 shows the descriptive statistics of all the variables in the model.

Here we must test the stability of the variable sequences firstly because many sequences of variables may be nonstationary. If the test results show that these variables are nonstationary sequences, we must change them into stationary sequences so that the relevant methodology can be applied to the next empirical analysis. Fisher-ADF test, Fisher-PP test, and IPS test are the three main test methods which allow each cross-section sequence with individual unit root process and are widely used [36, 37]. Therefore, this paper applies them to conduct the panel unit root test. Table 6 shows the results of panel unit root tests by these three methods. The results show that all of the variables are stationary series at level. Based on the panel data from a sample area of four cities, three independent variables are bivariate-cointegrated with coupling coordination degree among three decomposed effects. According to the results shown in Table 7, there is a cointegration relationship between each effect and coupling coordination degree at different confidence levels. In addition, the cointegration relationship between coupling coordination degree among three decomposed effects and all of the explanatory variables is checked by the KAO panel test [37]. The result is revealed in Table 8 which demonstrates the significance of ADF test statistics. Therefore, it is certainly believed that the cointegration relationship between variables exists at the significance level of 1 percent.

The next step is to choose the type of panel data model. The panel data model usually includes three types which are mixed effects model, fixed effects model, and random effects model. According to the different characteristics of panel data, it is necessary to select appropriate panel data model to analyze the impact of independent variables on dependent variable. The specific process of selecting panel data model contains the following several steps. Firstly, we will select between mixed effects model and fixed effects model using the likelihood ratio test. If the P value of the F-test statistic is less than a specified level of significance, we will choose the fixed effects model. If it is not the case, the mixed effects model will be selected for the empirical analysis. Secondly, if the mixed effects model was rejected, we use the Hausman test to choose the type of panel data regression model between fixed effects model and random effects model for the empirical analysis. If the Hausman test value is large and the corresponding P value is much less than the predetermined level of significance (i.e., 1%, 5%, and 10%), we will build a fixed effects model. Otherwise, we would establish a random effects model. For this case, both of

Table 5: The statistical description of the variables used in the analysis.

Variable	N	Min	Max	Average	Standard variation
Coupling coordination degree (H)	44	0.0000	0.8631	0.4092	0.2403
Treating waste effect (U_1)	44	0.0000	0.9927	0.4271	0.2846
Purifying air effect (U_2)	44	0.0312	1.0000	0.3422	0.2091
Regulating climate effect (U_3)	44	0.0000	0.5253	0.3640	0.1038

Table 6: Results of panel unit root tests.

Series		Fisher ADF		Fisher PP		IPS	
		Constant	Trend and constant	Constant	Trend and constant	Constant	Trend and constant
Levels	Coupling coordination degree (H)	31.7465^{***}	29.6140^{***}	30.8591^{***}	48.3989^{***}	-4.2248^{***}	-2.8118^{***}
	Treating waste effect (U_1)	15.1631^{*}	29.2713^{***}	22.7840^{***}	45.2431^{***}	-1.3685^{*}	-3.8934^{***}
	Purifying air effect (U_2)	18.1417^{**}	45.6276^{***}	32.9974^{***}	36.2627^{***}	-2.0446^{**}	-10.3790^{***}
	Regulating climate effect (U_3)	38.4111^{***}	32.3955^{***}	30.1320^{***}	25.6777^{***}	-30.4845^{***}	-15.7087^{***}

Note: lags are all selected automatically by AIC and SC standard.
∗ means significant at confidence level 10%.
∗∗ means significant at confidence level 5%.
∗ ∗ ∗ means significant at confidence level 1%.

the results of the Hausman test and the likelihood ratio test suggest that the fixed effects model should be used to analyze the impacts of three effects on coupling coordination degree among them in four cities (Table 9).

The estimation results are shown in Table 10, which show that all of the independent variables are statistically significant. The result of F-test indicates the significance of the model. All of the regression coefficients are positive means where three decomposed effects are all positively related to coupling coordination degree among them. The elasticity of treating waste effect is greatest (0.2050), indicating that a 1% increase in treating waste effect would lead to 0.205% increase in coupling coordination degree among three decomposed effects when other factors keep constant. The elasticity of purifying air effect is smallest (0.1193). The results reveal that treating waste effect is the most important contributor to increase coupling coordination degree among three decomposed effects of four cities, regulating climate effect is the second, and purifying air effect is the last. But the difference among the elasticity of three effects is smaller. It shows that the impacts of three decomposed effects on coupling coordination degree among them are fairly close.

4. Conclusions and Policy Implications

This paper determined the weights of indices of four cities and calculated urban infrastructure environment benefit, respectively, by the entropy method at first, then analyzed the coupling coordination degree among three decomposed effects of urban infrastructure environment benefit of four cities by means of constructing coupling coordination degree model, and finally studied the impacts of three decomposed effects on coupling coordination degree among them using panel data regression model.

4.1. Conclusions.

According to the above empirical results, several useful findings of this paper are summarized as follows:

(1) The coupling coordination degrees among three decomposed effects of urban infrastructure environment benefit of four cities were all at a lower level. The coordinated development levels of three decomposed effects of four cities mainly varied between moderately unbalanced development and barely unbalanced development from 2004 to 2014. The development levels of three decomposed effects of urban infrastructure environment benefit of four cities were obviously different.

(2) The change trends of coupling coordination degree among three decomposed effects of urban infrastructure environment benefit of four cities were similar to the change trends of urban infrastructure environment benefit level of four cities from 2004 to 2014. When urban infrastructure environment benefit level increased, coupling coordination degree among three decomposed effects of it would be also improved. In other words, the improvement of urban infrastructure environment benefit would enhance coupling coordination degree among three decomposed effects of it and vice versa.

(3) The impacts of three decomposed effects on coupling coordination degree among them in four cities were fairly close. Although the impact of treating waste effect on coupling coordination degree among three decomposed effects was biggest, the impact of it was not much bigger than that of the smallest one. In addition, according to the results in Figure 1, the levels of three decomposed effects of four cities mainly

Table 7: Testing for bivariate-cointegration between coupling coordination degree and each effect.

Test statistics	Treating waste effect (U_1)	Purifying air effect (U_2)	Regulating climate effect (U_3)
Panel v-statistic	−0.0452	1.4218*	1.3979*
Panel rho-statistic	−2.0574**	−2.3280***	−2.1286**
Panel PP-statistic	−5.0828***	−7.1448***	−3.9119***
Panel ADF-statistic	−4.4274***	−1.7392**	−0.9003
Group rho-statistic	−0.6734	−0.3919	−0.3698
Group PP-statistic	−4.3608***	−4.8426***	−3.0606***
Group ADF-statistic	−6.7818***	0.0658	−1.2254

Note: lags are all selected automatically by AIC and SC standard.
$*$ means significant at confidence level 10%.
$**$ means significant at confidence level 5%.
$***$ means significant at confidence level 1%.

Table 8: Kao panel cointegration test.

Panel of four cities	ADF test statistics	Residual variance	HAC variance	Probability value
	−2.5763	0.0053	0.0026	0.0050

Note: H0: there is no cointegration relationship between the variables. H1: there is a cointegration relationship between the variables.

Table 9: Panel data model selection.

Test type	
Likelihood ratio test	2.8805**
Hausman test	27.7865***
Model type	FE

Note: FE is fixed effects model. $**$ means significant at confidence level 5% and $***$ means significant at confidence level 1%.

Table 10: Panel regression model estimation results.

Variables	
Treating waste effect (U_1)	0.2050***
Purifying air effect (U_2)	0.1193***
Regulating climate effect (U_3)	0.1201***
Constant	0.1424***
R^2	0.880
Adjusted R^2	0.871
F-statistic	97.4874***
Sum squared residuals	0.1150
Obs.	132
Individuals	4

Note: $***$ means significant at confidence level 1%.

were at a lower level. Therefore, almost all of three effects of four cities need enhancement. The increase of every effect will necessarily raise the coordinated development level of three decomposed effects of urban infrastructure environment benefit.

4.2. Policy Implications. According to the research conclusion, several specific policy implications are shown as follows:

(1) The related government agencies should pay more attention to monitor the factors related to coupling and comprehend the most significant variable for coupling coordination degree among three effects. Treating waste effect has the most significant impact on coupling coordination degree among them. Four cities should give priority to improving this effect. The special vehicle for urban appearance and sanitation, household waste hazard-free treatment factory, and polluted water treatment factory refer to this effect. In the future, four cities should strengthen the investment on these infrastructures and enlarge the construction scale of them. Most importantly, the technology level and operational efficiency of them should be raised. This means that increasing the efficiency of eliminating waste is the key to raising treating waste effect.

(2) Other two effects also should be valued highly. According to the panel regression results, the distinction among the impacts of three effects on coupling coordination degree among them is smaller. Increasing purifying air effect and regulating climate effect are equally important to increasing treating waste effect. These two effects are mainly brought about by urban public green space and park. From now on four cities need not only to expand the area of urban public green space and add the amount of urban park but also to intensify the protection of existing public green space and urban park. The related agencies can set up the minimum standard of area of garden green space to ensure the amount of urban green infrastructure and found the special fund for the maintenance of it. The plant species of urban park should be diversified to maintain the ecological balance. Furthermore, more and more green ecological park should be built to reinforce the environment protection function of urban park.

(3) Four cities should attach importance to the proportion among different infrastructures. Urban infrastructure environment benefit emerges from a variety of infrastructures. The inputs on them should roughly equal. And the performance of their utilization must be controlled and regulated strictly. In addition, the inputs of different infrastructures should fit the demand of urban development. In this way, the gap among different decomposed effects of urban infrastructure environment benefit can be narrowed.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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