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Analysis on the Mechanism and Influencing Factors of the Coordinated Development of Economy and Environment in China's Resource-Based Cities

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Abstract: In order to explore how to achieve the coordinated development of the economy and environment, this paper uses the logistic model to verify that the city economy and the environment can achieve coordinated symbiosis. Next, an evaluation index system was used as empirical testing in order to measure the performance of the economy and environment. Further, the degree of coupling and coordination between them was obtained, and an econometric model was used to find the factors that affect the coordination and symbiosis between them. Finally, the following conclusions were obtained: (1) Resource-based cities of different development types do not show obvious differences in environmental carrying capacity and are basically at a medium carrying capacity level. (2) The level of the economic strength of resource-based cities is constantly improving, although with short-term fluctuations but with a general pace of improvement. (3) The synergy between economy and environment in resource-based cities is not high that the environment lags behind obviously. (4) The factors affecting the coordinated development of the environment and economy of resource-based cities are the annual average population and industrial wastewater discharge, which are contributing to the coordinated development of the economy and environment in resource-based cities. At the same time, the proportion of secondary industry in GDP, investment in fixed assets, and comprehensive utilization rate of general industrial solid waste inhibit the coordinated development of the economy and environment in resource-based cities. Based on the above conclusions, the paper puts forward relevant countermeasures and suggestions.

Keywords: resource-based city; coupling coordination degree; economy and ecological environment; coordinated development

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1. Introduction

Since the implementation of the reform and opening up in 1978, China's economy has continued to develop at high speed and has made world-renowned achievements, but at the same time, it has also brought environmental degradation. How to maintain harmony between the economy and environment becomes an insurmountable barrier during the development of many countries. Beginning in 2013, our country has experienced large-scale air pollution such as smog, which makes people realize the importance of environmental protection. Based on the analysis of the current problems of China's ecological environment, many experts and scholars believe that this is caused by the contradiction between China's extensive economic growth mode and environmental protection. Among them, the most typical environmental problem is caused by the exploitation of resources, especially in resource-based cities.

For a long time in the past, China's economic development has depended on the economy of the resource-based cities, which have played a dominant role in economic development to some extent. With the rapid and stable economic development of other cities, the reliance of the national economy on resource-based cities starts to decline. However, fundamentally speaking, the economic foundation of resource-based cities has not changed. In China's primary energy consumption structure, coal still accounts for more than 60% of the country's primary energy consumption, and the output of pig iron, crude steel, cement, and other products has occupied the world's largest output. It can be seen that resource-based industries provide important support for the economic development of the cities and even the country. China's extensive resource-mining activities and energy consumption have made resource-based industries the main source of environmental problems. The impact of resource mining on the urban ecological environment makes the environmental conditions of resource-based cities worrying.

Under the unsustainable economic growth model, environmental protection is bound to be hindered [1,2]. Studying the relationship between the economic system and the ecological environment system can help China achieve its sustainable development goals [3]. How to find breakthroughs for economic growth in resource-based cities and solve environmental problems has always been a hot issue in the academic field. Establishing an eco-economic development model with "low energy consumption, low emissions, and low pollution" requires us to focus on the endogenous power of resource-based city development, environmental protection and governance, and to emphasize the relationship between economic development speed and quality in urban areas. To achieve harmony between economic development and ecological environment, we need to transform the previous "economic-oriented" development into a coordinated development of "economy-environment" and finally achieve sustainable development in especially resource-based cities.

The main contributions and innovations of this article are as follows: In this article, the Logistic model is used to verify whether the economic system and the environmental system in the context of resource-based cities can be coordinated theoretically; and based on the data collected, the factors that affect the coordination and symbiosis of the environmental system and the economic system were analyzed from an empirical level. An evaluation index system was constructed in this article for assessing environmental carrying capacity and economic strength, 109 resource-based cities were analyzed to obtain the degree of coupling and coordination, an econometric model was constructed, and finally, conclusions were drawn.

2. Literature Review

The academic circles have been studying the development of resource-based cities for a long time. As early as 1930, Canadian geographer H.A. Innis launched research on resource-based cities. The term "resource curse" originated from the research on the phenomenon of "Dutch Disease" in resource-based cities [4]. The term "resource curse" was first proposed by Auty [5], which described a social phenomenon: the abundance of resources in a country's natural environment is often opposite to the rate of economic growth. This phenomenon is attributed by scholars to excessive dependence on natural resources, which worsens the terms of trade. Subsequent research was carried out around the relationship between resource conditions and economic growth. The American economists Sachs and Warner studied the relationship between these two variables in 97 countries from 1970 to 1989 and discovered what subverted people's previous perceptions: Natural resources and economic growth were shown to have a negative correlation [6]. This finding has also been continuously verified in subsequent studies. Gylfason [7], Cole and Neumayer [8], Larsen [9], Papyrakis and Gerlagh [10,11] also found that countries that simply use natural resources to develop their economy have a monotonous opposite to their resource stock and economic growth in the long run. Of course, some scholars have given different conclusions, such as Mikesell [12], Wright and Czelusta [13,14], Wen and Stephen [15], Martin [16], Boschini and Pettersson [17], Same [18] thought that natural resources are not the direct factors limiting economic growth in resource-based regions, and Boschini and Pettersson [17] believed that the impact of natural resources on economic growth not only depends on the abundance of natural resources themselves but also largely depends on the quality of the institutional environment.

All in all, while verifying the existence of the "resource curse", these studies have also intrigued academic thinking about the relationship between the abundance of natural resources and the economy and further triggered the thinking about the relationship between the environment and the economy. The research in this field originated from the Kuznets curve hypothesis, which believes that there is an inverted U-shaped curve relationship between the environment and the economy [19,20]. In further research, Joachim H. proposes whether sustained economic growth can bring environmental sustainability [21]. Later, scholars cited the coupling model of the complex relationship between the measurement systems to analyze the coordination between the economic system and the environmental system [22–25]. The process of coordinated development is also the process of system coupling evolution [26]. The interaction between systems is crucial and can yield qualitative changes, in addition to quantitative changes [27]. The coupling degree model is widely used in the study of coordination between different systems. Veena Srinivasan and other scholars used the coupled human-environmental system modeling method to explore the relationship between urbanization and water vulnerability [28]. Fang et al. used the coupling degree model to study the interaction between urbanization and ecosystem [29]. Kun et al. used the coupling coordination index to evaluate the coordination between regional water and soil resources and ecological environment systems [30]. In the study of the coordination between economy and environment with the coupling model, many scholars further put forward that the coordinated development between economy and environment is a necessary condition for achieving sustainable development [31–34].

Moreover, in plenty of studies, the comprehensive index synthesis method is used to establish and characterize the economic and environmental system. Ronald and Yuji proposed a social–ecological state index (SESI) based on social–ecological elasticity and pressure to measure the actual situation of socio-economic status [35]. Yurii et al. used modern comprehensive evaluation methods to evaluate Ukraine's social security system (including economic indicators) [36]. Yang et al. established evaluation index systems at different levels to assess and analyze the ecological environment of water and soil resources [37].

Most of the previous studies only used the coupling coordination model to analyze the symbiosis or constraint relationship between the various subsystems or dimensions in the sustainable development of the city [38,39]. However, few documents analyzed the factors that affect the degree of coupling and coordination between the environment and the economy. This article starts with the model, looking for indicators that affect the degree of coupling and coordination between the environment and the economic system and draws corresponding conclusions.

3. Mechanism Analysis and Hypothesis

The early economic development of resource-based cities relies on the characteristics of urban resource endowments. Therefore, the development of other economic factors is often based on resource-based industries, that is, economic resource "path dependence". According to the positive/negative feedback mechanism of increasing returns, resource-based cities will develop and expand the industrial structure associated with resource industries, while other industries will gradually lose development advantages and opportunities over time. However, if this resource becomes its only competitive advantage, eventually, the city will be positioned in industries where resource development and processing are the mainstays. When resources are depleted, or substitutes for resources appear, these cities are most likely to decline.

The development of resources is essential for resource-based cities. However, the development model and intensity can be varied independently. In order to achieve the harmony of environment, resources, and economy, we must pay attention to environmental protection and governance during resource development. At the same time, we must also pay attention to the way of resource development because most natural resources are non-renewable. Therefore, resources should be well conserved while they are exploited. Economic development is also necessary, and the industrial transformation and upgrading of resource-based cities are required too. The successful transformation can lay a strong material basis for environmental governance. Otherwise, the decline of the environment is inevitable. Based on this, the following hypothesis is proposed:

Hypothesis 1 (H1). *The environment and economy of resource-based cities can realize coordinated development*.

According to the characteristics of the economic and environmental system, this study uses a logistic model to explain the symbiotic benefits produced by the system to test the hypothesis. Since its inception, the logistic equation has been widely used in biology, medicine, economic management, and so on. It has been proved one of the best mathematical models to describe the law of population growth under the condition of limited resources. The central idea of the model is that social resources are limited, and population or population growth will reach a certain limit due to resource constraints. Assuming total resources N, population x, if individuals increase x/N unit resources, other biological surplus resources $(1 - x/N)$, when the output is continuous, use the logistic model to describe the human impact on the environment:

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{N}\right) \tag{1}$$

$$\begin{cases} \frac{dx_1}{dt} = r_1 x_1\left(1 - \frac{x_1}{N_1}\right) \\ \frac{dx_2}{dt} = r_2 x_2\left(1 - \frac{x_2}{N_2}\right) \end{cases} \tag{2}$$

In the formula, r is the growth rate of human activities and $\frac{dx}{dt}$ is the rate at which human activities affect the environment. x_1 and x_2 are the output levels of economic development and ecological environment, respectively. When the two are in a state of symbiosis, they promote each other to improve the overall output, and the mutual promotion is presented in the formula, and we achieve:

$$\begin{cases} \frac{dx_1}{dt} = r_1 x_1\left(1 - \frac{x_1}{N_1} + \delta_1 \frac{x_2}{N_2}\right) \\ \frac{dx_2}{dt} = r_2 x_2\left(1 - \frac{x_2}{N_2} + \delta_2 \frac{x_1}{N_1}\right) \end{cases} (\delta_1 > 0, \delta_2 > 0) \tag{3}$$

When the symbiosis model reaches a balanced and stable state, the above formula can be expressed as:

$$\begin{cases} f(x_1, x_2) = \frac{dx_1}{dt} = r_1 x_1\left(1 - \frac{x_1}{N_1} + \delta_1 \frac{x_2}{N_2}\right) = 0 \\ g(x_1, x_2) = \frac{dx_1}{dt} = r_2 x_2\left(1 - \frac{x_2}{N_2} + \delta_2 \frac{x_1}{N_1}\right) = 0 \end{cases} \tag{4}$$

The above formula was solved to achieve the stable point:

$$\mathrm{E}(x_1, x_2) = \left\{\frac{N_1(1+\delta_1)}{1-\delta_1\delta_2}, \frac{N_2(1+\delta_2)}{1-\delta_1\delta_2}\right. \tag{5}$$

When $x_1 > 0$, $x_2 > 0$, and $\delta_1\delta_2 < 1$ occur at the same time, there is a symbiotic relationship between the ecological environment and economic development. Perform a first-order Taylor expansion on the differential mode group:

$$\begin{cases} \frac{dx_1}{dt} = r_1\left(1 - \frac{2x_1}{N_1} + \delta_1 \frac{x_2}{N_2}\right)(x_1 - x_1') + r_1 x_1 \delta_1 \frac{(x_2 - x_2')}{N_2} \\ \frac{dx_2}{dt} = \frac{r_2 x_2 \delta_2}{N_1}(x_1 - x_1') + r_2\left(1 - \frac{2x_2}{N_2} + \delta_2 \frac{x_1}{N_1}\right)(x_2 - x_2') \end{cases} \tag{6}$$

Substitute the stable point into the above formula to obtain the system matrix:

$$A = \begin{bmatrix} -r_1\frac{(1+\delta_1)}{1-\delta_1\delta_2}, r_1x_1\delta_1\frac{(1+\delta_1)}{N_2(1-\delta_1\delta_2)} \\ r_2x_2\delta_2\frac{(1+\delta_2)}{N_1(1-\delta_1\delta_2)}, -r_2\frac{(1+\delta_2)}{1-\delta_1\delta_2} \end{bmatrix} \tag{7}$$

The condition for a stable solution of the equations is $\delta_1\delta_2 < 1$, therefore, the condition for achieving a stable symbiosis between the environment and the economy is $\delta_1\delta_2 < 1$.

When the resource-based city economy and the environmental system exist independently, according to the logistic model, the relationship between the two can be obtained as follows:

$$\frac{dInd(t)}{dt} = r_1Ind(t)\frac{\lambda C(t) - Ind(t)}{\lambda C(t)} \tag{8}$$

$$\frac{dEco(t)}{dt} = r_2Eco(t)\frac{\phi C(t) - Eco(t)}{\phi C(t)} \tag{9}$$

Lotka–Volterra equations, also called predator-prey equations, consist of two first-order nonlinear differential equations. They are often used to describe the interaction dynamics between predators and prey in biological systems, that is, the growth and decline of their population size, which is suitable for the description of the competitive and cooperative relationship between economic and environmental systems in this study. The improved Lotka–Volterra model of economic-environment coupling system symbiosis relationship can be expressed by two independent nonlinear differential equations:

$$\frac{dInd(t)}{dt} = r_1Ind(t)\frac{\lambda C(t) - Ind(t) - \alpha(t)Eco(t)}{\lambda C(t)} \tag{10}$$

$$\frac{dEco(t)}{dt} = r_2Eco(t)\frac{\phi C(t) - Eco(t) - \beta(t)Ind(t)}{\phi C(t)} \tag{11}$$

In order to find the equilibrium point of the system, according to the geometric theory of differential equations, the above two equations are set equal to *0*, where: *Ind(t)* is the economic development level index, reflecting the sustainable economic development level of resource-based cities, and the pressure factor in the structural model. The index of the system and response subsystem is obtained with the help of fuzzy comprehensive evaluation method; *Eco(t)* is the environmental, ecological level index, reflecting the degree of impact on the ecosystem, which can be calculated by the impact subsystem tabulation system in the structural model; *C(t)* is the ecological environment carrying capacity, which indicates the threshold value of the carrying capacity of a regional environment to human social and economic activities in a certain period and under a certain environmental state. It can be calculated from the evaluation index system of environmental carrying capacity by using the entropy method (the evaluation index system can be seen in the later context). *α(t)* is the competitive effect of the ecological environment on economic development; that is, the environment inhibits economic development. Due to environmental protection requirements, the development of some unqualified enterprises is limited, which hinders the improvement of the economic level to a certain extent. *β(t)* Is the competitive effect of economic development on the ecological environment; that is, the economy inhibits environmental development. Overexploitation of resources is bound to cause damage to the environment, such as water pollution, haze, and so on. *r1* is the level of economic development; *r2* is the development level of the ecological environment; *λ* and *Φ* are the contribution coefficients of the ecological environment capacity for economic development or environmental protection, respectively; *t* is the time.

In the economic-environment coupling system, both the economic development level *Ind(t)* and the ecological environment level *Eco(t)* depend on urban resources. From the two equations and the definition of *λ(t)* and *β(t)*, it can be deduced that the influence coefficient of the ecological environment system *Eco(t)* on the economic development system *Ind(t)* is $\alpha(t)/\lambda C(t)$. The influence coefficient of the system *Ind(t)* on the ecological environment system *Eco(t)* is $\beta(t)/\Phi(t)$, and when $\alpha(t) > 0$, it indicates an inhibition of the development of the ecological environment safety level on the economic development, when $\alpha(t) < 0$, it indicates that the ecological environment promotes economic development. When $\alpha(t) = 0$, it indicates that the ecological environment and economic development are irrelevant. The same is true for that of $\beta(t)$.

In order to find the equilibrium point of the system, according to the geometric theory of differential equations, the two equations are equal to 0, and then:

$$\frac{dInd(t)}{dt} = r_1 Ind(t)\frac{\lambda C(t) - Ind(t) - \alpha(t)Eco(t)}{\lambda C(t)} = 0 \tag{12}$$

$$\frac{dEco(t)}{dt} = r_2 Eco(t)\frac{\phi C(t) - Eco(t) - \beta(t)Ind(t)}{\phi C(t)} = 0 \tag{13}$$

When $\alpha(t) = \beta(t) = 1$, four equilibrium points can be obtained, namely $O1(0,0)$, $O2(\lambda C(t),0)$, $O3(0, \Phi C(t))$, $O4\ \{\lambda Ct(1 - \alpha t)/(1 - \alpha(t)\beta(t)), \phi Ct(1 - \beta t)/(1 - \alpha(t)\beta(t))\}$. From the above balance point, the following results can be obtained, as shown in Table 1.

Table 1. Equilibrium point operation result.

For the ecological system	$Ind(t) = 0$ $Eco(t) = 0$	$Eco(t) = \lambda C(t)/\alpha(t)$ $Ind(t) = \lambda C(t)$
For the environmental ecosystem	$Ind(t) = 0$ $Eco(t) = 0$	$Eco(t) = \Phi C(t)$ $Ind(t) = \Phi C(t)/\beta(t)$

When different regions are formed by $\lambda C(t)/\alpha(t)$, $\lambda C(t)$ and $\Phi C(t)/\beta(t)$, $\Phi C(t)$, which represent the capacity of *Ind(t)* and *Eco(t)*, and their development can be divided into four situations: a, b, c, and d.

a. When $\lambda C(t) > \Phi C(t)/\beta(t)$, $\Phi C(t) < \lambda C(t)/\alpha(t)$, the economy can continue to develop, but the ecological environment will have reached the maximum carrying capacity and cannot continue for growth; the economic development of resource-based cities will ultimately prevail.
b. When $\lambda C(t) < \Phi C(t)/\beta(t)$, $\Phi C(t) > \lambda C(t)/\alpha(t)$, the result of the competition is that the ecological environment wins, and the urban economic development stagnates or even regresses.
c. When $\lambda C(t) < \Phi C(t)/\beta(t)$, $\Phi C(t) < \lambda C(t)/\alpha(t)$, the two enter a stable state of coexistence and development, and E is the equilibrium point *(Ind(t), Eco(t))*.

$$Ind(t) = \lambda C(t) - \alpha(t)Eco(t) \tag{14}$$

$$Eco(t) = \phi C(t) - \beta(t)Ind(t) \tag{15}$$

d. When $\lambda C(t) > \Phi C(t)/\beta(t)$, $\Phi C(t) > \lambda C(t)/\alpha(t)$, the two are in an unstable state of competition, and both sides have the possibility of winning.

In summary, when the economic development and the ecological environment are in an unstable state, the two continue to co-evolve. The system's own capacity is maximized when a balanced state is reached.

When the relevant principles of cybernetics are used to solve the stable conditions of the symbiotic coupling system of economy and environment, the competitive effect of the ecological environment on economic development $\alpha(t)$ and the competitive effect of economic development on ecological environment $\beta(t)$ are obtained:

$$\alpha(t) = \frac{\lambda C(t) - Ind(t)}{Eco(t)} \tag{16}$$

$$\beta(t) = \frac{\phi C(t) - Eco(t)}{Ind(t)} \tag{17}$$

Based on the calculations, the relationship between the economic development system and the ecological environment system is listed in Table 2.

Table 2. Definition of the relationship between economic development and ecological environment.

Definition	Value	Relationship
1	$\alpha(t) > 0$ and $\beta(t) > 0$	Competitive relationship
2	$\alpha(t) > 0$ and $\beta(t) < 0$	Favor symbiosis
3	$\alpha(t) < 0$ and $\beta(t) > 0$	/
4	$\alpha(t) < 0$ and $\beta(t) < 0$	Benign interaction

It is not difficult to see that the ecological environment subsystem and economic development subsystem in the economy-environment coupling system indirectly realize the coupling symbiosis through common natural resources. In order to realize the balanced development of the two major subsystems and the mutually beneficial symbiosis of economy and environment, the symbiosis and coordination relationship model of the coupled system should be designed to analyze and study the evolution trend of the system. In order to quantitatively analyze the coordinated relationship between the development of the two, the symbiosis index *RHS(t)* is solved as follows:

$$RHS(t) = -\frac{\alpha(t) + \beta(t)}{\sqrt{\alpha^2(t) + \beta^2(t)}} \tag{18}$$

When $\alpha(t)$ and $\beta(t)$ are not equal to 0 at the same time, according to the arithmetic mean and geometric mean inequalities:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{19}$$

If and only if $\alpha(t) = \beta(t)$, the equal sign holds, that is:

$$|RHS(t)| = \left| -\frac{\alpha(t) + \beta(t)}{\sqrt{\alpha^2(t) + \beta^2(t)}} \right| \leq \sqrt{2} \tag{20}$$

When $\alpha(t)$ and $\beta(t)$ are not equal to 0 at the same time, if and only when $\alpha(t) = \beta(t)$, the equal sign holds. Therefore, the value range of the symbiosis degree *RHS(t)* is $(-\sqrt{2}, \sqrt{2})$, and the larger the value is, the more the two tend to reach symbiosis; the smaller the value is, the more they tend to compete.

The economic development and ecological environment symbiosis index *RHS(t)* is used to evaluate the development basis of resource-based cities. In order to further analyze the corresponding relationship between the symbiosis index and resource-based cities, the ecological security status is divided into the following major spaces:

When $RHS(t) \in \left(1, \sqrt{2}\right)$, the two are in a benign interactive relationship, and the resource-based city is in a safe area; when $RHSt \in (0,1)$, the two are mutually beneficial and reach a symbiosis state. When $RHS(t) \in \left[-\sqrt{2}, 0\right)$, the two are in a state of competition with each other, and these two intervals are in an unsafe zone; when $RHS(t) = 1$, it represents a state of partial benefit symbiosis (ecological safety threshold); when $RHS(t) = 0$, it enters the ecologically unsafe zone and is the bottom line of ecological safety. It can be seen that symbiosis can effectively measure environmental security and more accurately reflect the ecological and economic significance. Through the symbiosis relationship between the environment and the industrial system, it reflects the development trend and evolution law of environmental security(Can be seen in Table 3).

Table 3. Relationship between symbiotic model of economic development ecosystem and competition coefficient.

Classify	Relationship	Value
Symbiosis model	Mutually beneficial symbiosis model	$\alpha(t) < 0$ and $\beta(t) < 0$
	Partial force symbiosis model	$\alpha(t) \leq 0$, $\beta(t) \leq 0$ and α and β are not 0 at the same time
Non-symbiotic model	Partial harm model	$\alpha(t) \geq 0$, $\beta(t) \geq 0$ and α and β are not 0 at the same time
	Single harm mode	$\alpha(t)\beta(t) < 0$
	Competitive model	$\alpha(t) > 0$ and $\beta(t) > 0$

By improving the Lotka–Volterra model, constructing a symbiotic coupling measurement model, the article expects the resource-based city subsystems to experience three stages: mutual competition, favored symbiosis, and benign interaction, and eventually achieve dynamic and balanced development.

In conclusion, the evolution of the resource-based city economy-ecology coupling system can promote the formation of closer links between various subsystems and build a symbiotic structure, that is, the economy and environment of the resource-based city can achieve a coordinated symbiosis state, and what is more, we need to focus on coordination, prevent excessive competition, balance both the competition and cooperation and cooperation within the coupled system and its subsystems to realize the upgrade and evolution of the coupled system through coordination and compatibility. Therefore, the hypothesis can be preliminarily confirmed, and then it will be verified again from an empirical perspective.

4. Research Methods

4.1. Constructing an Evaluation Index System

4.1.1. Evaluation Index System of Environmental Carrying Capacity of Resource-Based Cities

This article analyzes the carrying capacity of resource-based cities from two perspectives: environmental pollution discharge pressure and urban social and economic development environmental response. The former reflects the environmental damage caused by urban development and refers to the reliance and needs of economic, social life in resource-based cities on their natural resources. Life's demands and utilization of urban resources from the environment highlight the output pressure that the urban ecological environment system needs to bear; while the latter emphasizes the responsiveness of resources and environmental elements to the intensity of urban economic and social activities [40], highlights the response of resource-based cities to environmental pollution discharge pressures.

This article refers to the publications and master's and doctoral dissertations from CNKI since 2012 about "resource-based cities" and "eco-environmental". CNKI's literature derivation and analysis are used based on the keyword search. The resource-based city's ecological environment evaluation index system was sorted out accordingly. Based on the concept of "environment" defined narrowly in this article, the indicators related to the quality of economic and social development in the existing literature were excluded. As the research object of this paper is resource-based cities, the common environmental characteristics of these cities, which are closely related to resource exploitation, were figured out. Moreover, the existing evaluation indicators were screened, classified, and sorted out according to the three basic aspects—air quality, water environment, and land environment [41]. Finally, the following resource-based cities' comprehensive environmental carrying capacity evaluation index system was formulated (Can be seen in Table 4).

Table 4. Resource-based city comprehensive environmental carrying capacity evaluation index system.

Target Layer	Environmental Factors	Evaluation Index	Attributes
Comprehensive carrying capacity of resource-based cities	Air quality	Sulfur dioxide production [42]	−
		Sulfur dioxide emissions	−
		Industrial smoke (powder) dust removal	+
		Industrial smoke (dust) emissions	−
	Water	Industrial wastewater discharge	−
		Centralized treatment rate of sewage treatment plant	+
	Land	Comprehensive utilization rate of general industrial solid waste	+
		Harmless treatment rate of domestic garbage	+

4.1.2. Resource-Based City Economic Strength Evaluation Index System

The environmental carrying capacity evaluation index is used as the evaluation index of the environmental subsystem to evaluate the coupling coordination degree. To assess the economic subsystem, we rely mainly on the results of relevant literature on the economic development evaluation of resource-based cities. In order to meet the requirements of the new normal of the economy, long-term development indicators are emphasized while the short-term nature is downplayed, and the focus on economic development is shifted from speed to quality. Thus, the economic development status of resource-based cities is evaluated from two aspects: the status quo and the driving force of urban economic development. The status quo of urban economic development is assessed through the following factors:

(1) City GDP. The city's GDP is a basic indicator for evaluating the current status of the city's economic development, reflecting the total annual economic development of a city. This article uses per capita GDP to evaluate the economy.
(2) Economic growth rate. Economic growth rate reflects the dynamic index of resource-based city economic development while per capita GDP reflects the stock index of resource-based city economic development.
(3) Proportion of added value by industry. The proportion of sub-industry added value reflects the degree of importance of each industry in the urban economy and is a common indicator that reflects the status of the industrial structure in urban economic development. According to Clark's theorem, the advancement and rationalization of industrial development is a process of transition from industrialization to post-industrialization. Therefore, the main indicators to measure the industrial structure of resource-based cities are the proportion of the added value of the secondary industry and the proportion of the added value of the tertiary industry.
(4) Disposable income of residents. The disposable income of residents reflects the income of residents, which is another indicator that reflects the economic development of resource-based cities. This article uses standardized per capita disposable income as the evaluation index.

The driving force of urban economic development includes the following:

(1) Investment in fixed assets. The situation of urban GDP and industrial added value reflects the economic output capacity of resource-based cities, while fixed resource investment reflects the continuity of economic development.
(2) Unemployment rate. As a negative evaluation indicator of economic development, the unemployment rate reflects the stability and dynamics of economic development more clearly, compared to indicators such as the number of employees.

(3) Urban public service level. Urban public financial expenditure reflects the level of social and public service in the city. The higher the level of public financial expenditure is, the higher the level of urban construction and public services is, the more stably the city develops, the stronger the driving force of the city's development grows.

(4) The driving force of science and technology development. From the perspective of urban input factors, according to the Cobb–Douglas production function, the traditional input factors are mainly labor and capital, but the rate of technological progress and technological factors have a stronger effect on urban economic development. The science and technology expenditure index reflects the city's investment in science and technology. The higher the value, the more it reflects the importance of local technological progress, which further indicates the city's technological development potential and the city's long-term development momentum.

Based on the information above, the resource-based city economic system evaluation index system is shown in the Table 5.

Table 5. Resource-based city economic system evaluation index system.

Target Layer	Environmental Factors	Evaluation Index	Attributes
The current state of the city's economy	City GDP	GDP per capita	+
	Economic growth rate	Annual economic growth rate	+
	Proportion of added value by industry	Proportion of secondary industry	+
		The proportion of tertiary industry	+
	Disposable Personal income	Per capita disposable income	+
The Driving force of City economy	Investment in fixed assets	Total investment in fixed assets	+
	Unemployment rate	Urban unemployment rate	−
	Urban public service level	Public Finance Expenditure	+
	Science and technology	Science and Technology Expenditure	+

4.2. Evaluation Method

In this paper, the entropy method is used to determine the weight of the evaluation index of the coupling and coordination degree of resource-based city economy and environment. Specially speaking, the entropy method in information theory combined with the judgment matrix composed of evaluation index values is used to determine the weight of each evaluation index [43]. Entropy method for the measurement of uncertainty is commonly used in the current socio-economic evaluation research. The index weight is determined on the basis of the information provided by the observed values of each index. In the original index data matrix $X = \left(x_{ij}\right)_{m\times n}$, m represents the number of schemes to be evaluated, and n denotes the number of the evaluation indexes. For a certain index x_j, the greater the gap between the index value X_{ij} is, the greater the role of the index in the comprehensive evaluation is. If the index values of an index are all equal, the index will not play a role in the comprehensive evaluation.

The principle of the entropy method is to judge the dispersion degree of the index through the entropy value, which reflects the disorder degree of the index. The smaller the entropy value is, the higher the order degree of the index is, the greater the dispersion degree of the index is, and the smaller the uncertainty is. The larger the entropy value is, the lower the order degree of the index is, the smaller the dispersion degree of the index is, and the greater the uncertainty is. In this way, entropy method can be used to evaluate the order degree and influence of system indicators. With the entropy method, a judgment matrix can be constructed to determine the index weight, which largely eliminates the human interference in the calculation of each index weight as much as possible and can well solve the information overlap problem between multi-index variables in the evaluation process.

The calculation process of entropy method is as follows:

(1) Construction of the index data matrix:

$$A = \begin{pmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \vdots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{pmatrix}_{n \times m}$$

where, X_{ij} is the value of the j-th index of the i-th scheme. If the indicator is negative, the data should be transformed to be non-negative.

(2) Data standardization: Positive indicators:

$$X'_{ij} = \frac{X_{ij} - \min(X_{1j},\ X_{2j}, \cdots, X_{nj})}{\max(X_{1j},\ X_{2j}, \cdots, X_{nj}) - \min(X_{1j},\ X_{2j}, \cdots, X_{nj})}$$

Negative indicators:

$$X'_{ij} = \frac{\max(X_{1j},\ X_{2j}, \cdots, X_{nj}) - X_{ij}}{\max(X_{1j},\ X_{2j}, \cdots, X_{nj}) - \min(X_{1j},\ X_{2j}, \cdots, X_{nj})}$$

Perform data translation to avoid meaningless logarithm when calculating entropy:

$$X''_{ij} = X'_{ij} + 1$$

(3) Calculate the proportion of the i-th scheme under the j-th index in this index:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}\ (j = 1, 2, \cdots, m)$$

(4) Calculate the entropy of the j-th index:

$$e_j = -k * \sum_{i=1}^{n} P_{ij} \log(P_{ij})$$

In the above formula, the constant k is related to the number of samples m, and $k > 0$. Generally, the calculation formula of k is as follows:

$$k = \frac{1}{\ln m}$$

(5) Calculate the difference coefficient:

For the j-th index, the greater the difference of index value X_{ij} is, the greater the effect on scheme evaluation is, and the smaller the entropy is. The larger the difference coefficient *gi is*, the more important the index is.

$$g_j = 1 - e_j$$

(6) Calculate weight:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j}, j = 1, 2, \cdots, m$$

(7) Calculate the comprehensive score of each scheme:

$$S_i = \sum_{j=1}^{m} W_j * P_{ij} \ (i = 1, 2, \cdots, n)$$

4.3. Empirical Verification Method

In the section of mechanism analysis, through the Logistic model and the improved Lotka–Volterra model, the study has proved that the coordinated development of environment and economy can be realized. According to the setting of resource-based city economy and environment coupling coordination degree calculation model, this part conducts an empirical test on the factors that affect the resource-based city economy and environment coupling coordination degree. Specifically, it is divided into the following two processes.

(1) With the indicators related to economic development and urban, comprehensive carrying capacity set as independent variables, the resource-based city economy and environment coupling coordination degree as the dependent variable, a basic regression model was established to explore the effect of these variables on resource-based city economy and environment coupling coordination degree effect.
(2) Resource-based cities mainly include four types: mature, growth, decline, and regeneration(according to the standards issued by the State Council). This paper again uses the basic regression model to carry out regression analysis on the data of mature resource-based cities to further verify the robustness of the regression model. (Because the data of growth-declining and renewable resource-based cities is not sufficient to do effective regression, this article only uses the data of mature resource-based cities).

Figure 1 shows the logic of the full text.

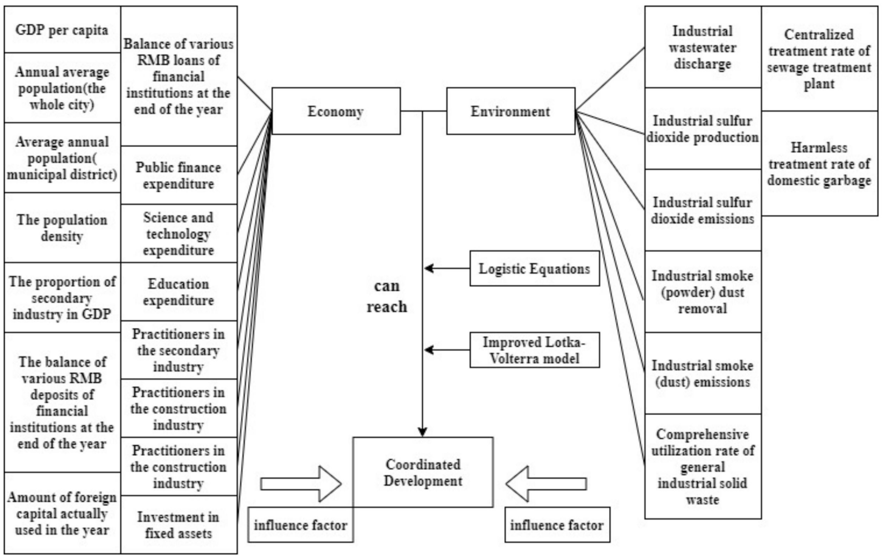

Figure 1. Article frame diagram.

4.3.1. Calculation Model of Coupling and Coordination Degree of Resource-Based City Economy and Environment

This paper evaluates the coordinated development degree of resource-based city economy and environment based on the coupling degree model, represented by the equation below, in which the coupling degree of resource-based city economy and environment is denoted as C:

$$C = \left[\frac{f(x)d(y)}{\left[\frac{f(x)+d(y)}{k}\right]^k} \right]^k \quad (21)$$

In this equation, *f(x)* represents the environmental carrying capacity index, *d(x)* represents the economic strength index, *k* is the adjustment coefficient, and x and y represent the various evaluation sample objects. Since article focuses on the coupling degree of two systems—the economy and environment, the adjustment coefficient *k* is set as 2.

The index of coupling and coordination degree of resource-based city's economy and environment is derived from the index of coupling degree, based on the formula below:

$$\mathrm{R} = \sqrt{C \times T} \tag{22}$$

$$\mathrm{T} = \alpha f(x) + \beta\, d(y) \tag{23}$$

In the above formula, *C* represents the degree of coupling, R represents the degree of coupling coordination, T represents the comprehensive coordination index, and α and β are the undetermined coefficients of system importance. According to sustainable development, both economic and environmental benefits must be promoted in the current process of urban development. Therefore, this article assumes that economic development and environmental protection are equally important, so the coefficients are equal, that is, $\alpha = \beta = 0.5$.

As a comprehensive evaluation index, there are different criteria for the coupling coordination degree at home and abroad when dividing the evaluation standards. In this study, the evaluation standards of the coupling coordination degree of economy and environment in the resource-based cities were divided into ten levels (Can be seen in Table 6):

Table 6. Evaluation criteria of the coordination degree of economy and environment in the resource-based cities.

The-First Level	The-Second Level	Contrast Relationship	Types
(0.90, 1.00)	High-qualitied coordinated development	$f(x) > d(y)$	Economic lag
		$f(x) = d(y)$	Environmental and economic synchronous
		$f(x) < d(y)$	Environmental lag
(0.80, 0.90)	Good coordinated development	$f(x) > d(y)$	Economic lag
		$f(x) = d(y)$	Environmental and economic synchronous
		$f(x) < d(y)$	Environmental lag
(0.70, 0.80)	Medium coordinated development	$f(x) > d(y)$	Economic lag
		$f(x) = d(y)$	Environmental and economic synchronous
		$f(x) < d(y)$	Environmental lag
(0.60, 0.70)	Primary coordinated development	$f(x) > d(y)$	Economic lag
		$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) < d(y)$	Environmental lag
(0.50, 0.60)	Barely coordinated development	$f(x) > d(y)$	Economic lag
		$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) < d(y)$	Enviromental lag
		$f(x) > d(y)$	Economic lag

Table 6. *Cont.*

The-First Level	The-Second Level	Contrast Relationship	Types
(0.40, 0.50)	Maladjustment on the verge of decline	$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) > d(y)$	Environmental lag
		$f(x) < d(y)$	Economic lag
(0.30, 0.40)	Mild maladjustment recession	$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) < d(y)$	Environmental lag
		$f(x) > d(y)$	Economic lag
[0.20, 0.30)	Moderate maladjusted recession	$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) < d(y)$	Environmental lag
		$f(x) > d(y)$	Economic lag
(0.10, 0.20)	Severe maladjustment recession	$f(x) = d(y)$	Environmental and Economic synchronous
		$f(x) < d(y)$	Environmental lag
		$f(x) > d(y)$	Economic lag
(0, 0.10)	Extreme maladjustment recession	$f(x) = d(y)$	Envirronmetal and Economic synchronous
		$f(x) < d(y)$	Environmental lag

4.3.2. Basic Regression Model

Basic regression model in the Equations (24)–(26):

$$cc_i = \lambda_0 + \sum_{i=1}^{15} \lambda_i EC_i + \varepsilon_i \tag{24}$$

$$cc_i = \lambda_0 + \sum_{i=1}^{8} \lambda_i EN_i + \varepsilon_i \tag{25}$$

$$cc_i = \lambda_0 + \sum_{\mathrm{i}=1}^{15} \lambda_{\mathrm{i}} EC_{\mathrm{i}} + \sum_{i=16}^{23} \lambda_i EN_i + \varepsilon_i \tag{26}$$

In those equations, i represents each resource-based city, and EC represents the relevant indicators of resource-based city economic development, including 15 independent variables such as regional GDP, per capita regional product, annual average population (city), annual average population (municipal district), and population density, the proportion of the industrial structure (secondary industry) in the regional GDP, fiscal capacity (financial institution loan balance, financial institution deposit balance), public financial expenditure, science, and technology expenditure, education expenditure, workers in the secondary industry, construction industry practitioners, the amount of foreign investment actually used in the year, investment in fixed assets, etc. EN is the evaluation index of the overall carrying capacity of resource-based cities, namely industrial waste water discharge, industrial sulfur dioxide production, industrial sulfur dioxide emissions, industrial smoke (dust) and dust discharge volume, industrial smoke (dust) discharge volume, comprehensive utilization rate of general industrial solid waste, centralized treatment rate of sewage treatment plant, and harmless treatment rate of household garbage; ε_i represents a random disturbance item. cc_i represents the degree of coupling, 0 is a constant, and i represents a residual term.

5. Data Source and Variable Description

5.1. Data Source

The data comes from the "China City Statistical Yearbook". This article takes the prefecture-level cities from the List of resource-based cities of The State Council as the research object. The indicators data of which was then classified and sorted out based on the types of development stages to analyze the differences in their development stages. When considering the comparability and referentiality of the indicators, the forest industry cities have been excluded from the resource-based cities by this paper, and a total of 119 resource-based cities are listed. As the data of autonomous prefectures and cities in some provinces is not available, these samples were excluded from the catalog. As a result, a total of 109 sample cities were obtained and divided into the following categories according to the development stage: 58 mature cities, 14 growth cities, 21 declining cities, and 13 regeneration cities.

5.2. Variable Description

The descriptive statistics of variables are shown in Table 7.

Table 7. Descriptive statistics of the main variables.

Variables	Max	Min	Average	Standard Error	Observed Value
Coupling coordination degree	0.745	0.520	0.589	0.036	109
GDP	6103.060	0.000	1411.806	1096.197	109
GDP per capita	20.716	0.000	4.013	3.304	109
Annual average population (the whole city)	1186.310	39.560	369.914	251.278	109
Average annual population (municipal district)	332.070	22.680	97.797	61.785	109
The population density	1024.360	10.250	341.281	256.900	109
The proportion of secondary industry in GDP	0.715	0.000	0.417	0.197	109
The balance of various RMB deposits of financial institutions at the end of the year	7456.807	324.588	1655.585	1122.796	109
Balance of various RMB loans of financial institutions at the end of the year	9027.592	145.846	1147.186	1081.190	109
Public finance expenditure	752.460	52.173	258.843	136.280	109
Science and technology expenditure	86.835	0.000	3.377	8.576	109
Education expenditure	152.350	7.139	46.393	28.266	109
Practitioners in the secondary industry	61.914	1.900	16.420	12.091	109
Practitioners in the construction industry	30.037	0.000	4.531	5.254	109
Amount of foreign capital actually used in the year	25.537	0.000	3.305	4.582	109
Investment in fixed assets	4543.877	0.000	1191.406	1012.983	109
Industrial wastewater discharge	712,158.0	0.000	12,493.340	69,285.150	109
Industrial sulfur dioxide production	212.346	0.000	23.561	30.100	109
Industrial sulfur dioxide emissions	22.553	0.000	5.480	4.828	109
Industrial smoke (powder) dust removal	1471.849	0.776	271.919	239.069	109
Industrial smoke (dust) emissions	46.690	0.431	4.798	5.829	109
Comprehensive utilization rate of general industrial solid waste	1.000	0.000	0.775	0.254	109
Centralized treatment rate of sewage treatment plant	1.000	0.000	0.865	0.136	109
Harmless treatment rate of domestic garbage	1.000	0.000	0.902	0.201	109

Note: ECi represents the relevant indicators of economic development, of resource-based city i. ENj represents the evaluation index of the overall carrying capacity of resource-based city j.

6. Analysis of Empirical Results

6.1. Analysis of Environmental Carrying Capacity of Resource-Based Cities

According to the calculations (see Appendix A, Table A1), the overall carrying capacity of the 109 samples at three time points is slightly higher than 0.4, which is at a medium level. The atmospheric mass carrying capacity is the highest among the atmospheric environment, water environment, and land environment, which is higher than 0.7, indicating a medium to high carrying capacity level, while the water environment and land environment carrying capacity are both lower than 0.4, which indicates a medium-to-low level. The land environmental carrying capacity is the lowest, which is less than 0.3. The specific values are shown in the Table 8.

Table 8. Average of overall environmental carrying capacity of resource-based cities.

Years	Air quality	Water	Land	General Environment
2009	0.7095429	0.314384	0.2197904	0.41457244
2012	0.7292113	0.3023484	0.2109992	0.41418629
2015	0.75295	0.31154	0.2624	0.441495
Carrying capacity level	Medium to high carrying capacity	Low to medium carrying capacity	Low to medium carrying capacity	Medium capacity

It can be seen from above that, over the past ten years, the environmental carrying capacity of resource-based cities has only increased by less than 0.03. The overall environmental carrying capacity of resource-based cities is limited by the problems of the water environment and land environment. Generally speaking, the air environment of resource-based cities has a relatively high carrying capacity, which is contributed to the relatively good atmospheric and climatic conditions in most of the resource-based cities, which are located in windy and high-altitude places in the middle west regions of China at present. The resource-based cities in the central and eastern regions have relatively few mine resource reserves. Compared with problems relating to water and land resources, the air quality problem is not significant. The mining industry, which is the basis of resource-based cities, has more significant damage to the land environment and water environments, such as the precipitation of heavy metals, land subsidence, and the damage of groundwater resources caused by mineral mining. What is worse, the discharge of waste water has caused the pollution of surface water resources, and the leakage and overflow of groundwater after the land subsidence has become prominent.

According to the calculation of the overall environmental carrying capacity model of resource-based cities (see Appendix A, Table A1), a specific analysis of the types and characteristics of resource-based cities was carried out in Table 9.

Table 9. Comparison of average environmental carrying capacity of different types of resource-based cities in 2015.

City Types	Air Quality	Water	Land	Overall Environmental Carrying Capacity
Growing city	0.7585	0.30718	0.30096	0.455547
Mature city	0.75794	0.30115	0.25381	0.436198
Declining city	0.74118	0.30779	0.23005	0.426341
Regenerative city	0.74361	0.29423	0.2338	0.423879

From Table 9, it can be concluded that the overall environmental carrying capacity of resource-based cities at different developmental stages is fairly the same, and they are all at a medium level. However, with the advancing of the development stage, the overall environmental carrying capacity of the city decreases. Among them, the overall environmental carrying capacity of declining cities and regenerative cities is lower than that of growing cities and mature cities. Comparing the carrying capacity levels of various specific environmental elements, we found that the average of the atmospheric environmental carrying capacity of various cities is nearly the same, and they are all at a medium-to-high level. The value is low in declining cities and regenerative cities, which contributes to its low land carrying capacity, which is consistent with the historical characteristics of the development of these two types of cities.

6.2. Analysis of the Economic Strength of Resource-Based Cities

In this paper, the economic strength of resource-based cities in China was measured and evaluated in 2009, 2012, and 2015 according to the evaluation criteria of environmental carrying capacity index data. See Appendix A, Table A2 for detailed results.

We adopt the previous evaluation standard of carrying capacity level to evaluate. According to the economic strength evaluation, it can be found that from 2009 to 2015, the economic strength of resource-based cities did not undergo drastic changes. Influenced by the support of the development of resource-based industries, the economic strength of resource-based cities remained at a medium-to-high carrying capacity level. See Table 10 below.

Table 10. Average economic strength of resource-based cities.

Years	The Current State of the City's Economy	City Economic Power	General Economic Strength
2009	0.86350452	0.61556952	0.739537019
2012	0.83733099	0.64113436	0.739232671
2015	0.83714836	0.6413114	0.739229877
Evaluation grade	High capacity	Medium to high carrying capacity	Medium to high carrying capacity

From the table above, it can be found that although the resource-based industry has experienced a roller coaster-like development from 2009 to 2015, the economic strength of resource-based cities has not been significantly affected. However, judging from the current situation of urban economic growth, resource-based cities still undergo a slight decline. The city's economic power, on the contrary, has been improved in a difficult situation. This shows that when the development of resource-based industries is hindered, resource-based cities have taken relative countermeasures and have performed a lot of work in dealing with employment and investment, thereby this leads to a decline in the current economic development figures but an increase in the economic power.

From the perspective of the differences in the development stages of resource-based cities and the comparison of regional classifications, resource-based cities at different development stages do not show obvious differences in economic strength, but from the comparison of provinces, it can be seen that the economic strength score of resource-based cities in Hunan, Henan, Hubei, Guangdong, Guangxi, and Sichuan is significantly higher than that of other provinces, and the value is more than 0.8, indicating a high level of carrying capacity. The economic strength of resource-based cities in western provinces is around 0.7, lower than average; in terms of geographical location, most of these resource-based cities with obvious economic strength are located in the southeast and central-south of our country. The economic development foundations of these provinces are quite different from those of resource-based cities in the western region. The strong driving ability of the surrounding areas, the relatively weak dependence on resource-based enterprises, and the better performance of the market economy are the reasons for the strong economic strength of these cities.

When it comes to regional differences in specific indicators, there are contrasting differences between economic status indicators and economic power indicators: cities with higher economic strength indicators show relatively high values in economic development status and economic power indicators, except for Sichuan. Among other cities with relatively low comprehensive economic strength scores, resource-based cities in the six provinces of Guizhou, Yunnan, Shaanxi, Gansu, Ningxia, and Xinjiang have significantly higher economic development status scores (around 0.9) than other provinces such as Hebei and Shanxi. However, the economic development power is obviously low, only slightly higher than 0.5, which is lower than other provinces (0.6). That is to say, according to the evaluation criteria, the economic development momentum of these provinces is only at a medium level, while other provinces advance to the middle-to-high level.

6.3. Analysis of Coupling Coordination Degree between Economy and Environment in Resource-Based Cities

ArcGIS software was used to mark the coupling and coordinated development level of economy and environment of various resource-based cities on the map so as to more intuitively display the regional distribution characteristics of the coupling and coordinated state of economic development environment of resource-based cities, as shown in the following figure (considering the length, only the data of 2009, 2012 and 2015 are displayed, Figures 2–4).

In Figure 2, the coupling coordination degree of economy and environment of China's resource-based cities showed obvious spatial-distribution differences as a whole in 2009. Except for Hegang City in Heilongjiang Province, most of the northern and eastern regions were at the primary coordination level. In the northern regions, the coordination level of Shanxi province, Shaanxi province, and Gansu province was low, and all the resource-based cities in the northern region were at the primary coordination level. During this period, these resource-based cities in the northern region were in the growth stage; the development there is highly characterized by the extensive exploitation and utilization of resources. With the early immature production mode, the resource utilization rate was low, which means the economic development in these cities was achieved at the cost of the environment. Hence, the economy and environment were in the primary coordination state. In the south, there were relatively fewer resources, and the resource-based cities there were generally in a mature and declining state. Therefore, the economic development there no longer relied on resources unilaterally. They had sought a path for transformation and development. The relationship between economy and environment there gradually eased, so the coordination degree was generally better than that in the north.

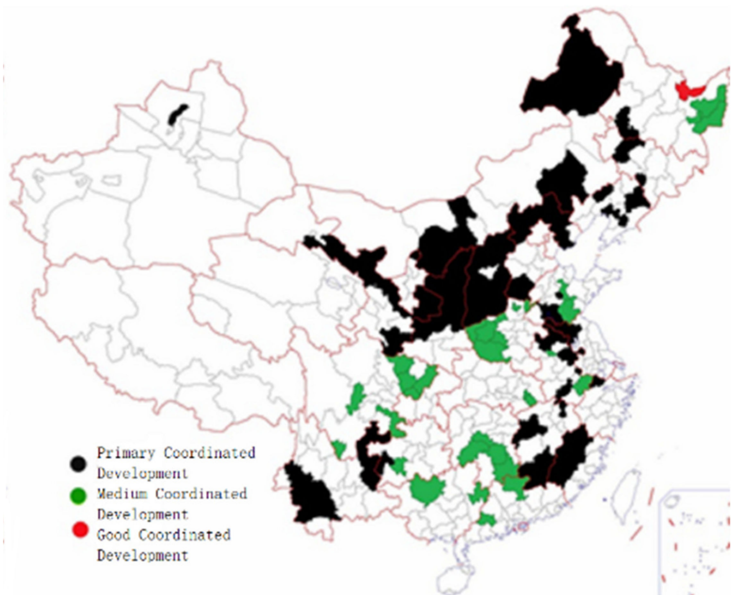

Figure 2. Geographical distribution of economic and environmental coordination level of resource-based cities in 2009.

In Figure 3, the number of resource-based cities in good coordination was 0 in 2012. The number of resource-based cities in intermediate coordination decreased, and the coordination level in these cities gradually degenerated to the primary state. There were no good or intermediate coordination areas in the north, and the coordination degree in the south was still generally higher than that in the north. At that time, with the low awareness of environmental protection and low-carbon, the cities were still under the over-development style just like in 2009, resulting in an increasingly disharmonious relationship between economy and environment.

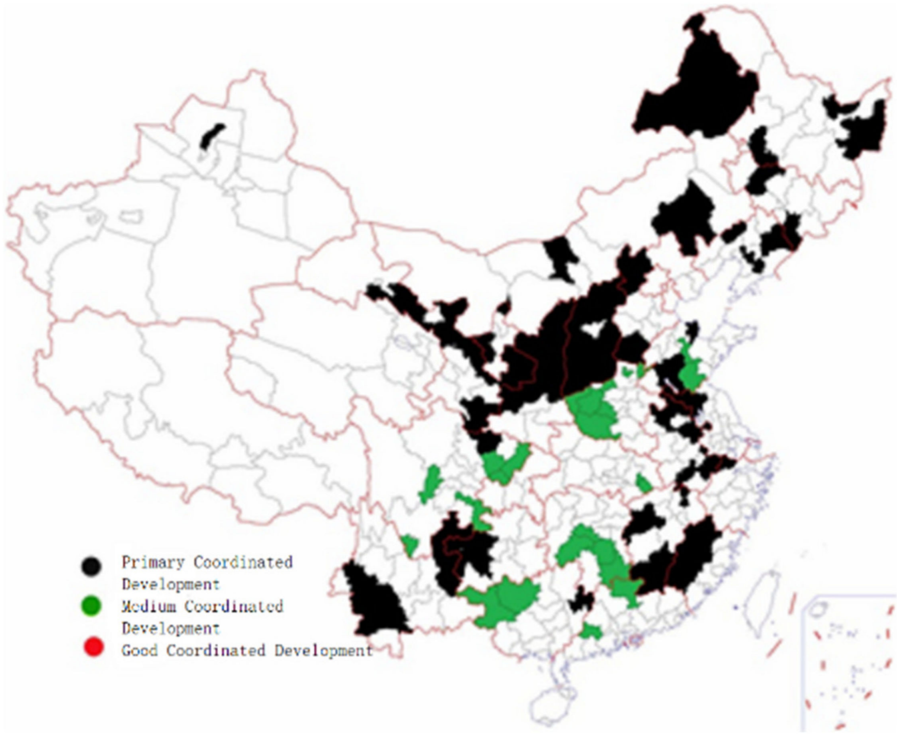

Figure 3. Geographical distribution of economic and environmental coordination level of resource-based cities in 2012.

In Figure 4, the coordination level of the economy and environment of resource-based cities in 2015 showed an improvement compared with previous years, with obvious geographical differences in coordination level, low in East China and high in Central China. The resource-based cities in the eastern region have a long history of development. Some cities have entered a period of resource decline and regeneration, and the environmental carrying capacity is at a low level. However, after a long-term development, the economic system of resource-based cities in the eastern region has been relatively comprehensive. Driven by the economic development mode of other cities in the region, the concept of urban development has changed, and many innovations have been made in the industrial structure, as well as the scientific and technological development. Therefore, it has a high performance in development power, keeping its economic strength in a relatively stable state. However, there is an obvious environmental lag between the economic system and the environmental system. Therefore, the coordination level of the overall economy and environment of the resource-based cities in the eastern region is not high. Most of the resource-based cities in the central and western regions are in the growth stage. Therefore, due to the relatively short development process, the typical manifestation of their economic strength is that the economic growth rate is relatively stable, but the subsequent long-term development power is not strong. Compared with the cities in the eastern region, the urban environment in western regions has a better carrying capacity. That is, the performance of its environmental lag is not as eye-catching as that of the resource-based cities in the East.

So the coordinated development level of the economy and environment in West China is better than that of the resource-based cities in East China.

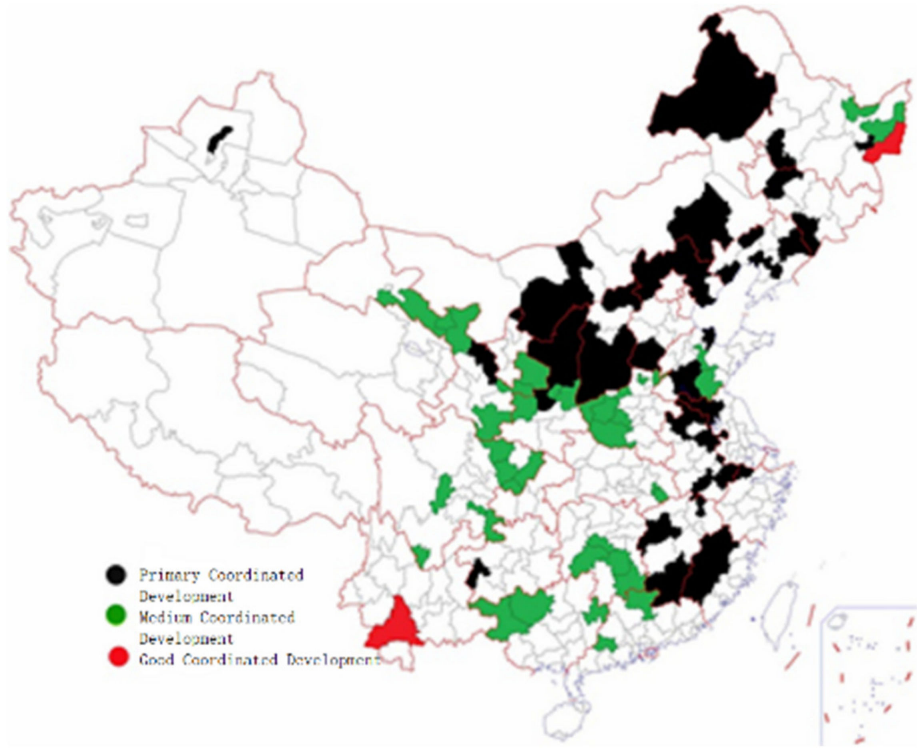

Figure 4. Geographical distribution of economic and environmental coordination level of resource-based cities in 2015.

The above is the coupling and coordination of economy and environment in 109 resource-based cities in China. Next, the influential factors of the coupling and coordination degree will be analyzed.

6.4. Analysis of Factors Affecting the Coordinated Development of Environment and Economy in Resource-Based Cities

In order to explore the effect of influencing factors on the coordination degree of the economy and environment of resource-based cities, this chapter adopts the OLS regression analysis method to carry out the analysis, and the calculation is realized by STATA15.0 software.

The value of LR chi2(15) in the regression results is 42.06, and the p value is 0.0002. The significance test indicates that the regression model is overall significant and the regression results have clear meaning. Table 11 shows the effect of economic development evaluation indicators on the degree of coupling and coordination of resource-based cities. From Table 11, the regression coefficients of regional GDP, annual average population (the whole city), population density, workers in the construction industry, and the amount of foreign investment actually used in the year on the coupling coordination degree of resource-based cities are 0.3522, 0.3260, 0.0400, 0.2438 and 0.1126, respectively, indicating that these five indicators have a direct positive effect on the coupling coordination degree, but only the annual average population has passed the significance test. The reason is that the increase in the average population leads to the increase of labor resources and the enhancement of labor quality in the city. Therefore, it fills the vacancy in the labor market and promotes economic growth. The increase in the number can promote more labor to work in environmental protection and the improvement of the two leads to an increase in the degree of coupling and coordination.

Table 11. The direct effect of economic variables on the coupling coordination degree of resource-based cities.

Influencing Factors	Coefficient	*p*-Value
GDP	0.3522	0.1650
GDP per capita	−0.0405	0.8280
Annual average population (the whole city)	0.3260 *	0.0870
Average annual population (municipal district)	−0.0904	0.4590
The population density	0.0400	0.6270
The proportion of secondary industry in GDP	−0.1840 **	0.0230
The balance of various RMB deposits of financial institutions at the end of the year	−0.1851	0.4560
Balance of various RMB loans of financial institutions at the end of the year	−0.0033	0.9840
Public finance expenditure	−0.1421	0.5530
Science and technology expenditure	−0.0777	0.5980
Education expenditure	−0.0715	0.7570
Practitioners in the secondary industry	−0.1028	0.5820
Practitioners in the construction industry	0.2438	0.1400
Amount of foreign capital actually used in the year	0.1126	0.2570
Investment in fixed assets	−0.3800 **	0.0190
Constant term	0.4284 ***	0.0000

Note: *** presents $p < 0.01$; ** presents $0.01 < p < 0.05$; * presents $0.05 < p < 0.1$.

The negative regression coefficients of other indicators indicate that with the growth of such indicators, the coupling and coordination between the economy and the environment of resource-based cities will decrease. Among them, the regression coefficient of the secondary industry's share of GDP on the coupling and coordination of resource-based cities' economy and environment is −0.1840, and the significance test means that every time when the secondary industry's share of GDP increases by 1, the coupling coordination degree of economy and environment decreases by 0.1840. The reason is that resource development and utilization dominate in resource-based cities, and the secondary industry accounts for a very large proportion of resource development and utilization, but the resource development, though it leads to rapid growth in the economy, is accompanied by environmental disruption, and the overall carrying capacity of the city will decrease, leading to an imbalance between the two. The regression coefficient of fixed asset investment on the coupling coordination degree of resource-based cities is −0.3800, and it has passed the significance test. The reason is that the fixed asset investment in resource-based cities is mainly used to improve the city's municipal administration, protect the environment, and repair the environmental damage from resource mining. The subsidence area has reduced the investment in economic development, which consequently slows down the increase in the economy; while in the meantime, it has increased the stress on environmental protection, resulting in an improvement in the coupling and coordination between the two, and a change in the direction of inharmony.

In the regression results, the value of LR chi2(8) is 27.81, and the *p*-value is 0.0005. The significance test indicates that the regression model is generally significant, and the regression results have clear significance. Table 12 shows the impact of the city's carrying capacity indicators on the degree of coupling and coordination of resource-based cities. It is not difficult to find that the estimated parameter of the coupling and coordination degree of industrial waste water discharge to resource-based cities is 0.3018, and the result that they pass the significance test means that every additional unit of industrial waste water discharge will lead to 0.3018 unit increase in coupling coordination degree. This is in line with the correlation between the coupling and coordination of resource-based cities and the amount of industrial waste water discharge. The reason is that with the development of industrialization, the level of productivity has increased significantly, and resource cities have continued to expand, which leads to increased utilization of resources. At the same time, the annual increase in the discharge of industrial waste water has slowed down the development of cities. Therefore, cities need to take the environment into account, strengthen environmental protection, and force the slowdown of urban development and the improvement of development quality—the association of those two drives the coordinated development of the economy and the environment. The estimated parameter of industrial sulfur dioxide emissions to the coupling coordination degree of resource-based cities is 0.0238, which reveals that industrial sulfur dioxide emissions promote the improvement of resource-based city coupling coordination, and the reason is the same as that of industrial waste water discharge.

Table 12. The direct effect of urban comprehensive carrying capacity index on the coupling coordination degree of resource-based cities.

Influencing Factors	Coefficient	*p*-Value
Industrial wastewater discharge	0.3018 *	0.0560
Industrial sulfur dioxide production	−0.0687	0.5340
Industrial sulfur dioxide emissions	0.0238	0.8000
Industrial smoke (powder) dust removal	−0.0987	0.4960
Industrial smoke (dust) emissions	−0.2405	0.1200
Comprehensive utilization rate of general industrial solid waste	−0.1153 *	0.0530
Centralized treatment rate of sewage treatment plant	−0.2499	0.0340
Harmless treatment rate of domestic garbage	−0.0450	0.5510
Constant term	0.6910 ***	0.0000

Note: *** presents $p < 0.01$; * presents $0.05 < p < 0.1$.

However, the other six indicators are shown to possess an inhibitory effect on the coupling and coordination of resource-based cities. Among them, the overall utilization rate of general industrial solid waste is better because of the high rate of harmless treatment of household garbage. The centralized treatment rate of sewage treatment plants and the overall utilization rate of general solid waste are positive indicators for evaluating the overall carrying capacity of the city. With the continuous increase of the three, the overall carrying capacity of the city further grows. However, in addition to that, the city needs to increase the investment in science and technology, for example, to advance the existing technology to improve efficiency, though this might slow down economic development. Under the influence of these three factors, the relationship between the environment and economy will decrease, and the degree of coordination will decrease as well. The reasons that industrial smoke (dust) and dust removal have a negative effect on the degree of coordination between the environment and economy are similar to the first three. The reasons for industrial sulfur dioxide and industrial smoke (dust) emissions resulting in a decrease in the degree of urban coupling and coordination are due to the fact that the rate of environmental destruction and the reduction of the overall capacity of the city surpass the slowdown of economic growth.

6.5. Analysis of the Economic Strength of Resource-Based Cities

The small sample size of growing, declining, and renewable resource-based cities in 2015 do not meet the conditions for applying the Tobit model. Therefore, this section only analyzes the factors affecting the coordinated development of the economy and environment in mature resource-based cities.

Table 13 shows the effect of economic development indicators on the degree of coupling and coordination of mature resource-based cities. The value of LR chi2(15) in the regression results is 35.47, and the *p*-value is 0.0021. The significance test indicates that the regression model is overall significant, the regression result has a clear meaning.

From Table 13, it can be seen that the average annual population (municipal districts), the proportion of the secondary industry in GDP, and fixed asset investment have a significant inhibitory effect on the degree of coupling and coordination of resource-based cities. At the end of the year, financial institutions' RMB deposit balances, science and technology expenditures, education expenditures, and the amount of foreign investment actually used in the year show no significant inhibitory effect on the coupling and coordination of resource-based cities and other variables have a slight promotion effect on the coupling and coordination of resource-based cities. The parameter estimation results of the economic development indicators for the coupling coordination degree of mature resource-based cities are nearly the same as those of the full sample resource-based cities. The difference is that the annual average population of the full sample resource-based cities (the whole city) has a significant effect on the coupling coordination degree. The average annual population (municipal districts) has an insignificant inhibitory effect on the coupling coordination degree, while the annual average population of mature resource-based cities (the whole city) has an insignificant promotion effect on the coupling coordination degree. The annual average population (Municipal district) has a significant inhibitory effect on the degree of coupling coordination.

Table 13. The direct effect of economic development index on the coupling coordination degree of mature resource-based cities.

Influencing Factors	Coefficient	*p*-Value
GDP	0.0915	0.7740
GDP per capita	0.4558	0.1950
Annual average population (the whole city)	0.5184	0.1410
Average annual population (municipal district)	−0.3654 **	0.0410
The population density	0.0825	0.5430
The proportion of secondary industry in GDP	−0.2310 **	0.0870
The balance of various RMB deposits of financial institutions at the end of the year	−0.8948	0.0360
Balance of various RMB loans of financial institutions at the end of the year	0.1159	0.5260
Public finance expenditure	0.6129	0.2430
Science and technology expenditure	−0.2634	0.2060
Education expenditure	−0.6494	0.1750
Practitioners in the secondary industry	0.0982	0.7270
Practitioners in the construction industry	0.2423	0.4330
Amount of foreign capital actually used in the year	−0.0595	0.7230
Investment in fixed assets	−0.4462 *	0.0750
Constant term	0.4817 ***	0.0000

Note: *** presents $p < 0.01$; ** presents $0.01 < p < 0.05$; * presents $0.05 < p < 0.1$.

Table 14 shows the effect of the city's carrying capacity index on the degree of coupling and coordination of mature resource-based cities. Among them, the value of LR chi2(8) is 29.43, and the *p*-value is 0.0003. The significance test indicates that the regression model is overall significant, and the regression result has a clear meaning. It can be seen from the table that the discharge of industrial waste water, the discharge of industrial smoke (dust), and the centralized treatment rate of sewage treatment plants have a significant inhibitory effect on the coupling and coordination of mature resource-based cities. Industrial sulfur dioxide emissions have a positive effect on mature resource-based cities' coupling coordination degree, while industrial sulfur dioxide production, industrial smoke (dust) dust removal, and general industrial solid waste overall utilization rate have an insignificant inhibitory effect on the coupling coordination degree of mature resource-based cities. The harmless treatment rate of household waste does not significantly promote the coupling and coordination of mature resource-based cities. In comparison to the regression results of the full sample of resource-based cities, it is found that the effect of industrial waste water discharge, industrial sulfur dioxide production, industrial smoke (dust) removal, and the harmless treatment rate of household waste on the coupling coordination degree is only a numerical change while the direction of action and significance remain fairly unchanged. Although the direction of action of the parameter estimates of the remaining four variables has not changed, their values and significance levels have changed.

Table 14. The direct effect of urban comprehensive carrying capacity index on the coupling coordination degree of mature resource-based cities.

Influencing Factors	Coefficient	p-Value
Industrial wastewater discharge	0.4206 **	0.0160
Industrial sulfur dioxide production	−0.0312	0.8630
Industrial sulfur dioxide emissions	0.2349 *	0.0660
Industrial smoke (powder) dust removal	−0.3004	0.1630
Industrial smoke (dust) emissions	−0.5335 **	0.0300
Comprehensive utilization rate of general industrial solid waste	−0.0858	0.2680
Centralized treatment rate of sewage treatment plant	−0.4301 *	0.0130
Harmless treatment rate of domestic garbage	0.0809	0.6240
Constant term	0.7213 ***	0.0000

Note: *** presents $p < 0.01$; ** presents $0.01 < p < 0.05$; * presents $0.05 < p < 0.1$.

7. Discussion

This study focuses on the typical characteristics and universal laws of the resource-based cities in China and uses the combination of qualitative method and quantitative method to study the coordinated development of the economy and environment in resource-based cities. However, due to the limitations of various conditions, there are still some deficiencies in this study, which are summarized as follows:

(1) The 109 prefecture-level resource-based cities, recognized by the sustainable development plan of resource-based cities of the State Council, are of various resource conditions, including coal, metal mines, oil, etc. With different resource endowments, these cities show different environmental pollution emission intensities. Thus, these cities are facing different environmental pollution emission pressures. In order to solve this problem, different resource-based cities have issued different measures. In this study, only the common characteristics of resource-based cities were considered, with the individual characteristics which cannot reflect the impact of different resource endowment conditions ignored.

(2) The resource-based cities in China are mostly the prefecture-level cities of various provinces and regions, which are often not the core cities in their provinces or regions. Many of them are of less advanced urban development and short development cycle, resulting in great uncertainty in the environmental- and industrial-related data collected. Therefore, the research indicators and data selected in this study also have certain limitations. As the environmental pollution emission data of specific industrial sectors cannot be obtained, the strength, proportion, and employment of each branch industrial sector of resource-based cities cannot be analyzed.

In view of the deficiencies in this study, the following aspects can be further discussed in future research:

(1) In the following research, new classification methods can be adopted. For example, the resource endowment characteristic indicators and data can be collected according to the different resource conditions of the research object. Thus, an in-depth comparison and analysis of the coordinated development characteristics of economic systems and ecological environment systems in different resource-based cities can be conducted, combined with the commonness analysis of this paper.

(2) The scope of index data collection can be expanded. Through abstract field investigation, the microdata of the resource-based urban economic system and ecological environment system can be collected so as to modify the research data of this paper and more accurately reflect the actual situation of the resource-based urban economic system and ecological environment system, thus enhancing the microdata basis of this paper.

8. Conclusions

This paper studies the status quo of the resource-based city economy and environmental development, the mechanism of coordinated development of resource-based city economy and environment, and various influencing factors, and the following conclusions are obtained:

(1) The environmental carrying capacity of resource-based cities is at a medium level, among which water and land resources are relatively poor. Most resource-based cities have only just reached the medium carrying capacity level. Resource-based cities of different development types do not show obvious differences in environmental carrying capacity and are basically at the same carrying capacity level. However, by a numerical comparison, a shift in it occurs from growth-oriented resource-based cities to mature, declining, and regenerated ones, showing a trend of gradual decline.
(2) The level of the economic strength of resource-based cities is constantly improving yet fluctuating. Due to the dominance of resource-based industries, the overall economic strength of resource-based cities in China is at a medium-to-high level. The economic conditions of these cities are relatively good, and the overall difference between resource-based cities in various regions of China is fairly small, indicating that the economy of these cities in China shares common development characteristics.
(3) The synergy between economy and environment in resource-based cities is not high that the environment lags behind obviously. It is easy to pay attention to that there are regional differences in coordination degree that the overall coordination of the eastern region is low, and the central and western regions show a high level.
(4) The factors affecting the coordinated development of the economy and environment in resource-based cities are dense and obvious. The research results confirmed that indicators such as urban GDP, investment in fixed assets, and per capita solid waste discharge had played an important role in the coordinated development of resource-based cities' economies and environment.

According to the above conclusions, this paper puts forward the following suggestions:

(1) The government should improve the attractiveness of the urban manpower, provide complete welfare benefits for both the migrant workers and local workers, and improve the population quality of employees.
(2) The government should enhance the urban industrial structure, increase the support for high value-added industries, strictly supervise pollution-intensive industries, encourage innovation and cultivate the high-tech industries.
(3) While controlling environmental pollution and repairing ecological damage, the government should also pay attention to economic development to avoid economic weakness caused by excessive investment.

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Appendix A

Table A1. Sub-item value of environmental carrying capacity.

Air Quality			Water		
2009	**2012**	**2015**	**2009**	**2012**	**2015**
0.752059	0.750398	0.751473	0.289526	0.29062	0.289974
0.750005		0.749413	0.290727		0.29129
0.751075	0.751338	0.750163	0.290106	0.289962	0.290689
0.750823	0.752605	0.751276	0.290364	0.2893	0.290123
0.752365		0.751993	0.289383		0.289674
0.724623	0.752104	0.751947	0.30623	0.289602	0.289706
0.750048	0.747721	0.748388	0.29091	0.29236	0.291945
0.752203	0.751359	0.751143	0.289536	0.290058	0.290201
0.752061	0.750694	0.747788	0.289567	0.290456	0.292219
0.725015	0.71167		0.305689	0.314047	
0.743917	0.751169	0.748413	0.294647	0.290189	0.291905
0.745091	0.713491	0.747473	0.293831	0.311648	0.292447
0.745985	0.751317	0.745874	0.29327	0.290062	0.293442
0.747701	0.751148	0.749932	0.292257	0.290213	0.290961
0.752295	0.753001	0.752215	0.289496	0.28906	0.289546
0.748528	0.749794	0.75073	0.291761	0.291025	0.290441
0.750457		0.753454	0.290646		0.288768
0.749232	0.752009	0.751407	0.291421	0.28967	0.290056
0.746994	0.745178	0.744518	0.292782	0.293887	0.29427
0.750292	0.750977	0.746678	0.290721	0.290301	0.292978
0.75157	0.752116	0.751162	0.289843	0.289566	0.290152
0.750995	0.748487	0.749936	0.290304	0.291803	0.290949
0.752608	0.751755	0.750742	0.289243	0.289812	0.290457
0.75258	0.749822	0.748414	0.289253	0.29097	0.291847
0.744473		0.74702	0.293846		0.292602
0.745638	0.749891	0.735022	0.293432	0.290891	0.299865
0.753088	0.752334	0.75019	0.288979	0.289154	0.29074
0.753357	0.752304	0.752089	0.288684	0.289385	0.28958
		0.752442			0.289141
		0.752334			0.289413
0.936888	0.749592	1.598564	0.235454	0.291022	0.401434
1.296465	0.753536	0.937323	0.454302	0.288647	0.358945
0.930656	0.75099	0.936639	0.238547	0.290217	0.359492
0.93699	0.75413	0.752522	0.235408	0.288308	0.289304
0.751847	0.75264	0.75254	0.289713	0.289232	0.289309
0.74527	0.744407	0.740109	0.292367	0.293936	0.296381
0.749836	0.7538	0.753547	0.290636	0.288476	0.288641
0.75288	0.751889	0.752272	0.288992	0.289636	0.289367
0.741561	0.727169	0.75335	0.290921	0.302729	0.288798
0.935246	0.753795	0.75335	0.3606	0.288524	0.288798
0.732686	0.752329	0.753722	0.293701	0.289316	0.288529
0.747844	0.750414	0.748822	0.292207	0.29063	0.291614
0.928764	0.753616	0.752609	0.363633	0.288619	0.289221

Table A1. *Cont.*

Air Quality			Water		
2009	**2012**	**2015**	**2009**	**2012**	**2015**
0.751559	0.751061	0.750308	0.289785	0.290174	0.290654
0.715748	0.74716	0.740155	0.307551	0.29264	0.29682
0.752677	0.752717	0.75318	0.289087	0.289184	0.288906
0.75361	0.752932	0.751516	0.28827	0.288802	0.289567
0.753069	0.753896	0.7534	0.288293	0.28837	0.288727
0.750448	0.754245	0.754371	0.290391	0.288262	0.288182
0.752834	0.697935	0.751357	0.288994	0.270997	0.289881
0.751559	0.751061	0.750308	0.289785	0.290174	0.290654
0.751622	0.67235	0.749614	0.289866	0.296012	0.291162
0.668151	0.75216	0.753039	0.315143	0.289361	0.288912
0.751686	0.752158	0.751656	0.289821	0.289532	0.289832
	0.744411	0.743291		0.294121	0.294856
0.752477	0.752274	0.751341	0.289298	0.289436	0.290009
	0.751553	0.747545		0.289893	0.292217
0.735343	0.751252	0.750921	0.299807	0.290148	0.290359
0.751599	0.753081	0.753069	0.289668	0.288953	0.28897
0.74937	0.75125	0.75143	0.29114	0.2901	0.28998
0.75215	0.75209	0.7513	0.28944	0.28956	0.29006
0.7471	0.75127	0.75132	0.29271	0.29009	0.29005
0.75324	0.752503	0.75151	0.28884	0.289294	0.28993
0.75296	0.752893	0.75152	0.28904	0.289099	0.28996
0.75171	0.75296	0.75258	0.28948	0.288981	0.28921
0.75319	0.753555	0.75328	0.28828	0.28859	0.28877
0.74992	0.753149	0.75178	0.29094	0.288949	0.28979
0.75329	0.750815	0.75311	0.28866	0.290301	0.28894
0.7356	0.752863	0.75108	0.29911	0.289118	0.29024
0.73765	0.742593	0.74688	0.2982	0.29539	0.29281
0.74844	0.752225	0.7429	0.29155	0.289421	0.29509
0.75203	0.75112	0.75049	0.28956	0.290135	0.29052
0.73473	0.748581	0.75024	0.29611	0.29148	0.29052
0.73506	0.736469	0.75162	0.29906	0.29842	0.28989
0.75261	0.738215	0.75106	0.28897	0.296927	0.29014
0.74569	0.749018	0.75336	0.29315	0.29129	0.28882
	0.750542	0.75053		0.290497	0.29055
0.67594	0.730121	0.73277	0.3258	0.301652	0.30051
0.67728	0.752843	0.74458	0.32967	0.288908	0.29382
0.68896	0.676266	0.67061	0.31309	0.3236	0.32476
0.75135	0.748646	0.73671	0.28986	0.29168	0.29811
0.73034	0.753144	0.75152	0.30129	0.288964	0.28998
0.75037	0.752125	0.75192	0.29068	0.2896	0.28973
0.72803	0.746557	0.74852	0.30297	0.292822	0.29165
0.74928	0.751016	0.74959	0.29131	0.290261	0.29116
0.75048	0.752256	0.74982	0.29052	0.289529	0.29101
0.72087	0.752156	0.73337	0.30692	0.289547	0.30082
0.784468	0.784398	0.584707	0.230687	0.23071	0.501019
0.655221	0.658985	0.55386	0.352217	0.350143	0.329968
	0.665189	0.829243		0.346387	0.364868
0.780499	0.785238	0.58558	0.232757	0.230276	0.458963
0.665401	0.654813	0.660048	0.345837	0.352474	0.358517
0.674493	0.626961	0.796009	0.338656	0.36906	0.345267
0.677786	0.670514	0.583785	0.338893	0.343146	0.333267
0.644091	0.670483	0.59196	0.359903	0.343376	0.093165
0.674382	0.654613	0.613681	0.341015	0.353041	0.382211
0.640081	0.582205	0.561135	0.35796	0.390625	0.303102

Table A1. *Cont.*

Air Quality			Water		
2009	**2012**	**2015**	**2009**	**2012**	**2015**
0.67144	0.659397	0.567867	0.339794	0.34897	0.377249
0.64932	0.596281	0.539441	0.35463	0.38792	0.402051
0.671199	0.675924	0.715323	0.342966	0.340035	0.321485
0.669892	0.674569	0.852626	0.343732	0.340859	0.308013
0.65813	0.660694	0.675472	0.350781	0.349264	0.329737
0.660462	0.669929	0.524097	0.349359	0.343698	0.361825
0.661404	0.666709	0.74041	0.348091	0.344668	0.315423
0.655905	0.636648	0.851786	0.350203	0.362707	0.305371
0.6436	0.676072	0.920043	0.359163	0.338628	0.338407
0.677044	0.677404	0.758067	0.339354	0.339129	0.360516
0.667373	0.674494	0.994378	0.345218	0.340879	0.222976
0.614518	0.65371	0.560969	0.376628	0.353616	0.343661
0.675398	0.674266	0.601362	0.339915	0.341025	0.18931
Land			**General environment**		
2009	**2012**	**2015**	**2009**	**2012**	**2015**
0.199678	0.200335	0.199835	0.413754	0.413784	0.413761
0.20068		0.200708	0.413804		0.413804
0.200155	0.200016	0.200539	0.413779	0.413772	0.413797
0.200142	0.1993	0.199893	0.413776	0.413735	0.413764
0.199487		0.199582	0.413745		0.413750
0.211798	0.199533	0.199593	0.414217	0.413746	0.413749
0.200409	0.201416	0.201126	0.413789	0.413832	0.413820
0.199496	0.199874	0.199959	0.413745	0.413764	0.413768
0.199629	0.200184	0.201504	0.413752	0.413778	0.413837
0.211892	0.216975		0.414199	0.414231	
0.203179	0.199939	0.201134	0.413914	0.413766	0.413817
0.202795	0.214864	0.201592	0.413906	0.413334	0.413837
0.202373	0.199922	0.202255	0.413876	0.413767	0.413857
0.201584	0.199937	0.20049	0.413847	0.413766	0.413794
0.199435	0.199115	0.199466	0.413742	0.413725	0.413742
0.201179	0.20056	0.200159	0.413823	0.413793	0.413777
0.200241		0.198926	0.413781		0.413716
0.200763	0.199564	0.199816	0.413805	0.413748	0.413760
0.201755	0.202504	0.202776	0.413844	0.413856	0.413855
0.200344	0.200033	0.201887	0.413786	0.413770	0.413848
0.199879	0.199567	0.199996	0.413764	0.413750	0.413770
0.200014	0.201188	0.200496	0.413771	0.413826	0.413794
0.199364	0.199699	0.200131	0.413738	0.413755	0.413777
0.199385	0.200613	0.201234	0.413739	0.413802	0.413832
0.203471		0.201959	0.413930		0.413860
0.20258	0.200625	0.206711	0.413883	0.413802	0.413866
0.19911	0.199794	0.200452	0.413726	0.413761	0.413794
0.19914	0.199558	0.199579	0.413727	0.413749	0.413749
		0.199684			0.413756
		0.199487			0.413745
0.247724	0.200804		0.473355	0.413806	0.666666
0.240965	0.198974	0.123781	0.663911	0.413719	0.473350
0.251177	0.200126	0.123955	0.473460	0.413778	0.473362
0.247661	0.19867	0.199394	0.473353	0.413703	0.413740
0.199705	0.199338	0.199363	0.413755	0.413737	0.413737
0.204289	0.203463	0.20559	0.413975	0.413935	0.414027
0.200981	0.198862	0.198966	0.413818	0.413713	0.413718

Table A1. *Cont.*

Air Quality			Water		
2009	**2012**	**2015**	**2009**	**2012**	**2015**
0.199341	0.199749	0.199614	0.413738	0.413758	0.413751
0.210056	0.212889	0.199011	0.414179	0.414262	0.413720
0.124312	0.19881	0.199011	0.473386	0.413710	0.413720
0.216766	0.199609	0.198892	0.414384	0.413751	0.413714
0.201478	0.200301	0.200993	0.413843	0.413782	0.413810
0.128571	0.198912	0.199391	0.473656	0.413716	0.413740
0.199959	0.200089	0.200412	0.413768	0.413775	0.413791
0.216946	0.201653	0.204555	0.413415	0.413818	0.413843
0.199467	0.199304	0.199087	0.413744	0.413735	0.413724
0.199328	0.199505	0.200275	0.413736	0.413746	0.413786
0.199944	0.198875	0.199039	0.413769	0.413714	0.413722
0.200545	0.198588	0.198534	0.413795	0.413698	0.413696
0.199389	0.277649	0.200083	0.413739	0.415527	0.413774
0.199959	0.200089	0.200412	0.413768	0.413775	0.413791
0.199788	0.279414	0.200629	0.413759	0.415925	0.413802
0.262742	0.199756	0.199249	0.415345	0.413759	0.413733
0.199768	0.199553	0.199792	0.413758	0.413748	0.413760
	0.203074	0.203454		0.413869	0.413867
0.199453	0.199529	0.199943	0.413743	0.413746	0.413764
	0.199833	0.201751		0.413760	0.413838
0.206816	0.199893	0.200035	0.413989	0.413764	0.413772
0.200053	0.199148	0.19914	0.413773	0.413727	0.413726
0.20093	0.19996	0.19988	0.413813	0.413770	0.413763
0.19967	0.1996	0.19994	0.413753	0.413750	0.413767
0.20271	0.199946	0.19992	0.414173	0.413769	0.413763
0.19909	0.199426	0.19984	0.413723	0.413741	0.413760
0.19919	0.199198	0.1998	0.413730	0.413730	0.413760
0.20015	0.199258	0.19943	0.413780	0.413733	0.413740
0.19982	0.199017	0.19913	0.413763	0.413721	0.413727
0.20053	0.19907	0.19969	0.413797	0.413723	0.413753
0.19925	0.200223	0.19913	0.413733	0.413780	0.413727
0.20758	0.199209	0.19999	0.414097	0.413730	0.413770
0.20592	0.203646	0.2018	0.413923	0.413876	0.413830
0.20156	0.199605	0.20381	0.413850	0.413750	0.413933
0.19967	0.200053	0.20033	0.413753	0.413769	0.413780
0.21186	0.201449	0.20065	0.414233	0.413837	0.413803
0.20814	0.206789	0.19977	0.414087	0.413893	0.413760
0.19969	0.206939	0.20012	0.413757	0.414027	0.413773
0.20285	0.201167	0.19898	0.413897	0.413825	0.413720
	0.200315	0.20026		0.413785	0.413780
0.24172	0.209904	0.20851	0.414487	0.413892	0.413930
0.23536	0.199481	0.20325	0.414103	0.413744	0.413883
0.24245	0.243471	0.24818	0.414833	0.414446	0.414517
0.2001	0.201119	0.20612	0.413770	0.413815	0.413647
0.21048	0.199062	0.19978	0.414037	0.413723	0.413760
0.2003	0.199507	0.1996	0.413783	0.413744	0.413750
0.2112	0.202241	0.20134	0.414067	0.413873	0.413837
0.20082	0.200039	0.20066	0.413803	0.413772	0.413803
0.20035	0.19944	0.20057	0.413783	0.413742	0.413800
0.21373	0.199533	0.20792	0.413840	0.413745	0.414037
0.230685	0.230736	0.579895	0.415280	0.415281	0.555207
0.239119	0.237259	0.36414	0.415519	0.415462	0.415989
	0.234602	0.232006		0.415393	0.475372
0.232763	0.230289	0.619636	0.415340	0.415268	0.554726

Table A1. *Cont.*

Air Quality			Water		
2009	2012	2015	2009	2012	2015
0.234896	0.239099	0.645392	0.415378	0.415462	0.554652
0.232661	0.250339	0.190266	0.415270	0.415453	0.443847
0.229001	0.232302	0.744881	0.415227	0.415321	0.553978
0.242506	0.232102	0.160135	0.415500	0.415320	0.281753
0.230421	0.238726	0.666623	0.415273	0.415460	0.554172
0.249221	0.275336	0.382737	0.415754	0.416055	0.415658
0.235029	0.238099	0.301732	0.415421	0.415489	0.415616
0.242902	0.263582	0.301732	0.415617	0.415928	0.414408
0.231771	0.229797	0.62704	0.415312	0.415252	0.554616
0.232358	0.230383	0.50325	0.415327	0.415270	0.554630
0.237412	0.236297	0.659474	0.415441	0.415418	0.554894
0.236494	0.232367	0.362078	0.415438	0.415331	0.416000
0.236778	0.234721	0.609103	0.415424	0.415366	0.554979
0.240345	0.247197	0.506695	0.415484	0.415517	0.554617
0.243752	0.231049	0.405707	0.415505	0.415250	0.554719
0.229312	0.229164	0.544434	0.415237	0.415232	0.554339
0.233477	0.23044	0.446197	0.415356	0.415271	0.554517
0.255959	0.239266	0.343402	0.415702	0.415531	0.416011
0.230463	0.230531	0.18931	0.415259	0.415274	0.326661

Note: City name has been removed.

Table A2. Sub-item value of economic indicators.

The Current State of the City's Economy			City Economic Power			General Economic Strength		
2009	2012	2015	2009	2012	2015	2009	2012	2015
0.080618	0.080612	0.080608	0.061024	0.061029	0.061032	0.708208	0.708205	0.708203
0.080627	0.080620	0.080612	0.061016	0.061022	0.061029	0.708212	0.708209	0.708205
0.080607	0.080607	0.080601	0.061033	0.061033	0.061038	0.708202	0.708202	0.708199
0.080602	0.080600	0.080596	0.061038	0.061039	0.061044	0.708200	0.708199	0.708196
0.080606	0.080607	0.080601	0.061034	0.061033	0.061039	0.708202	0.708202	0.708199
0.080636	0.080625	0.080617	0.061007	0.061017	0.061024	0.708217	0.708211	0.708208
0.080699	0.080718	0.080663	0.060951	0.060934	0.060983	0.708249	0.708258	0.708231
0.080644	0.080633	0.080613	0.061000	0.061010	0.061028	0.708221	0.708216	0.708205
0.080663	0.080654	0.080627	0.060983	0.060991	0.061016	0.708231	0.708226	0.708212
0.080631	0.080626	0.080612	0.061012	0.061017	0.061029	0.708215	0.708212	0.708205
0.080646	0.080633	0.080615	0.060999	0.061010	0.061026	0.708222	0.708215	0.708206
0.080637	0.080625	0.080609	0.061007	0.061017	0.061031	0.708218	0.708212	0.708203
0.080624	0.080617	0.080607	0.061019	0.061024	0.061033	0.708211	0.708208	0.708202
0.080644	0.080636	0.080612	0.061000	0.061007	0.061029	0.708221	0.708217	0.708205
0.080658	0.080651	0.080623	0.060988	0.060994	0.061020	0.708228	0.708225	0.708210
0.080638	0.080639	0.080643	0.061006	0.061005	0.061001	0.708218	0.708219	0.708221
0.080652	0.080642	0.080643	0.060993	0.061002	0.061001	0.708225	0.708220	0.708221
0.080891	0.080841	0.080813	0.060778	0.060822	0.060848	0.708341	0.708318	0.708305
0.080619	0.080613	0.080616	0.061022	0.061028	0.061025	0.708209	0.708205	0.708207
0.080633	0.080627	0.080628	0.061010	0.061015	0.061015	0.708216	0.708213	0.708213
0.080703	0.080667	0.080695	0.060948	0.060980	0.060954	0.708250	0.708232	0.708247
0.080673	0.080650	0.080755	0.060974	0.060995	0.060900	0.708236	0.708224	0.708277
0.080646	0.080641	0.080682	0.060998	0.061003	0.060966	0.708222	0.708219	0.708240
0.080636	0.080623	0.080625	0.061008	0.061019	0.061017	0.708217	0.708210	0.708212
0.080678	0.080665	0.080667	0.060969	0.060981	0.060979	0.708238	0.708232	0.708233
0.080668	0.080647	0.080774	0.060979	0.060997	0.060884	0.708233	0.708223	0.708286
0.080627	0.080638	0.080631	0.061016	0.061005	0.061012	0.708212	0.708218	0.708214
0.080655	0.080682	0.080684	0.060990	0.060966	0.060964	0.708227	0.708240	0.708242

Table A2. *Cont.*

The Current State of the City's Economy			City Economic Power			General Economic Strength		
2009	2012	2015	2009	2012	2015	2009	2012	2015
0.080629	0.080641	0.080637	0.061014	0.061003	0.061006	0.708213	0.708219	0.708218
0.080580	0.080577	0.080672	0.061156	0.061158	0.061072	0.708680	0.708679	0.708723
0.080650	0.080614	0.080632	0.061093	0.061125	0.061109	0.708713	0.708697	0.708705
0.080678	0.080665	0.080826	0.061067	0.061079	0.060933	0.708726	0.708720	0.708793
0.080610	0.080581	0.080756	0.061129	0.061155	0.060996	0.708695	0.708681	0.708762
0.080692	0.080778	0.080806	0.061054	0.060976	0.060951	0.708732	0.708771	0.708784
0.080513	0.080512	0.080507	0.061217	0.061218	0.061222	0.708649	0.708649	0.708647
0.080506	0.080507	0.080504	0.061223	0.061223	0.061225	0.708646	0.708646	0.708645
0.080561	0.080557	0.080549	0.061174	0.061177	0.061184	0.708672	0.708670	0.708666
0.080544	0.080528	0.080522	0.061188	0.061203	0.061209	0.708664	0.708656	0.708653
0.080557	0.080550	0.080532	0.061177	0.061183	0.061200	0.708670	0.708667	0.708658
0.080581	0.080565	0.080535	0.061155	0.061170	0.061197	0.708681	0.708674	0.708660
0.080530	0.080531	0.080521	0.061201	0.061201	0.061210	0.708657	0.708658	0.708653
0.080578	0.080587	0.080558	0.061158	0.061150	0.061176	0.708680	0.708684	0.708670
0.080529	0.080541	0.080530	0.061203	0.061192	0.061202	0.708657	0.708662	0.708657
0.080537	0.080545	0.080539	0.061195	0.061188	0.061193	0.708661	0.708664	0.708662
0.080648	0.080634	0.080550	0.061095	0.061107	0.061184	0.708712	0.708706	0.708666
0.080585	0.080544	0.080527	0.061152	0.061189	0.061204	0.708683	0.708664	0.708656
0.080545	0.080541	0.080523	0.061188	0.061191	0.061208	0.708664	0.708663	0.708654
0.080543	0.080542	0.080526	0.061190	0.061190	0.061205	0.708663	0.708663	0.708655
0.080567	0.080549	0.080526	0.061168	0.061185	0.061205	0.708675	0.708666	0.708655
0.080573	0.080585	0.080564	0.061162	0.061151	0.061171	0.708678	0.708683	0.708673
0.080572	0.080591	0.080583	0.061163	0.061146	0.061154	0.708677	0.708686	0.708682
0.080545	0.080548	0.080542	0.061188	0.061185	0.061191	0.708664	0.708666	0.708663
0.080525	0.080518	0.080509	0.061206	0.061212	0.061221	0.708655	0.708652	0.708647
0.080529	0.080534	0.080515	0.061202	0.061198	0.061215	0.708657	0.708659	0.708650
0.080571	0.080556	0.080537	0.061164	0.061178	0.061195	0.708677	0.708669	0.708661
0.080523	0.080519	0.080510	0.061208	0.061212	0.061219	0.708654	0.708652	0.708648
0.080527	0.080520	0.080515	0.061204	0.061210	0.061215	0.708656	0.708653	0.708650
0.080641	0.080610	0.080574	0.061101	0.061129	0.061161	0.708709	0.708695	0.708678
0.080551	0.080539	0.080524	0.061182	0.061193	0.061206	0.708667	0.708661	0.708655
0.084989	0.084980	0.085968	0.080082	0.082091	0.080101	0.825357	0.835352	0.830345
0.084953	0.084950	0.084946	0.080114	0.080117	0.080120	0.825337	0.825335	0.825333
0.084992	0.084990	0.084971	0.080079	0.080082	0.080098	0.825359	0.825357	0.825347
0.085024	0.085018	0.085000	0.080051	0.080056	0.080073	0.825376	0.825373	0.825363
0.084975	0.084965	0.084956	0.080095	0.080103	0.080112	0.825349	0.825344	0.825338
0.084974	0.084974	0.084964	0.080096	0.080095	0.080105	0.825348	0.825349	0.825343
0.084979	0.084973	0.084963	0.080092	0.080097	0.080105	0.825351	0.825348	0.825342
0.084956	0.084955	0.084949	0.080111	0.080113	0.080117	0.825339	0.825338	0.825335
0.084950	0.084948	0.084945	0.080117	0.080119	0.080122	0.825335	0.825334	0.825332
0.085078	0.085056	0.085021	0.080003	0.080023	0.080054	0.825405	0.825393	0.825374
0.085004	0.084993	0.084972	0.080069	0.080079	0.080097	0.825365	0.825359	0.825347
0.084971	0.084966	0.084952	0.080098	0.080103	0.080116	0.825347	0.825344	0.825336
0.103809	0.085965	0.084955	0.061262	0.080104	0.080113	0.825357	0.830343	0.825338
0.084953	0.084954	0.086747	0.080114	0.080114	0.080119	0.825337	0.825337	0.834334
0.103819	0.084981	0.084965	0.061254	0.080090	0.080104	0.825364	0.825352	0.825344
0.103805	0.084998	0.084991	0.061266	0.080074	0.080080	0.825354	0.825361	0.825358
0.103813	0.084984	0.084972	0.061259	0.080087	0.080098	0.825360	0.825354	0.825347
0.103827	0.084958	0.084962	0.061247	0.080109	0.080107	0.825369	0.825340	0.825342
0.103835	0.085001	0.084980	0.061240	0.080072	0.080090	0.825375	0.825363	0.825352
0.103828	0.084972	0.084972	0.061246	0.070098	0.080097	0.825370	0.775347	0.825347
0.103831	0.084957	0.084953	0.061244	0.080111	0.080115	0.825372	0.825339	0.825336
0.103823	0.084972	0.084957	0.061250	0.080098	0.080111	0.825367	0.825347	0.825339
0.109950	0.084978	0.084978	0.055749	0.090093	0.080092	0.828496	0.875350	0.825350

Table A2. *Cont.*

The Current State of the City's Economy			City Economic Power			General Economic Strength		
2009	2012	2015	2009	2012	2015	2009	2012	2015
0.103826	0.084980	0.084969	0.061247	0.080090	0.080100	0.825369	0.825352	0.825345
0.103807	0.085015	0.085003	0.061264	0.080060	0.080070	0.825356	0.825371	0.825365
0.103789	0.085069	0.085058	0.061279	0.080011	0.080021	0.825343	0.825400	0.825394
0.103825	0.084961	0.084955	0.061249	0.080107	0.080113	0.825368	0.825341	0.825338
0.103815	0.085018	0.085002	0.061257	0.080057	0.080071	0.825361	0.825372	0.825364
0.091552	0.090787	0.090295	0.050867	0.051746	0.052269	0.712095	0.712665	0.712820
0.090591	0.090168	0.089955	0.051958	0.052398	0.052609	0.712745	0.712830	0.712820
	0.090094	0.089885		0.052471	0.052676		0.712825	0.712805
0.090098	0.089899	0.089848	0.052467	0.052663	0.052712	0.712825	0.712810	0.712800
0.091365	0.090684	0.090384	0.051089	0.051858	0.052176	0.712270	0.712710	0.712800
	0.090746	0.090439		0.051792	0.052119		0.712690	0.712790
0.091673	0.090633	0.090302	0.050721	0.051914	0.052261	0.711970	0.712735	0.712815
0.090892	0.090379	0.090214	0.051631	0.052181	0.052350	0.712615	0.712800	0.712820
0.091928	0.091082	0.090709	0.050405	0.051417	0.051832	0.711665	0.712495	0.712705
0.090198	0.089933	0.089901	0.052367	0.052630	0.052611	0.712825	0.712815	0.712560
0.090097	0.089862	0.089715	0.052468	0.052698	0.052838	0.712825	0.712800	0.712765
0.089925	0.089736	0.089740	0.052638	0.052819	0.052815	0.712815	0.712775	0.712775
0.090263	0.089970	0.089800	0.052301	0.052593	0.052758	0.712820	0.712815	0.712790
0.090139	0.089906	0.089826	0.052426	0.052656	0.052733	0.712825	0.712810	0.712795
0.091581	0.091001	0.090727	0.050832	0.051509	0.051812	0.712065	0.712550	0.712695
0.091120	0.090584	0.090505	0.051374	0.051966	0.052050	0.712470	0.712750	0.712775
0.091575	0.090622	0.090301	0.050839	0.051925	0.052263	0.712070	0.712735	0.712820

Note: City name has been removed.

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