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The modeling and analysis for coupled system of regional economy and environment — Based on multi - objective grey analytic hierarchy process (AHP)

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ABSTRACT

The comprehensive index of environmental and economic development is calculated through applying multi-objective grey analytic hierarchy process (AHP), the coordination degree of influencing factors in the system of economy and environment is explored, as well as the coupling model of regional economy and environment system is established based on Mode Coupling Theory, then the coordination degree of influencing factors in environmental carrying capacity has been performed with quantitative analysis through taking Xi'an as an example.

KEYWORDS

Environmental carrying capacity; Regional economy; Coupling; Coordination; Gray - analytic hierarchy process.

INTRODUCTION

The relationship among population, resources, environment and economic development has appeared a series of sharp contradictions, which has constituted a serious threat to human survival and social development. Nobel prize-winning economist Arrow and other international well-known economists and ecologists had published the paper of 'economic growth, carrying capacity and the environment' in 1995[1], which has caused great attention of related problems about environmental carrying capacity from academics and politicians. The essence of environmental carrying capacity refers to that environment is an open system which could communicate with external material, energy and information, the parameter controlled by external factors would make the system transform from random state into macro order within a certain threshold through the coordinating role of each subsystem in internal system, namely the self-organization role of system[2]. Environment system can not only provide material support for the development of regional economy, it is the restriction factor of regional economic development at the same time as well. Environmental bearing capacity has built the link bridge between the environment and human activities, thus makes the coordination of environment and social economy have macro criterion. The consumption of resources and environmental damages in the economic development can not exceed the environment carrying capacity[3]. This paper studies the coupling relationship among regional economy - environment and the coupling theory, explores the supportive ability of resources environment to regional economy, and provides a reference for regional development planning through using multi - objective grey analytic hierarchy process (AHP) and mode coupling theory.

THE INTERACTION MECHANISM AMONG INFLUENCING FACTORS OF ECONOMY - ENVIRONMENT SYSTEM UNDER THE PERSPECTIVE OF MODE COUPLING THEORY

As the physics concept, "coupling" originally refers to the phenomenon that two (or more) systems or forms of motion influence each other through various mutual actions. The coupling degree is to describe the extent of mutual influence among systems or elements[4]. Look from the perspective of synergetics, coupling effect and its coordination degree determines that which sequence and structure the system would enter when the system is up to the critical areas, which determines that the trend of the system would transform from disorder to orderly state. System synergy between internal order parameter is the key to making system transform from disorder to orderly mechanism, it drives the characteristics and law of phase transition in system. The coupling degree is the measurement of reflecting such synergy effect. Thus, we can define the produced degree of two factors influencing the regional economic development and natural environment state of environmental carrying capacity through their respective coupling elements as the coupling degree of regional economy - natural environment. Its size reflects the coordination degree of regional society - economy - environment system[5]. Environmental bearing capacity can be made of a series of mutual restriction and corresponding variables and constraints. The rapid development of the population growth, urbanization and the expansion of the economy will consume a large amount of resources and cause damage to the natural environment, thus increases the pressure of ecological environment; The development of economy also can alleviate the pressure of ecological environment, for example, more environmental protection investment and strict intervention policies, as well as more advanced clean production technology can make the total emission of pollutants under control and reduce the adverse impact of the economic development on ecological environment. The threatening mechanism of regional economy to environment is performed under the interaction of such positive and negative power[6] (Figure 1).

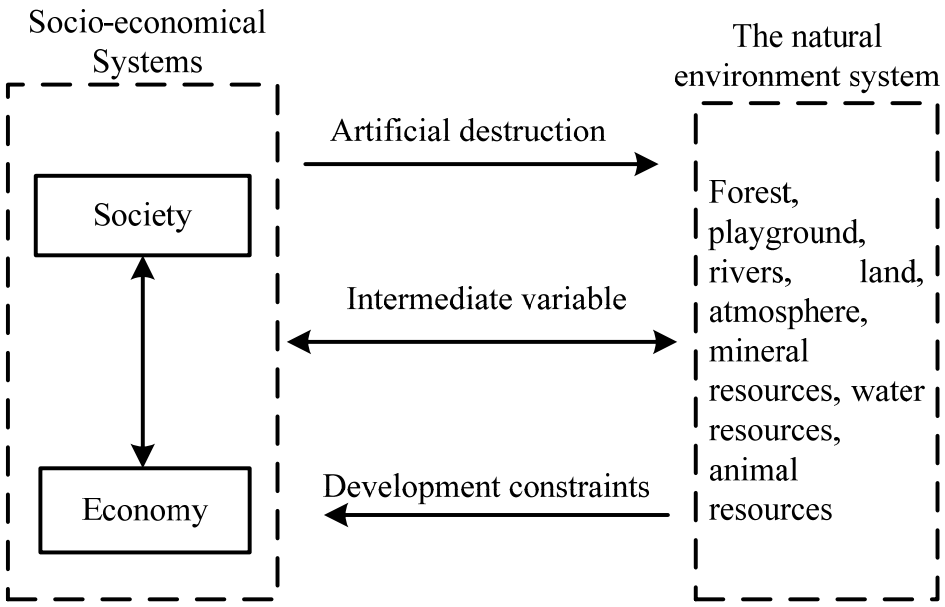

Figure 1 : The coupling relationship of economy-environment system

THE COUPLING DEGREE MODEL OF INFLUENCING FACTORS IN ENVIRONMENTAL CARRYING CAPACITY

Effect function

Make the optimal index set at the bottom

The improved grey multi-level theory is applied to solve the comprehensive development index of each sub-system[7]. The sub-system of regional economy and ecological environment is divided into three levels respectively, the top level (comprehensive development index of regional economy and the index of ecological environment bearing capacity), middle level (assessment indicator of the first grade is $F^{(i)}$, i = 1, 2,.., m) and the bottom level (corresponding with the evaluation indicator of the first level $F^{(i)}$, i = 1,2,...,m, the evaluation indicator of the second grade is F_{ij},= 1, 2,..., ni). X (s) represents the comprehensive index of the s th evaluated sub-system.

Let $d_{js}^{(i)}$ be the s th contestant project corresponding with the original numerical value of the j (j = 1, 2,..., ni) th indicator in assessment projects of the second grade of $F^{(i)}$ in system, the original data is denoted as $D^{(i)}=\left(d_{js}^{\ i}\right)_{ni\times q}$ with Marti; in order to eliminate the difference of dimension, standardization processing is performed to matrix $D^{(i)}$, thus matrix $C^{(i)}=\left(c_{js}^{\ i}\right)_{ni\times q}$ is obtained. Let $c_j^{(i)}$ be the optimal value of the j th indicator in q contestant project (high excellent indicator takes the maximum value, low excellent indicator takes the minimum value), thus $C_{max}^{(i)}=\left[c_1^{(i)}, c_2^{(i)}, \ldots, c_{ni}^{(i)}\right]$ is the optimal indicator set in this system.

Determine the Evaluation Matrix.

The $C_{max}^{(i)}=\left[c_1^{(i)}, c_2^{(i)}, \ldots, c_{ni}^{(i)}\right]^T$ is taken as the row of reference data, $C^{(i)}{}_s=\left[c_{1s}^{(i)}, c_{2s}^{(i)}, \ldots, c_{nis}^{(i)}\right]^T$ is taken as the comparable row of number, the correlation coefficient $\xi_{js}^{(i)}$ (i = 1, 2,..., m; j = 1, 2,..., ni; s = 1, 2,..., q) between the j th indicator in the s th project and the optimal indicator of the j th indicator is solved respectively through applying the type

$$\xi_{js}=\frac{\min\limits_{k}\left|c_k^{(i)}-c_{ks}^{(i)}\right|+\rho\max\limits_{k}\left|c_k^{(i)}+c_{ks}^{(i)}\right|}{\left|c_j^{(i)}-c_{js}^{(i)}\right|+\rho\max\limits_{k}\left|c_k^{(i)}-c_{ks}^{(i)}\right|}$$, thus the determination matrix $A^{(i)}=\left(\xi_{js}^{(i)}\right)_{n_i\times q}$ is obtained, the distinguishing co-efficient $\rho\in(0,1)$ in the type is generally taken the value of 0.5 or being less than 0.5.

Determine the Weight of Evaluation Indicator at the Bottom[8,9]

The determination of evaluation indicator weight at the bottom is implemented with the concept of hierarchical structure in this paper, the complex multi-index problem will be decomposed step by step from the top to the lower level which is then evaluated by relevant experts, thus the weight value of evaluation index is obtained, the value is the priority degree of the received programmer. This method is mainly of pairwise comparison by experts focusing on its importance. If the decisions' status has n evaluation index, then the decision maker should perform pairwise comparison for $C(n,2)=\frac{n-1}{2}$ times, then the relative importance after these pairwise comparison allows the existing of inconsistency to a certain extent, which is totally divided into 3 steps.

The first step, paired comparison matrix will be constructed.

The elements of a level take certain elements in its higher level as evaluation basis, and the pairwise comparison among elements would be performed. If there are N elements, then the pairwise comparison would be performed for $\frac{n(n-1)}{2}$ times. The value used in pairwise comparison is $\frac{1}{9},\frac{1}{8},\ldots,1,2,\ldots9$ respectively, and the measurement of the comparison results among n elements will be put into the top triangle part of paired comparison matrix A, while the numerical value's reciprocal of relative position in the lower triangle part, that is $a_{ij}=\frac{1}{a_{ij}}$, the ratio of its elements is formed into comparison matrix, as it is shown in the following:

$$A=\lfloor a_{ij}\rfloor=\begin{bmatrix}a_{11}&a_{12}&\ldots&a_{1n}\\a_{21}&a_{22}&\ldots&a_{2n}\\\ldots&\ldots&\ldots&\ldots\\a_{n1}&a_{n2}&\ldots&a_{nn}\end{bmatrix}=\begin{bmatrix}1&a_{12}&\ldots&a_{1n}\\1/a_{12}&1&\ldots&a_{2n}\\\ldots&\ldots&\ldots&\ldots\\1/a_{n1}&1/a_{n2}&\ldots&1\end{bmatrix}$$

In the type: $a_{ij}=\frac{w_i}{w_j}$, $W=[w_1,w_2,\ldots,w_n]^T$, w_i is the criteria weights, i = 1, 2,..., n.

It can thus be seen that paired comparison matrix A is the positive reciprocal matrix, namely the elements in the matrix is not only the positive number, but also has reciprocal specialty.

$$\sum_{j=1}^{n}a_{ij}\left(\frac{w_j}{w_i}\right)=n,i=1,2,\ldots,n\qquad or\sum_{j=1}^{n}a_{ij}w_j=nw_i,i=1,2,\ldots,n$$

The second step, the criteria weight vector W will be solved.

As a_{ij} is the appraise through comparison given by subjective judgment when performing pairwise comparison among decision makers, and it has some gap with the real value of $\frac{w_i}{w_j}$ to a certain extent, thus AW = nW is unreasonable, so when A is the consistency matrix, it will be replaced with the

biggest characteristic value λ_{max} in matrix A, thus criteria weight vector W could be solved by the type $(A-\lambda_{max})w=0$.

The third step, the consistency check of weight W_i is performed.

If the paired comparison matrix A is positive reciprocal matrix, then the decision maker is required to achieve the throughout consistency in pairwise comparison, while it is relatively difficult, so it needs consistency check, in order to check the rationality degree of decision makers' determination, the consistency of weight W_i is inspected with coincidence indicator (C.I) and consistency ratio(C.R). When C.I $\leq$ 0.1, C.R $\leq$ 0.1, its consistence could only be guaranteed.

Make Comprehensive Evaluation to Interlayer

When the interlayer is needed to be comprehensively evaluated, each secondary evaluation results among them is $R^{(i)}=(W^{(i)})^T A^{(i)}, i=1,2,...,m$. The matrix $R=[R^{(1)},R^{(2)},...,R^{(m)}]^T$ is composed of evaluation results $R^{(1)},R^{(2)},...,R^{(m)}$ at sheer level, then its corresponding set of optimal indicator is to be found out, which will be transformed into evaluation matrix A through applying the method in 2. 1. 2 finally. Weight coefficient $w_i(i=0,1,...,m)$ of interlayer indicators is calculated through applying the method described in 2.1.3. Then the comprehensive development index in sub-system will be solved to be $X_k=WA=x_k$. In the type, variable $x_k(k=1,2)$ is the number of comprehensive development index in each sub-system.

Construct Efficacy Function Model[10]

Let variable $X_i(i=1,2,..,n)$ be the order parameter of the regional economy and environment system, its value is $x_i(i=1,2,...,n)$. α_i,β_i is the upper and lower limit of order parameter at critical point of system stability respectively. Thus the efficacy of regional economy — ecological environment system on orderly system could be denoted as

$$u_i=\begin{cases}(X_i-\beta_i)/(\alpha_i-\beta_i) & u_i \quad \textbf{positive effect}\\ (\beta_i-X_i)/(\beta_i-\alpha_i) & u_i \quad \textbf{negative effect}\end{cases} \tag{1}$$

The efficacy coefficient constructed according to (1) has following characteristics: u_i reflects the satisfaction degree that each indicator achieves objective, that u_i approaches to 0 indicates it is most unsatisfied, that u_i approaches to 1 indicates it is most satisfied. Thus, $0\leq u_i\leq 1$. The upper and lower limit of order parameter refers to the construction standard of ecological city and sustainable development respectively, specific values could refer to the planning period value, comparing standard value or ideal value in each region.

The coupling function

Take the concept of capacitive coupling and the model of capacity coupling coefficient in physics, the coupling model of interaction among multiple systems (or elements) could be derived, that is

$$C_n=\left\{\frac{[(U_A(u_1).U_A(u_2)...U_A(u_n))]}{\Pi(U_A(u_i)+U_A(u_i))}\right\}^{1/n} \tag{2}$$

Thus the coupling function of regional economic development level and natural environment could be directly obtained, which could be denoted as

$$C=\left\{\frac{[(U_A(u_1).U_A(u_2))]}{\Pi[(U_A(u_1)+U_A(u_2))(U_A(u_1)+U_2A(u_2))]}\right\}^{1/2} \tag{3}$$

The boundary of coupling value is between 0 and 1. When C = 1, the coupling degree is the biggest, the benign resonance coupling system achieved among systems or in internal system will tend to new ordered structure; when C = 0, the coupling degree is the minimum, the elements among systems or in internal system is in independent state, and the system will develop towards disorder state.

When $0 < C \leq 0.3$, the regional economic development and environmental carrying capacity is in lower level of coupling phase, the current development of regional economy is still in lower level, if the ecological environmental carrying capacity is strong, the damage of economic development to environment would not be serious, ecological environment could completely bear and digest the consequence caused by economic development; when $0.3 < C \leq 0.5$, the development of regional economy and environmental bearing capacity would be in antagonism period, then the regional economy will enter into the rapid development period, and its development needs to be supported by a lot of money, resources and population transferring, thus the load capacity of ecological environment would decline, and could not digest and absorb the influence caused by economic development; when $0.5 < C \leq 0.8$, the development of regional economy and ecological environment would enter running - in stage, as the economic development is restricted by the ecological environmental damage at earlier stage, its considerable amount of development funds have been invested into restoring ecological environment, economic development and ecological environment has begun the benign coupling; when $0.8 < C \leq 1$, the level of regional economic development would not only get great progress in terms of quantity, the construction of regional economy and ecological environment would bring out the best in each other as well, and they would step into the high level of coupling phase[11].

CASE STUDY

The construction of comprehensive development index in economy — environment system of Xi'an city

This paper takes the economic and environmental development of Xi'an city from 1995 to 2004 as studying objects, the data comes from 'Xi'an Evening News', the selected indicators strictly follows the criteria of development evaluation index system based on system's function and efficiency (rate), the assessment indicator system of 'economy — environment' developmental level is shown as TABLE 1.

TABLE 1 : Economy-environment system developing synthesized index of Xi'an city

Comprehensive economic development index	economic capability	per capita GNP
		Per capita total retail sales of social commodities
	economic benefit	Local finance income per capita
		social labor productivity
		profit-tax rate of capital
	economic structure	The proportion of the tertiary industry's output value in GDP
		The proportion of the tertiary industry output value in whole labor
Environmental Comprehensive development index	Atmospheric environment variable	SO2 emission
		Inhalable particles concentration
	Water environment variable	processing rate of scrap
		COD emissions
		treatment rate of industrial sewage
		quantity of wastewater effluent
		Soil and water losses
	Ecological hypotheses	forest coverage rate
		coverage rate of city green
	Inhalable association of economy and environment variables	The proportion of environmental protection investment in gross national product (GNP)

The determination of order parameter and coupling degree in sub-system of economy and environment

According to the algorithm steps proposed in 2. 1, the order parameter of economic subsystem and environment subsystem from 1995 to 2004 of Xi'an is calculated, where the upper and lower limit of order parameter refers to the value in planning period of 1990 and 2010 respectively, Then according to the coupling model in 2. 2, the coupling degree of economic subsystem and environment subsystem from1995 to 2004 of Xi'an city is obtained. The specific calculation results are shown in TABLE 2.

TABLE 2 : Simulation of the coupling for economy-environment system of Xi'an city

Year	Comprehensive economic index	Comprehensive environmental index	The order parameter of economy	The order parameter of environment	The coupling degree of system
1995	0.115	0.046	0.021	0.033	
1996	0.153	0.284	0.076	0.338	0.488
1997	0.179	0.130	0.113	0.141	0.386
1998	0.190	0.319	0.129	0383	0.496
1999	0.221	0.351	0.172	0.424	0.453
2000	0.272	0.421	0.245	0.514	0.468
2001	0.313	0.541	0.304	0.668	0.463
2002	0.347	0.640	0.353	0.795	0.461
2003	0.406	0.557	0.437	0.688	0.487
2004	0.467	0.511	0.524	0.630	0.498

The analysis of computing result

Looked from the results obtained from index evaluation system, we could find that Xi 'an economy system has developed very rapidly, its economy grows steadily and rises straightly with upward trend, while the status of the environmental system is unstable, representing the rising trend of broken line, relevant government (Figure 2, 3).

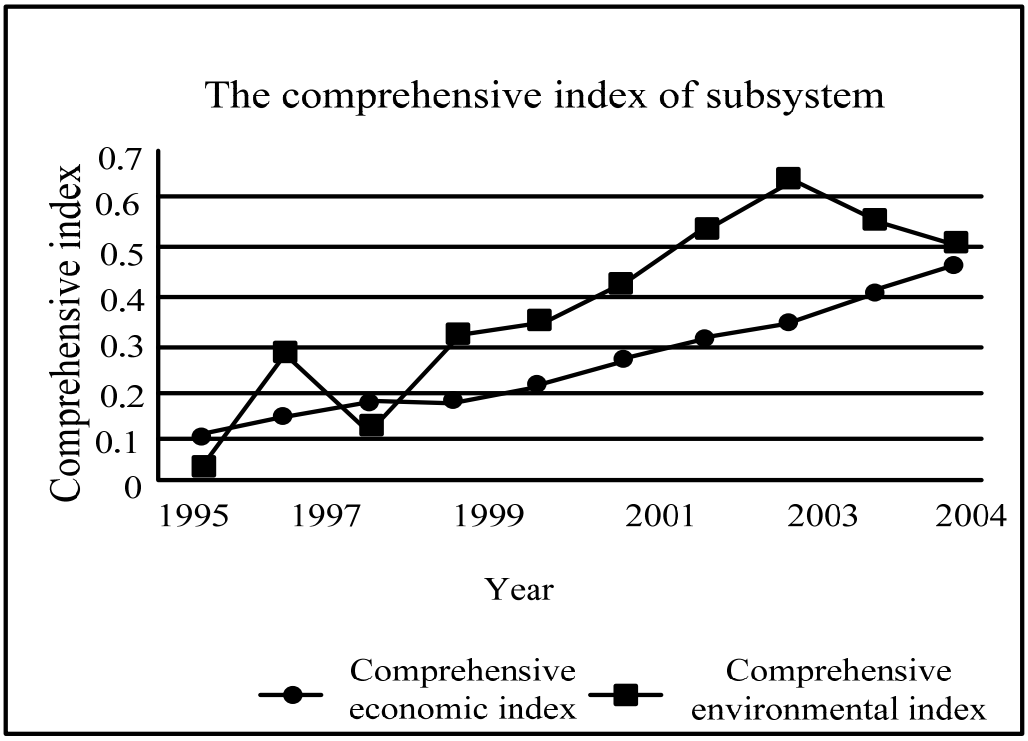

Figure 2 : Synthesis index of subsystems

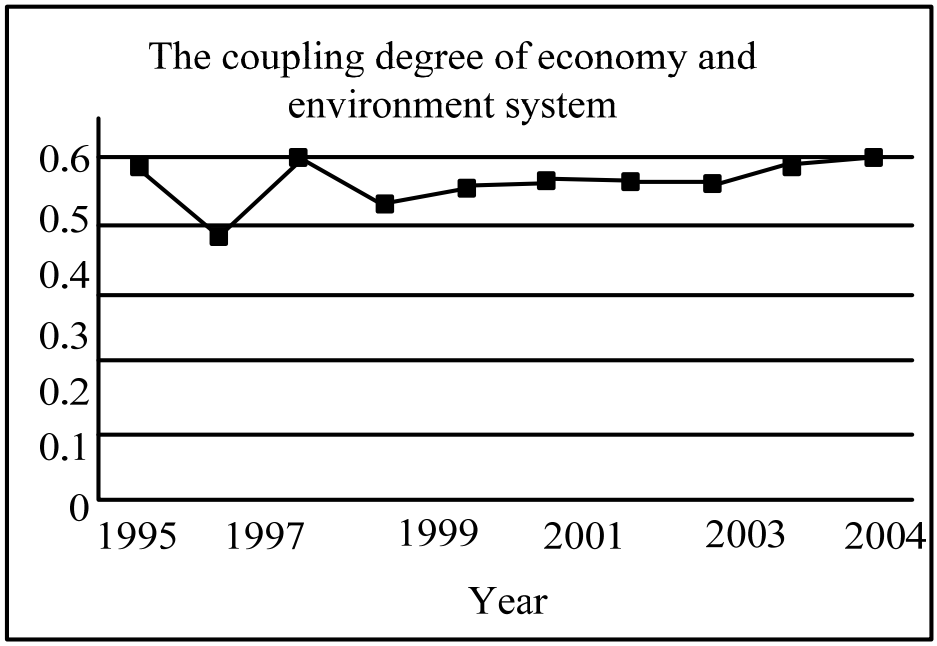

Figure 3 : Coupling factor of economy-environment system

The coupling degree of economy- environment system in Xi'an city basically represents a upward trend since 1998, which demonstrates that the economic development and environmental protection of Xi'an city is developing toward relatively coordinating direction, while its numerical value of coupling degree is still lower than 0.5, which indicates that the development of Xi'an's economy and environment is in the period of antagonism, the rapid development of economy makes the environment pressure increase gradually, and the environment of Xi 'an city's development still has a lot of increasing space.

CONCLUSION

Through modeling and case study, we could draw following 3 points of view.

1) There exists interaction coupling relationship between regional economy and environment, as two sub-systems, the interaction between them has four stages including low level of coupling, antagonism, running - in, high level of coupling; and they are in interaction with each other, coordinating the development of their relationship well is the basis of developing a benign and large economy - environment system.

2) The coupling degree of economic development and ecological environment could represent the strength degree of synergistic effect among order parameters in the interacting process between regional economy and ecological environment, and it reflects the system's developing trend of transforming from disorder to orderly state. The development of economic system can cause the deterioration of ecological environment, and when the economic develops to a certain extent, it will promote the environmental protection. The coupling degree model in this developing process is composed of efficacy function, coupling function and coupling index system respectively. Among them, the upper and lower limit of order parameter in effect function, as well as the construction of coupling index system is the key of whether the model could be applied right.

3) The coupling status quo of economic and environmental system in Xi'an from 1995 to 2004 is analyzed through applying coupling degree model. Since 1998, the coupling degree between economic subsystem and environment subsystem represents the gradually increasing trend, but it is in the period of antagonism, in other words, namely the rapid development of economy has caused serious influence to the environment. If we only pay attention to the economic development and ignore environmental protection, then the large economy - environment system would be in the danger of imbalance on a

whole. This shows that the coordinated degree between economic development and ecological environment of Xi'an city remains to be further improved.

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