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Research on the data pattern construction and model analysis method for evaluating the regional ecological economic efficiency

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ABSTRACT

In this paper, we investigate the data pattern construction and model analysis method for evaluating the regional ecological economic efficiency with uncertain linguistic variables. We utilize the uncertain linguistic choquet integral (ULCI) operator to aggregate the uncertain linguistic variables corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one (s). Finally, an illustrative example is given.

KEYWORDS

Economic efficiency;
Uncertain linguistic variables;
Uncertain linguistic choquet integral (ULCI) operator;
Data pattern construction;
Model analysis.

INTRODUCTION

Because the scale of human beings' economic activities becomes larger and larger, people need more and more natural resources. Furthermore, we also make negative influence on earth environment. According to that population is one of important motivations of economic development; China has to envisage more pressure from ecological system because of its biggest population of the world. On the one hand, Chinese government must find ways to satisfy people's existence and higher material needs. On the other hand, the government has to take polices to keep the balance of ecology with limit resources and developing space. In recent years, Chinese central government has been concentrate on harmonizing development between economy and ecology system, and also made a series of polices to resolve the conflicts between two systems which appeared in many areas all over the country. When talked about regional problems on the base of regional economics, we always consider that areas belong to medium economics in the national economic system. As the result, region takes an important role in establishing and executing policies and resolving different economic problems. But when regional government and private make choice on the views of short-term economic benefits, they may only carry out some parts of national eco-policies that leads to policies' efficiency lost. The efficiency lost is caused by short-term economic view of regional governments on the one hand and on the other hand, it may also be caused by different regional conditions which do not apply to national policies. Therefore, regional governments should choose suitable methods to carry out eco-policies that cater for district's characteristics, namely regional ecological economic policy. Furthermore, the region will increase

the possibility that taking the balance of ecology and developing economy at same time, as we called "ecological economy"[6-11].

The problem of data pattern construction and model analysis method for evaluating the regional ecological economic efficiency with uncertain linguistic variables is the multiple attribute decision making problems. The aim of this paper is to investigate the data pattern construction and model analysis method for evaluating the regional ecological economic efficiency with uncertain linguistic variables. Then, we utilize the uncertain linguistic choquet integral (ULCI) operator to aggregate the uncertain linguistic variables corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one (s). The remainder of this paper is set out as follows. In the next section, we introduce some basic concepts related to uncertain linguistic variables. In Section 3 we introduce the data pattern construction and model analysis method for evaluating the regional ecological economic efficiency with uncertain linguistic variables. Then, we utilize the uncertain linguistic choquet integral (ULCI) operator to aggregate the uncertain linguistic corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one (s) by using the formula of the degree of possibility for the comparison between two uncertain linguistic variables. In Section 4, an illustrative example for evaluating the regional ecological economic efficiency with uncertain linguistic variables is pointed out. In Section 5 we conclude the paper and give some remarks.

PRELIMINARIES

Let $S = \{s_i \mid i = 1, \cdots, t\}$ be a linguistic term set with odd cardinality. Any label, s_i represents a possible value for a linguistic variable, and it should satisfy the following characteristics[12-13]:

(1) The set is ordered: $s_i > s_j$, if $i > j$;

(2) There is the reciprocal operator: $neg(s_i) = s_j$ such that $i + j = t + 1$;

Max operator: $\max(s_i, s_j) = s_i$ if $s_i \geq s_j$;

Min operator: $\min(s_i, s_j) = s_i$ if $s_i \leq s_j$.

For example, S can be defined as

$S = \{s_1 = extremely\ poor, s_2 = very\ poor, s_3 = poor, s_4 = medium, s_5 = good, s_6 = very\ good, s_7 = extremely\ good\}$

However, the above aggregation operators with triangular fuzzy linguistic variable is based on the assumption that the attribute of decision makers are independent, which is characterized by an independence axiom[14-15], that is, these operators are based on the implicit assumption that attributes of decision makers are independent of one another; their effects are viewed as additive. For real decision making problems, there is always some degree of inter-dependent characteristics between attributes. Usually, there is interaction among attributes of decision makers. However, this assumption is too strong to match decision behaviors in the real world. The independence axiom generally can't be satisfied. Thus, it is necessary to consider this issue.

Let $\mu(x_i)(i = 1, 2, \cdots, n)$ be the weight of the elements $x_i \in X\ (i = 1, 2, \cdots, n)$, where μ is a fuzzy measure, defined as follows:

Definition 1[16]. A fuzzy measure μ on the set X is a set function $\mu : \theta(x) \to [0,1]$ satisfying the following axioms:

(1) $\mu(\phi) = 0$, $\mu(X) = 1$;

(2) $A \subseteq B$ implies $\mu(A) \leq \mu(B)$, for all $A, B \subseteq X$;

(3) $\mu(A \cup B) = \mu(A) + \mu(B) + \rho\mu(A)\mu(B)$, for all $A, B \subseteq X$ and $A \cap B = \phi$, where $\rho \in (-1, \infty)$.

Especially, if $\rho = 0$, then the condition (3) reduces to the axiom of additive measure:

$\mu(A \cup B) = \mu(A) + \mu(B)$, for all $A, B \subseteq X$ and $A \cap B = \phi$.

If all the elements in are independent, and we have

$\mu(A) = \sum_{x_i \in A} \mu(\{x_i\})$, for all $A \subseteq X$.

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Definition 2[17]. Let f be a positive real-valued function on X, and μ be a fuzzy measure on X. The discrete Choquet integral of f with respective to μ is defined by

$$C_\mu(f)=\sum_{i=1}^{n} f_{\sigma(i)}\left[\mu\left(A_{\sigma(i)}\right)-\mu\left(A_{\sigma(i-1)}\right)\right] \quad (1)$$

where $(\sigma(1),\sigma(2),\cdots,\sigma(n))$ is a permutation of $(1,2,\cdots,n)$, such that $f_{\sigma(i-1)}\geq f_{\sigma(i)}$ for all $j=2,\cdots,n$, $A_{\sigma(k)}=\left\{x_{\sigma(j)}\,|\,j\leq k\right\}$, for $k\geq 1$, and $A_{\sigma(0)}=\phi$.

It is seen that the discrete Choquet integral is a linear expression up to a reordering of the elements.

Definition 3 Let LOWA: $\bar{S}^n\to\bar{S}$,if

$$LOWA_w\left(s_{\alpha_1},s_{\alpha_2},\cdots,s_{\alpha_n}\right)=\left(w_1\otimes s_{\beta_1}\right)\oplus\left(w_2\otimes s_{\beta_2}\right)\oplus\cdots\oplus\left(w_n\otimes s_{\beta_n}\right)=s_{\tilde{\beta}} \quad (2)$$

where $\tilde{\beta}=\sum_{i=1}^{n} w_i\beta_i$, $w=(w_1,w_2,\cdots,w_n)^T$ is the associated weighting vector with $w_i\in[0,1]$, $\sum_{i=1}^{n} w_i=1$.

Based on Definition 2, In what follows, we shall develop the ordered weighted continuous linguistic choquet ordered averaging (OWCLCOA) operator based on the well-known Choquet integral[18].

Definition 4. Let $\left[s_{a_i},s_{b_i}\right](i=1,2,\cdots,n)$ be the uncertain linguistic terms sets on X, and μ be a fuzzy measure on X, then we call

$$\begin{aligned}&\mathrm{OWCLCOA}_\mu\left(\left[s_{a_1},s_{b_1}\right],\left[s_{a_2},s_{b_2}\right],\cdots,\left[s_{a_n},s_{b_n}\right]\right)\\&=\bigoplus_{j=1}^{n}\left(\left(\mu\left(A_{\sigma(j)}\right)-\mu\left(A_{\sigma(j-1)}\right)\right)\otimes f_\rho\left(\left[s_{a_{\sigma(j)}},s_{b_{\sigma(j)}}\right]\right)\right)\end{aligned} \quad (3)$$

the ordered weighted continuous linguistic choquet ordered averaging (OWCLCOA) operator, where $(\sigma(1),\sigma(2),\cdots,\sigma(n))$ is a permutation of $(1,2,\cdots,n)$, such that $f_\rho\left(\left[s_{a_{\sigma(j-1)}},s_{b_{\sigma(j-1)}}\right]\right)\geq f_\rho\left(\left[s_{a_{\sigma(j)}},s_{b_{\sigma(j)}}\right]\right)$ for all $j=2,\cdots,n$ $f_\rho\left(\left[s_{a_{\sigma(j)}},s_{b_{\sigma(j)}}\right]\right)(j=1,2,\cdots,n)$ is calculated by Eq. (3) or (4), $A_{\sigma(k)}=\left\{x_{\sigma(j)}\,|\,j\leq k\right\}$, for $k\geq 1$, and $A_{\sigma(0)}=\phi$.

Especially, if $\mu\left(\left\{x_{\sigma(j)}\right\}\right)=\mu\left(A_{\sigma(j)}\right)-\mu\left(A_{\sigma(j-1)}\right)$, $j=1,2,\cdots,n$, then OWCLCOA operator reduce to WCLWA operator. If $\mu(A)=\sum_{x_j\in A}\mu\left(\left\{x_j\right\}\right)$, for all $A\subseteq X$, where $|A|$ is the number of the elements in the set A, then $w_j=\mu\left(A_{\sigma(j)}\right)-\mu\left(A_{\sigma(j-1)}\right)$, $i=1,2,\cdots,n$, where $w=(w_1,w_2,\cdots,w_n)^T$, $w_j\geq 0$, $j=1,2,\cdots,n$, and $\sum_{j=1}^{n} w_j=1$, then, OWCLCOA operator reduce to OWCLOWA operator.

It's easy to prove that the OWCLCOA operator has the following properties.

Theorem 1 (Commutativity).

$$\begin{aligned}&\mathrm{OWCLCOA}_\mu\left(\left[s_{a_1},s_{b_1}\right],\left[s_{a_2},s_{b_2}\right],\cdots,\left[s_{a_n},s_{b_n}\right]\right)\\&=\mathrm{OWCLCOA}_\mu\left(\left[s'_{a_1},s'_{b_1}\right],\left[s'_{a_2},s'_{b_2}\right],\cdots,\left[s'_{a_n},s'_{b_n}\right]\right)\end{aligned}$$

where $\left(\left[s'_{a_1},s'_{b_1}\right],\left[s'_{a_2},s'_{b_2}\right],\cdots,\left[s'_{a_n},s'_{b_n}\right]\right)$ is any permutation of $\left(\left[s_{a_1},s_{b_1}\right],\left[s_{a_2},s_{b_2}\right],\cdots,\left[s_{a_n},s_{b_n}\right]\right)$.

Theorem 2. (Idempotency) If $\left[s_{a_j},s_{b_j}\right]=\left[s_a,s_b\right]$ for all j, then

$$\mathrm{OWCLCOA}_\mu\left(\left[s_{a_1},s_{b_1}\right],\left[s_{a_2},s_{b_2}\right],\cdots,\left[s_{a_n},s_{b_n}\right]\right)=\left[s_a,s_b\right]$$

Theorem 3. (Monotonicity) If $\left[s_{a_j},s_{b_j}\right]\leq\left[s'_{a_j},s'_{b_j}\right]$ for all j, then

$$\begin{aligned}&\mathrm{OWCLCOA}_\mu\left(\left[s_{a_1},s_{b_1}\right],\left[s_{a_2},s_{b_2}\right],\cdots,\left[s_{a_n},s_{b_n}\right]\right)\\&\leq\mathrm{OWCLCOA}_\mu\left(\left[s'_{a_1},s'_{b_1}\right],\left[s'_{a_2},s'_{b_2}\right],\cdots,\left[s'_{a_n},s'_{b_n}\right]\right)\end{aligned}$$

RESEARCH ON THE DATA PATTERN CONSTRUCTION AND MODEL ANALYSIS METHOD FOR EVALUATING THE REGIONAL ECOLOGICAL ECONOMIC EFFICIENCY

The following assumptions or notations are used to represent the multiple attribute decision making problems for evaluating the regional ecological economic efficiency with uncertain linguistic variables. Let $A=\{A_1, A_2, \cdots, A_m\}$ be a discrete set of alternatives. Let $G=\{G_1, G_2, \cdots, G_n\}$ be a set of attributes. The information about attribute weights is completely known. Let $\omega=(\omega_1, \omega_2, \cdots, \omega_n)$ be the weight vector of attributes, where $\omega_j \geq 0$, $j=1,2,\cdots,n$. S Suppose that $\tilde{R}=(\tilde{r}_{ij})_{m\times n}$ is decision matrix, where $\tilde{r}_{ij} \in \tilde{S}$ is an uncertain linguistic variable, given by the decision maker for the alternative $A_i \in A$ with respect to the attribute $G_j \in G$.

In the following, we apply the OWCLCOA operator to multiple attribute decision making for evaluating the regional ecological economic efficiency with uncertain linguistic variables.

Step 1. Determine the fuzzy measure of attribute of $G_j\ (j=1,2,\cdots,n)$ and attribute sets of G. There are a few methods for the determination of the fuzzy measure. For example, linear methods, quadratic methods, heuristic-based methods and genetic algorithms and so on are available in the literature.

Step 2.Utilize the OWCLCOA operator

$$z_i(w)=\mathrm{OWCLCOA}_\mu(\tilde{r}_{i1},\tilde{r}_{i2},\cdots,\tilde{r}_{in})$$
$$=\overset{n}{\underset{j=1}{\oplus}}\left(\left(\mu(G_{\sigma(j)})-\mu(G_{\sigma(j-1)})\right)\otimes f_\rho(\tilde{r}_{\sigma(ij)})\right),\ i=1,2,\cdots,m. \quad \textbf{(4)}$$

to derive the overall preference values $z_i(w)(i=1,2,\cdots,m)$ of the alternative A_i.

Step 4. Rank all the alternatives $A_i\ (i=1,2,\cdots,m)$ and select the best one (s) in accordance with the collective overall preference values $z_i(w)(i=1,2,\cdots,m)$.

Step 5. End.

NUMERICAL EXAMPLE

A region is a huge complex system of ecological economics. According to the theories of ecological economics, social economic system is one of subsystems of natural system, that is larger than social economics system, and human society and natural system wholly integrated. With the point of ecological, economic and social integrated, learned about ecological crises human are faced could lead us to deal with the relationship between human and nature. Sustainable development build on the theories of ecological economics have become the main theme of society to develop. Counties, as we know, are ecological economic system with complexity like other social systems. County system is a main basic unit to reconstruct demonstration eco-region in China. The goal of reconstructing demonstration eco-region according to principles of ecological economics is to implement a sustainable development of regional system. What needed to be concerned is the harmonization of the relationships among the social, economic and natural subsystems. Once the requirement meets the ecological environment will be protected and improved. As a result, life quality of peoples in the region will be improved and problem of the relationship between economic development and environmental protection will be solved. How to study the relationship between human society and nature, built indicator system and find method to assessment regions objectively have significant for improving ecological reconstruction and life quality of peoples, protecting environment. There are not enough freshwater for living and production and cropping index (CI) is higher in China. Considering cropping index and freshwater in calculation of ecological footprint, it could reflect the regions more reasonable. This section presents a numerical example to evaluate the regional ecological economic efficiency with uncertain linguistic variables to illustrate the method proposed in this paper. There are five prospect ecological industrial parks $A_i\ (i=1,2,3,4,5)$ for four attributes $G_j\ (j=1,2,3,4)$. The four attributes include circular economy development level (G_1), ecological

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benefits (G_2), management level (G_3) and prospects for development (G_4) respectively. The five possible ecological industrial parks $A_i(i=1,2,\cdots,5)$ are to be evaluated using the linguistic term set by the decision maker under the above four attributes, as listed in the following matrix.

$$\tilde{R}=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array}\begin{array}{c} \begin{array}{cccc} G_1 & G_2 & G_3 & G_4 \end{array} \\ \begin{pmatrix} [s_2,s_3] & [s_3,s_4] & [s_2,s_3] & [s_0,s_1] \\ [s_3,s_4] & [s_2,s_3] & [s_1,s_3] & [s_{-2},s_1] \\ [s_1,s_2] & [s_0,s_1] & [s_{-3},s_{-2}] & [s_2,s_3] \\ [s_{-1},s_1] & [s_{-2},s_{-1}] & [s_{-2},s_0] & [s_3,s_4] \\ [s_{-2},s_0] & [s_1,s_2] & [s_2,s_3] & [s_1,s_2] \end{pmatrix} \end{array}$$

In the following, we apply the OWCLCOA operator to multiple attribute decision making for evaluating the regional ecological economic efficiency with uncertain linguistic variables. Then, we utilize the uncertain linguistic approach developed to get the most desirable ecological industrial parks.

Step 1. Suppose the fuzzy measure of attribute of $G_j\,(j=1,2,\cdots,n)$ and attribute sets of G as follows:

$$\mu(G_1)=0.25,\mu(G_2)=0.30,\mu(G_3)=0.35,\mu(G_4)=0.25,\mu(G_1,G_2)=0.75,$$
$$\mu(G_1,G_3)=0.65,\mu(G_1,G_4)=0.60,\mu(G_2,G_3)=0.55,\mu(G_2,G_4)=0.55,$$
$$\mu(G_3,G_4)=0.45,\mu(G_1,G_2,G_3)=0.70,\mu(G_1,G_2,G_4)=0.80,$$
$$\mu(G_1,G_3,G_4)=0.85,\mu(G_2,G_3,G_4)=0.75,\mu(G_1,G_2,G_3,G_4)=1.00$$

Step 2. Utilize the decision information given in matrix $\tilde{R}$, and the OWCLCOA operator, we obtain the overall preference values $z_i(w)$ of the ecological industrial parks $A_i(i=1,2,\cdots,5)$.

$$z_1(w)=s_{1.34},z_2(w)=s_{2.65},z_3(w)=s_{4.21},z_4(w)=s_{0.56},z_5(w)=s_{1.97}$$

Step 4. Rank all the high-tech enterprises $A_i(i=1,2,\cdots,5)$ in accordance with the preference degree $z_i(w)\,(i=1,2,\cdots,5): A_3\succ A_4\succ A_1\succ A_5\succ A_2$, and thus the most desirable ecological industrial park is A_3.

CONCLUSION

Since the reforming and opening, our country has made tremendous strides on the economic development and whole social progress. But, the problems such as environment pollution, ecological damage and resource shortage are becoming the bottleneck of further economic development. At this moment, our country is experiencing the historic transition period about institution transition, style changes and structural adjustment, different regions are facing the unprecedented challenges and opportunities. The development of Circulation Economy is the need of sustainable development, and the Eco-Industrial Chain (EIC) is the effective way to develop Circulation Economy. Both central government and Qingdao municipal government point out in the twelfth "five-year plan" of that we should develop Circulation Economy and Construct EIC with great effort. Under such kind of situation, the research on the constructing of Regional EIC is the important content to develop Circulation Economy and realize the sustainable development. Furthermore, the stability of EIC is the key to the success of Circulation Economy. In this paper, we investigate the data pattern construction and model analysis method for evaluating the regional ecological economic efficiency with uncertain linguistic variables. We utilize the uncertain linguistic choquet integral (ULCI) operator to aggregate the uncertain linguistic variables corresponding to each alternative and get the overall value of the alternatives, then rank the alternatives and select the most desirable one (s). Finally, an illustrative example is given.

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