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Dynamic Evaluation of China's Low-carbon Agriculture Development Level from the Perspective of Fuzzy Incentives and Punishments

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Abstract:

Based on the panel data of 30 provinces in China from 2014 to 2019. Firstly, this paper using the catastrophe progression method established static evaluation for the provincial low-carbon agriculture development level. Secondly, the dynamic evaluation model of regional low-carbon agriculture development level is established based on the perspective of fuzzy incentives and punishments, and empirically analyzed the effect of fuzzy incentives and punishments on the development of low-carbon agriculture in various provinces .The results go as follows: Areas with high static evaluation values of the regional low-carbon agricultural development level are subject to more incentives. The areas with low static evaluations are subject to more punishments .This paper implements fuzzy incentives and punishments and achieves encouragement and punishment in different regions, which provides the certain incentive effect for development of low-carbon agriculture in various provinces, and also compensates for the limitations of clear boundaries of incentive and punishment in actual regional low-carbon economic development.

Keywords: *Catastrophe progression, Fuzzy incentives and punishments, Low-carbon agriculture development level, Dynamic evaluation*.

I. INTRODUCTION

On October 24, 2021, the CPC Central Committee and the State Council issued the opinions on fully and accurately implementing the new development concept and doing a good job in carbon peak and carbon neutralization, pointing out that we should unswervingly follow the high-quality development path of ecological priority and green and low-carbon, and actively promote the green and low-carbon development of counties and rural areas. Low carbon agriculture is a green economic development model spawned under the background of low-carbon economy. It aims to reduce agricultural greenhouse gas emissions. It integrates economic, ecological and social functions by improving carbon sink capacity and reducing carbon sources. It is an environment-friendly agricultural production mode with the characteristics of low energy consumption, low material consumption, low emission and low pollution[1].Developing low-carbon agriculture is not only the only way to alleviate the pressure of rural ecological resources and promote the sustainable development of rural economy, but also an important way

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to release rural ecological dividends and promote rural revitalization.

II. LITERATURE REVIEW

Chinese scholars have made rich research achievements in the theoretical analysis and practical application of low-carbon agricultural economy, especially in the evaluation of regional low-carbon agricultural development level and policy evaluation. Some domestic scholars used various evaluation and analysis tools, such as analytic hierarchy process[2], addition and multiplication hybrid synthesis method[3], trend analysis method[4], linear weighting and comprehensive evaluation model[5], factor analysis method[6] and other methods to evaluate and analyze the agricultural low-carbon development level of a province in China. Some scholars also used some econometric model methods, such as DEA Malmquist model[7], super efficiency SBM model[8] and other research methods to analyze the development level of low-carbon agriculture in China's provinces and regions, and evaluated the implementation effect of low-carbon agricultural policies in different regions. In addition, Other scholars proposed to build a regional distribution model of carbon emission rights, formulate reward and punishment schemes for carbon emission reduction based on the initial balance of carbon emission rights in each province[9], and the government issued policy means of "reward and subsidy" and "regulation"[10], actively develop agricultural carbon market, and make good use of financial means to promote low-carbon agricultural technology[11].

Through literature review, it is found that most of the existing studies are static comprehensive evaluation studies on the development level of low-carbon agriculture in a region, and have done a lot of research and Analysis on the selection of evaluation indicators and evaluation methods, but few use dynamic evaluation methods to dynamically and systematically investigate the differences of provincial low-carbon agriculture development level. The scientific and objective dynamic comprehensive evaluation method can not only reflect the development and changes of the evaluated objects, but also objectively highlight the differences among the evaluated objects[12].In fact, affected by the characteristics of resource and environmental endowment, the level of agricultural economic development, energy utilization structure, agricultural industrial structure and other comprehensive factors, there are some differences in the development level of low-carbon agriculture in various regions. Therefore, based on the ecological compensation theory, this paper evaluates the reward and punishment of provincial low-carbon agriculture by means of fuzzy reward and punishment control line, so as to investigate the dynamic changes of provincial low-carbon agriculture in a continuous period of time, so as to make the evaluation results more reasonable. When rewarding the good and punishing the bad, taking into account the differences of regional resource and environmental endowments and economic and social development, in order to ensure regional food security, we can effectively avoid the negative impact of "one size fits all" by using fuzzy reward and punishment to blur the boundary and implementing flexible management. Therefore, this paper attempts to establish a dynamic evaluation model of the development level of low-carbon agriculture from the perspective of fuzzy reward and punishment, and makes an empirical analysis based on China's provincial panel data from 2014 to 2019, so as to achieve the purpose of accurate and comprehensive evaluation of the development level of regional low-carbon agriculture, in order to provide some reference for scientifically formulating regional low-carbon agriculture development policies and realizing rural

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revitalization.

III.DYNAMIC EVALUATION MODEL

3.1 Static Evaluation Model of Low-carbon Agriculture Development Level based on Catastrophe Progression Method

The development level of regional low-carbon agriculture involves multiple factors and indicators, and there is an interactive relationship between the indicators. The development subsystem of various factors will also change to varying degrees with the change of some indicators, which may be continuous or discontinuous, which is basically consistent with the principle of catastrophe theory. Based on the above analysis, the catastrophe progression method is suitable for the comprehensive evaluation of the development level of provincial low-carbon agriculture in China.When using the catastrophe progression method to calculate the development level of low-carbon agriculture, firstly, construct the evaluation index system (see text 3.1) and decompose the overall research objectives at multiple levels; Secondly, standardize the indicators, including dimensionless indicators and consistency indicators, and calculate the index weight; Then, the normalization formula is derived by combining the bifurcation point set equation in catastrophe theory with fuzzy mathematics, and the normalization formula is used for comprehensive quantitative calculation (see text 3.2); Finally, the ranking analysis of evaluation objectives is carried out for comprehensive evaluation.

3.1.1 Calculation of index weight

In order to reduce the human subjective influence in the evaluation process, this paper uses the entropy weight method to calculate the index weight, which makes the evaluation process more objective. The specific steps are as follows:

The first step is data standardization. Let the evaluated object set $Z=(Z_1,Z_2,Z_3,...,Z_m)$, the evaluation index set $W=(W_1,W_2,W_3,...,W_n)$,and the value of the evaluated object Z_i to the index W_j be recorded as X_{ij} (I = 1,2,3..., m; J = 1,2,3,... n).The decision matrix is constructed as $A=(a_{ij})_{m\times n}$. The normalized matrix $V=(v_{ij})_{m\times n}$ is obtained by dimensionless processing . If the indicator is positive, use the positive indicator formula; When the indicator is negative, the negative indicator formula is used. Of which:

Positive indicators are:

$$v_{ij}=\frac{a_{ij}-\min_{1\le i\le m}(a_{ij})}{\max(_{1\le i\le m}a_{ij})-\min_{1\le i\le m}(a_{ij})}\quad ,i=1,2,3\ldots,m;j=1,2,3,\ldots,n$$

Negative indicators are:

$$v_{ij}=\frac{\max_{1\le i\le m}(a_{ij})-a_{ij}}{\max_{1\le i\le m}(a_{ij})-\min_{1\le i\le m}(a_{ij})}\quad ,i=1,2,3\ldots,m;j=1,2,3,\ldots,n \tag{1}$$

The second step is to calculate the entropy. The calculation formula is as follows:

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$$v'_{ij} = \frac{v_{ij}}{\sum_{i=1}^{m} v_{ij}}$$
$$E_{ij} = -\frac{1}{\ln m}\sum_{i=1}^{m}(v'_{ij}\ln v'_{ij}) \quad (2)$$

The third step is to calculate the weight of each index. The calculation formula is as follows:

$$W_j = \frac{1-E_j}{\sum_{i=1}^{n}(1-E_j)} \quad (3)$$

3.1.2 Construction of catastrophe progression model

The type of catastrophe system is determined by the state variable X of a system f(x) and the coefficients a, b, c and d of the control variable x. If an index can be decomposed into two sub indexes, the system is a cusp catastrophe system corresponding to two control variables; By analogy, the swallowtail mutation system corresponds to three control variables and the butterfly mutation system corresponds to four control variables. BThen the normalization formula is deduced according to the bifurcation point set equation of the catastrophe system. Finally, the total membership function is obtained from the normalization formula for ranking evaluation. The catastrophe model and normalization formula are shown in the Table I below:

TABLE I. Catastrophe model and normalization formula

CATASTROPHE MODEL	CONTROL VARIABLE	POTENTIAL FUNCTION	NORMALIZATION FORMULA	WEIGHT SORTING
CUSP MUTATION	2	$F(X)=X^4+aX^2+bX$	$X_a=\sqrt{a}$, $X_b=\sqrt[3]{b}$	$W_a > W_b$
SWALLOWTAIL CATASTROPHE	3	$F(X)=\frac{1}{5}X^5+\frac{1}{3}aX^3+\frac{1}{2}bX^2+cX$	$X_a=\sqrt{a}, X_b=\sqrt[3]{b}, X_c=\sqrt[4]{c}$	$W_a > W_b > W_c$
BUTTERFLY MUTATION	4	$F(X)=\frac{1}{6}X^6+\frac{1}{4}aX^4+\frac{1}{3}bX^3+\frac{1}{2}cX^2+dX$	$X_a=\sqrt{a}, X_b=\sqrt[3]{b}, X_c=\sqrt[4]{c}, X_d=\sqrt[5]{d}$	$W_a > W_b > W_c > W_d$

According to the theory of multi-objective fuzzy decision-making, the strategies of "complementary principle" and "non complementary principle" are adopted in the decision-making of multi-level evaluation index system. If the indexes of the evaluation object are highly correlated and complementary, the "complementary principle" is adopted, and the state variable x takes the average value of the initial mutation level of each control variable as the static evaluation value of the evaluation object; If the indexes of the evaluation object have weak correlation and are independent of each other, the "non complementary

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principle" is adopted to calculate the initial mutation level value of each control variable according to the method of selecting the minimum value from all numbers to obtain the static evaluation value of the evaluation object.

3.2 Dynamic Evaluation Model of Low-carbon Agriculture Development Level from the Perspective of Fuzzy Reward and Punishment Characteristics

3.2.1 Fuzzy membership degree of regional low-carbon agriculture development level

Let the static evaluation value of the evaluated object Z_i(i=1,2,3,..., m) at time t_k (k=1,2,3,..., t) to be φ_i（t_k）, and the time sequence information matrix of the evaluated object at different times is obtained as follows:

$$(\varphi_{ik})_{m\times T}=\begin{bmatrix}\varphi_1(t_1) & \varphi_1(t_2) & \cdots & \varphi_1(t_T)\\ \varphi_2(t_1) & \varphi_2(t_2) & \cdots & \varphi_2(t_T)\\ \vdots & \vdots & & \vdots\\ \varphi_m(t_1) & \varphi_m(t_2) & \cdots & \varphi_m(t_T)\end{bmatrix} \tag{4}$$

The maximum and minimum values of regional low-carbon agriculture development level within t_k(k = 1,2,3,..., t) can be obtained from the evaluation matrix. If Y_T is set as the set of evaluation values of m evaluated objects in the t-th period, Y_T=$[Y_T^{min}, Y_T^{max}]$(Y_T^{min} is the minimum value of m evaluated objects in the t-th period, Y_T^{max} is the maximum value).Based on the research of some scholars[13,14]on fuzzy membership, for anyY_T, three states of reward, punishment and no reward and punishment can be set to distinguish the evaluation value of the evaluated object.The three fuzzy sets can be expressed asφ_{T1}= "reward", φ_{T2}="no reward and punishment" andφ_{T3} = "punishment".The assumption is "no reward and punishment point", which is the critical value of reward and punishment of decision-makers, that is, the reference value for judging reward or punishment. The membership degrees ofφ_{T1}、φ_{T2} and$\varphi_{T3}$are 0,1,0 respectively.If $y_T \in Y_T$, the membership functions ofφ_{T1}、φ_{T2} and$\varphi_{T3}$are respectively:

$$\varphi_{T1}=\begin{cases}0, & y_T \le \theta_T\\ \dfrac{y_T-\theta_T}{Y_T^{max}-\theta_T}, & y_T > \theta_T\end{cases}$$

$$\varphi_{T2}=\begin{cases}1-\frac{y_T-\theta_T}{Y_T^{max}-\theta_T}, & y_T > \theta_T\\ 1, & y_T = \theta_T\\ 1-\frac{\theta_T-y_T}{\theta_T-Y_T^{min}}, & y_T < \theta_T\end{cases} \tag{5}$$

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$$\varphi_{T3}=\begin{cases}0\quad, & y_T \ge \theta_T\\ \frac{\theta_T-y_T}{\theta_T-Y_T^{min}}\quad, & y_T < \theta_T\end{cases}$$

3.2.2 Low carbon agricultural development level fuzzy reward and punishment line

Based on the research of other scholars[12-14], this paper sets the membership degree F（Y_T）=（s_1,s_2,s_3） to represent the membership degree of the evaluation value φ_i（t_k） of the evaluated object to the three fuzzy sets, where S_1, S_2 and S_3 respectively representφ_{T1}（Y_T）、φ_{T2}（Y_T） andφ_{T3}（Y_T）， $S_1 + S_2 + S_3 = 1$.With the gradual change of membership degree F（Y_T）, the degree of the evaluation value of the evaluated object in the three states of reward, punishment and no reward and punishment also changes, so as to realize the reward or punishment for the change of the evaluated object.About the reward and punishment line, the fuzzy reward and punishment control line is jointly affected by the maximum and minimum values of all the evaluated objects in a certain period of time, and the evaluated values φ_i of the evaluated objects may be rewarded or punished at any time.Set $\gamma_i$as the fuzzy reward and punishment control line for the development level of regional low-carbon agriculture, the fuzzy reward and punishment control line in a certain period of time is:

$$\gamma_i = \delta (Y_{min} + Y_{max}) \tag{6}$$

δ depends on the overall development level of regional low-carbon agriculture.

3.2.3 Dynamic comprehensive evaluation of regional low-carbon agriculture development level from the perspective of fuzzy reward and punishment characteristics

After determining the fuzzy reward and punishment control line and membership degree F（Y_T）, the evaluation value of the evaluated object in the state of "reward", "punishment" and "no reward and punishment" in each period can be obtained through the aggregation model.The value of rewards, punishments and no rewards and punishments within $[t_k, t_{k+1}]$ is expressed respectively by the mathematical integral formulasμ_{iT}^+,μ_{iT}^- andμ_{iT}^0.The formula expression is:

$$\begin{cases}\mu_{iT}^+ = \int_{t_k}^{t_T}\psi_{T1}(y_{iT})f_{iT}(t)dt + \int_{t_T}^{t_{k+1}}\psi_{T1}(y_{iT})f_{iT}(t)dt\\ \mu_{iT}^- = \int_{t_k}^{t_T}\psi_{T3}(y_{iT})f_{iT}(t)dt + \int_{t_T}^{t_{k+1}}\psi_{T3}(y_{iT})f_{iT}(t)dt\\ \mu_{iT}^0 = \int_{t_k}^{t_{k+1}} f_{iT}(t)dt - \mu_{iT}^+ - \mu_{iT}^-\end{cases} \tag{7}$$

$y_{iT} = f_{iT}(t)$ is the evaluation value function of the evaluated object $Z_i$in the t-th period, and $t_T$is the abscissa corresponding to no reward and punishment point θ_T.In order to obtain the specific rewards and

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punishments of the development level of regional low-carbon agriculture within $[t_k, t_{k+1}]$, Order respectively δ^+ and δ^- as rewards and punishment coefficients. It is assumed that the sum of positive and negative rewards and punishments of all evaluated objects is equal, and the sum of total rewards and punishments is 1. Then:

$$\begin{cases} \delta^+ \sum_{i=1}^{M} \sum_{T=1}^{N-1} \mu_{iT}^+ = \delta^- \sum_{i=1}^{M} \sum_{T=1}^{N-1} \mu_{iT}^- \\ \delta^+ + \delta^- = 1 \end{cases} \tag{8}$$

According to formula(8), δ^+ and δ^- can be calculated,which results of rewards and punishments can promote the continuous improvement of the development level of regional low-carbon agriculture, so the evaluation value with fuzzy reward and punishment in a certain period of time of the development of regional low-carbon agriculture is:

$$\mu_{iT}^{\pm} = (1+\delta^+)\mu_{iT}^+ + (1-\delta^-)\mu_{iT}^- + \mu_{iT}^0 \tag{9}$$

The corresponding evaluation value of regional low-carbon agriculture development level with fuzzy rewards and punishments is obtained from formula(9), and the dynamic comprehensive evaluation value μ_i of regional low-carbon agriculture development level is obtained according to the information aggregation of time dimension.

$$\mu_i = \sum_{i=1}^{N-1} \mu_{iT}^{\pm} \tag{10}$$

IV. EMPIRICAL ANALYSIS

4.1 Index System Construction and Data Source

This study refers to the research of some Chinese scholars[5,6,15-17], and constructs the index system from four aspects: the level of agricultural economic development, the input level of agricultural production factors, the low-carbon level of energy utilization, and the level of resource and environmental security. At the same time, considering the continuous availability and comparability of regional index data, Finally, a comprehensive evaluation index system of low-carbon agricultural economy composed of 15 single indexes is constructed. The index system is shown in Table II below.

In order to better evaluate the development level of regional low-carbon agriculture, this paper selects the relevant data on the development of low-carbon agriculture in 30 provinces of China (excluding Tibet, Hong Kong, Macao and Taiwan). The data required for each index in Table II are mainly from the 2014-2019 China Rural Statistical Yearbook, China Statistical Yearbook and the government statistical bulletin issued by the China agriculture and rural department and other relevant departments.

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4.2 Static Evaluation of Regional Low-carbon Agriculture Development Level based on Catastrophe Progression

According to the calculation steps (1)—(3)of the above entropy weight method, the weight of each index in the evaluation index system of low-carbon agricultural development level (as shown in Table II) is obtained as the basis for ranking the importance of the index. The static evaluation value of provincial low-carbon agriculture development level is calculated by catastrophe progression method. The results are as follows (Table III):

TABLE II. Indicator system and weight of regional low carbon agriculture development level

TARGET INDICATORS	PRIMARY INDEX AND WEIGHT	SECONDARY INDEX	SECONDARY INDEX WEIGHT	ATTRIBUTE
LOW CARBON AGRICULTURE DEVELOPMENT LEVEL	Agricultural economic development level (0.17)	Total agricultural output value	0.30	Forward direction
		Input output ratio	0.11	Forward direction
		Land output rate	0.36	Forward direction
		Engel coefficient of rural residents	0.23	Negative direction
	Input level of agricultural production factors (0.25)	Fertilizer application intensity	0.24	Negative direction
		Pesticide application intensity	0.13	Negative direction
		Diesel application intensity	0.15	Negative direction
		Agricultural mechanization level	0.48	Forward direction
	Low carbon level of energy utilization (0.20)	Agricultural carbon emission intensity	0.28	Negative direction
		Agricultural carbon emission density	0.15	Negative direction

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		Agricultural energy efficiency	0.31	Forward direction
		Agricultural carbon productivity	0.26	Forward direction
	Safety level of resources and environment (0.38)	Forest coverage	0.27	Forward direction
		Effective irrigation coefficient	0.38	Forward direction
		Per capita cultivated land occupation	0.35	Forward direction

TABLE III. Static evaluation value of regional low-carbon agriculture development level

EVALUATION VALUE / REGIO	2014	2015	2016	2017	2018	2019
	STATIC EVALUATION VALUE	STATIC EVALUATION VALUE	STATIC EVALUATION VALUE	STATIC EVALUATION VALUE	STATIC EVALUATION VALUE	STATIC EVALUATION VALUE
BEI JING	0.7702	0.7774	0.7701	0.7858	0.7751	0.7650
TIAN JIN	0.8105	0.8199	0.8194	0.8448	0.8428	0.8365
HE BEI	0.8606	0.9166	0.8631	0.8920	0.8911	0.8913
SHAN XI	0.8051	0.8359	0.7859	0.8215	0.8115	0.6426
INNER MONGOLIA	0.7907	0.7898	0.7260	0.7575	0.6150	0.7797
LIAO NING	0.8189	0.8336	0.7698	0.8021	0.8121	0.8211
JI LIN	0.7472	0.7716	0.6203	0.7272	0.7573	0.7613
HEI LONG JIANG	0.7653	0.6459	0.5861	0.6216	0.8115	0.7916
SHANG HAI	0.4590	0.6499	0.6520	0.6366	0.6586	0.6413
JIANG SU	0.8401	0.8516	0.8490	0.8801	0.8757	0.8801
ZHE JIANG	0.6021	0.6124	0.6078	0.6324	0.6280	0.4726
AN HUI	0.8897	0.8576	0.8540	0.8836	0.8857	0.8787

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FU JIAN	0.7694	0.6433	0.7834	0.8167	0.8146	0.8307
JIANG XI	0.8545	0.8310	0.8284	0.8578	0.8717	0.8638
SHAN DONG	0.8512	0.8610	0.8583	0.8887	0.8850	0.8887
HE NAN	0.8200	0.8259	0.8197	0.8511	0.8499	0.8536
HU BEI	0.8488	0.8519	0.8446	0.8801	0.8900	0.8844
HU NAN	0.8517	0.8611	0.8576	0.8867	0.8826	0.8808
GUANG DONG	0.5967	0.6108	0.6081	0.6293	0.6231	0.6256
GUANG XI	0.8327	0.8511	0.8103	0.8483	0.8571	0.8817
HAI NAN	0.6171	0.6412	0.6048	0.6401	0.6341	0.6644
CHONG QING	0.7832	0.8142	0.7453	0.7772	0.8051	0.8376
SI CHUAN	0.8399	0.8379	0.8077	0.8479	0.8641	0.8697
GUI ZHOU	0.7605	0.7929	0.8263	0.6609	0.6780	0.8213
YUN NAN	0.7613	0.8101	0.7421	0.7715	0.7978	0.8337
SHAN XI	0.8038	0.8327	0.7725	0.8032	0.8131	0.8372
GAN SU	0.6144	0.7576	0.6721	0.6978	0.7147	0.7464
QING HAI	0.8189	0.8123	0.7866	0.8235	0.8386	0.8360
NING XIA	0.7890	0.8114	0.7664	0.8082	0.8133	0.8145
XIN JIANG	0.6389	0.6207	0.5961	0.5971	0.6249	0.6316

Through the calculation of the comprehensive evaluation value of low-carbon agricultural development in various provinces and regions, the development level of low-carbon agriculture in China has a high score and the overall situation is good, but the development level difference between provinces is significant.Referring to some scholars' classification of low-carbon agricultural development grade evaluation criteria, the low-carbon agricultural development level is divided into six grades[3], and Y is set to represent the comprehensive evaluation value of low-carbon agricultural development. The evaluation of low-carbon agricultural development level is as follows:

TABLE IV. Evaluation criteria for development level of low carbon agriculture

GRADE	**COMPREHENSIVE EVALUATION VALUE OF LOW CARBON DEVELOPMENT**	**EVALUATION OF DEVELOPMENT LEVEL**
FIRST	$Y \geq 0.9$	Low carbon intensity
SECO	$0.8 \leq Y < 0.9$	Strong low carbon

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ND		
THIRD	$0.7 \leq Y < 0.8$	Near low carbon
FOURTH	$0.6 \leq Y < 0.7$	Medium carbon
FIFTH	$0.5 \leq Y < 0.6$	Higher carbon
SIXTH	$Y < 0.5$	High carbon

It can be seen from Table III and Table IV that the comprehensive evaluation value of low-carbon agricultural development in Hebei, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan and Sichuan is between 0.8 and 0.9, which belongs to the stage of strong low-carbon development level. Some regions (Tianjin, Hebei and Jiangsu) have strong economic strength, complete agricultural infrastructure, and actively introduce emerging technologies such as low-carbon cleaning, so the low-carbon development level is relatively stable; Anhui, Shandong, Henan, Hubei, Sichuan and other major agricultural provinces have fertile soil, rich resources, diversified agricultural industrial structure and high land output rate, which promote the efficient development of low-carbon agriculture; Guangxi, Chongqing and other regions have developed three-dimensional ecological agriculture model in recent years, and the low-carbon development level has also been significantly improved. The comprehensive evaluation value of low-carbon agriculture development in Beijing, Inner Mongolia, Jilin, Heilongjiang, Gansu and other regions is between 0.7 and 0.8, which belongs to the stage of near low-carbon development level. These regions occupy a large amount of cultivated land due to industrial and mining enterprises and urban and rural construction, resulting in the reduction of cultivated land area, the decline of soil fertility and low ecological benefits, thus inhibiting the development of low-carbon agriculture. The comprehensive evaluation value of low-carbon agricultural development in Shanghai, Zhejiang, Guangdong, Hainan, Xinjiang and other regions is between 0.6 and 0.7, which belongs to the stage of medium carbon development. On the one hand, the area of agricultural arable land is small, on the other hand, agricultural production is excessively dependent on agricultural chemicals, which is the main factor restricting the development of low-carbon agriculture.

4.3 Dynamic Evaluation of Regional Low-carbon Agriculture Development Level based on Fuzzy Reward and Punishment Characteristics

According to actual development of low-carbon agriculture development level, $\delta=0.55$ is calculated by formula 6, and the fuzzy reward and punishment control line of each inter district section evaluated to $\theta_1=0.6850$, $\theta_2=0.8264$, $\theta_3=0.8129$, $\theta_4=0.8190$, $\theta_5=0.8284$.The evaluation values of reward and punishment, no reward and punishment and punishment for the development level of low-carbon agriculture in each interval are calculated according to equations (5)and(7).

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TABLE V. Reward, no reward and punishment and punishment value of regional low-carbon agriculture development level

TIME / REGION	2014-2015			2015-2016			2016-2017			2017-2018			2018-2019		
	S+	**S0**	**S-**	**S+**	**S0**	**S-**	**S+**	**S0**	**S-**	**S+**	**S0**	**S-**	**S+**	**S0**	**S-**
BEI JING	0.2967	0.4771	0	0	0.7738	0.1697	0	0.7779	0.1260	0	0.7805	0.1475	0	0.7701	0.2107
TIAN JIN	0.4582	0.3570	0	0	0.8196	0.0234	0.2025	0.6296	0	0.2904	0.5534	0	0.1488	0.6908	0
HE BEI	0.7824	0.1062	0	0.6281	0.2617	0	0.7179	0.1596	0	0.8970	0.0055	0	0.8896	0.0016	0
SHAN XI	0.4805	0.3401	0	0.0082	0.7996	0.0031	0.1035	0.6623	0.0379	0.0036	0.8116	0.0013	0	0.7270	0.3344
INNER MONGO LIA	0.3591	0.4312	0	0	0.5429	0.2149	0	0.4973	0.2444	0	0.6863	0.4383	0	0.6973	0.4178
LIAO NING	0.5040	0.3223	0	0.0037	0.7967	0.0014	0	0.7859	0.0979	0	0.8071	0.0472	0	0.8166	0.0454
JI LIN	0.2440	0.5154	0	0	0.6959	0.3701	0	0.6737	0.4302	0	0.7423	0.2789	0	0.7593	0.2460
HEI LONGJIANG	0.0678	0.6378	0	0	0.6160	0.5382	0	0.6038	0.5846	0	0.7165	0.3452	0	0.8015	0.1010
SHANG HAI	0	0.5544	0.1948	0	0.6510	0.4754	0	0.6443	0.5033	0	0.6476	0.5440	0	0.6499	0.5436
JIANG SU	0.5874	0.2584	0	0.2246	0.6257	0	0.5658	0.2988	0	0.7174	0.1605	0	0.6906	0.1873	0
ZHE JIANG	0	0.6073	0.1326	0	0.6101	0.5492	0	0.6201	0.5539	0	0.6302	0.5834	0	0.6503	0.5421
AN HUI	0.7120	0.1617	0	0.2786	0.5773	0	0.6153	0.2535	0	0.8058	0.0789		0.7539	0.1282	0
FU JIAN	0.1449	0.4672	0.0942	0	0.7134	0.3289	0.1316	0.6203	0.0482	0	0.8156	0.0135	0.0781	0.7216	0.0230
JIANG XI	0.57	0.26	0	0.02	0.80	0	0.32	0.52	0	0.54	0.31	0	0.54	0.32	0

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	43	85		98	00		29	02		95	52		26	52	
SHANDONG	0.6325	0.2236	0	0.3163	0.5433	0	0.6701	0.2033	0	0.8343	0.0525	0	0.8235	0.0633	0
HE NAN	0.4901	0.3328	0	0	0.8228	0.0127	0.2384	0.5970	0	0.3714	0.4791	0	0.3150	0.5367	0
HU BEI	0.6071	0.2432	0	0.2049	0.6433	0	0.5407	0.3217	0	0.8116	0.0735	0	0.8292	0.0580	0
HU NAN	0.6338	0.2226	0	0.3131	0.5462	0	0.6542	0.2179	0	0.8058	0.0788	0	0.7470	0.1347	0
GUANG DONG	0	0.6038	0.1377	0	0.6095	0.5503	0	0.6187	0.5566	0	0.6262	0.5918	0	0.6244	0.5970
GUANG XI	0.5703	0.2716	0	0.0403	0.7644	0.0260	0.0009	0.8280	0.0003	0.3988	0.4539	0	0.5671	0.3023	0
HAI NAN	0	0.6292	0.0986	0	0.0960	0.5270	0	0.0735	0.5489	0	0.0690	0.5681	0	0.1045	0.5448
CHONG QING	0.3923	0.4064	0	0	0.7797	0.1500	0	0.7613	0.1819	0	0.7912	0.1076	0.1087	0.6806	0.0320
SI CHUAN	0.5574	0.2815	0	0.0199	0.7954	0.0075	0.0035	0.8229	0.0013	0.4395	0.4165	0	0.5301	0.3368	0
GUI ZHOU	0.3078	0.4689	0	0	0.7531	0.0565	0.0056	0.7359	0.0021	0	0.6694	0.4908	0	0.7496	0.2689
YUN NAN	0.3424	0.4433	0	0	0.6150	0.1611	0	0.7568	0.1964	0	0.7847	0.1318	0.1690	0.5970	0.0497
SHAN XI	0.4709	0.3473	0	0.0029	0.7986	0.0011	0	0.7879	0.0912	0	0.8081	0.0430	0.0639	0.7425	0.0188
GAN SU	0.2230	0.3179	0.1450	0	0.3854	0.3295	0	0.2791	0.4059	0	0.7063	0.3902	0	0.7306	0.3348
QING HAI	0.4598	0.3558	0	0	0.7097	0.0897	0	0.7704	0.0346	0.1390	0.8310	0	0.1175	0.8373	0
NING XIA	0.3982	0.4020	0	0	0.6663	0.1226	0	0.6945	0.0928	0	0.7780	0.0327	0	0.7583	0.0556
XIN JIANG	0	0.62	0.09	0	0.05	0.55	0	0.00	0.59	0	0.61	0.62	0	0.62	0.58

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		98	76		66	18		15	81		10	28		82	94

It can be seen from the analysis in Table V that from 2014 to 2019, the development level of low-carbon agriculture in Hebei, Jiangsu, Anhui, Jiangxi, Shandong, Hunan, Hubei and other places has always been in the stage of reward and no reward and punishment. It is also the region with the highest static evaluation value. The corresponding comprehensive development level of low-carbon agriculture has received a large degree of reward and a small degree of no reward and punishment. According to Table III, the low-carbon development level of Hebei, Shandong, Jiangsu, Hubei and other regions is far ahead of other regions. These regions are China's traditional agricultural provinces, with good agricultural economic development conditions, high comprehensive capacity of low-carbon utilization of energy and abundant agricultural resources, which promote the high level of low-carbon development of agricultural economy. Therefore, giving rewards to these areas with high low-carbon development level, compensating their contributions to ecological and environmental protection, and encouraging their low-carbon development level to upgrade and transform to a higher level can play a leading role in the transformation of regional agricultural low-carbon economy and actively play an exemplary radiation effect. From 2014 to 2019, the development level of low-carbon agriculture in Shanghai, Guangdong, Hainan, Xinjiang and other regions has always been in the stage of punishment. As can be seen from Table III, it is the region with lower static evaluation value. Affected by the restrictions of agricultural production conditions, high-intensity input of agricultural chemicals and the scarcity of land resources, these areas have seriously hindered the development of low-carbon agriculture. Therefore, these areas with low-carbon development level should be punished, and these areas should be improved in low-carbon output, low-carbon consumption, low-carbon resources and low-carbon environment at a high cost, so as to gradually improve the continuous decline of the current low-carbon agricultural development level. From 2014 to 2019, the development level of low-carbon agriculture in Beijing, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanxi, Ningxia and other regions began to be in the stage of reward, no reward and punishment, and then in the stage of punishment. It can be seen from Table III that the static comprehensive evaluation values of these regions are in the middle and lower position, and the agricultural low-carbon economy is in the middle development level, mainly due to the economic development of these regions in recent years, The economic center of gravity has been continuously inclined to the secondary and tertiary industries, and agricultural land has been reduced. Ecological resources and environment have also been greatly damaged. At the same time, it shows that the distribution of natural resources in these areas is uneven, the industrial structure needs to be optimized and adjusted, the investment of funds and technology in the agricultural field should be strengthened, and different rewards and punishments should be taken to ensure the development of regional economy. To sum up, the development of regional agricultural low-carbon economy should not be one size fits all, but should follow the differentiated low-carbon development level in combination with the actual development situation of each region. Through continuous reward and punishment measures, the boundary of reward and punishment will be blurred, and the reward and punishment will be more flexible on the premise of fairness.

The corresponding reward and punishment coefficients obtained from equations (8) and (9) are respectively δ^{+}=0.41， $\delta^{-} = 0.59$, and the dynamic comprehensive evaluation value of the development

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level of regional low-carbon agriculture with fuzzy reward and punishment is obtained in combination with equation (10).

TABLE VI. Dynamic evaluation value of regional low-carbon agriculture development level from the perspective of fuzzy reward and punishment

REGION	EVALUATION VALUE OF REWARD	EVALUATION VALUE OF PUNISHMENT	DYNAMIC COMPREHENSIVE EVALUATION VALUE WITH FUZZY REWARD AND PUNISHMENT	DYNAMIC COMPREHENSIVE EVALUATION VALUE WITHOUT FUZZY REWARD AND PUNISHMENT
BEI JING	0.4158	0.2624	4.2575	4.6437
TIAN JIN	1.5412	0.0094	4.6010	4.9738
HE BEI	5.4858	0	6.0204	5.3146
SHAN XI	0.8348	0.1511	4.3266	4.7025
INNER MONGO LIA	0.5032	0.5278	3.8860	4.4587
LIAO NING	0.7113	0.0770	4.3169	4.8576
JI LIN	0.3419	0.5317	4.2602	4.3849
HEI LONG JIANG	0.0950	0.6295	4.1002	4.2220
SHANG HAI	0	0.9072	4.0544	3.6974
JIANG SU	3.9036	0	5.4342	5.1766
ZHE JIANG	0	0.9474	4.0653	3.7553
AN HUI	4.4357	0	5.6352	5.2493
FU JIAN	0.4969	0.2038	4.0386	4.6580
JIANG XI	2.8292	0	5.0583	5.1073
SHAN DONG	4.5915	0	5.6776	5.2328
HE NAN	1.9827	0.0051	4.7561	5.0201
HU BEI	4.1945	0	5.5343	5.1998
HU NAN	4.4195	0	5.6197	5.2205
GUANG DONG	0	0.9764	4.0589	3.6937
GUANG XI	2.2102	0.0106	4.8411	5.0811

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HAI NAN	0	0.9177	1.8899	3.8018
CHONG QING	0.7021	0.1892	4.3104	4.7626
SI CHUAN	2.1726	0.0035	4.8292	5.0671
GUI ZHOU	0.4392	0.3283	4.1444	4.5398
YUN NAN	0.7165	0.2163	4.1296	4.7165
SHAN XI	0.7534	0.0618	4.2997	4.8625
GAN SU	0.3125	0.6441	3.3758	4.2030
QING HAI	1.0037	0.0499	4.5579	4.9159
NING XIA	0.5580	0.1219	3.9790	4.8029
XIN JIANG	0	0.9868	2.9139	3.7093

According to the analysis in Table VI, the dynamic comprehensive evaluation value of the development level of regional low-carbon agriculture with fuzzy rewards and punishments is less than that without fuzzy rewards and punishments, except for a few regions such as Hebei, Shanghai, Jiangsu and Guangdong. It shows that after the implementation of fuzzy reward and punishment evaluation in most areas, the difference of regional dynamic change is reduced. The dynamic comprehensive evaluation value ranking of the development level of low-carbon agriculture in Beijing, Shanxi, Jilin, Heilongjiang, Shanghai, Zhejiang, Guangdong and other regions has increased, with the largest increase in Guangdong. The ranking of the dynamic comprehensive evaluation value of the development level of low-carbon agriculture in Inner Mongolia, Shanxi, Yunnan, Gansu, Ningxia and other regions has decreased, of which the decline in Ningxia is large, which reflects the effect of fuzzy reward and punishment on the development level of regional low-carbon agriculture. The dynamic evaluation value of the development level of low-carbon agriculture in Hebei, Jiangsu, Anhui, Hubei, Hunan and other regions ranks in the forefront of all provinces, and its static evaluation value ranking is also relatively high. The dynamic evaluation value of the development level of low-carbon agriculture in Hainan, Ningxia, Xinjiang and other regions seriously lags behind other provinces, and its static evaluation value is also relatively backward. It can be seen from Table III that the static comprehensive evaluation value of the development level of low-carbon agriculture in Hebei, Jiangsu, Anhui, Hubei, Hunan and other regions is higher than the reward and punishment control line, and there are more subordinate degrees belonging to the reward, which means that more rewards can be obtained. The punishment evaluation value of these areas is 0, and the evaluation value of rewards is large. They are basically in the forefront of the development level of low-carbon agriculture in all provinces, which is consistent with their static evaluation value. The static comprehensive evaluation value of the development level of low-carbon agriculture in Shanghai, Zhejiang, Guangdong, Hainan, Xinjiang and other regions is lower than the reward and punishment control line. There are more subordinate degrees belonging to punishment, which means more punishment. The reward evaluation value of these areas is 0, and the evaluation value of punishment is large. They are basically at the end of the development level of low-carbon agriculture in each province, which is consistent with their static evaluation value. Because the development level of regional low-carbon agriculture is in a dynamic

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and changing development process, the development level of agricultural economy, the input level of agricultural production factors, the low-carbon level of energy utilization and the security level of resources and environment all have an important impact on the development level of low-carbon agriculture. Regions that have been awarded will give full play to their advantages in resources, talents, technology and geography to promote the continuous development of regional agriculture to a strong and low-carbon economy.In the areas that get punishment, the effective development of low-carbon agriculture is hindered by high energy consumption, large environmental damage and low level of economic development. Therefore, some punishment measures are taken to warn these areas and urge them to strengthen the protection of agricultural ecological environment, improve energy utilization efficiency and "low-carbon" agricultural production mode to improve the development level of low-carbon agriculture.

V. CONCLUSION AND SUGGESTIONS

Based on the research and analysis of the development level of low-carbon agriculture in 30 provinces in China, this paper constructs the evaluation index system of low-carbon agriculture development level from the four index levels of agricultural economic development level, agricultural production factor investment level, low-carbon energy utilization level and resource and environmental security level by using entropy method, and calculates the static comprehensive evaluation value of low-carbon agriculture development level in 30 provinces by using catastrophe progression method, From the perspective of fuzzy reward and punishment characteristics, the static evaluation results are deeply analyzed, and the dynamic evaluation model of regional low-carbon agriculture development level is constructed by combining the means of "reward and punishment". The empirical results show that: (1) the higher the static evaluation value of the development level of regional low-carbon agriculture, such as Hebei, Jiangsu, Anhui, Shandong, Hubei, Hunan and other regions are in the stage of reward and no reward and punishment, the evaluation value of reward is also relatively high, and the reward range is also relatively large. The regions with lower static evaluation value of regional low-carbon agriculture development level, such as Shanghai, Zhejiang, Guangdong, Hainan, Xinjiang and other regions, are in the punishment stage, the evaluation value of reward is 0, and the range of punishment is relatively large. Beijing, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shaanxi, Ningxia and other regions are at the middle level of low-carbon agricultural development, and the ranking of static evaluation values is also in the middle. These regions are sometimes in the reward stage and sometimes in the punishment stage.(2) According to the comparative analysis of the dynamic comprehensive evaluation values from different perspectives of the development level of low-carbon agriculture in each province, the implementation of fuzzy reward and punishment evaluation can reduce the dynamic change differences in each region and reward the good and punish the bad in each region, which not only plays a certain incentive role for the development of low-carbon agriculture in each region, but also makes up for the limitations of the clear boundary of reward and punishment in the development of low-carbon economy in the actual region. Through the information aggregation of rewards, no rewards and punishments and punishments in each stage of provincial low-carbon agriculture development level, it reflects the internal differences in the development level of low-carbon agriculture among provinces, and more objectively reflects the actual situation of the development level of low-carbon agriculture in China.

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According to the empirical research results, this paper puts forward the following suggestions:

First, all regions actively promote the revitalization of rural construction, innovate new ways of agricultural development, transform the ecological advantages of rural areas into economic advantages, gradually improve the income level of rural residents, and maximize the economic and environmental benefits of all regions. Formulate energy-saving and emission reduction policies according to local conditions and in combination with the actual situation of each region. At the same time, actively adopt low-carbon agricultural technology, develop rural renewable energy, and formulate low-carbon agricultural ecological compensation mechanism, so as to promote the transformation of regional agricultural economy from "high input, high emission and high pollution" to "low input, low emission and low pollution".

Second, In order to improve the development level of low-carbon agriculture among regions, reasonable reward and punishment incentive measures are very necessary. According to the principle of fuzzy rewards and punishments and the boundary of fuzzy rewards and punishments, we will continue to increase the range of rewards for areas with significant improvement in the development of regional low-carbon agriculture; For the areas where the development level of regional low-carbon agriculture is reduced or backward, continue to increase the punishment to ensure the development of regional agricultural economy in the direction of low-carbon and high efficiency.

Third, On the basis of summarizing the main factors of regional low-carbon agriculture development level differentiation, we should follow the inter provincial low-carbon agriculture development path differentiation. Low carbon agriculture is the fundamental goal of promoting regional economic development and promoting regional competitiveness. We need to give full play to the late development advantages of backward rural areas, and strengthen support for capital, technology and talents in backward areas, so as to realize regional linkage development.

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