Performance Evaluation Research of Ecological Civilization Policy Based on Stochastic Frontier Analysis and Artificial Neural Networks Model

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Abstract

Ecological civilization is a new form of human civilization that solves the contradiction between development and environment. Because the ecological civilization policy system has is complex and nonlinear, this paper combines artificial neural network technology with the Stochastic Frontier Analysis(SFA) method and proposes the hybrid SFA-Artificial Neural Network (SFANN) model to estimate the impact of ecological civilization policy on economic development. The model uses regional eco-efficiency evaluated by SFA as one of the inputs for the neural network; the neural network integrates the total input and output results to provide a quantitative estimate of the ecological civilization policy in different provincial regions from 2003-2016. By training and examining the evaluation results with the SFANN model, this paper tries to predict the impact of 13th Five-Year Total Emission Reduction Policy on economic development. The empirical research results and suggestions can improve the ecological civilization policy performance by negative feedback mechanisms.

Keywords: Eco-efficiency; Ecological Civilization Policy; Performance Evaluation; Stochastic Frontier Analysis; Artificial Neural Network

1. Introduction

In the age of industrial civilization, the unlimited extraction of natural resources and unrestrained discharge of contaminants led to many serious consequences, such as energy exhaustion, resource shortages, environmental pollution, and ecological imbalance. Thus, natural disasters and ecological crises crop up frequently. Such a phenomenon is especially serious in developing countries such as China. Although China's reform and opening up resulted in the impressive "China Speed", the extensive style of economic growth nevertheless created many environmental problems, including soil desertification, water quality degradation, and air pollution. These environmental problems not only significantly depress people's heath and quality of life but also corrode economic milestones. To balance the contradiction between economic development and environmental quality, the Chinese Government proposed a new form of human civilization based on the theory and practice of sustainable development in developed western countries called ecological civilization and published a series of policies(Ji-Hong, 2007).

Ecological civilization policy is a new form of ecological policy that exists only in China. Based on foreign environmental policy, ecological civilization policy in China is defined as all the normalization, straitjacket, and guidance rules for supporting, promoting, and ensuring the realization of ecological civilization. This policy consists of enforcement measures, such as legislation, and non-enforcement measures, such as public participation(Xiuyu Zhang, Li, Shi, & Yang, 2015). The performance of ecological civilization policy refers to the environmental reception and achievement arising from the implementation of ecological civilization policy. It describes not only the effect of the ecological civilization construction on the local economic environment but also the cost of decreasing resource utilization and environmental contamination. It thus reflects the concept of ecological efficiency(Aibao, 2010). Although the policy in general does not have an immediate effect, the feasibility and effectiveness of one policy can be predicted through the use of scientific evaluation tools and specific mathematical models. Thus, it is possible to regulate the policy by observing the difference between the predicted result and the expected. As a result, policy performance evaluation is the ending as well as the starting point of the policy(Cao & Cao, 2010).

The evaluation index system for foreign sustainable development includes:

1. A causation framework model, such as the Pressures-State-Responses Model proposed by the Organisation for Economic Co-operation and Development (OECD) (OECD, 1998) (Figure 1), the Drivers-Pressures-State-

Impact-Responses Model proposed by the Commission on Sustainable Development (CSD)(WBCSD, 1996), , or the Drivers-Pressures-State-Impact-Responses model proposed by the European Environment Agency (EEA)(Maxim, Spangenberg, & O'Connor, 2009). (Figure 2). These models are intuitive and have a relatively precise description of the casual link between humans and the environment, but it is impossible to simulate a complex nonlinear system such as a policy system.

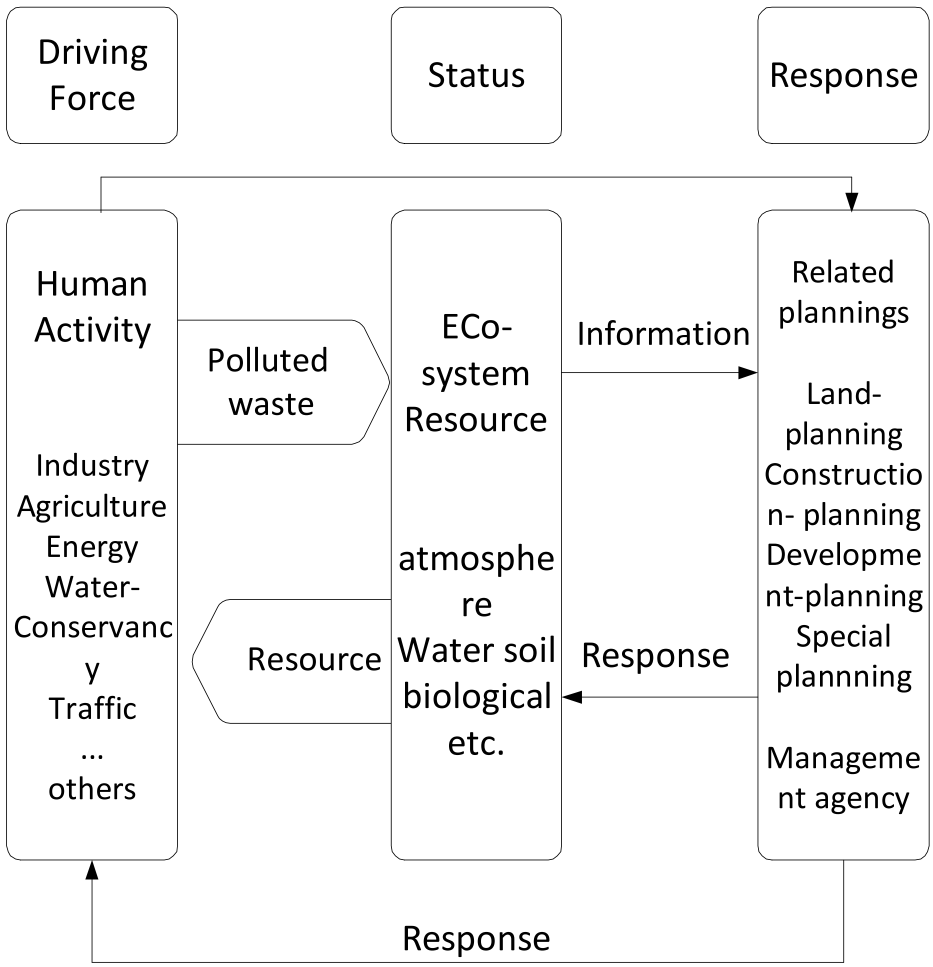


Figure 1. The Pressures-State-Responses model

2. A theme framework model, such as the Environmental Performance Index proposed by Yale University in collaboration with Columbia University (Vörösmarty et al., 2010). The indicators are selected according to the objectives of the environmental policy. Under each environmental theme, there are several subtopics with parallel relationships, and each subtopic is the basis for selecting the indicators at the next level. This model could stress the policy focus and effectively avoid the repeat set problems, but it adopts a simple additive algorithm in describing the coupling relation between subjects of the same level.

3. An Input-Output-Outcome-Impact framework model, such as the Ecological Footprint Indicators proposed by Canadian eco-economists(van den Bergh & Verbruggen, 1999). This model is a kind of economics direction model. It selects indicators from the four aspects of input, output, outcome, and impact according to the regulation of energy and material flow and reflecting the relationship between economic input and output. This model depicts the relation between economics and the environment directly, but it is unable to quantify the evaluation system thoroughly.

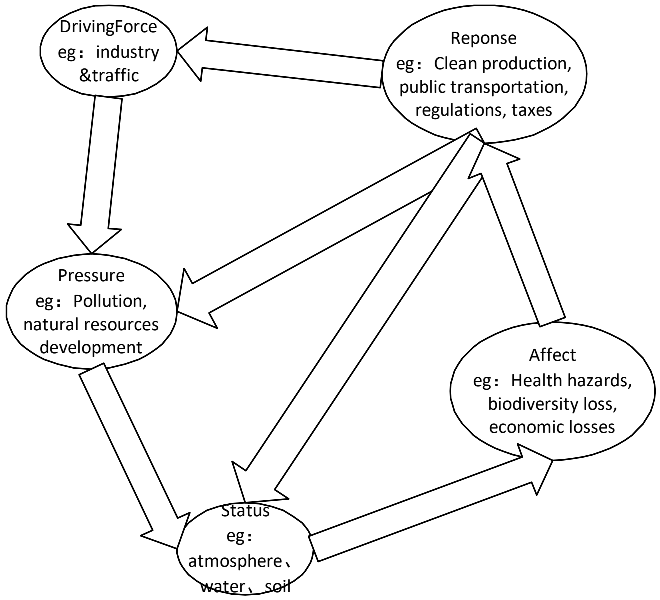


Figure 2. The Drivers-Pressures-State-Impact-Responses model

For the ecological civilization policy proposed by the Chinese government, the evaluation index system is just beginning to develop. The provincial Ecological Civilization Index presented by the Ecological Civilization Research Centre at Beijing Forestry University(Liu, 2010) and the provincial Green Development Index advanced by the Ministry of Ecology and Environment of the People's Republic of China (Li-Yang, Zheng, & Wang, 2013) are both constructed by the theme framework model. Regardless of the evaluation index, the Analytic Hierarchy Process (AHP) algorithm(Gass & Vargas, 2017), a kind of linear evaluation method, is widely used in the performance evaluation of ecological civilization policy at present.

In this paper, we propose a new ecological civilization policy evaluation method by using the Input-Output-Outcome-Impact framework model based on the principle of economics. To our knowledge, such a quantified economic model has never been reported. In addition, when constructing the evaluation algorithm, the artificial neural network model was adopted to enable the algorithm to simulate the characters of the complex nonlinear system. In comparison with the currently used linear evaluation method, our method has significant advantages in predicting the impact of ecological civilization policies on the economy.

2. Methodology

2.1 The impact of ecological civilization policy on the economy

The viability of ecological civilization policy is dominated by the technical and economic feasibility. It is easy to estimate the technical practicability; however, the relation between economics and the environment is complex, and it is very difficult to strike a balance between these two. The Chinese government is undergoing a continuous deepening of understanding regarding the relation between economics and the environment (Figure 3). At the beginning of the period of reform and opening up, economics dominated and environmental protection was ignored. Better invaluable assets than clear water and lush mountains. With the idea of sustainable development gradually taking root, the government has published numerous policies to protect the environment. However, as economic development and environmental protection are simply considered to be independent, the effect of these policies on economic development is studied exclusively when making these policies. Clear water, lush mountains and invaluable assets are all considered as well. The ecological civilization policy was proposed at the 17th conference of the CCP and embedded in the five-pronged approach to modernize socialism for China at the 18th conference of the CCP. Included in the idea of ecological civilization is the idea that economic development and environmental economics affect the protection of the environment, and a beautiful environment promotes economic development. Clear water and lush mountains are invaluable assets (Xiao Zhang & Yue, 2017).

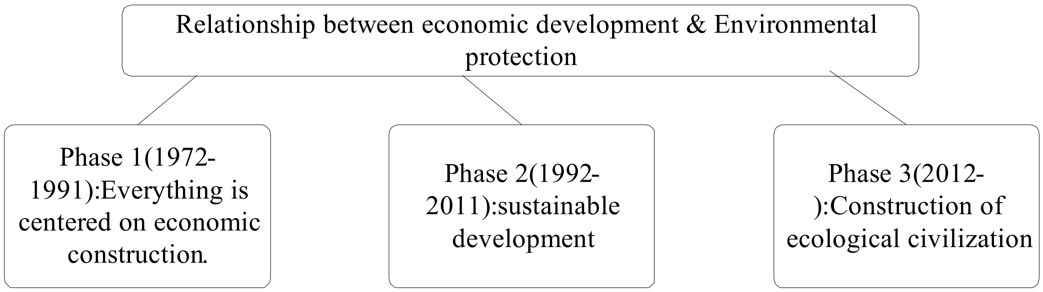


Figure 3. Relationship between economic development & environmental protection

Specifically, ecological civilization policy boosts economic growth from two aspects. One is to improve the ecological efficiency, which is the ratio of the value of economic activity to that of consumed resources and the environmental load. As a result, higher ecological efficiency corresponds to more product output and less unexpected output under the same productive investment and environmental cost. The other result is the control of the total amount of environmental cost and pollution discharge. These two aspects are related. For example, controlling the total amount directly limits the amount of input in the short term; however, in the long run, it also forces the economy to create innovative technology to boost efficiency.

2.2 Application of Artificial Neural Network in Performance Evaluation of Ecological Civilization Policy

The ecological civilization policy system is a complex system the includes economics, society, and the environment. It has characteristics including obvious nonlinearity and uncertainty. Due to the lack of a physical prototype of abstract systems such as the social system, the economic system, and the ecological system, the relevant model is based upon a logical deduction. As the linear model arising from conventional econometrics is inadequate to estimate a complex system, the artificial neural network method is introduced to the new method of evaluating the performance of ecological civilization policy.

The artificial neural network has advantages such as a strong adaptive capability, a self-learning capability, and a fault-tolerant capability (Xiao, Ye, Zhong, & Sun, 2009). Its multi-input multi-output structure is suitable for non-massive parallel calculation. In 2006, Hinto et al. proposed deep learning, which significantly improves the calculation capacity of an artificial neural network by a relatively simple violence calculation (Y. Zhang & Wu, 2009). Today, the process of using a neural network to predict the economy is as follows: network topological structure design, data sample acquisition, input and output data pretreatment, network training, and examination and prediction of network prediction capability(Sc, Cowan, & Grant, 1991).

To precisely predict and evaluate the total effect of the ecological civilization policy on economics, the environment, and society, the model should be able to simulate the multi-effect of the policy. In this paper, we use a combined forecasting method comprising the following four steps.

(1) Choosing the ecological efficiency index and providing the static, quantitative ecological efficiency of the local area.

(2) Using static ecological efficiency as one of the inputs of the neural network, which integrates the total input and output results, constructing a hybrid SFA-Artificial Neural Network model for evaluating the performance of ecological civilization policy.

(3) Training the neural network and examining the result using another sample data.

(4) Using the SFANN model to predict the effect of ecological civilization policy on economics.

3. Evaluation of regional eco-efficiency using the SFA model

3.1 SFA model with the impact of environmental capacity

Ecological civilization policy promotes economic development by boosting ecological efficiency. In this paper, the local ecological efficiency was predicted using the SFA model with environmental capacity(Reinhard, Knox Lovell, & Thijssen, 2000).

The SFA model is one of parametric approaches for evaluating efficiency. It defines a priori except for a finite set of unknown parameters that are estimated from data. The parameters may for example refer to the relative importance of different cost drivers or to the parameters in the possibly random noise and efficiency distributions(Battese & J. Coelli, 1988).

A stochastic production frontier is defined by

$$\ln y_i = \beta_0 + \sum_1^k \beta_k \ln x_{ki} + \ln\xi_i + v_i - u_i \quad (1)$$

where for all farms indexed with a subscript i;

yi denotes the production level;

x_i is a vector of normal inputs (such as x_{1i} is the labour, x_{2i} the capital, x_{3i} the variable inputs, x_{4i} a vector of year dummies reflecting technological and regulatory developments);

β and ξ are parameters to be estimated;

v_i is a symmetric random error term independently and identically distributed as $N(0,\sigma_1)$, intended to capture the influence of exogenous events beyond the control;

u_i is a nonnegative random error term, independently and identically distributed as $N'(0,\sigma_2)$

Now we consider environmentally detrimental inputs.

The inputs of the SFA model are p_{lj}^b and δ_j , their definitions are

$$p_{lj}^b = y_{lj}^b / Co_{lj}$$
$$\delta_j = \sum_{l=1}^t \alpha_l p_{lj}^b \quad (2)$$

where y_{rj} and y_{lj}^b are the rth expected and lth unexpected outputs of jth , Co_{lj} is the environmental capacity of lth unexpected outputs of jth , α_l is the loss coefficient,

$O_{rj} = y_{rj}/\delta_j$ refers to the regulated expected output, $O_{rj} = y_{rj}/\delta_j$， r=1,2,...s is the adjusted total outputs and β_j is the risk attitude representing the efficiency of the decision maker.

Now we have

$$ln\, y_{ri} - ln\, \delta_i = \beta_0 + \sum_1^{k\Sigma_i + \iota_i} \beta_k\, ln\, x_{ki} + ln \quad (3)$$
$$\delta_j = x_{(k+1)j}, \beta_{(k+1)} = 1 \quad (4)$$
$$ln\, y_{ri} = \beta_0 + \sum_1^{k+1\Sigma_i + \iota_i} \beta_k\, ln\, x_{ki} + ln \quad (5)$$

Environmental capacity refers to the maximum contaminant capacity which does not significantly harm the ecological system(Luo, 2012).

We use r_i as the environmental capacity of the selected region we want to study. It also obey normal distribution or chi-square distribution(G. King, I. Plosser, & Rebelo, 2002).

$$\ln y_i = \beta_0 + \sum_1^{k+1\Sigma_{i_{\iota_i}}} \beta_k\, ln\, x_{ki} + ln \quad (6)$$

3.2 Selection of regional ecological efficiency evaluation indicators

From the data listed in the China Statistical Yearbook, we calculate the local evaluation index of every province in China. Tibet is excluded due to incomplete data statistics. In some years, there is no total industrial exhaust gas emission data, which is replaced by the total amount of smoke (powder) dust emissions. Since the calculation is a region's annual eco-efficiency, there is no cross-year impact. All data used are from the China Statistical Yearbook 2003-2016(China, 2003-2016).

Table 1. Selection of ecological efficiency evaluation indicators

Index	Name	Detailed description
Input	Amount of capital	Fixed capital(0.1 billion Yuan)
	Amount of human resources	The labor (ten thousands)
	Amount of assumed energy	100M kW·h
Expected output	Economic output	Local GDP(0.1 billion Yuan)
Unexpected output		Amount of waste water(ten hundreds ton)
		Amount of waste gas(0.1 billion cubic meter)

3.3 evaluation result of local ecological efficiency

From the data listed in the China Statistical Yearbook, we calculate the local evaluation index of every province in China. Tibet is excluded due to incomplete data statistics. In some years, there is no total industrial exhaust gas emission data, which is replaced by the total amount of smoke (powder) dust emissions. Since the calculation is a region's annual eco-efficiency, there is no cross-year impact. All data used are from the China Statistical Yearbook 2003-2016(China, 2003-2016).

The calculation results are listed in the table below.

Table 2. The calculation results of local ecological efficiency

	2003	2004	2005	2006	2007	2008	2009
Beijing	0.4481851	0.4954173	0.6071799	0.6031369	0.6144830	0.6806032	0.6401211
Tianjin	0.6547441	0.8007699	0.7760539	0.7789601	0.8010553	0.8329289	0.8739967
Hebei	0.3401713	0.3543931	0.3611803	0.2430798	0.3273836	0.3599068	0.3337259
Shanxi	0.3504620	0.3810005	0.4080705	0.1705280	0.3669328	0.3838532	0.3689959
Nei Mongol	0.4471054	0.4340108	0.5313067	0.2837428	0.5243722	0.5593135	0.5491291
Liaoning	0.3439232	0.3687327	0.3513648	0.2360818	0.3697268	0.3305128	0.3946011
Jilin	0.5064905	0.5511887	0.5779920	0.3183468	0.6138826	0.6052004	0.6091394
Heilongjiang	0.5072045	0.5796902	0.5773094	0.2840720	0.5147979	0.5427942	0.4948064
Shanghai	0.4334701	0.4935565	0.5479974	0.6027889	0.5383759	0.5332427	0.5371739
Jiansu	0.3100029	0.3356848	0.3426132	0.3212541	0.3672658	0.3765540	0.3830782
Zhejiang	0.3948517	0.4194474	0.4148300	0.3710101	0.3916158	0.3706168	0.3533597
Anhui	0.4360134	0.4860202	0.4945800	0.2880155	0.4468744	0.4455281	0.4536905
Fujian	0.4668048	0.4704569	0.4502020	0.3658211	0.4298526	0.4257224	0.4242645
Jiangxi	0.4881134	0.5404811	0.5608223	0.3060613	0.5242123	0.5343699	0.5304054
Shandong	0.3386684	0.3668438	0.3629842	0.2866578	0.3535525	0.3516810	0.3491034
Henan	0.3126098	0.3398903	0.3498247	0.2081944	0.3498267	0.3515174	0.3416706
Hubei	0.3484773	0.3709641	0.3680810	0.2597585	0.4029066	0.4026202	0.4081032
Hunan	0.3638803	0.4014957	0.4202329	0.2238537	0.4232108	0.4327462	0.4237674
Guangdong	0.2634016	0.2899007	0.3126512	0.3024011	0.3169591	0.3209709	0.3165064
Guangxi	0.3491200	0.3589145	0.3729480	0.2416380	0.3634274	0.3611646	0.3795375
Hainan	0.9524520	0.9964487	0.9907939	0.9553034	0.9954190	0.9593492	0.9784249
Chongqing	0.4646565	0.5074940	0.5235644	0.3372729	0.4961558	0.5262665	0.4851076
Sichuan	0.3373443	0.3742235	0.3786302	0.2370386	0.3402674	0.3834045	0.3932356
Guizhou	0.4988735	0.5452514	0.6166058	0.3083357	0.4878509	0.6443778	0.6210713
Yunnan	0.5322736	0.5590896	0.5955488	0.3740565	0.5259864	0.5645711	0.5166952
Shaanxi	0.4602171	0.5057509	0.5407160	0.2720856	0.5305565	0.5152907	0.5060612
Gansu	0.5854470	0.6841674	0.6799426	0.3707109	0.6360880	0.6546783	0.6825792
Qinghai	0.9856687	0.9732032	0.9755061	0.9899182	0.9621627	0.9760146	0.9728759
Ningxia	0.6537416	0.6727847	0.6706504	0.4574878	0.7181004	0.7883163	0.8032753
Xinjiang	0.5473160	0.5840970	0.5975647	0.3103107	0.5714207	0.5808265	0.5704460

	2010	2011	2012	2013	2014	2015	2016
Beijing	0.6417642	0.6531069	0.7541431	0.9149307	0.8296898	0.7252711	0.7589733
Tianjin	0.7814954	0.6909507	0.6789032	0.8671803	0.7562392	0.6837094	0.7748075
Hebei	0.3067170	0.2727536	0.2794444	0.3185844	0.2870340	0.1991098	0.2292756
Shanxi	0.3139510	0.3004042	0.3443741	0.3946492	0.3702602	0.1842354	0.2768133
Nei Mongol	0.5044687	0.4915259	0.5229006	0.5728774	0.4872829	0.3122898	0.3773137
Liaoning	0.3819343	0.3515755	0.3648117	0.4395278	0.3672360	0.2651626	0.3339398
Jilin	0.5764215	0.5500565	0.5897822	0.7520957	0.6716793	0.4056204	0.5678384
Heilongjiang	0.5032531	0.4875700	0.5058963	0.6351338	0.5530856	0.3096839	0.3672020
Shanghai	0.4783291	0.4941208	0.5616891	0.6862169	0.6327447	0.5501573	0.5966957
Jiansu	0.3524482	0.3157944	0.3276320	0.3400925	0.3005621	0.2619756	0.2981941
Zhejiang	0.3333036	0.3260972	0.3727623	0.4552090	0.4055155	0.3394506	0.3877070
Anhui	0.4254377	0.3467439	0.3731608	0.4587991	0.4059777	0.2993870	0.3767023
Fujian	0.3932713	0.3555127	0.4287553	0.5118058	0.4457913	0.3387588	0.3963468
Jiangxi	0.4966026	0.4158080	0.4770290	0.5875184	0.5478671	0.3395279	0.3861419
Shandong	0.3047192	0.2840090	0.2938743	0.3387625	0.2946428	0.2237829	0.2562110
Henan	0.3229587	0.2687497	0.2823854	0.3147893	0.2767586	0.2097189	0.2737797
Hubei	0.3900179	0.3372231	0.3833929	0.4644424	0.4044834	0.3196340	0.3934400
Hunan	0.3914635	0.3760428	0.3928500	0.4717469	0.4358366	0.3372926	0.4159659
Guangdong	0.2923190	0.1454558	0.3005189	0.3582235	0.3108057	0.2189057	0.2834179
Guangxi	0.3631001	0.3414642	0.3533849	0.4593002	0.4282728	0.3408629	0.4030907
Hainan	0.9530852	0.9850138	0.9666136	0.9833183	0.9830935	0.9825937	0.9562796
Chongqing	0.4999147	0.4978723	0.5815277	0.6917279	0.6224802	0.4729544	0.5442778
Sichuan	0.3620418	0.3442544	0.3896750	0.4848928	0.4284747	0.3214764	0.3666093
Guizhou	0.5738526	0.5437887	0.5270854	0.5223386	0.4670348	0.3775688	0.4488717
Yunnan	0.4710401	0.3731459	0.4065183	0.4854036	0.4237257	0.3303215	0.3652472
Shaanxi	0.4686056	0.1823431	0.4769874	0.5464730	0.4805249	0.2893349	0.3806060
Gansu	0.6982809	0.5494128	0.5883489	0.7281180	0.6487596	0.3984338	0.4905297
Qinghai	0.9310086	0.2995270	0.8440800	0.9796880	0.8914924	0.4804231	0.6128669
Ningxia	0.5315265	0.6607165	0.6856841	0.8322059	0.7043213	0.4954588	0.5557223
Xinjiang	0.5389264	0.5017647	0.4581467	0.4996854	0.4151450	0.2611565	0.2976669

4. Training and examining of the hybrid SFA-Artificial Neural Network (SFANN) model used to evaluate the performance of ecological civilization policy

4.1 Construction of the model and selection of an evaluating index

Now we have obtained the regional annual eco-efficiency value above, but the evaluation result is static. Since the implementation of the ecological civilization policy has multiple effects on the economy and has a time accumulation effect, we use a multiple neural network with hidden layers in order to evaluate and predict the dynamic and cumulative efficiency of the ecological civilization policy.

The output layer node is the final output value, so the number of output layer nodes is 1 where the regional Gross Domestic Product (GDP) is used. The input layer node (ecological civilization policy) includes two parts: the production input policy and the reduction of major pollutants emissions policy. The production input policy stipulates the fixed capital input (total investment in fixed assets)and total wage bills of employed persons. Reduction of the major pollutants emission policy includes the allowed total amount of COD, ammonia nitrogen and SO2, taking into account the factor of DEA eco-efficiency evaluation and the region serial number;

therefore, the number of input layer nodes is 7.

We select a neural network with two hidden layers, and the number of nodes is determined by the following empirical formula:

$$H = \sqrt{N + O} + \alpha, 1 < \alpha < 10 \qquad (7)$$

where N is the number of input layer nodes and O is the number of output layer nodes.

We then normalize the input data of the neural network, and the normalization function is as follows:

$$u(z) = \frac{z - z_{min}}{zmin_{max}} \qquad (8)$$

where z is the input (output) sample, and zmin and zmax are the minimum and maximum values of the input (output) sample, respectively. That is to say, the data are normalized in the [0,1] interval.

The training parameters of the Neural Network are as follows:

Training function: Gradient Descent Optimizer

Activation function: f(x)= max (x, 0) (relu)

Learning rate: 0.03

Maximum number of iterations: 24000

Transfer function: linear transfer function (purelin)

After repeated training and adjustment, the number of nodes of the two hidden layers are: 11,7.

4.2 Training and examination of the hybrid model

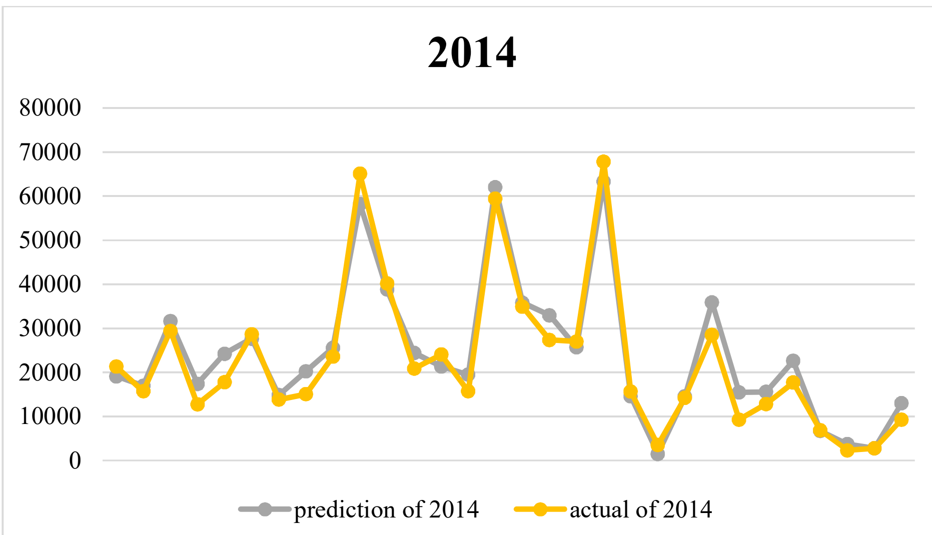
Since there is retardation of the impact of policies on the economy, when the model is trained and examined, the data are used in the following way: using the evaluation results of the regional eco-efficiency of the previous year to match the total investment in fixed assets, the total wage bills of employed persons, COD, ammonia nitrogen and SO2 of the year. The data from 2003-2013 are used as the trained set, the data from 2014-2016 are used as the examined set. All the data come from the 2003-2016 China Statistical Yearbook, and normalization processing is applied to the data(China, 2003-2016).

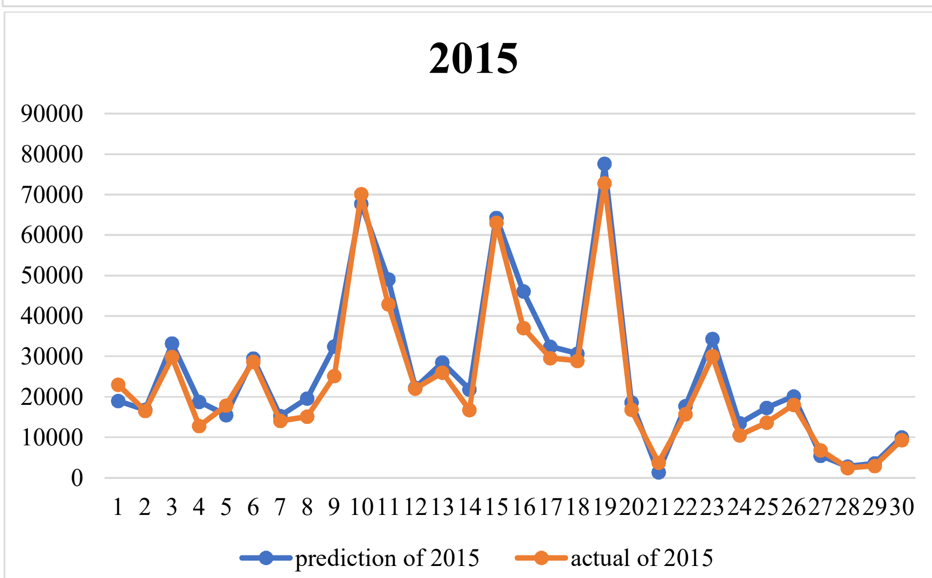
Substituting the data into the model, the prediction and error of the examined set are as follows(Table 4).

Table 3. The comparison of prediction and actual value

(Billion Yuan)	Prediction of 2014	Actual of 2014	Prediction of 2015	Actual of 2015	Prediction of 2016	Actual of 2016
Beijing	18887.9126	21330.83036	18712.70006	23014.59013	23544.23	25669.13
Tianjin	17188.77801	15726.93031	17061.03645	16538.18991	13644.02	17885.39
Hebei	31588.1589	29421.15	33176.86107	29806.10998	33156.51	32070.45
Shanxi	16761.26866	12761.48986	18780.1518	12766.49024	12030.84	13050.41
Nei Mongol	24758.79016	17770.1903	15694.22408	17831.50972	17681.77	18128.1
Liaoning	26961.15015	28626.57978	29283.27672	28669.02024	14566.29	22246.9
Jilin	14569.47578	13803.14028	14840.1562	14063.13022	14143.37	14776.8
Heilongjiang	20465.38121	15039.3798	19463.51476	15083.67025	14286.38	15386.09
Shanghai	26305.52939	23567.70013	31813.18174	25123.44971	25736.67	28178.65
Jiansu	60625.65887	65088.31966	68813.96007	70116.38027	71287.02	77388.28
Zhejiang	37890.71381	40173.02963	49056.26089	42886.49009	43785.4	47251.36
Anhui	24979.03296	20848.75004	22154.10447	22005.62967	28114.34	24407.62
Fujian	21505.38417	24055.76014	29924.90158	25979.81975	26234.51	28810.58
Jiangxi	19795.50291	15714.62973	21676.42641	16723.7801	19623.1	18499
Shandong	63182.84944	59426.59015	63333.14042	63002.33033	62964	68024.49
Henan	36646.45653	34938.24028	46481.1213	37002.16002	45440.76	40471.79
Hubei	32443.06764	27379.22017	32554.43604	29550.1902	31215.39	32665.38

Hunan	24602.68914	27037.32026	32113.17321	28902.20979	30522.24	31551.37
Guangdong	62907.72371	67809.8496	75667.61259	72812.55023	64434.82	80854.91
Guangxi	14667.35941	15672.89017	19130.6597	16803.11988	16649.02	18317.64
Hainan	1458.840687	3500.720207	1359.200858	3702.759985	3602.8	4053.2
Chongqing	14737.34787	14262.59979	18397.31039	15717.26994	16077.03	17740.59
Sichuan	35558.5254	28536.65987	34288.07679	30053.10006	29795.54	32934.54
Guizhou	14937.06366	9266.389843	14132.68471	10502.56016	13177.65	11776.73
Yunnan	15030.30574	12814.59012	16611.14162	13619.16994	15877.73	14788.42
Shaanxi	22669.75545	17689.9396	19718.91112	18021.85968	18163.31	19399.59
Gansu	6611.619107	6836.820398	5611.894253	6790.320252	9065.593	7200.37
Qinghai	3652.197244	2303.320131	2743.899195	2417.050188	2538.641	2572.49
Ningxia	2741.203328	2752.099727	3487.383481	2911.769862	2311.831	3168.59
Xinjiang	12930.33093	9273.4599	9854.21226	9324.80029	10082.66	9649.7





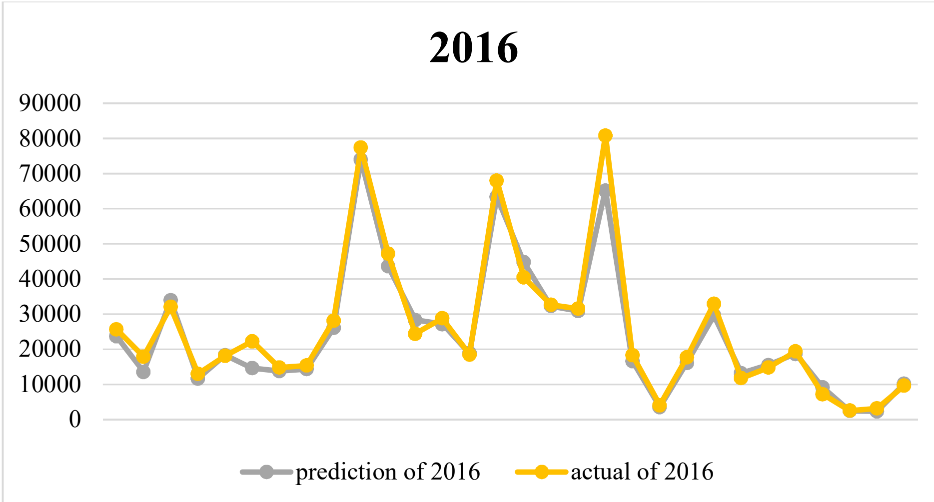


Figure 4. The comparison of prediction and actual value

It can be seen from the Figure 4 that the SFANN model has good accuracy in predicting policy performance. Some large errors , such as the error for Northern China in 2014, may be due to severe winter smog. Since there are emergency plans in ecological civilization policies, the predicted results are generally higher than the actual value. Most of the predictions are accurate if the policy remains stable and continuous to some degree.

5. Prediction of the economic impact of the Total Emission Reduction Policy by using the SFANN model on a five-year plan (2016-2020)'s data

The trained SFANN model system can help us predict the impact of ecological civilization policies on the economy, help us assess whether policies are feasible and can help in achieving established policy goals.

In the following case, we try to predict the supposed emission and energy consumption data from the set goal of saving energy and cutting emissions, which was issued in the five-year plan (2016-2020) by the State Council of China on Jan 5, 2017(Council, 2016). Additionally, we assume that the increase in total wages is the same as the rate of GDP growth. The data of Xinjiang Province is the sum of Xinjiang and China Xinjiang Production and Construction Corps in the five-year plan.

We adjust different input values, the fixed asset investment, of the trained SFANN model system until the output value, the predicted economic growth rate, is greater than the lowest set economic growth rate. The final fixed asset investment growth is shown in the next table(Table 4).

We can treat this as the basis for measuring whether a policy is feasible. If we cannot afford a high production input, then we have to reduce environmental requirements and allow more emissions. Otherwise, if we want to maintain economic growth and protect the environment, we must increase investment. Additionally, the efficiency improvement caused by technological transformation accumulates growth year by year2.

Table 4. The target of economic growth

	Lower limit of GDP(Billion)	Lower limit of Total wage(Billion)	Upper limit of COD(Ten thousand tons)	Upper limit of Ammonia nitrogen (Ten thousand tons)	Upper limit of SO_2(Ten thousand tons)
Beijing	31531.98282	10532.68	13.8244	1.38435	4.628
Tianjin	22658.75356	2951.17	17.89896	1.99682	13.9425
Hebei	40836.9538	4062.99	97.8561	7.784	79.8048
Shanxi	17491.19769	3042.83	33.38024	4.1082	89.648
Nei Mongol	24430.71404	2291.2	77.62724	4.3617	109.5501
Liaoning	39279.04196	4494.16	101.1055	8.78256	77.504

Jilin	19267.70686	2178.3	68.94384	4.81104	29.7578
Heilongjiang	20665.9351	2785.52	130.9138	7.5609	40.6107
Shanghai	34421.30378	8975.85	16.9974	3.6805	13.664
Jiansu	96065.51712	13086.52	91.2229	11.92482	66.808
Zhejiang	58758.20799	9134.09	55.20256	8.1164	44.6374
Anhui	30149.62018	3605.52	78.48611	8.29576	40.3284
Fujian	35594.6049	4739.13	58.44146	8.21215	33.79
Jiangxi	22913.02794	2902.25	68.48292	8.13852	46.4728
Shandong	86318.6521	8967.77	155.19608	13.18052	111.3761
Henan	50696.16593	6294.45	105.03552	11.20062	82.3896
Hubei	40486.32122	4755.98	88.84761	10.26414	44.112
Hunan	39598.53246	3836.38	108.57223	13.58389	47.0445
Guangdong	99759.50368	16118.8	143.97824		65.7951
Guangxi	23021.73062	2466.7	70.4088	7.5933	36.6444
Hainan	5073.102094	688.88	18.56452	2.0601	3.23
Chongqing	21534.02201	3094.48	35.16948	4.69437	40.6556
Sichuan	41175.3515	5813.28	103.45408	11.31354	60.2784
Guizhou	14389.41739	2177.89	29.12445	3.23232	79.329
Yunnan	18659.44318	2615.91	43.83477	4.78179	57.7863
Shaanxi	24691.51004	3647.72	44.019	5.004	62.475
Gansu	9303.326872	17089.09	33.57126	3.4224	52.4952
Qinghai	3311.56797	490.9	10.31527	0.986	14.1752
Ningxia	3989.377244	581.33	20.8468	1.60866	31.4688
Xinjiang	12775.78412	2555.35	64.97352	4.43232	74.39467584

From the data in the Table 5 we can see the following trend: In key areas, especially those suffering from heavy pollution, when emissions are heavily cut, those provinces have to input(invest) more than others to achieve the same economic growth rate. The increased investment can be invested in low emission industries, or in transforming the technology of existing production capacity to cut emissions. In contrast, in the 'greener ' areas, the investment growth needs less input. Such a nonlinear relationship is well expressed by the SFANN model.

Table 5. The prediction of fixed asset investment growth rate, which can suit 2020's economic growth target

	Fixed asset investment growth rate in 2020 (%)
Beijing	28.32466431
Tianjin	37.78462552
Hebei	27.91036208
Shanxi	16.24425275
Nei Mongol	24.21763524
Liaoning	48.83809452
Jilin	20.01606723
Heilongjiang	19.77744736
Shanghai	26.66693875
Jiansu	7.160918072
Zhejiang	38.24451596
Anhui	15.06136148
Fujian	9.207697159
Jiangxi	4.650525687
Shandong	58.32698191
Henan	24.25488431
Hubei	23.3531327
Hunan	25.98054552
Guangdong	63.5407064
Guangxi	10.17626221
Hainan	20.85351803
Chongqing	15.31349729
Sichuan	18.19825216
Guizhou	15.0595301
Yunnan	9.633360071
Shaanxi	15.52037702
Gansu	7.601759223
Qinghai	7.327958411
Ningxia	15.16193598
Xinjiang	5.513145586

6. Conclusions and Policy Implications

This paper proposes the SFANN model, which is used to evaluate the performance of ecological civilization policy on the basis of regional eco-efficiency evaluation. By training and examining the evaluation results, this paper provides a quantitative evaluation of the ecological civilization policy in different provincial regions from 2003-2016 and tries to predict the performance of emissions reduction policy in environmental planning in the 13th Five-Year Plan.

Based on the study's results, we can draw the following conclusions. (1) Development and the environment can achieve a win-win situation. We cannot obtain economic development at the expense of environmental pollution, and we cannot pursue environmental protection at the risk of economic stagnation. In addition to protecting the environment, the ecological civilization policy has a huge impact on economic development. We can achieve a dynamic balance between economic development and environmental protection by controlling the input of ecological civilization policies. (2) Regional eco-efficiency differs based on not only on the input of ecological civilization policy but also on the local environmental capacity and risk attitude. Therefore, when the ecological civilization policy is evaluated, a different method should be used the main functions and positions of different areas. (3) The performance of ecological civilization policy in the regions of different eco-efficiencies can be regulated through different policies. In developed areas with high ecological efficiency, although current environmental problems are prominent, , it will not be difficult to achieve the goal of environmental quality improvement due to a good foundation. Less-developed areas with low ecological efficiency need to make a great effort to improve the quality of ecological environment. Developing areas with high ecological efficiency require a large number of policies for support, in order to protect their fragile ecological environment and develop their economy at the same time; developed areas with low ecological efficiency need precise control of policies because of their large development base. It is necessary to avoid both over-regulation and a lack of regulation.

Because of the Artificial Neural Network's special negative feedback mechanisms, we suggest eight ways to improve the performance of ecological civilization from the evaluation result: (1) boost the legislation regarding ecological civilization, (2) complete an organizational decision-making mechanism of ecological civilization, (3) establish an economic policy system for ecological civilization, (4) strengthen the adjustment mechanics of interests, (5) set up public participation mechanisms, (6) construct a supervision mechanism for ecological civilization policy, (7) improve the performance evaluation mechanics of ecological civilization policy, and (8) deepen the structural reform of the supply-side for supporting systems.

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