Original Research

Green Total Factor Productivity of Hog Breeding in China: Application of SE-SBM Model and Grey Relation Matrix

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Abstract

Green total factor productivity (GTFP) is an index that demonstrates the concept of sustainable development. It can be used to measure the degree of coordination between industrial development and environmental protection. Considering shortage of studies on agricultural GTFP and the urgency of hog breeding's long-term development, our paper puts forward the study of GTFP of pig-breeding in China for the first time. Firstly, five main pollutants discharged by hog breeding of 18 provinces from 2007 to 2011 are estimated respectively. They are added into a variables list that is commonly used to estimate total factor productivity. Then, based on those data, the Super-SBM model is employed to estimate GTFP of hog breeding for three kinds of scales in these provinces. The empirical result shows: 1) GTFP of 18 provinces are higher than that at the national level, but the majority of them do not achieve efficient production; 2) hog breeding industry transferred from traditional producing areas to middle areas is not followed up with efficiency improvement. other areas, like northeast, coast, and southwest see GTFP transference that is more efficient due to their resource endowments.Via gray correlation analysis, this paper finds that, in most cases, GTFP is discouraged by increasing pollution control degree. Finally, we proposed some suggestions to promote sustainable development of hog breeding.

Keywords: hog breeding, green total factor productivity, super efficiency, slack-based measure, DEA

Introduction

Green Productivity is a strategy for enhancing productivity and environmental performance for overall socio-economic development [1]. Green total factor productivity (GTFP) can be used to demonstrate the concept of sustainable development. With agricultural nonpoint source pollution being caught greater attentions [2, 3], GTFP has been gradually applied to agriculture study abroad to offer an approach to assess environmental efficiency of it since 1990s [4, 5]. But in China it is still mostly used in research regarding industry. There are only a few articles accounting environmental elements into the total factor productivity of agriculture [3, 6], and no article evaluates that of hog breeding.

As traditional animal husbandry, the hog industry makes up a large proportion of Chinese animal husbandry. But nowadays it is taking criticism for its environmental damage, especially its negative impact on water environment. How to stabilize hog production has been the primary task for development of animal husbandry [7], which will still be for a long time to come. According to literature, we find that lots of Chinese scholars have tried to discuss this subject through total factor productivity. Those studies appear in two main research directions: (1) How to use natural resources effectively to improve production efficiency

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and achieve industrial upgrading is becoming very popular in this research field. Nowadays, some researchers have tried to estimate the efficiency of Chinese hog breeding industry development from the perspective of province and scale. They estimated hog-bleeding's total factor productivity of different scales and provinces, and gave advice of optimal breeding scale for different provinces and areas [8, 9]. Zhang Zhen and Qiao Juan [10] studied provinces that have advantages of hog breeding and found that their large-scale farming and medium-scale farming is relatively inefficient. (2) Some scholars studied domestic layout changes of the hog breeding industry to analyze the hog industry development trend. They found the eastern region was tending to retire from the column of the main producing areas, and the hog industry was transferring from the economically developed eastern coastal area to inland and remote areas [11-13]. Furthermore, we think the relationship between hog-breeding regional distribution and its environmental efficiency should not be generally ignored. But in fact, discussion combining both of them can help to assess whether the hog breeding industry is shifting to input-led development areas or environment-led development area objectively, and whether it aims at sustainable development or not.

Given the above, this paper intends to solve two major problems:

(1) Estimate GTFP of hog breeding for 18 provinces.

(2) In order to make sure whether the transfer of industry is followed up with environment efficiency improvement, based on the GTFP estimation, this paper will make a comparative study on GTFP between provinces and regions.

Methodology

Method of Data Envelopment Analysis (DEA) is adopted in this paper. In contrast to Stochastic Frontier Analysis (SFA), DEA neither needs to assume function form in advance nor to test the validity and rationality of estimated parameters. This method is more objective and convenient for it does not need to endow relative weight to index subjectively and deal with the multi-input and multi-output more efficiently [14].

Tone [15] put forward the Slacks-based measure of efficiency model (SBM) that introduces slack variable to object function. Since then deficiency of using a traditional DEA model (like CCR and BCC models) with radial and angular methods is solved. Meanwhile this model provides a new approach to analyze the effects of environmental factor inputs.

The task of estimating efficiency of (x_0, y_0) by the SBM model requires us to formulate the following fractional program in λ, s^-, s^+ [15].

$$\text{Min} \quad \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\frac{1}{s}\sum_{i=1}^{s} s_i^+ / y_{i0}} \tag{1}$$

Subject to

$$x_0 = X\lambda + s^-, \quad y_0 = Y\lambda - s^+, \quad \lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0 \tag{2}$$

...where $X = (x_{ij}) \in R^{m\times n}$ and $Y = (y_{ij}) \in R^{s\times n}$ indicate input and output matrices, respectively. λ is a non-negative vector in R^n. The vectors $s^- \in R^m$ and $s^+ \in R^s$ indicate the input excess and output shortfall, respectively. They are called slacks. From the conditions $X>0$ and $\lambda \geq 0$ it holds $x_0 \geq s^-$.

While estimating efficiency by traditional CCR [16] and BCC models [17], scholars always found more than one DMU score 1. It made them fail to rank those DMUs. To solve this problem, a super-efficiency-DEA model (SE-DEA) was put forward by Andersen and Petersen [18]. After introduction of SBM model, super-efficiency-SBM model (SE-SBM) was put forward to solve the same problem that occured by using this new model. Both SBM and SE-SBM models have options between assumptions of constant return to scale (CRS) and variable return to scale (VRS). VRS is thought to match the actual situation of the hog industry better. So in the process of estimating TFP, SBM-VRS model is adopted by this paper. If more than one GTFP of DMU scoring 1 arises, super-SBM-VRS model will be adopted.

The super-efficiency of (x_0, y_0) can be defined as the optimal objective function value δ^* of the following program:

$$\delta^* = \min \delta = \frac{\frac{1}{m}\sum_{i=1}^{m} \bar{x}_i / x_{i0}}{\frac{1}{s}\sum_{r=1}^{s} \bar{y}_r / y_{r0}} \tag{3}$$

Subject to

$$\bar{x} \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j, \quad \bar{y} \leq \sum_{j=1,\neq 0}^{n} \lambda_j x_j, \quad \bar{x} \geq x_0 \text{ and } \bar{y} \leq y_0, \quad \bar{y} \geq 0,\ \lambda \geq 0. \tag{4}$$

Index Selection and Data Statement

Selection of Provinces

The National Layout Plan of Hog Dominant Producing Region (2008-15) lists 19 provinces those have advantage of producing hog. Hog production in these provinces accounts for more than 80% of national output. So they can be viewed as major productive forces of the Chinese hog breeding industry. Considering availability of data, Fujian Province is excluded owing to the lack of some crucial data. Therefore, the paper mainly focuses on the other 18 hog breeding advantageous provinces. Those are Jiangsu, Zhejiang, and Guangdong in coastal areas of China; Liaoning, Jilin and Heilongjiang in the northeastern area of China; Hebei, Shandong, Anhui, Jiangxi, Henan, Hubei, and Hunan in the Middle area of China; Guangxi, Sichuan, Chongqing, Yunnan, and Guizhou in southwest China. All the data range from 2007 to 2011. National level data are collected according to a national cost-benefit agricultural compilation. Removing provinces whose data is incomplete, finally small-scale includes 24 provinces, both medium-scale and large-scale containing 27 provinces[1)].

Selection of Input and Output Variables

While selecting variables, we try to choose those in the form of physical quantity as many as possible. So, finally, the labor input of each accounting unit (day), amount of concentrated feed (kg), piglet weight (kg), and material and service fee[2)] (in RMB) are chosen as input index. Desirable output indexes choose net output of main product (the weight of main product minus piglet weight, kg) and output value of by-products (RMB). Undesirable output variables are the major pollutants' emissions. For the sake of estimating GTFP more accurately, our paper takes as many pollutants as possible into consideration. Finally, chemical oxygen demands (COD), total nitrogen (TN), total phosphorous (TP), CH_4 and N_2O, are selected.

Pollutant is undesirable output in the process of producing. While estimating input-output efficiency, how to deal with it has also been discussed. Like Hailu and Veeman [19] treated it as input. Seiford and Zhu [20] converted pollutants to "normal output." Färe and Grosskopf [21] dealt with pollutants as "bad output" by direction of the distance function approach. Korhonen and Luptacik [22] proved that results of dealing undesired output with various methods are convergent. Also Coelli T, Perelman S [23] believes that in most cases, those choices will not affect the outcome too much. Considering that the pollutant has similar characteristics of input variables – both of them are thought to be as little as possible – we list it as an input variable of environmental factor. In fact, some economics theories also viewed it as input[3)].

Data Sources

All the data come from National Cost-Benefit Compilation of Agricultural Product and China Husbandry Yearbook (2008-12). The sources and usage of relevant pollution coefficients refer to the First National Census of Pollution Sources and IPCC Good Practice Guidelines for National Greenhouse Gas Inventories and Uncertainty Management.

Data Processing Instructions

The paper uses the min-max standardized approach to integrate the five undesirable output variables into one variable. This method allows data to be dimensionless and makes data comparable. It also can help to integrate substances of different properties without losing their original characteristics. In addition, it will not only be convenient to discuss the contribution of environmental input factor to GTFP, but also make the number of input-output index up to the DEA rule of thumb proposed by Golany and Roll – the number of DMU should be at least twice as many as that of the input-output variable [24]. The standardization treatment formula is shown as follows:

$$x_i' = 0.1 + 0.9 \times \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

...where x_i, $x_{\min}$, $x_{\max}$, and x_i' represent the actual value, maximum value, minimum value, and standardized value for some index in some year, respectively. After treatment, the value of x_i' is [0.1, 1]. For convenience and without losing generality, the paper also processes the other date in the same way.

Empirical Analysis

Overall Analysis

There are divergent views on the relationship between environmental damage and productivity. Some support environmental damage contributing to productivity [25], some think it will inhibit productivity [26], and some proved it should be viewed dependent on different study objects [27, 28]. It means if we ignore the impact of hog breeding industry growth on environmental services quality, GTFP of hog breeding will likely be overestimated or underestimated.

DEA-Solver-Pro 8.0 soft is adopted to carry out research. In order to compare GTFP between scales, we use a panel data containing three sizes to build a production frontier. GTFP estimated by model of SBM-VRS show that efficiencies of most decision making unions (DMU) score 1. In order to rank those DMUs, we re-estimate those by using the SE-SBM model. Table 1 lists estimate results for

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1) Small scale includes: Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan, Chongqing, Jiangxi, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia; medium-scale includes: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan, Chongqing, Jiangxi, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; large-scale includes: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Shanghai, Fujian, Zhejiang, Anhui, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan, Chongqing, Jiangxi, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia.

2) Excludes statistical indicators of physical form, the other statistical indicators of fee forms are lumped into the cost of material and services.

3) Some neoclassical growth models view pollution as input factors, such as the optimal control model (Keeler, Spenee and Zeekhauser, 1971) [29] and two regional general equilibrium models (Gradus, Smulders, 1993) [30]. With the development of Endogenous Growth Theory, some endogenous growth models start to treat pollution as input factors. For example, Bovenberg and Smulders (1995, 1996) [31, 32] revised an endogenous growth theory model created by Romer (1986, 1990) [33, 34] to be a model involving an environmental variable.

Table 1. GTFP of large-scale hog breeding.

DMU	2007					2011				
	SBM-V		SUP		SUP ranking	SBM-V		SUP		SUP ranking
	A	B	A	B		A	B	A	B	
HB	0.243	0.250	0.243	0.250	18	1	1.000	1.326	1.261	2
LN	0.377	0.352	0.377	0.352	12	0.785	0.758	0.785	0.758	13
JL	0.309	0.319	0.309	0.319	16	1.000	1.000	1.006	1.006	12
HLJ	1.000	1.000	1.035	1.028	4	0.351	0.341	0.351	0.341	17
JS	0.184	0.253	0.184	0.253	17	1.000	1.000	1.157	1.147	3
ZJ	0.308	0.385	0.308	0.385	11	0.402	0.476	0.402	0.476	16
AH	0.330	0.441	0.330	0.441	9	0.670	0.697	0.670	0.697	14
JX	0.378	0.496	0.378	0.496	8	0.608	0.646	0.608	0.646	15
SD	0.331	1.000	0.331	1.027	5	0.232	0.256	0.232	0.256	18
HEN	0.325	0.328	0.325	0.328	13	1.000	1.000	1.099	1.081	5
HUB	0.379	0.394	0.379	0.394	10	1.000	1.000	1.100	1.080	6
HUN	1.000	1.000	1.238	1.266	2	1.000	1.000	1.009	1.009	11
GD	0.303	0.322	0.303	0.322	15	1.000	1.000	1.056	1.045	8
GX	0.284	0.323	0.284	0.323	14	1.000	1.000	1.088	1.071	7
CQ	1.000	1.000	1.105	1.084	3	1.000	1.000	1.404	1.576	1
SC	1.000	1.000	1.000	1.342	1	1.000	1.000	1.148	1.119	4
GZ	1.000	1.000	1.023	1.023	6	1.000	1.000	1.001	1.041	9
YN	0.330	0.501	0.330	0.501	7	1.000	1.000	1.012	1.020	10

Values listed under SBM-V represent the efficiency score estimated by the SBM-VRS model, SUP represents the efficiency score estimated by Super-SBM-VRS model. HEB, LN, JL, HLJ, JS, ZJ, AH, JX, SD, HEN, HUB, HUN, GD, GX, CQ, SC, GZ, YN respectively stand for Hebei province, Liaoning province, Jilin province, Heilongjiang province, Jiangsu province, Zhejiang province, Anhui province, Jiangxi province, Shandong province, Henan province, Hubei province, Hunan province, Guangdong province, Guangxi province, Chongqing province, Sichuan province, Guizhou province, and Yunnan province. “A” refers to TFP score, “B” refers to GTFP score.

large-scale hog breeding. We find changes between these two indexes. In 2007 most DMUs’ GTFP are higher than TFP, but in 2011 the reverse happens. This means something important may be ignored by TFP.

Table 2 displays the correlation coefficient between input and output indexes of large-scale hog breeding. The correlation coefficient between pollutant and main product reaches 0.550, only less than correlation a coefficient between feed inputs and piglet weight. Such a correlation coefficient for medium-scale hog breeding reaches 0.650, for small-scale hog breeding is 0.755 (due to space limitations, correlation coefficient measurement results of these two are no longer listed). Compared with other indexes, correlation coefficients between the environmental factor input index and output index is higher, and positive. It indicates that hog breeding depends more on environmental factor inputs. It also can say GTFP depends more on environmental factor, and verifies the rationality of the introduction of environmental factors input indexes.

Having a look at the average GTFP of 18 provinces while developing the trend of hog breeding GTFP on every scale is basically identical with that of the whole nation (Table 3). But compared to the year or the average five years, the GTFP of 18 provinces is far above that of the whole nation. This also verifies the rationality of The National Layout Plan of Hog Dominant Producing Region (2008-15), taking these 18 provinces as hog breeding advantageous provinces. Even though the average GTFP of 18 provinces with breeding superiority still does not score 1. This means that even the provinces with breeding superiority still have space to improve their efficiency.

Considering hog breeding GTFP of 2011 in particular, results (Table 3) show that the national level GTFP of small-scale hog breeding in 2011 is 0.388, the GTFP of medium scale is 0.532, and GTFP of large scale is 0.450, which illustrates that the efficiency of hog breeding is not so high for all. Compared with the average GTFP of three hog breeding scales in the last five years, the small and medium scales are similar, but the large hog breeding GTFP

Table 2. The correlation coefficient between indexes of large-scale hog breeding.

	LI	PW	CF	MSF	POL	BYP	MP
LI	1	-0.227	-0.029	-0.109	0.295	-0.168	0.067
PW	-0.227	1	-0.407	-0.096	-0.776	0.043	-0.576
CF	-0.029	-0.407	1	0.156	0.617	0.395	0.755
MSF	-0.109	-0.096	0.156	1	0.029	0.263	0.200
POL	0.295	-0.776	0.617	0.029	1	-0.007	0.550
BYP	-0.168	0.043	0.395	0.263	-0.007	1	0.456
MP	0.067	-0.576	0.755	0.200	0.550	0.456	1

LI, PW, CF, MSF, POL, BYP, MP indicate labor input of each accounting unit (day), piglet weight (kg), amount of concentrated feed (kg), Material and service fee (RMB), pollution, value of byproduct (RMB), weight of main product (kg).

Table 3. National level GTFP and 18 province level GTFPs estimated by SE-SBM-VRS model.

Scale type	DMU	2007	2008	2009	2010	2011	Average score of five years	Average year-on-year change rate (%)
Small scale	Nation	0.673	0.595	0.53	0.47	0.388	0.531	-26.386
	18 province	0.883	0.81	0.91	0.731	0.546	0.776	-15.125
Medium scale	Nation	0.532	0.521	0.496	0.451	0.532	0.507	-6.034
	18 province	0.954	0.743	0.732	0.843	0.864	0.827	-16.66
Large scale	Nation	0.416	0.397	0.403	0.449	0.450	0.423	2.002
	18 province	0.619	0.688	0.76	0.84	0.924	0.766	29.793

is 0.1 lower than the other. Generally speaking, the average GTFP of small-scale hog breeding declined from 2007 to 2011 by 42.439%. In these 5 years its average year-on-year change rate is -26.386%. GTFP of Medium-scale hog breeding has a trend of pick up after a previous slight decline. It declined 0.014% in five years and its average year-on-year change rate is -6.034%. GTFP of large-scale hog breeding shows a growing trend from 2008. It increased by 8.045% in 5 years and its average year-on-year change rate is 2.002%. So the efficiency of large-scale hog breeding nowadays is highest, medium-scale ranked second, and small-scale is the lowest. Keeping current trends of GTFP, large-scale and medium-scale hog breeding will become the relatively advantageous kinds of hog breeding scale in the future.

Table 4 offers changes for ranking and average score of large-scale hog breeding GTFP which is observed based on Table 1. The "Rank for average score" column changes the rate of average ranked GTFP, with which we can compare average GTFP between provinces. "Rank for year-on-year change" lists rankings for average year-on-year change rate of GTFP, which can be used to compare the overall extent of change trends and fluctuations between provinces. Adding these two indexes together, we can get one comprehensive index. In the same way, we estimate comprehensive index for medium-scale and small-scale (the results are listed in Table 5). The paper ranks comprehensive index to further compare hog breeding efficiency between 18 provinces. We find the smaller the comprehensive index is, the higher position it will be ranked.

According to Table 5, comprehensive ranking of large-scale hog breeding GTFP is: Hebei > Guangxi > Yunnan > Chongqing > Guangdong > Hubei > (Jilin, Sichuan, Guizhou) > Jiangxi > Anhui > (Heilongjiang, Jiangsu) > (Zhejiang, Shandong).

Comprehensive ranking of medium-scale hog breeding GTFP is: Hebei > Yunnan > Guangdong > Zhejiang > (Jiangsu, Jiangxi) > Hunan > Guangxi > Heilongjiang > Guizhou > Hubei > Chongqing > (Anhui, Sichuan) > Liaoning > (Jilin, Shandong) > Henan.

Comprehensive ranking of small-scale hog breeding GTFP is: Hebei > Jiangxi > Chongqing > Guizhou > Hunan > Heilongjiang > Zhejiang > Sichuan > (Jiangsu, Guangdong) > Guangxi > Yunnan > Jilin > Liaoning > Anhui > Hubei > Henan.

An Analysis on GTFP of 18 Provinces on Perspective of Region

By summarizing comprehensive indexes of provinces included in four areas (those are northeast, coastal, middle, and southwest area of China) we get an approach to compare environmental efficiency between these four areas. In Table 6 it is easy to find that ranking for large scale is:

Table 4. Changes for ranking and average score of large-scale hog breeding GTFP.

DMU	SUP ranking change	Average score of five years	Rank for average score	Average year-on-year increase rate (%)	Rank for year-on-year change
HB	16	0.828	6	289.113	1
LN	-1	0.583	16	82.101	8
JL	4	0.642	13	126.677	4
HLJ	-13	0.719	10	-37.533	17
JS	14	0.419	18	82.055	9
ZJ	-5	0.443	17	18.923	13
AH	-5	0.621	15	51.184	11
JX	-7	0.748	8	63.686	10
SD	-13	0.644	12	-46.633	18
HEN	8	0.642	14	119.277	5
HUB	4	0.738	9	109.378	7
HUN	-9	0.987	4	-27.569	16
GD	7	0.693	11	143.831	3
GX	7	0.767	7	171.838	2
CQ	2	1.265	1	20.888	12
SC	-3	1.054	2	-26.847	15
GZ	-3	1.050	3	3.330	14
YN	-3	0.943	5	110.169	6

southwest area > northeast area > coastal area > middle area. Ranking for medium scale is: coastal area > northeast area > southwest area > middle area. Ranking for small scale is: coastal area > northeast area > southwest area > middle area.

Middle area is a new rising dominant hog breeding region adjacent to the eastern area. This geographical advantage is good for it to introduce new breeding technology. It is also rich in rice, wheat, and green feed. But this area lacks of some of the main feed supply such as corn and soybean [5] and relies too much on input-led growth, belonging to the typical factor input leading pattern [3]. So compare to other areas, all three kinds of hog breeding scale in middle area are found to be the lowest. It is roughly in line with reality. Ranking for three scales of the middle area shows: large scale > medium scale > small scale. Relatively speaking, large-scale takes advantage of environmental efficiency in this area.

Northeast is one of the three main producing areas of maize. So it is a place rich in feed resources, which brings low production costs. It is also a place hog production has a higher degree of scale and organization. So that production efficiency of the northeast area ranked second among four areas. Ranking for three kind scales of northeast area shows as: small scale > large scale > medium scale.

Because of the geographic advantage and urban planning requirements, a certain degree of self-sufficiency and exports increase become coastal area's development goal. It is an economically developed region, where capital is abundant and its geographical advantage makes it easier to access international advanced production technology. But this area bears the highest cost of labor and capital. Ranking for three kind scales of coastal area shows as: medium scale > small scale > large scale. We can find small-scale and medium-scale farming ranked higher than large-scale farming. This is also in line with reality, because small-scale and medium-scale farming require lower technology and factor inputs than large-scale farming.

Southwest area is another main producing area of maize in China. Cost advantages of labor, land, and other factors make the the southwest area more conducive to large-scale farming. In contrast to the other three areas, large-scale farming of the southwestern area possesses highest efficiency. Ranking for three scales of the southwest shows as: large scale > small scale > medium scale. We can find that its large scale is better than small scale and medium scale. This means the southwest area can make full use of geographical advantages, and develop hog industry on the basis of local conditions.

In view of the above analysis, it can be concluded: coastal areas have advantages of capital and technology, northeast and southwest regions have that of resources. These three areas can make full use of its comparative

Table 5. Comprehensive ranking of 18 provinces' GTFPs.

	HEB	LN	JL	HLJ	JS	ZJ	AH	JX	SD	HEN	HUB	HUN	GD	GX	CQ	SC	GZ	YN
Large-scale	3.5	12	8.5	13.5	13.5	15	13	9	15	9.5	8	10	7	4.5	6.5	8.5	8.5	5.5
Rangking	1	13	7	15	15	17	14	10	17	11	6	12	5	2	4	7	7	3
Medium-scale	2	14.5	15.5	8	6	5.5	13.5	6	15.5	17.5	11	6.5	5	7.5	11.5	13.5	8.5	3.5
Ranking	1	15	16	9	5	4	13	5	16	18	11	7	3	8	12	13	10	2
Small-scale	3	13	12	7	9.5	7	13.5	5	15	16.5	14	6.5	9.5	10	5.5	8	6	10
Ranking	1	14	13	6	9	6	15	2	17	18	16	5	9	11	3	8	4	11

Table 6. Comprehensive ranking of four areas' GTFPs.

	Large-scale	Ranking	Medium-scale	ranking	Small-scale	Ranking
Northeast area	34	2	38	2	32	2
Coastal area	35.5	3	16.5	1	26	1
Middle area	68	4	72	4	73.5	4
Southwest area	33.5	1	44.5	3	39.5	3

advantages to improve their production efficiency. So it is not surprising to find relative environmental efficiency of some scale of hog breeding in one corresponding area. In contrast, as an emerging producing area, the middle area performs at relatively low efficiency, without late-mover advantage.

An Analysis on Grey Relationship between Pollution Control and GTFP

Consideration of environmental factors is what makes GTFP different from TFP. The above have proved there is a close relationship between pollutant and output. In fact, the redundant[4)] environmental factor input offered by DEA-Solver-Pro 8.0 also supports the importance of its influence. In this part, we try to find how pollution control will affect GTFP. We employ gray correlation matrix of gray correlation analysis to make an objective assessment for whether it is strong pollution-control-led, and then compare their correlation grade between hog breeding GTFP and pollution control.

Gray correlation matrix of gray correlation analysis is a method created to analyze the advantage of system features and related factors. Its principle is shown as follows:

Given Y_i (i = 1, 2,..., s) is a sequence of system characteristic behavior and X_j (j = 1, 2,..., m) is a sequence of related factor behaviors. γ_{ij} is correlation grade between Y_i and X_j.

$$\Gamma = (\gamma_{ij}) = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1m} \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \gamma_{s1} & \gamma_{s2} & \cdots & \gamma_{sm} \end{bmatrix} \tag{5}$$

Equation (5) is the gray relational matrix. If there is $l, j \in \{1, 2, ..., m\}$ meet $\gamma_{il} \geq \gamma_{ij}$ (i = 1, 2,..., s), we can say system factor X_l is superior to system factor X_j. It can be marked as $X_l \phi X_j$. If always $\forall j$ = 1, 2,..., m, and $X_l \phi X_j$, X_l will be optimal factor.

In order to identify GTFP of provinces are strong pollution-control-led or weak pollution-control-led, this paper uses the provinces' GTFP as behavior sequence Y_i (i = 1, 2,..., 18). Pollution control of a national level and province are used as level relative factor behavior sequence X_j (j = 1, 2). National level pollution control represents the behavior of a relatively weak pollution control behavior. 18 provinces level pollution control represents the behavior of a relatively strong pollution control behavior. Gray correlation matrix can be expressed as:

$$\Gamma' = (\gamma_{ij}) = \begin{bmatrix} \gamma_{11} & \gamma_{21} & \cdots & \gamma_{181} \\ \gamma_{12} & \gamma_{22} & \cdots & \gamma_{182} \end{bmatrix}^T$$

...where i = 1,2 ... 18, on behalf of Hebei, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Chongqing, Sichuan, Guizhou, and Yunnan, respectively. j = 1, 2, respectively, on behalf of national level and 18 province levels.

We use growth rate of pollutant emission to represent pollution control degree. Low growth rate refers to weak pollution control degree. High growth rate refers to strong pollution control degree. Fig. 1 displays growth rate of the nation and 18 provinces. We can find that all the scale of farming growth rate of 18 provinces is higher than that of the nation (Fig. 1). Therefore, the paper views the national level sequence as related factors behavior sequence of relatively high pollution control degree, and views 18 province-level sequences as related factors behavior sequence of relatively low pollution control degree.

Γ_1', Γ_2', Γ_3' represent GTFP-pollution control gray correlation matrix of large-scale farming, medium-scale farming, and small-scale farming, respectively. Results are listed in Table 7. In the case of large-scale farming, γ_{11} (=0.959) > γ_{12} (=0.895). That means in Hebei national level pollution control-GTFP gray correlation is stronger than 18 province levels. Its GTFP is under strong pollution control. Similarly, we can learn that GTFP of Liaoning, Heilongjiang, Jiangsu, Anhui, Jiangxi, Henan, Hubei, Guangxi, and Chongqing are under strong pollution control. That means GTFP of these provinces are more affected by pollution control degree. Firstly we rank provinces under strong pollution control, and then rank provinces under pollution control. The ranking for pollution control-GTFP gray correlation of 18 provinces is: Hebei > Guangxi > Jiangxi > Hubei > Liaoning > Henan > Heilongjiang > Anhui > Jiangsu > Chongqing > Yunnan > Guangdong > Jilin > Hunan > Zhejiang > Guizhou > Sichuan > Shandong.

Compare with GTFP comprehensive ranking of large-scale farming (Table 7), we find gray correlation ranking of Hebei and Guangxi strictly correspond to the GTFP rank-

4) Redundancy is projection of input (or undesirable output) data on "best practices" technology frontier, on behalf of ratio of inputs (or undesirable output) can be reduced.

Table 7. Gray correlation matrix.

Province	Γ_1'		Γ_2'		Γ_3'	
	National	18 province	National	18 province	National	18 province
HB	0.959	0.895	0.604	0.851	0.571	0.558
LN	0.613	0.597	0.542	0.559	0.540	0.541
JL	0.562	0.595	0.555	0.574	0.549	0.540
HLJ	0.540	0.536	0.553	0.586	0.581	0.551
JS	0.551	0.545	0.810	0.794	0.588	0.558
ZJ	0.563	0.569	0.548	0.533	0.551	0.550
AH	0.565	0.556	0.559	0.598	0.562	0.546
JX	0.690	0.663	0.567	0.623	0.548	0.547
SD	0.542	0.545	0.535	0.527	0.535	0.535
HEN	0.600	0.586	0.533	0.542	0.537	0.532
HUB	0.625	0.607	0.562	0.587	0.543	0.536
HUN	0.558	0.583	0.559	0.598	0.550	0.546
GD	0.756	0.853	0.545	0.567	0.557	0.545
GX	0.702	0.674	0.558	0.596	0.621	0.618
CQ	0.549	0.544	0.536	0.527	0.882	0.769
SC	0.546	0.549	0.544	0.565	0.549	0.548
GZ	0.555	0.560	0.544	0.563	0.563	0.549
YN	0.719	0.912	0.590	0.731	0.561	0.559

Table 8. Ranking of gray correlation degree and GTFP for large-scale hog breeding.

Province	HEB	LN	JL	HLJ	JS	ZJ	AH	JX	SD
Gray correlation degree	1	5	13	7	9	15	8	3	18
GTFP	1	13	7	15	15	17	14	10	17
Province	HEB	HUB	HN	GD	GX	CQ	SC	GZ	YN
Gray correlation degree	6	4	14	12	2	10	17	16	11
GTFP	11	6	12	5	2	4	7	7	3

ing, other provinces do not fit that in different degrees. It says that Hebei, Hubei, and Guangxi possess strong pollution control-GTFP gray correlation and high GTFP. Zhejiang, Shandong, and Hunan possess weak GTFP pollution control gray correlation and low GTFP. The rest provinces show that the higher the ranking of GTFP, the lower the ranking of pollution-control-GTFP gray correlation will be.

With the same approach, we find that according to medium-scale hog breeding, Jiangsu, Zhejiang, Shandong, and Chongqing possess GTFP under strong pollution control. GTFP of Jiangsu and Zhejiang ranked ahead, and that of Shandong and Chongqing ranked lowest. Ranking for gray correlation degree of medium-scale hog breeding is: Jiangsu > Zhejiang > Chongqing > Shandong > Hebei > Yunnan > Jiangxi > (Anhui, Hunan) > Guangxi > Hubei > Heilongjiang > Jilin > Guangdong > Sichuan > Guizhou > Liaoning > Henan. Compared with GTFP comprehensive ranking of medium-scale farming, our paper finds that Anhui, Shandong, Guangdong, and Chongqing have obvious reverse correlation between GTFP and pollution control GTFP gray correlation. The remaining province rankings for pollution control-GTFP gray correlation is generally consistent with GTFP rankings.

For small-scale pig farming, only GTFP of Liaoning Province withstands pollution control, and the rank for pol-

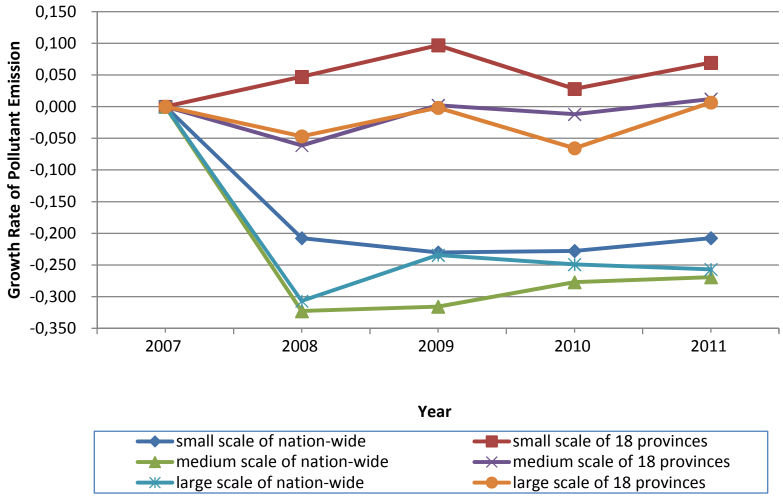

Fig. 1. Growth rate of pollutant emission.

lution control-GTFP gray correlation degree is: Chongqing > Guangxi > Jiangsu > Heilongjiang > Hebei > Guizhou > Yunnan > Anhui > Guangdong > Zhejiang > Hunan > (Jilin, Sichuan) > Jiangxi > Hubei > Henan > Shandong > Liaoning. Anhui, Jiangxi, Hunan, Guangxi, Sichuan and Yunnan have obvious reverse correlations between GTFP and pollution control-GTFP gray correlation. The remaining province rankings for pollution-control GTFP gray correlation is generally consistent with ranking for GTFP.

Conclusions

Overall, although GTFP of eighteen provinces are higher than the national level, that of some provinces still not reach efficient level. Besides, our paper finds that the southwest and northeast can make better use of their advantages, but a middle area's improvement on environmental efficiency of hog breeding cannot follow up with its growth. All above indicate that there is still space to improve environmental efficiency of 18 provinces. Its hog breeding industry development still needs taking environmental efficiency into consideration. Compared with ranking of gray correlation degree and GTFP, we find that two kinds of ranking do not match in most provinces. We even find that the stronger the correlation is, the smaller GTFP will be, most obviously for the large-scale farming. This means that, in most cases, GTFP is discouraged by increasing pollution control degree.

According to the above conclusions, three suggestions are proposed:

(1) According to Pareto Optimality, which is used to depict the state of optimal production, government shouldn't simply rely on original advantages and resource endowments, so as to ignore resource utilization. How to use less input to get more output is a right approach to enhance industrial strength. This viewpoint can also be applied to the discussion on environmental elements input. It ask for governments to enhance media publicity and make laws to encourage green production, and promote binding rewards and punishment systems to lead famers to protect the environment initiative.

(2) Local governments need to promote communication of environmental technology between provinces, so as to raise GTFP with less cost or time. The case of middle area shows, there were many provinces paid too much attention on creating growth by expanding the input. They ignored to introduce techniques to increase desirable output and decrease undesirable output. The big differences of total factor productivity between different provinces also proved that the environmental technology gap between provinces should be taken seriously.

(3) Government should ask for some policy tools to balance cost and gains of farmer's environmental behaviors, such as subsidies, environment protection project, agricultural technology support, etc. Pollution is one source of factor inducing the reduction of GTFP, but we also find hindering power from pollution control. This means improvement of GTFP required to reduce control cost, otherwise farmers will be less motivated to adopt environmentally friendly advice.

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