

Assessing Total Factor Productivity for Soybean Production in China Based on DEA-Malmquist Index: 2005-2017

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Abstract

The low and slowly increasing soybean yield restricts the development of soybean production. Accurate measures of total factor productivity (TFP) for soybean production can be helpful in identifying conditions, institutions or policies that promote soybean production development in China. In this paper, TFP growth for soybean production was estimated for a panel data of 10 major soybean producing provinces from 2005 to 2017. Results reveal that TFP grew at an average rate of 1.3% over the whole period, with technical progress contributing 2.3% and efficiency change providing the other -1.0%. The change of TFP for soybean production over that time, whether increase or decline, was mainly derived by technical change except in three years (2005-2007). Positive TFP growth in the provinces of Liaoning and Inner Mongolia, and negative TFP growth in Hebei and Anhui were mainly driven by efficiency change, specifically scale efficiency change except pure technical efficiency in Liaoning.

Keywords

Total Factor Productivity (TFP), Soybean, DEA-Malmquist Index

1. Introduction

China is the original country of soybean. Once, it was the largest producer and exporter of soybean in the world. However, with the development of Chinese economy and the change of consumption structure, soybean demand continues to grow in China and soybean imports continue to increase, which has ac-

counted for 80% of the total soybean supply. The soybean planted area in China has declined since 2005 due to its disadvantage of price compared with imported soybean and low benefit compared with other competitive crops. The contribution rate of planting area to total soybean production showed a downward trend due to the limited arable land resource in China. Therefore, soybean production in China will mainly depend on the increase of soybean yield. We estimate the total factor productivity (TFP) of soybean and analyze the contributing factors, so that effective measures will be taken to improve soybean yield to further promote the development of soybean production in China.

TFP is an important variable to measure the contribution of factor input efficiency to production growth and also an important index to reflect whether the economy may achieve sustainable development. Since J. Tinbergen, the Dutch economist, first proposed the concept in 1942 [1], it has attracted wide attention in academia. Some literature focused more on the basic theory and methodology of TFP, such as the Production Function analysis of R. Solow [2], E. Denison [3] and Jorgenson [4] *et al.*, the Production Frontier Theory of Farrell [5], the Stochastic Frontier Model of Aigner [6], DEA Method of Charnes [7], Malmquist Index Method of Caves [8], proposed by Malmquist in 1953 [9], Hicks-Moorsteen TFP Index Method of Briec and Kerstens [10], and so on. Abundant empirical studies have been carried out in various fields, especially in agriculture [11]-[20], and Coelli *et al.* listed 17 studies in agriculture that have been conducted from 1993 to 2003, which provide a reference for our study [21].

There are still differences in the definition of the connotation of TFP in academic circles at present from the existing theoretical research. TFP in the traditional sense, refers to an increase in output resulting from technical advances and capacity realization other than inputs of various elements (such as capital and labor, etc.). These elements are the residuals of the exclusion of factor input contributions, also known as “Solow residual” [2], meaning TFP is an alternative metric for technical progress. With the deepening of the research, the connotation of the concept of TFP has been further expanded. Productivity growth was originated from four factors, namely technical change, efficiency change, scale efficiency change and mixed output effect. In the case of yield, the mixing effect of output is equal to 1 [21]. Therefore, in this paper, TFP growth is separated into components of technical change, efficiency change (efficiency improvements due to labor proficiency and management improvements) and scale efficiency change (productivity gains due to economies of scale).

Method and data are the keys to the research in the process of TFP estimation from the existing empirical research. Generally speaking, there are two main types of assessing methods, parametric method and nonparametric method. Parametric method mainly includes production function (e.g. C-D production function, Transcendental Logarithmic production function, Constant Elasticity of Substitution production function) and Stochastic Frontier Model, etc. Non-parametric method mainly includes Data Envelopment Analysis (DEA) and in-

dex method (e.g. Fisher, Tornqvist, Hicks-Moorsteen TFP index and Malmquist index), etc. The hypothesis condition of production function is strict (e.g. Solow residual), which is often difficult to realize in a real economy. Although the Stochastic Frontier Model allows technical inefficiency and separates TFP into technical change and technical efficiency change, strictly speaking, this method is more applicable to measure efficiency [22]. Data required by Transcendental Logarithmic production function, Constant Elasticity of Substitution production function, Fisher index and Tornqvist index are not available [23]. It can be seen that each method has its own specific applied environment, which should be selected according to the characteristics of the sample data. The DEA-Malmquist index effectively avoids the problems caused by the selection of specific production functions in the parametric method and has been proved by Caves and others to be superior to Tornqvist index and Fisher index under certain conditions [24] and applied widely [2] [13] [25] [26].

Scholars have also begun to pay attention to soybean production efficiency, and carried out special research in recent years, such as the use of Stochastic Frontier production function to analyze technical efficiency [27] and to analyze the technical progress and technical efficiency [28] [29] for soybean in China. However, due to the limitations of the research methods, these studies only analyzed technical efficiency or separated the TFP for soybean production into technical progress and technical efficiency. Although Tian (2009) used Malmquist index and DEA to separate the TFP for soybean into technical progress, pure efficiency and scale efficiency, his conclusions are questionable due to unscientific selection in variable (one output variable, two input variables) [30]. Therefore, DEA-Malmquist index model is used in this paper, which is suitable for panel data, and we considered as far as possible a variety of input factors to estimate TFP for soybean in 10 provinces from 2005 to 2017. The TFP for soybean is separated into technical change and efficiency change, and efficiency change is further decomposed into pure efficiency change and scale efficiency change to judge the drivers of productivity growth for soybean in China.

2. Methodology and Model Establishment

2.1. Methodology

DEA-Malmquist index is a common method for calculating TFP in the present application, which was constructed in 1994 by Rolf Fare, Grosskopf, Norris and others on the basis of Malmquist index and DEA. This approach uses Malmquist index to construct the distance function, and uses DEA to measure the distance function, then estimates TFP according to distance function value.

Malmquist index was developed based on the concept of Malmquist quantity index and distance function by Caves, Christensen and Diewert [23]. The basic principle is to construct productivity index by the ratio of distance functions, namely, to measure TFP growth of two digits through the distance ratio of each data point relative to the ordinary technology, and to separate TFP into three

aspects of technical change, pure efficiency change and scale efficiency change¹. Therefore, calculating distance function is the key of Malmquist index. At present, the calculation methods include DEA and Stochastic Frontier Analysis (SFA). As mentioned previously, DEA has been widely used because it effectively avoids selection of boundary production functions caused by using SFA.

The essence of DEA is a nonparametric statistical analysis to evaluate the relative efficiency of each decision unit by comparing the degree of the ineffective decision unit deviating from DEA effective production frontier surface. The advantage of DEA is to avoid the subjectivity of the evaluation results by using the linear programming method, which need not consider the function relation of input-output, need not estimate the parameters in advance and any weight hypothesis. At the same time, there is no requirement for the unit of measurement of input-output variables, and there is no need for data consistency, homogenization and other preprocessing.

2.2. Model Establishment

1) The first step of constructing Malmquist productivity index is to define the distance function. The distance function of the output indicator variable is defined as follows:

$$D_o = \{\delta(x, y/\delta) \in P(x)\}$$

where x and y denote matrices of input variables and output variables, respectively. δ denotes a directional output efficiency indicator, and $P(x)$ is defined as a possible production set. If y is the component of $P(x)$, then the value of the function will be less than or equal to 1. If y is on the external frontier surface of a possible production set, then the function value will be equal to 1, and conversely, if y is located outside of $P(x)$, then the function value will be greater than 1 (Li *et al.*, 2008).

2) Define Malmquist productivity index based on output indicator variables:

$$M_o^t = \frac{D_{oc}^t(x_{t+1}, y_{t+1})}{D_{oc}^t(x_t, y_t)} \quad (1)$$

$$M_o^{t+1} = \frac{D_{oc}^{t+1}(x_{t+1}, y_{t+1})}{D_{oc}^{t+1}(x_t, y_t)} \quad (2)$$

where subscript c denotes technology under constant return to scale (CRS); (x_t, y_t) and (x_{t+1}, y_{t+1}) denote input and output vector in t period and $t + 1$ period, respectively. $D_{oc}^t(x_t, y_t)$ and $D_{oc}^{t+1}(x_{t+1}, y_{t+1})$ denote the output distance function obtained by comparing the production point with the frontier surface technology at the same period (t and $t + 1$ periods), respectively. $D_{oc}^t(x_{t+1}, y_{t+1})$ and $D_{oc}^{t+1}(x_t, y_t)$ denote the output distance function obtained

¹The scale efficiency reflects the gap between the actual scale and the optimal production scale; the pure efficiency reflects the production efficiency of the input elements at a certain scale (optimal scale). The scale efficiency and the pure efficiency constitute the efficiency, which is the comprehensive measurement and evaluation of the ability of resource allocation, resource use efficiency and so on.

by comparing the production point with the frontier surface technology at the mixing period, respectively. M_o^t and M_o^{t+1} denote the technical efficiency change from t to $t + 1$ period using technology in t and $t + 1$ period as reference, respectively.

In order to avoid constraints or arbitrariness due to choosing reference technology, Malmquist index generally is calculated by the geometric mean of both, that is,

$$M_o(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{D_{oc}^t(x_{t+1}, y_{t+1})}{D_{oc}^t(x_t, y_t)} \times \frac{D_{oc}^{t+1}(x_{t+1}, y_{t+1})}{D_{oc}^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (3)$$

If $M_o(x_t, y_t, x_{t+1}, y_{t+1}) > 1$, it denotes that TFP grows from t to $t + 1$ period, and conversely, if $M_o(x_t, y_t, x_{t+1}, y_{t+1}) < 1$, then it declines.

The Equation (3) is further separated, that is:

$$M_o(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_{oc}^{t+1}(x_{t+1}, y_{t+1})}{D_{oc}^t(x_t, y_t)} \left[\frac{D_{oc}^t(x_{t+1}, y_{t+1})}{D_{oc}^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_{oc}^t(x_t, y_t)}{D_{oc}^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (4)$$

3) Under the assumption of CRS, separate (4) into technical change (TECH) and efficiency change (EFFCH).

$$\text{TECH} = \left[\frac{D_{oc}^t(x_{t+1}, y_{t+1})}{D_{oc}^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_{oc}^t(x_t, y_t)}{D_{oc}^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (5)$$

$$\text{EFFCH} = \frac{D_{oc}^{t+1}(x_{t+1}, y_{t+1})}{D_{oc}^t(x_t, y_t)} \quad (6)$$

4) Under the assumption of variable return to scale (VRS), efficiency changes (EFFCH) is further separated into pure efficiency change (PECH) and scale efficiency change (SECH).

$$\text{PECH} = \frac{D_{ov}^{t+1}(x_{t+1}, y_{t+1})}{D_{ov}^t(x_t, y_t)} \quad (7)$$

$$\text{SECH} = \frac{D_{ov}^t(x_t, y_t) / D_{oc}^t(x_t, y_t)}{D_{ov}^{t+1}(x_{t+1}, y_{t+1}) / D_{oc}^{t+1}(x_{t+1}, y_{t+1})} \quad (8)$$

where subscript v denotes technology under VRS.

Therefore, TFP change may be written as follows:

$$\text{TFPCH} = M_o(x_t, y_t, x_{t+1}, y_{t+1}) = \text{TECH} \times \text{EFFCH} = \text{TECH} \times \text{PECH} \times \text{SECH} \quad (9)$$

5) Calculate these four distance functions: $D_{oc}^t(x_t, y_t)$, $D_{oc}^{t+1}(x_{t+1}, y_{t+1})$, $D_{oc}^t(x_{t+1}, y_{t+1})$, $D_{oc}^{t+1}(x_t, y_t)$ using DEA linear programming method of CRS output-oriented.² At the same time, the constraint, $\sum_i \lambda_i^t = 1$, is added to the following linear programming and the distance functions under the condition of VRS, $D_{ov}^{t+1}(x_{t+1}, y_{t+1})$ and $D_{ov}^t(x_t, y_t)$, can be obtained.

²For a macroeconomic body, its input factor endowment is given and the scale is unlikely to be determined by itself, so input orientation or output orientation has no effect on the measurement results under the assumption of constant scale compensation [31].

$$\begin{aligned}
\left[D_{oc}^t(x_t, y_t) \right]^{-1} &= \max_{\phi, \lambda} \phi & \left[D_{oc}^{t+1}(x_{t+1}, y_{t+1}) \right]^{-1} &= \max_{\phi, \lambda} \phi \\
s.t. \quad -\phi y_{it} + Y_t \lambda &\geq 0 & s.t. \quad -\phi y_{i,t+1} + Y_{t+1} \lambda &\geq 0 \\
x_{it} - X_t \lambda &\geq 0 & x_{i,t+1} - X_{t+1} \lambda &\geq 0 \\
\lambda &\geq 0 & \lambda &\geq 0
\end{aligned}$$

$$\begin{aligned}
\left[D_{oc}^t(x_{t+1}, y_{t+1}) \right]^{-1} &= \max_{\phi, \lambda} \phi & \left[D_{oc}^{t+1}(x_t, y_t) \right]^{-1} &= \max_{\phi, \lambda} \phi \\
s.t. \quad -\phi y_{i,t+1} + Y_{t+1} \lambda &\geq 0 & s.t. \quad -\phi y_{it} + Y_t \lambda &\geq 0 \\
x_{i,t+1} - X_{t+1} \lambda &\geq 0 & x_{it} - X_t \lambda &\geq 0 \\
\lambda &\geq 0 & \lambda &\geq 0
\end{aligned}$$

6) By inserting the distance functions calculated by DEA into (5)-(9), TFP and its components can be obtained.

3. Variables and Data

3.1. Variables

Based on the input and output of soybean, we selected soybean yield as output variable and 6 indicators (land cost, seed fee, pesticide and fertilizer fee, labor cost, mechanical fee, other direct and indirect cost) as input variables considering the characteristics of soybean production and the actual composition of production costs, as well as the availability of sample data. The unit of output variable is “kg/mu”, and the unit of each input variable is “Yuan/mu”. In order to eliminate the impact of inflation on price data, input indicators were converted according to the corresponding Price Indexes in each province.

Soybean yield: the variable of soybean yield is substituted by output of main product, since National Bureau of Statistics of China has adjusted the data of food production since 2018, soybean production data are included in beans and no longer counted separately.

Land cost: This variable covers rent of circulation land and opportunity cost of land. Land cost was converted according to the Price Index of Agricultural Means of Production (AMPI) [32].

Seed fee: This variable is converted according to the Price Index of AMPI.

Labor cost: This variable covers hired labor and the opportunity cost of unpaid labor. Labor cost is converted according to Consumer Price Index (CPI) of rural residents.

Pesticide and fertilizer fee: This variable covers the fee of pesticide, organic fertilizer and chemical fertilizer. Pesticide and fertilizer fee is converted according to the Price Index of Chemical Fertilizer.

Mechanical fee: This variable covers the fee of fuel, lube, electricity, repairs, tool, mechanical operations, irrigation and drainage, and technical service. Mechanical fee is converted according to the Price Index of Mechanized Agricultural Tools.

Other direct and indirect costs: This variable covers the other direct fee, with the exception of the above fees and the indirect fees, which cover depreciation

for plant assets, insurance, administration expenses, sales charge, and financial charge. Other direct and indirect cost is converted according to the Price Index of AMPI.

3.2. Data Sources

The input-output data from 2004 to 2017 in the main 10 soybean producing provinces (including Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Anhui, Shandong, Henan and Shaanxi) were used as samples on the basis of variables and the availability of data. The output of main production and the soybean cost data of each province are derived from National Compilation of Agricultural Products Cost and Income. The various Price Indexes in each province are derived from China Statistical Yearbook.

4. Empirical Results and Discussion

Distance functions were calculated by using DEAP2.1 software, and selecting output orientation of constant return to scale (CRS)³ as parameter according to DEA-Malmquist index model established previous and related input-output statistics data. Then, Malmquist index and its components can be obtained according to the distance functions.

4.1. Change of TFP and Its Compositions for Soybean

Table 1 shows the average change of TFP and its components for soybean production in China over time. As a whole, the average value of TFP change for soybean production is 1.013, more than 1, from 2005 to 2017. It means 1.3% TFP growth, with efficiency change contributing 2.3%, making up the technical negative growth (-1.0%). So it can be judged that the efficiency change is the main driver. The resource allocation ability and resource use efficiency of soybean production in China have been improved to a certain extent, and soybean production technology in China still needs to be improved. In the change of efficiency, scale efficiency has increased by 0.5% on average, which indicates that soybean production in China basically achieved the optimal production scale. In the current optimal scale, the production efficiency of input factors (Pure Efficiency) has increased by an average of 1.8%. Therefore, the change of efficiency stems from the change of combined action of pure efficiency and scale efficiency.

Then, we consider the annual change of cumulative TFP and its components in **Figure 1**. The value of TFP growth for soybean production is positive in six years and negative in seven years of the past 13 years. The highest and the lowest growth rates were 59.5% in 2005 and 1.9% in 2015, respectively. The maximum and minimum reduction rates were 24.8% in 2009 and 5.4% in 2012, respectively.

³Since both CRS and VRS are used to construct various distance values, the choice of CRS and VRS does not affect the operation process of DEA [33]. At the same time, as mentioned earlier, under the condition of constant scale compensation, the result of output orientation and input orientation is consistent, and this paper selects output orientation.

The change of TFP from 2005 to 2007 stems from the change of the combined action of technical progress and efficiency. The main reason for the positive TFP growth in 2005 was the agricultural subsidy policy, especially agricultural machinery subsidy policy has been implemented in China since 2004, which has greatly promoted the rapid development of agricultural mechanization and the expansion of production. However, the change of TFP is roughly consistent with that of technical progress from 2008 to 2017 because the cumulative percentage of efficiency change is almost close to 0 in this period.

Table 1. TFP change and its components change for soybean production from 2005 to 2017.

Year	TFPCH	TECHCH	EFFCH	PECH	SECH
2005	1.595	1.235	1.291	1.227	1.052
2006	1.022	1.108	0.922	0.945	0.976
2007	0.922	0.846	1.089	1.086	1.003
2008	1.186	1.157	1.025	0.989	1.037
2009	0.752	0.751	1.001	0.997	1.004
2010	1.176	1.163	1.011	1.012	0.999
2011	0.932	0.934	0.998	0.996	1.001
2012	0.946	0.943	1.004	1.006	0.998
2013	0.881	0.887	0.993	1.000	0.993
2014	0.900	0.905	0.995	1.000	0.995
2015	1.019	1.020	0.998	1.000	0.998
2016	0.915	0.905	1.010	1.000	1.010
2017	1.147	1.150	0.997	1.000	0.997
Average	1.013	0.990	1.023	1.018	1.005

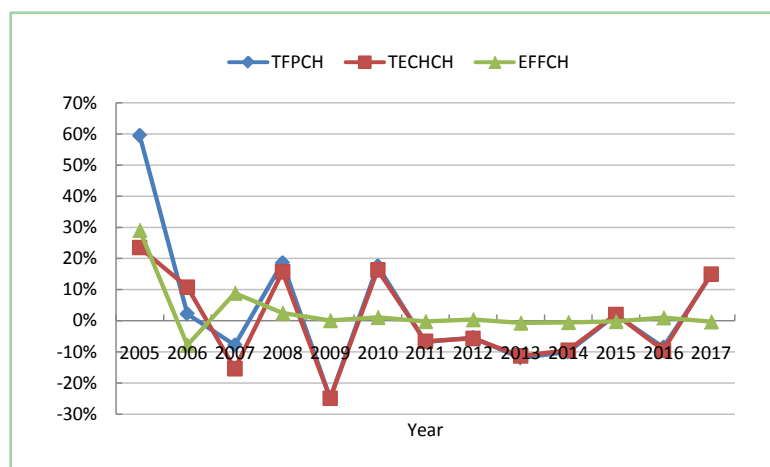


Figure 1. The cumulative change rate of TFPCH, TECHCH and EFFCH for soybean production.

Lastly, efficiency change was volatile and stemmed from the change of pure efficiency from 2005 to 2007. It was relatively stable and stems from the change of scale efficiency from 2008 to 2017 (**Figure 2**). It can be judged that the change of TFP stems from technical change and pure efficiency change from 2005 to 2007. This may be because different soybean producing regions were limited by natural resources and production conditions. There were great differences in soybean production technology, such as breeding, fertilization, dense planting, irrigation and other cultivation techniques, as well as technology application and management. The gap between regional soybean production and various factor input is large, and the annual fluctuation is large, which led to large annual fluctuation of soybean yield in China.

4.2. Change and Analysis of TFP and Its Components in Soybean Producing Regions

Table 2 shows the average TFP and its components for every province from 2005 to 2017. The highest positive TFP growth was achieved by Liaoning province with 18%. It was followed by Henan and Inner Mongolia provinces with 16.7% and 6.5%, respectively. The sources of TFP growth were diverging among different provinces. Technical progress (16.7%) played an important role in Henan. Inner Mongolia experienced technical progress with 1.1% and the efficiency change with 5.4%, and scale efficiency change (5.4%) was the main source of efficiency change. Efficiency change (19.4%) is the major source of TFP growth in Liaoning and pure efficiency change (19.4%) is the major source of efficiency change.

The other seven provinces showed negative TFP growth ranging between -6.5% and -0.6% . The highest negative TFP growth was achieved by Anhui with -6.5% , followed by Hebei with -6.3% , Heilongjiang with -4.2% , Jilin with -3.7% , Shandong with -3.2% , Shanxi with -0.6% , and Shaanxi with -0.5% in turn. Technical regress was the main driver of negative TFP growth. All seven provinces experienced technical change ranging between -6.2% and -0.6% . Hebei and Anhui were the only two provinces that experienced negative efficiency change with -0.1% and -0.5% , respectively, which were driven by scale efficiency change (-0.1% and -0.5% , respectively).

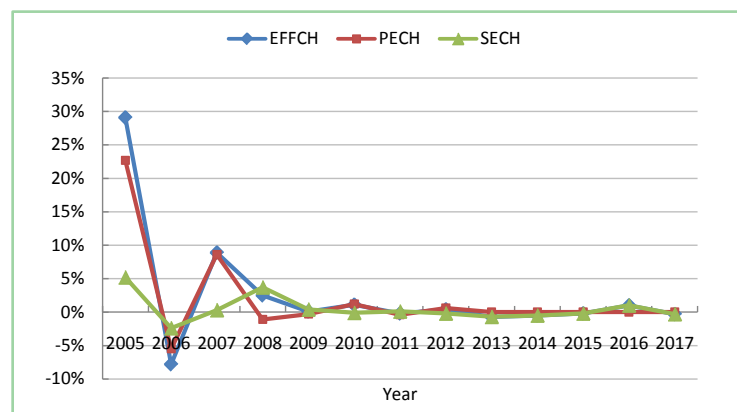


Figure 2. The cumulative change rate of EFFCH, PECH and SECH in soybean.

Table 2. The average TFP and its components in soybean producing regions from 2005 to 2017.

Province	TFPCH	TECHCH	EFFCH	PECH	SECH
Hebei	0.937	0.938	0.999	1.000	0.999
Shanxi	0.994	0.994	1.000	1.000	1.000
Inner Mongolia	1.065	1.011	1.054	1.000	1.054
Liaoning	1.180	0.988	1.194	1.194	1.000
Jilin	0.963	0.963	1.000	1.000	1.000
Heilongjiang	0.958	0.958	1.000	1.000	1.000
Anhui	0.935	0.940	0.995	1.000	0.995
Shandong	0.968	0.968	1.000	1.000	1.000
Henan	1.167	1.167	1.000	1.000	1.000
Shaanxi	0.995	0.994	1.001	1.000	1.001

Figures 3-5 depict the annual change of TFP and its components for every province over time. The change of TFP was characterized by fluctuation in the ten provinces, especially in Henan, Liaoning and Inner Mongolia. The highest positive and negative TFP growth were achieved by Henan with 94.9% in 2012 and Inner Mongolia with -51.8% in 2009, respectively (**Figure 3**).

Although technical progress (regress) plays an important role in the change of TFP growth (positive or negative), there were diverging trends among the different provinces. Positive (negative) technical change indicates progress (regress) in terms of soybean production technology (Ang *et al.*, 2017). The trend of technical progress (regress) and TFP growth was roughly coincident except for individual provinces and years, such as Inner Mongolia in 2006. The highest technical progress and regress were achieved by Henan in 2012 (94.9%) and Inner Mongolia in 2009 (-51.8%), respectively (**Figure 4**).

Technical efficiency change plays a minor role in TFP growth. Positive (negative) technical efficiency change indicates that the distance to the frontier decreases (increases) over the whole time period (Ang *et al.*, 2017). Negative technical efficiency change is quickly followed by positive changes. These spikes were visible in Inner Mongolia, Liaoning and Hebei. The highest technical efficiency was achieved by Inner Mongolia with 51.3% in 2005 and -37.5% in 2006, respectively. There was no change only in Shanxi, Shandong and Henan (**Figure 5**).

Figure 6 and **Figure 7** further depict the change of components of technical efficiency, pure efficiency and scale efficiency, which were the mirror image of the trend in technical change. Only Inner Mongolia, Hebei and Liaoning experienced change of pure efficiency. Inner Mongolia from 2005 to 2006 and in 2011, Hebei in 2008, and Liaoning in 2006 and in 2009 experienced pure ineffi-

ciency. While pure efficiency change in Hebei in 2009, Inner Mongolia in 2007 and in 2012, and Liaoning in 2005, from 2007 to 2008, and from 2010 to 2011 contributed to their technical efficiency. The highest pure efficiency and inefficiency were achieved by Liaoning in 2010 (12.5%) and Inner Mongolia in 2006 (−38.3%), respectively (Figure 6).

Positive (negative) scale efficiency change indicates that the provinces operate at a more (less) optimal scale over the whole time period (Ang *et al.*, 2017). There were no changes of scale efficiency in Shanxi, Jilin, Shandong, Henan and Shaanxi over the whole period. This means that the scale of production was optimal in the five provinces. The highest scale efficiency and scale inefficiency were achieved by Inner Mongolia with 96% in 2005 and −18% in 2007, respectively (Figure 7). The possible reason may be the irrational expansion of production scale.

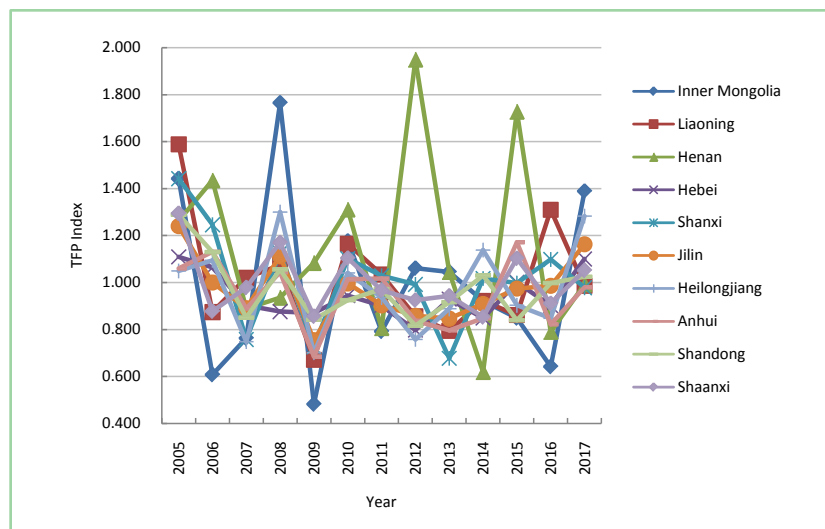


Figure 3. Annual TFP growth in different provinces.

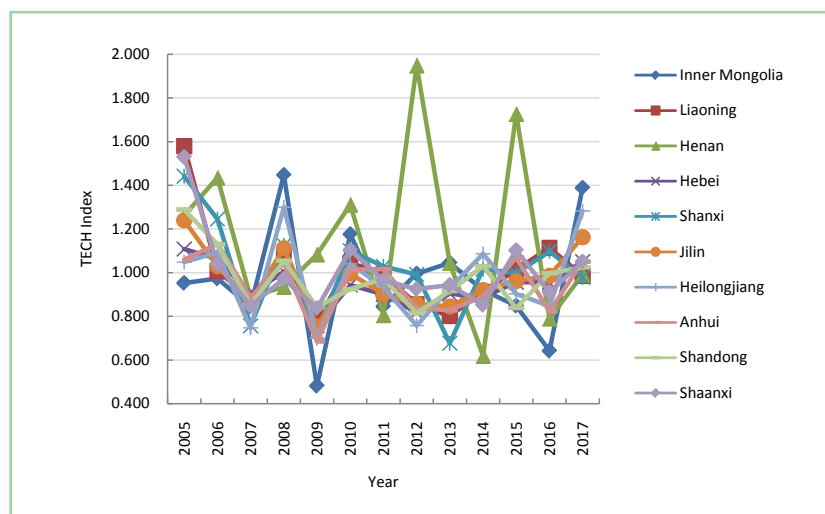


Figure 4. Annual technical change in different provinces.

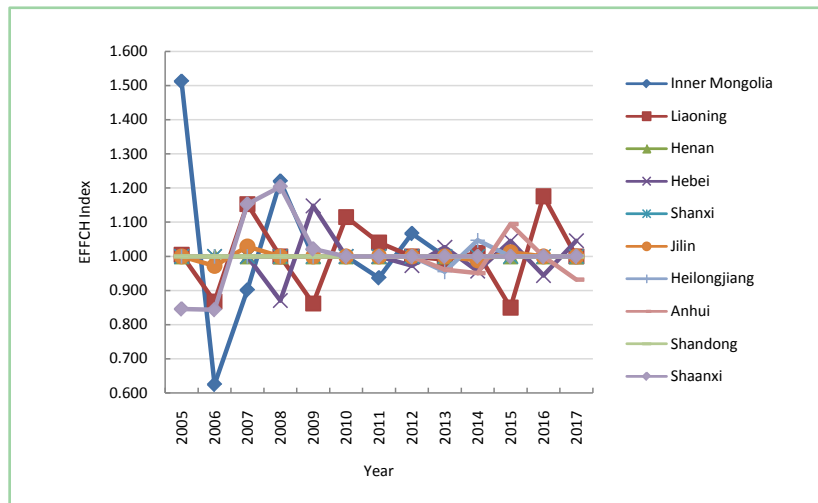


Figure 5. Annual technical efficiency change in different provinces.

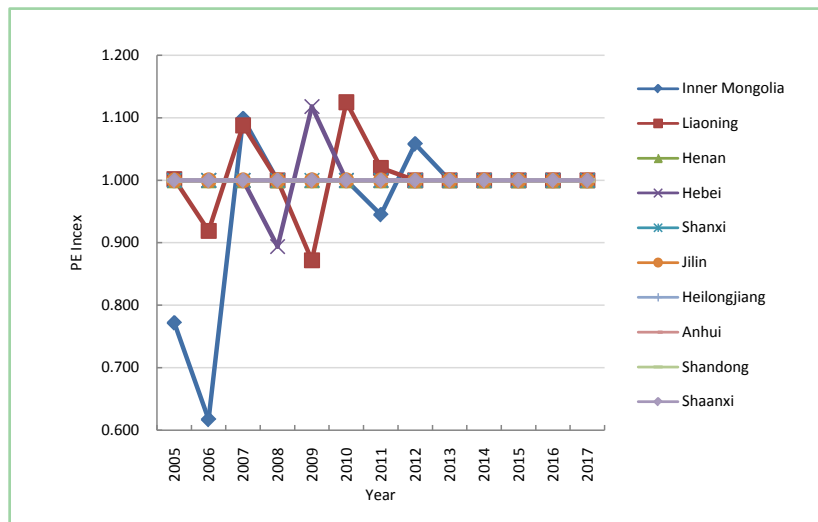


Figure 6. Annual pure efficiency change in different provinces.

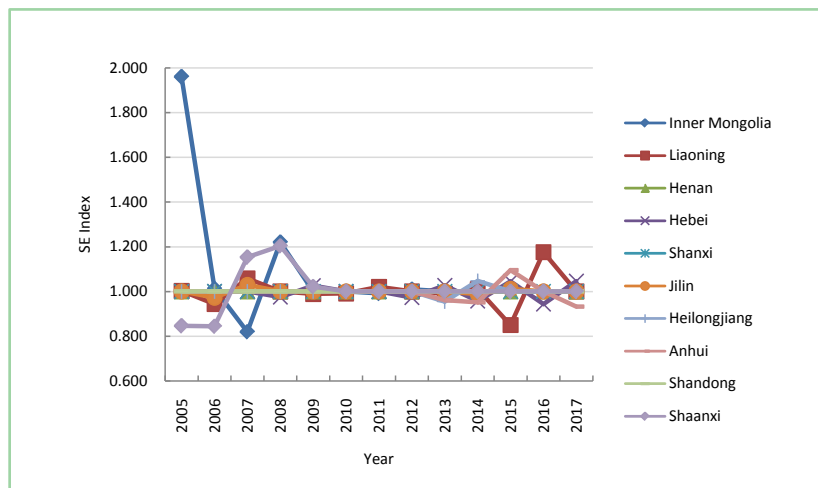


Figure 7. Annual scale efficiency change in different provinces.

5. Conclusions

This paper discusses the change of TFP indicator and its components for soybean production in China. TFP index was separated into technical change and efficiency change, and efficiency change was further separated into pure efficiency change and scale efficiency change over the period 2005 to 2017. The results show annual growth in TFP of 1.3%, with technical change contributing 2.3% and efficiency change providing the other -1.0%. The change of TFP for soybean production over that time, whether increase or decline, mainly was derived by technical change except for typical technology propulsion or efficiency driven characteristics from 2005 to 2007. In terms of each province performance, positive TFP growth was achieved by Liaoning, Henan and Inner Mongolia with 18%, 16.7% and 6.5% over the study period, respectively, which was mainly derived by efficiency change in Liaoning and Inner Mongolia and derived by technical change in Henan. The other seven provinces showed negative TFP growth driven by technical regress except Hebei and Anhui, in which TFP growth was driven by inefficiency, properly speaking scale inefficiency in addition to technical regress.

According to the conclusions, in order to promote the growth of TFP for soybean production in China, first of all, soybean production technology should be improved by research and popularization in order to continuously promote the process of high quality of varieties to adapt to different soil environments and to resist the influence of uncertain factors (e.g. drought and waterlogging natural disasters) on soybean yield. This technology includes excellent variety breeding technology, cultivation techniques closely combined with agricultural machinery and agronomy, technology of fertilizer application and pest detection, prediction, scientific prevention and controlling etc. Secondly, it should be considered to optimize soybean planting scale promotion in terms of local conditions except focusing on technology in Anhui and Hebei. At the same time, reasonable allocation of input elements to improve soybean production is necessary. Lastly, government should continue to strengthen agricultural policy support to ensure the optimization and application of good seeds, agricultural machinery, etc., to encourage the enthusiasm of soybean farmers.

Though the results are quite plausible and meaningful, the authors are quite conscious of the data limitations (only 10 provinces), and investigation of soybean input factors is necessary in more soybean planting provinces for further work in this area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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