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How to Maintain Sustainable Development of China's Agriculture under the Restriction of Production Resources? Research with Respect to the Effect on Output of the Substitution of Input Factors

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Abstract: China agricultural development has been facing the problem of resource constraints because its resources per capita such as land and energy are relatively lower than the global average. By applying the provincial agricultural panel data from 2000 to 2015 and fixed effect model based on the translog production function, this paper estimates both output elasticities and substitution elasticities of agricultural inputs, which may provide insights into sustainable agricultural development. The results show that, except for capital, the output elasticities of other production factors are all positive. Energy has always played an important role in agricultural production, whose elasticity in agriculture increased from 0.0203 in 2000 to 0.1694 in 2015. We also find a severe scarcity of land, and the high intensity of energy in the field of agriculture. Moreover, there exists a substitute relationship between all factors, which means that in the short term, one production factor can be employed to replace another to maintain agricultural development. From the empirical results of this paper, some policy suggestions are proposed as follows: it is crucial that more attention should be placed on land and to plan energy use wisely. In addition, on account of the current situation in China, the input of labor force should be stepped up and energy should be used more efficiently to make up for the shortage of land resources. The empirical results and policy suggestions in this paper may benefit the sustainable development of China's agricultural economy.

Keywords: agriculture; water; land; energy; output and substitution elasticities

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1. Introduction

1.1. Research Background

Natural resources, such as arable land and water, are the basis of agricultural production, and the quantity of them remains the most common restrictive condition in developing countries. Although China's total agricultural resources are abundant, its per capita level is far lower than those of developed countries. Taking agricultural cultivated land as an example, the amount of cultivated land per capita in China is only about half of that in the world, which is described in Figure 1. The scarcity of agricultural natural resources has a strong restrictive effect on the improvement of agricultural productivity, the expansion of the scale of agricultural operation and the adjustment of agricultural industrial structure, which further influences the mode and process of agricultural modernization in China [1–5]. At present, the main resource constraints faced by China's agricultural development are water and land.

Energy consumption in agriculture is increasing year by year, aggravating environmental constraints. As one of the most important inputs in agricultural production, energy contributes greatly to the economic benefit of agricultural production through agricultural mechanization. According to China Energy Statistics Yearbook, China's agricultural energy consumption continued to increase from 2005 to 2015, with a growth of 11.7% from

60.711 million TCE in 2000 to 67.484 million TCE in 2015. In general, China's agricultural energy consumption accounts for about 2% of total energy consumption nationwide and about one-third of energy consumption in the mining industry. China's energy consumption and carbon dioxide emissions have both ranked first in the world for several consecutive years, facing serious constraints on resources and environment. Energy savings and emissions reduction are common problems confronted by different industries, and agriculture is no exception [6–8].

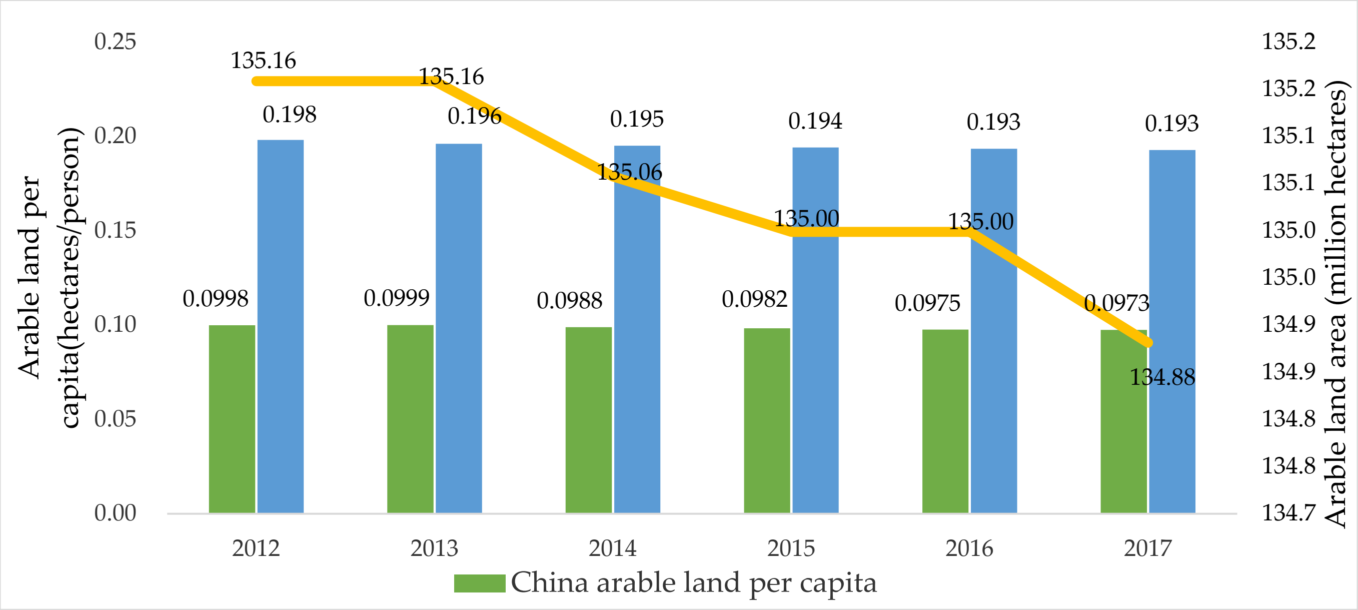

Figure 1. China's agricultural cultivated land area chart: 2010–2017. Data source: Industry Consulting Expert in China https://www.huaon.com/story/393954 (accessed on 18 May 2022). National Bureau of Statistics of China. https://www.askci.com/news/chanye/20181126/1459421137475.shtml (accessed on 18 May 2022).

On the other hand, the development of urbanization accelerates the reduction in agricultural land in China. In recent years, with the occupation of non-agricultural construction, disaster destruction and agricultural restructuring, the area of cultivated land in China has declined sharply. The total area of cultivated land decreased from 135.16 million hectares in 2000 to 134.88 million hectares in 2017. A study conducted by the Chinese government and the United Nations Development Program shows that population carrying capacity of land in China is 1.7 billion people, based on the warning line of 0.053 hm^2 per capita cultivated land determined by FAO (Food and Agriculture Organization of the United Nations). The premise, however, is that no less than 120 million hm^2 of cultivated land must be retained. Therefore, *Outline of China's Land Planning (2016–2030)* requires that cultivated land in China should be kept above 124.3 million hm^2 and above 121.6 million hm^2 by 2020 and 2030, respectively. Undoubtedly, China's agriculture is confronted with serious land constraints [9,10].

In summary, constraints on water resources and cultivated land have been the bottleneck restricting the sustainable development of China's agriculture. Generally, technological advancement serves as the ultimate force to improve the use efficiency of production factors and promote economic growth. However, technological development, together with its dissemination and popularization, often goes through a long process. From a short-term perspective, how to achieve sustainable development of agriculture with limited water resources and arable land supply is an urgent problem that China's agricultural development faces.

1.2. Research Motivation

The main feature of the early stage of agricultural development is that agricultural output accounts for a large proportion of the total output of the entire society, which means that more people are required to work in agriculture to produce food that meets the minimum survival requirements. With the development of agriculture and the whole society, the proportion of agriculture will decline. At the same time, there will be an asymmetry in the proportion of agricultural output value and labor force, that is, the proportion of labor force will be greater than the proportion of output value [11]. Because of this, the transfer of agricultural labor to non-agricultural industries can increase the comparative labor productivity of agriculture and realize the reallocation of resources, which is the so-called "Kuznets effect." Lewis' judgment on the existence of surplus labor in agriculture, and whether the surplus labor is absorbed by non-agricultural industries, and whether the marginal productivity of labor in agriculture and non-agricultural industries are consistent constitutes another theoretical tradition [12–14]. As an important contributor to this genre, Hayami and Ruttan (1970) [15] further added the relative scarcity of other agricultural production factors such as land and water resources from the perspective of and relative prices, and explained the different paths of agricultural modernization with the hypothesis of induced technological transition. According to the theory of induced technological transition, changes in agricultural technology respond to the relative scarcity of production factors or relative prices. That is, agricultural technology tends to save relatively scarce production factors, while intensively using relatively abundant production factors. This theoretical hypothesis inspired us to examine agricultural development or technological changes, which can be equivalent to examining the changing characteristics of agricultural production factors. For example, the substitution and complementarity of agricultural land and water resources reflects the interactive relationship between resource endowment changes and technological changes at a certain stage of the development of the Chinese agriculture [16–22].

Substitutional relation originates from production theory in economics. Whether and to what extent one input can be replaced by other production inputs is directly related to government policies on agricultural sustainable development. However, substitutional relations input factors, together with their extents, show great differences based on different samples and research methods. Current literature is mainly focused on energy and environmental economics. While exploring the relationship between input factors, researchers have also been investigating the reasons for the different results. Possible influencing factors are summarized as follows. (i) Whether the input factors show complementary or a substitutive relationship is related to sample selection [23]. (ii) The selection of calculation method influences the research results—that is, the relationship and its size will be different according to different calculation methods even if the samples for research are the same [24–26]. (iii) The results are also related to the segmentation of industries and elements [27–29]. Besides these aspects, when there exists an absence of omitted variables different results may also be derived. Some research indicates the difference is generated by omitting some important inputs in the production model. When the variables except capital and labor are omitted, the cost of energy and capital is relatively high, and the two tend to replace each other. Especially for the panel data, the information about intermediate inputs is always unavailable, and energy and capital are often represented as substitutes. When the other inputs are taken into consideration, the cost of energy and capital in the production model usually declines, which reflect the fact.

The literature can summarize the types of agricultural industries, mainly divided into independent agricultural industries formed by competitiveness and fragile agricultural industries formed by protection. This is of course related to the differences in agricultural comparative advantages caused by resource endowments, but also to policy choices guided by specific theories. The principle point is that the dominant "agricultural vulnerability" often appears in policy discussions, and as a core theoretical basis, it helps to form a policy system for protecting agriculture. The implementation effect is always counterproductive, often hurting the efficiency of agriculture, placing agriculture in these countries and regions into a dilemma [30]. China's agriculture has solved the problems of food and clothing and increased production, promoted the transfer of surplus agricultural labor, and realized a decline in agricultural shares and an increase in farmers' income. However, once the stage of development changes, even if China's agriculture continues to move forward on the path that has worked well in the past, it often encounters many insurmountable obstacles. In the past, especially after 2000, Chinese agriculture relied more on capital to drive capital deepening into agricultural growth. Agricultural capital deepening has been confirmed in some literature. At the same time, the shortage of agricultural land and water resources has become increasingly prominent. Based on the above analysis, this study tries to contribute to the available literature in three respects. First, this paper provides an idea for analyzing agricultural sustainability in terms of output elasticity and elasticity of substitution. This paper analyzes the payoffs of scale and the substitution relationships between the main factors of production over the sample period, providing an idea for sustainable agricultural economic development in the short term. Second, it analyzes the differences in the technological progress of energy, labor and water resources to determine the tendency of technological progress in the factors of production, which can provide correct guidance for China's technical inputs of agricultural production factors in the future. Third, in methodology, this paper employs a ridge regression method based on the fixed effects model to complete the empirical analysis, which can not only solve the problem of collinearity, but also deal with the estimation bias caused by missing variables.

2. Materials and Methods

2.1. Translog Production Function Model

The translog production function model, proposed by [31], is easily estimated and inclusive. The model is easy to estimate because it can be viewed as a simple linear model in form, and it is inclusive because it can be regarded as the approximation of production functions in any form. Being quadratic response surface model in structure, the translog production function model can be effectively employed to study the interaction of input factors in production functions and also the differences in technological progress of various input factors [32–37]. Applying the trans-log production function model, we can analyze both output elasticity and substitution elasticity of input factors in this paper. The general form of the translog production function is as follows:

$$lnY_t = \beta_0 + \beta_K lnK_t + \beta_L lnL_t + \beta_{LK}(lnK_t)^2 + \beta_{LL}(lnL_t)^2 + \beta_{KL} lnK_t lnL_t \tag{1}$$

where ln represents the natural logarithmic symbol and Y_t denotes the output in year t; K_t and L_t refer to the capital stock and labor input in year t, respectively; and β is the parameter vector to be estimated.

In an actual economic system, the effect of each input factor on output depends not only on the variation in the input factor itself, but also on its interaction with other input factors. In addition, the technological advancement of each input factor is out of synchronism. Considering that the translog production function model, a kind of variable elasticity production function model, is easily estimated and inclusive, we selected it to investigate both interactions and differences in the technological advancement of input factors in order to further explore the path to sustainable agricultural development.

In view of the objective of this paper, we apply the general form of the translog production function to agriculture from the perspective of technology and obtain the function:

$$
\begin{aligned}
lnY_{it} = \beta_0 \quad & +\beta_E lnE_{it} + \beta_S lnS_{it} + \beta_L lnL_{it} + \beta_W lnW_{it} + \beta_F lnF_{it} + \beta_{EE}(lnE_{it})^2 \\
& +\beta_{SS}(lnS_{it})^2 + \beta_{LL}(lnL_{it})^2 + \beta_{WW}(lnW_{it})^2 + \beta_{FF}(lnF_{it})^2 \\
& +\beta_{ES} lnE_{it} lnS_{it} + \beta_{EL} lnE_{it} lnL_{it} + \beta_{EW} lnE_{it} lnW_{it} \\
& +\beta_{EF} lnE_{it} lnF_{it} + \beta_{SL} lnS_{it} lnL_{it} + \beta_{SW} lnS_{it} lnW_{it} \\
& +\beta_{SF} lnS_{it} lnF_{it} + \beta_{LW} lnL_{it} lnW_{it} + \beta_{LF} lnL_{it} lnF_{it} \\
& +\beta_{WF} lnW_{it} lnF_{it} + \gamma_1 T + \tfrac{1}{2}\gamma_2 T^2 + \alpha_E lnE_{it} T + \alpha_S lnS_{it} T \\
& +\alpha_L lnL_{it} T + \alpha_W lnW_{it} T + \alpha_F lnF_{it} T
\end{aligned} \tag{2}
$$

In the expression above, "i" represents the cross-sectional unit and t indicates the time period; Y denotes the agricultural output and T signifies technological changes; E, S, L, W and F refer to inputs of energy, land, labor, water and capital, respectively.

2.2. Derivation of Output Elasticity and Substitution Elasticity

Based on the translog production function model we have constructed in expression (2), we can work out the output elasticity and substitution elasticity of agriculture. On the one hand, output elasticity can be defined as a relative change in output caused by a relative change in the amount of an input factor, namely the ratio of the percentage change in output to the percentage change in input factors, under the conditions of an unchanged level of technology and constant prices of input factors. The five input factors involved in the function we specified are energy, acreage of agricultural land, labor, water and capital, respectively. Therefore, there are altogether five kinds of output elasticity to be derived. Based on relevant economic theories, the five expressions, namely output elasticity of energy, land, labor, water and capital, can be solved, respectively, as:

$$
\begin{aligned}
\eta_E = \frac{dY/Y}{dE/E} \quad & = \frac{dlnY_{it}}{dlnE_{it}} \\
& = \beta_E + 2\beta_{EE} lnE_{it} + \beta_{ES} lnS_{it} + \beta_{EL} lnL_{it} + \beta_{EW} lnW_{it} \\
& +\beta_{EF} lnF_{it} + \alpha_E T
\end{aligned} \tag{3}
$$

$$
\begin{aligned}
\eta_S = \frac{dY/Y}{dS/S} \quad & = \frac{dlnY_{it}}{dlnS_{it}} \\
& = \beta_S + 2\beta_{SS} lnS_{it} + \beta_{SE} lnE_{it} + \beta_{SL} lnL_{it} + \beta_{SW} lnW_{it} + \beta_{SF} lnF_{it} \\
& +\alpha_S T
\end{aligned} \tag{4}
$$

$$
\begin{aligned}
\eta_L = \frac{dY/Y}{dL/L} \quad & = \frac{dlnY_{it}}{dlnL_{it}} \\
& = \beta_L + 2\beta_{LL} lnL_{it} + \beta_{LE} lnE_{it} + \beta_{LS} lnS_{it} + \beta_{LW} lnW_{it} + \beta_{LF} lnF_{it} \\
& +\alpha_L T
\end{aligned} \tag{5}
$$

$$
\begin{aligned}
\eta_W = \frac{dY/Y}{dW/W} \quad & = \frac{dlnY_{it}}{dlnW_{it}} \\
& = \beta_W + 2\beta_{WW} lnW_{it} + \beta_{WE} lnE_{it} + \beta_{WS} lnS_{it} + \beta_{WL} lnL_{it} \\
& +\beta_{WF} lnF_{it} + \alpha_W T
\end{aligned} \tag{6}
$$

$$
\begin{aligned}
\eta_F = \frac{dY/Y}{dF/F} \quad & = \frac{dlnY_{it}}{dlnF_{it}} \\
& = \beta_F + 2\beta_{FF} lnF_{it} + \beta_{FE} lnE_{it} + \beta_{FS} lnS_{it} + \beta_{FL} lnL_{it} \\
& +\beta_{FW} lnW_{it} + \alpha_F T
\end{aligned} \tag{7}
$$

On the other hand, substitution elasticity can be defined as the relative change in input ratio caused by relative change in the marginal rate of technical substitution, namely the ratio of the percentage change in input ratio to the percentage change in the marginal rate of technical substitution, under the conditions of an unchanged technological level and constant prices of input factors.

The value of substitution elasticity varies from zero to infinity. Zero indicates that the two factors are completely irreplaceable while infinity means that the two factors are completely replaceable. In the production function specific to agriculture above, we should concentrate on the substitution elasticity of energy, land, labor, water and capital.

We first take the substitution elasticity of energy for land for example. According to economic theories, the expression can be defined as

$$\sigma_{ES} = \frac{d\left(\frac{E}{S}\right)}{\left(\frac{E}{S}\right)} \Big/ \frac{d\left(\frac{MP_S}{MP_E}\right)}{\left(\frac{MP_S}{MP_E}\right)} = \frac{d\left(\frac{E}{S}\right)\cdot\left(\frac{MP_S}{MP_E}\right)}{d\left(\frac{MP_S}{MP_E}\right)\cdot\left(\frac{E}{S}\right)} \tag{8}$$

where MP_E and MP_S indicate marginal product of energy and land, respectively.

We also have

$$\frac{MP_S}{MP_E} = \frac{\partial Y}{\partial E} \Big/ \frac{\partial Y}{\partial S} = \frac{\eta_E}{\eta_S}\cdot\frac{S}{E} \tag{9}$$

Combining Formula (8) with Formula (9), we can get

$$\sigma_{ES} = \frac{d\left(\frac{E}{S}\right)}{d\left(\frac{MP_S}{MP_E}\right)}\cdot\frac{\eta_S}{\eta_E} = \frac{\eta_S}{\eta_E}\cdot\left[\frac{d\left(\frac{MP_S}{MP_E}\right)}{d\left(\frac{E}{S}\right)}\right]^{-1} = \frac{\eta_S}{\eta_E}\cdot\left[\frac{d\left(\frac{\eta_S}{\eta_E}\cdot\frac{E}{S}\right)}{d\left(\frac{E}{S}\right)}\right]^{-1} \tag{10}$$

Further, we have

$$\frac{d\left(\frac{\eta_S}{\eta_E}\cdot\frac{E}{S}\right)}{d\left(\frac{E}{S}\right)} = \frac{\eta_S}{\eta_E} + \frac{E}{S}\cdot\frac{d\left(\frac{\eta_S}{\eta_E}\right)}{d\left(\frac{E}{S}\right)} \tag{11}$$

$$d\left(\frac{\eta_S}{\eta_E}\right) = -\frac{\eta_S}{{\eta^2}_E}d(\eta_E) + \frac{1}{\eta_E}d(\eta_S) \tag{12}$$

$$d\left(\frac{E}{S}\right) = -\frac{E}{S^2}dS + \frac{1}{S}dE \tag{13}$$

Bringing Formulas (12) and (13) into Formula (11), we obtain the following equation

$$\frac{d\left(\frac{\eta_S}{\eta_E}\right)}{d\left(\frac{E}{S}\right)} = \frac{-\frac{\eta_S}{{\eta^2}_E}d(\eta_E) + \frac{1}{\eta_E}d(\eta_S)}{-\frac{E}{S^2}dS + \frac{1}{S}dE} = \frac{-\frac{\eta_S}{{\eta^2}_E}\frac{d(\eta_E)}{dS} + \frac{1}{\eta_E}\frac{d(\eta_S)}{dS}}{-\frac{E}{S^2} + \frac{1}{S}\frac{dE}{dS}} \tag{14}$$

Bringing Formulas (11) and (14) into Formula (10), we can get the substitution elasticity of energy for land expressed as

$$\sigma_{ES} = \left(\frac{\eta_E}{\eta_S}\right)^{-1}\left[\frac{\eta_S}{\eta_E} + \frac{E}{S}\frac{d\left(\frac{\eta_S}{\eta_E}\right)}{d\left(\frac{E}{S}\right)}\right]^{-1} = \left[1 + \frac{\eta_E}{\eta_S}\frac{E}{S}\frac{-\frac{\eta_S}{{\eta^2}_E}\frac{d(\eta_E)}{dS} + \frac{1}{\eta_E}\frac{d(\eta_S)}{dS}}{-\frac{E}{S^2} + \frac{1}{S}\frac{dE}{dS}}\right]^{-1} \tag{15}$$

According to differential and derivative theories, when E_t changes a unit, the variation in output elasticity of energy input η_E can be regarded as the derivative of ne to E_t. Based on Formula (3), we can work out the partial derivatives of E_t as below.

$$\frac{\partial(\eta_E)}{\partial S} = \frac{\beta_{ES}}{S} \tag{16}$$

That is,

$$\frac{d(\eta_E)}{dS} = \frac{\beta_{ES}}{S} \tag{17}$$

Similarly, when E_t changes a unit, the variation in output elasticity of land input ns is the derivative of ns to E_t. The partial derivative of E_t can be solved from Formula (4) and the result is shown as follows.

$$\frac{\partial(\eta_S)}{\partial S} = \frac{2\beta_{SS}}{S} \tag{18}$$

Namely

$$\frac{d(\eta_E)}{dS} = \frac{2\beta_{SS}}{S} \tag{19}$$

Bringing Formulas (17) and (19) into Formula (15), we can get the substitution elasticity of energy for land expressed as

$$\sigma_{ES} = \left[1 + \frac{\eta_E E}{\eta_S S} \frac{-\frac{\eta_S}{\eta^2{}_E}\frac{\beta_{ES}}{S} + \frac{1}{\eta_E}\frac{2\beta_{SS}}{S}}{-\frac{E}{S^2} + \frac{1}{S}\frac{dE}{dS}}\right]^{-1} = \left[1 + \frac{\frac{\eta_S}{\eta_E}\frac{EdS}{SdE}\beta_{ES} + 2\frac{EdS}{SdE}\beta_{SS}}{-\eta_S\frac{EdS}{SdE} + \eta_S}\right]^{-1} \tag{20}$$

Dividing Formula (3) by Formula (4), we have

$$\frac{\eta_E}{\eta_S} = \frac{EdS}{SdE} \tag{21}$$

Bringing Formula (21) into Formula (20), we can get the substitution elasticity of energy for land as follows.

$$\sigma_{ES} = \left[1 + \frac{\frac{\eta_S}{\eta_E}\frac{\eta_E}{\eta_S}\beta_{ES} + 2\frac{\eta_E}{\eta_S}\beta_{SS}}{-\eta_S\frac{\eta_E}{\eta_S} + \eta_S}\right]^{-1} = \left[1 + \frac{-\beta_{ES} + 2\frac{\eta_E}{\eta_S}\beta_{SS}}{-\eta_E + \eta_S}\right]^{-1} \tag{22}$$

Following the same procedures above, we can obtain the other substitution elasticities:

$$\sigma_{EL} = \left[1 + \frac{-\beta_{EL} + 2\frac{\eta_E}{\eta_L}\beta_{LL}}{-\eta_E + \eta_L}\right]^{-1} \text{(energy for labor)} \tag{23}$$

$$\sigma_{EW} = \left[1 + \frac{-\beta_{EW} + 2\frac{\eta_E}{\eta_W}\beta_{WW}}{-\eta_E + \eta_W}\right]^{-1} \text{(energy for water)} \tag{24}$$

$$\sigma_{EF} = \left[1 + \frac{-\beta_{EF} + 2\frac{\eta_E}{\eta_F}\beta_{FF}}{-\eta_E + \eta_F}\right]^{-1} \text{(energy for capital)} \tag{25}$$

$$\sigma_{SL} = \left[1 + \frac{-\beta_{SL} + 2\frac{\eta_S}{\eta_L}\beta_{LL}}{-\eta_S + \eta_L}\right]^{-1} \text{(land for labor)} \tag{26}$$

$$\sigma_{SW} = \left[1 + \frac{-\beta_{SW} + 2\frac{\eta_S}{\eta_W}\beta_{WW}}{-\eta_S + \eta_W}\right]^{-1} \text{(land for water)} \tag{27}$$

$$\sigma_{SF} = \left[1 + \frac{-\beta_{SF} + 2\frac{\eta_S}{\eta_F}\beta_{FF}}{-\eta_S + \eta_F}\right]^{-1} \text{(land for capital)} \tag{28}$$

$$\sigma_{LW} = \left[1 + \frac{-\beta_{LW} + 2\frac{\eta_L}{\eta_W}\beta_{WW}}{-\eta_L + \eta_W}\right]^{-1} \text{(labor for water)} \tag{29}$$

$$\sigma_{LF} = \left[1 + \frac{-\beta_{LF} + 2\frac{\eta_L}{\eta_F}\beta_{FF}}{-\eta_L + \eta_F}\right]^{-1} \text{(labor for capital)} \tag{30}$$

$$\sigma_{WF} = \left[1 + \frac{-\beta_{WF} + 2\frac{\eta_W}{\eta_F}\beta_{FF}}{-\eta_W + \eta_F}\right]^{-1} \text{(water for capital)} \tag{31}$$

2.3. Regression Approach—Ridge Regression

When there exists multicollinearity among independent variables, the variance of estimation of regression coefficient based on the OLS method would be very large, and thus the estimation would be instable. In this case, a kind of biased estimation was put forward by Hoerl and Kennard in 1970 [38], which is essentially an improvement in the OLS method when independent variables are multilinear. With respect to a multiple linear regression model $y = X\beta + \varepsilon$, the least squares estimation of β is $\hat{\beta} = (X'X)^{-1}X\prime y$. When there exists multicollinearity in the model, it leads to $|X'X| \approx 0$. In this situation, even if $\hat{\beta}$ is the unbiased estimator of β, $\hat{\beta}$ is instable, because the variance of the estimator is large and estimation is inaccurate. Supposing a matrix $kI(k > 0)$ is added to $X'X$, the proximity of $X'X + kI$ to a singular matrix will be reduced. The operation carried out is known as ridge estimation and the k employed is called the ridge parameter. When k equals 0, the ridge regression estimation turns to be the OLS estimate $\hat{\beta}(k) = (X'X + kI)^{-1}X'y$. Because ridge parameter k is not uniquely determined, the ridge regression estimation $\hat{\beta}(k)$ is actually a estimation family of regression parameter β. The value of k that makes the estimate $\hat{\beta}(k)$ stable is selected as the optimal solution.

3. Results

In this section, we provide a data description used in empirical modeling and then carry out a Hausman test and multiple collinearity test separately using STATA software. After determining the feasible model type, the fixed-effect ridge method is employed to estimate the parameter of the translog production function formula. Furthermore, the output elasticity and substitution elasticity of the mining industry are calculated and differences in technological progress among different production factors are explored.

3.1. Data Source Description

Considering research needs and data availability, the provincial data of China's agricultural sector from 2010 to 2015 are used in this study. To be specific, the production input factors include capital, energy, labor, land and water resources, and the output is agricultural output. The data of Hong Kong, Macau, Taiwan and Tibet provinces are not available currently, so they are excluded in the empirical samples. Descriptive statistical analysis of the sample is given in Table 1.

Table 1. Summary statistics for logarithmic output, labor, capital and energy.

Statistic	Obs	Mean	Std. Dev.	Min	Max
Y	480	6.7370	0.9614	4.0427	8.5228
capital	480	7.3704	0.8510	5.2903	9.1970
land	480	7.1956	0.9803	4.9225	8.6181
labor	480	6.4551	1.0846	3.5080	8.1771
energy	480	5.0288	0.8741	2.0754	6.6687
water	480	4.4473	0.9503	1.8563	6.3310

Note: data of agricultural GDP, labor, land and water resources are derived from China's National Bureau of Statistics and Provincial Statistical Yearbook, and capital is calculated, referring to Wu [39], by the perpetual inventory method.

3.2. Model Determination

In order to estimate the coefficients in the translog production model, the first step is to determine a correct model form, because the panel data model can generally be divided into three categories when the time dimension is smaller than the individual dimension, that is, the pooled regression model, fixed effects model or random effects model. Thus, Hausman tests are performed and the results are listed in Table 2.

Table 2. Hausman test results summary.

Tests	The Results of Statistic	*p* Value
Hausman tests (chi2)	75	0.000

The results demonstrate that the chi2 statistic is 75 with a *p* value of 0.000, which implies that the fixed effects model is more feasible than the random effects model. Thus, the fixed effects model was selected, which is convenient for subsequent research and analysis in the paper.

3.3. Multicollinearity Analysis

There usually exists a correlation between economic variables, especially when the labor and capital are simultaneously included in the model. Severe multicollinearity will lead to an inaccurate OLS estimator and an invalid test resulting in a single parameter, in which case the wrong statistical inference consequently occurs. Firstly, a correlation matrix of some variables of the model is worked out and described in Figure 2. The points in the graph are traces of a simple scatter plot between different variables, and the stronger the correlation between variables, the more linear the scatter plot tends to be. Apparently, pairwise correlation between most variables can be observed. Intuitively, it is reasonable to believe that there is a multi-collinearity problem of the explanatory variables in the model. Further, a VIF test of the regression model is conducted in order to present more rigorous judgment and the results are shown in Table 3. It can be noticed that the VIF values of all variables are greater than 10, and the mean value is 3558.15. Therefore, it is undoubted that the model has serious multi-collinearity problems.

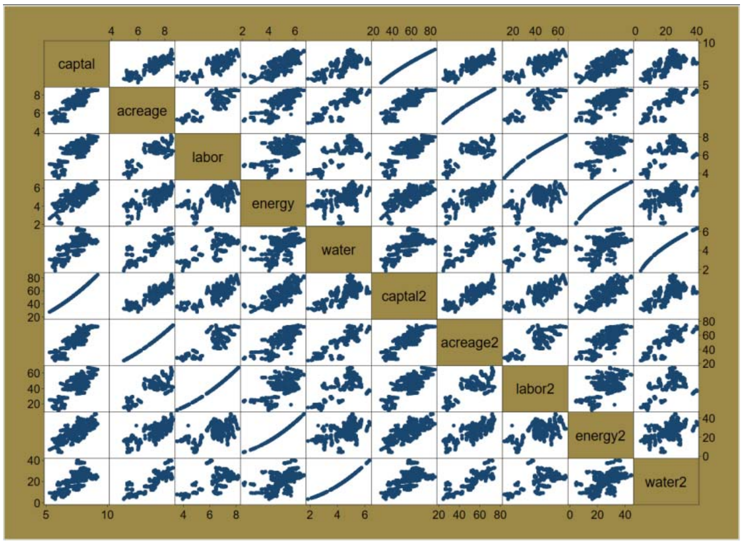

Figure 2. Matrix of correlation coefficients between variables.

Table 3. VIF values of each variable.

Variable	VIF	Variable
maximum	18,004.28	C acreage
minimum	820	labor
average	3558.15	

3.4. Results of Ridge Regression and Model Characteristics

When there is severe multi-collinearity in the model, adopting the ridge regression method instead of the OLS method to estimate Equation (2) can lead to more accurate parameters and make for more reasonable statistical inferences. Generally, the ridge trace is used to determine the value of parameter k in Section 2. The SPSS software is applied here to draw a preliminary ridge trace that is depicted in Figure 3. It can be discerned that, when k = 0.5, all the estimated coefficients together with the slope of residual sum of squares tend to be stable. Therefore, it is appropriate to determine the parameter of k as 0.5. Based on k = 0.5, the ridge regression method is applied to estimate the coefficients in the translog production function based on a fixed effect model, whose results are listed in Table 4. It can be easily observed that the values of the Wald Test statistic and F-Test statistic are 3912.9695 and 144.9248, respectively. Correspondingly, the *p* values are 0.0000 and 0.0000, respectively, with the Root MSE (Sigma) being 0.0912. Thus, the explanatory ability of the model on the whole is fair and convictive.

Table 4. Parameter estimates of the translog production model.

Ridge *k* Value = 0.10000			**Ordinary Ridge Regression**		
Sample Size = 480			Cross Sections Number = 30		
Wald Test = 3912.9695			*p*-Value > chi2(27) = 0.0000		
F-Test = 144.9248			*p*-Value > F(27, 423) = 0.0000		
(Buse 1973) R^2 = 0.9920			Raw Moments R^2 = 0.9998		
(Buse 1973) R^2 Adj = 0.9910			Raw Moments R^2 Adj = 0.9998		
Root MSE (Sigma) = 0.0912			Log Likelihood Function = 498.5156		
R^{2}h = 0.5816 R^{2}h Adj= 0.5263 F-Test = 23.28 *p*-Value > F(27, 423) 0.0000					
R^{2}v = 0.1216 R^{2}v Adj= 0.0053 F-Test = 2.32 *p*-Value > F(27, 423) 0.0003					
Variable	Coefficient	Std. Error	t-Statistic	*p*-value	95% Conf. Interval
capital	0.02091	0.00346	6.04	0.000	[0.01410, 0.02772]
acreage	0.02072	0.00338	6.14	0.000	[0.01408, 0.02735]
labor	−0.00209	0.00255	−0.82	0.415	[−0.00710, 0.00293]
energy	0.00666	0.00394	1.69	0.092	[−0.00109, 0.01441]
water	0.00903	0.00322	2.81	0.005	[0.00270, 0.01535]
capital^2	0.00084	0.00022	3.79	0.000	[0.00041, 0.00128]
acreage^2	0.00158	0.00024	6.63	0.000	[0.00111, 0.00205]
labor^2	0.00008	0.00022	0.37	0.712	[−0.00035, 0.00051]
energy^2	−0.00088	0.00041	−2.12	0.035	[−0.00169, −0.00006]
water$_2$	0.00117	0.00039	2.98	0.003	[0.00040, 0.00195]
C acreage	0.00133	0.00017	7.62	0.000	[0.00099, 0.00168]
C labor	0.00063	0.00019	3.42	0.001	[0.00027, 0.00100]
C energy	0.00045	0.00022	2.05	0.041	[0.00002, 0.00088]
C water	0.00157	0.00025	6.32	0.000	[0.00108, 0.00206]
A labor	0.00084	0.00019	4.34	0.000	[0.00046, 0.00122]
A energy	0.00126	0.00022	5.65	0.000	[0.00082, 0.00170]
A water	0.00148	0.00025	5.84	0.000	[0.00098, 0.00198]
L energy	0.00028	0.00026	1.05	0.294	[−0.00024, 0.00079]
L water	0.00072	0.00026	2.82	0.005	[0.00022, 0.00123]
E water	0.00174	0.00034	5.05	0.000	[0.00106, 0.00242]
t	0.00983	0.00087	11.30	0.000	[0.00812, 0.01154]
t2	0.00034	0.00008	4.18	0.000	[0.00018, 0.00050]
T capital	0.0006539	0.0000403	16.24	0.000	[0.00057, 0.00073]
T land	0.0009618	0.0000651	14.77	0.000	[0.00083, 0.00109]
T labor	0.0010027	0.0001148	8.73	0.000	[0.00078, 0.00123]
T energy	0.0006518	0.0001336	4.88	0.000	[0.00039, 0.00091]
T water	0.0018607	0.0001865	9.98	0.000	[0.00149, 0.00223]
_cons	5.49917	0.1567579	35.08	0.000	[5.1910, 5.8072]

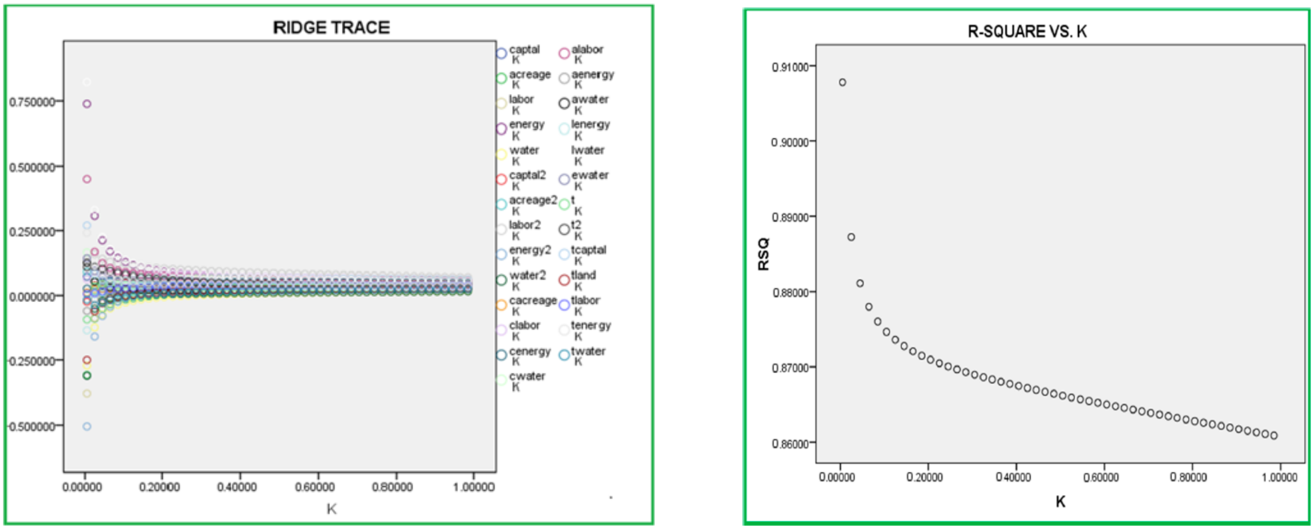

Figure 3. Maps of ridge trace.

According to the regression results, some conclusions can be derived as follows.

Firstly, economic growth benefits from the joint efforts of factor accumulation and technological advancement. In practical terms of the model in this paper, agricultural economic growth Y depends on the horizontal terms, the squared terms and the cross-terms between input factors, as well as the cross-terms among the time trend and each input factor.

Secondly, all the horizontal terms and squared terms have passed the test at the 1% significance level, which means that capital, labor, energy, land and water resources have direct effects on agricultural output. However, the effects of these impacts are different. Specifically, the impact of labor on agricultural output is negative while the effects of energy, capital, land and water resources on agricultural output are positive. These results show that over the sample time period, labor has mostly decreasing returns to scale, while energy, capital, land and water resources have increasing returns to scale.

Thirdly, concerning cross-terms, the coefficients of the interaction terms of energy and land, energy and water, and energy and capital are both positive, and the p values are 0.000, 0.000, 0.041, respectively. This shows that the combinations of energy and these resources at this stage are conducive to maintaining the growth of agriculture. The p value of the interaction terms of energy and labor is 0.294, which means the combination of energy and labor has an insignificant effect on agricultural growth. In particular, the coefficient of the interaction term between water and energy is 0.174, which is the largest coefficient among energy and other interaction terms. Therefore, the Chinese government should increase the coordinated management of water and energy in the agricultural sector to further promote the development of the agricultural economy.

Fourthly, the coefficients of the time trend term and its interaction with input factors are both positive, and all the p values are 0.0000. This implies that continuous R&D investment not only can promote economic growth, but also promote the positive effect of input factors on agricultural output.

4. Discussions

4.1. Output Elasticities

The output elasticity of agricultural input measures the percentage change in agricultural output when the input rises by 1%. This indicator can be used to judge the stage of scale returns of production factors. The estimation of coefficients in Equation (2), together with the computing Equations (3)–(6), can be applied to calculate the output elasticities of China’s agricultural input factors, and the results are shown in Table 5 (the whole country) and Figure 4. From Table 5, we can conclude that the output elasticities of energy, labor, land and water show an increasing trend, especially for energy and land, which rise from 0.0203 to 0.1694 and from 0.0710 to 1.1273, respectively. In addition, the output elasticity of capital decreased from 0.933 in 2000 to 0.0206 in 2003 and remained negative in the following years. The output elasticity of capital is basically negative, which indicates that the phenomenon of capital deepening in China's agricultural production has appeared and capital has shown a characteristic of decreasing marginal return. In recent years, with the vigorous support of China's policies for agriculture, investment in agricultural production has increased year by year, showing a capital-driven characteristic. However, with the annual investment of capital, its marginal output has shown a negative result. With regards to energy, the output elasticities show a significantly increasing trend. As the continuous development of agricultural mechanization in China has promoted the improvement of agricultural production efficiency, unit energy input can create more agricultural products. As for agricultural labor, the output elasticity rose from 0.0141 to 0.1388, in line with the realistic transformation of China's agricultural labor force. Although China has long been known for its large population and abundant labor force, with the rapid popularization of China's urbanization and the transformation of the concept of youth labor groups, more and more young and middle-aged groups have chosen to take up occupations in secondary and tertiary industries. Additionally, along with the spread of agricultural machinery and modernized agricultural technology, the growth in the number of agricultural laborers contributes further to agricultural production. With regards to land and water, outputs of these two factors are all positive and increase year by year. These results indicate that land and water factors are in the stage of increasing marginal returns, and increasing the factors can make the total agricultural output increase. This is in line with the reality of China's agricultural land and water resources. On one hand, rapid urbanization in China has resulted in a decline in agricultural land in recent years, from 2.027 billion acres in 2000 to 2.023 billion acres in 2017. Since land in China is under collective ownership, meaning that farmers do not have absolute autonomy in the process of land transfer, the market transaction price does not reflect its value as a scarce resource, and the cultivated land has been shrinking year by year because of state administration. On the other hand, China's water resources are used extensively, and the effective utilization coefficient of farmland irrigation water is far lower from the world's 0.7–0.8 level. In addition, water resource pollution is becoming more and more serious. From 2005 to 2015, the area of waterlogging removal and the area of soil and water erosion has continued to increase. All these effects have combined, leading to a growing shortage of agricultural water.

Table 5. Output elasticities of each input factor.

	Energy	**Capital**	**Labor**	**Land**	**Water**
2000	0.0203	0.0933	0.0141	0.0710	0.0543
2001	0.0302	0.0692	0.0224	0.1404	0.0609
2002	0.0401	0.0450	0.0308	0.2098	0.0674
2003	0.0501	0.0206	0.0390	0.2782	0.0736
2004	0.0600	−0.0035	0.0474	0.3477	0.0804
2005	0.0697	−0.0275	0.0558	0.4174	0.0873
2006	0.0796	−0.0516	0.0642	0.4872	0.0940
2007	0.0896	−0.0762	0.0724	0.5567	0.1001
2008	0.0997	−0.1005	0.0808	0.6312	0.1065
2009	0.1096	−0.1248	0.0890	0.7014	0.1129
2010	0.1194	−0.1492	0.0973	0.7726	0.1193
2011	0.1294	−0.1735	0.1056	0.8443	0.1257
2012	0.1394	−0.1977	0.1140	0.9163	0.1323
2013	0.1494	−0.2220	0.1222	0.9830	0.1385
2014	0.1594	−0.2463	0.1305	1.0545	0.1449
2015	0.1694	−0.2706	0.1388	1.1273	0.1514

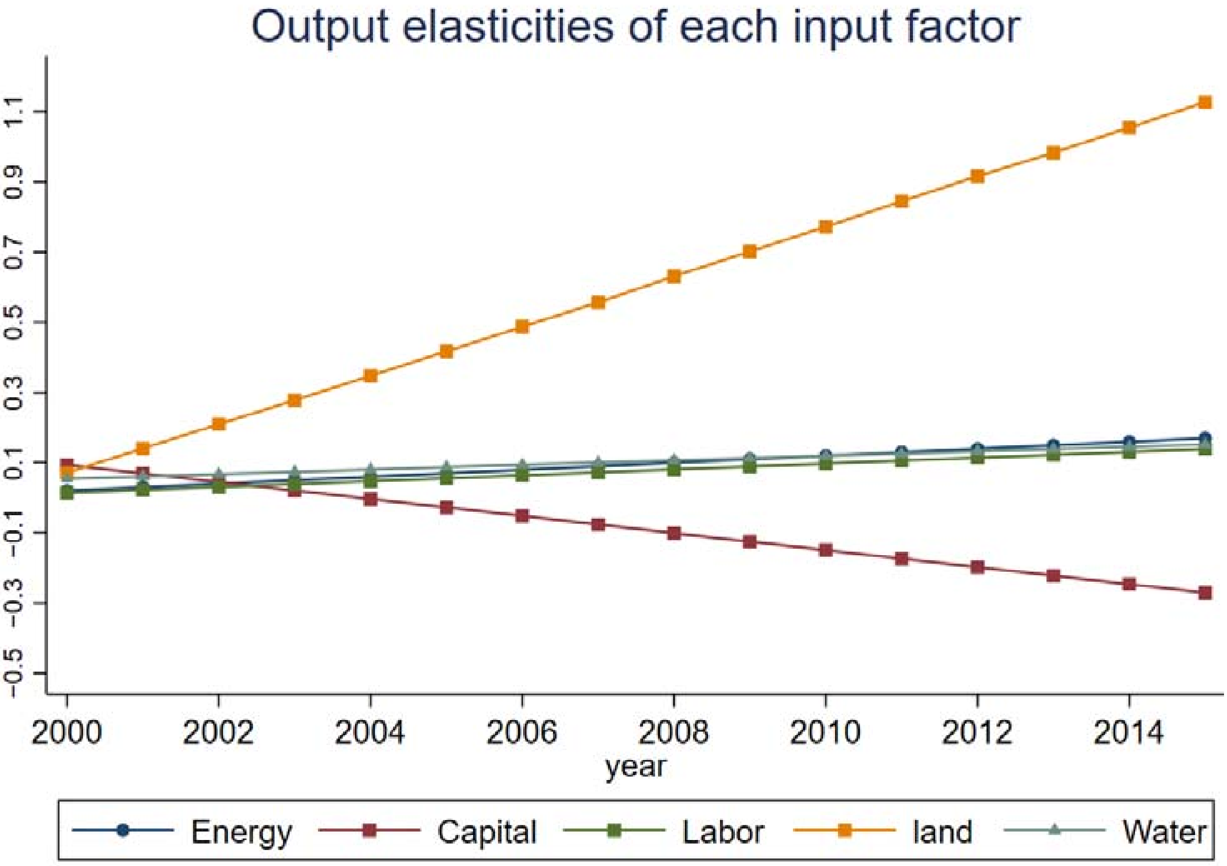

Figure 4. Output elasticities of each input factor.

In conclusion, among the agricultural production factors, labor, land, energy and water resources are all in the stage of increasing returns to scale while capital is in the stage of decreasing returns to scale. The characteristics shown by the input factors determine that China's current agricultural development is mainly driven by capital.

4.2. Substitution Elasticities

The substitution elasticity of production factors reflects the matching relationship between the structural change in input factors and technology, which is a key variable affecting technology selection. Substitution elasticities between different production factors are obtained based on the coefficients of the model and Equations (21)–(31). Some extreme values have been smoothed, and the results are reported in Table 6. Among them, the substitution elasticities of land and energy, land and labor, and land and water are all greater than one, which indicates that land has the function of substitution for energy, labor and water to maintain agricultural output in the sample interval. In terms of capital, its substitution for land, labor and water resources has changed from strong to weak. By and large, the rate of substitution between capital and all three factors is greater than one before 2004 and less than one after 2004. In other words, capital is no longer a strong substitute for the role of land, labor and water in agricultural production. In addition, the substitution elasticity of energy and labor is less than 1. The elasticities of substitution of other factors of production are sometimes greater than 1 and sometimes less than 1, so there is no specific law. Combined with China's basic national conditions, the above conclusions can help us to propose solutions to the problems of its improvement.

Table 6. Substitution relationship between different factors of production.

Year	Energy vs. Land	Energy vs. Labor	Energy vs. Water	Energy vs. Capital	Land vs. Labor	Land vs. Water	Land vs. Capital	Labor vs. Water	Labor vs. Capital	Water vs. Capital
2000	1.0070	0.9918	1.0264	1.0011	1.1605	1.1062	1.0016	1.0030	1.0049	1.0155
2001	1.0053	0.9917	1.0191	0.9913	1.0906	1.0527	1.0310	0.9963	1.0016	1.0179
2002	1.0039	0.9926	1.0123	0.9392	1.0636	1.0431	1.0446	0.9903	1.0174	1.0483
2003	1.0030	0.9935	1.0052	1.0947	1.0492	1.0378	1.0394	0.9847	1.1286	1.0404
2004	1.0025	0.9941	0.9975	1.3768	1.0400	1.0338	1.2571	0.9797	1.3883	1.2594
2005	1.0021	0.9945	0.9881	0.9466	1.0337	1.0306	0.9359	0.9750	0.9465	0.9361
2006	1.0018	0.9949	0.9687	0.9762	1.0291	1.0281	0.9679	0.9703	0.9759	0.9680
2007	1.0016	0.9954	0.9630	0.9852	1.0257	1.0262	0.9785	0.9645	0.9848	0.9786
2008	1.0014	0.9959	0.9054	0.9894	1.0229	1.0244	0.9838	0.9589	0.9890	0.9839
2009	1.0013	0.9962	0.9465	0.9918	1.0207	1.0229	0.9870	0.9527	0.9914	0.9871
2010	1.0012	0.9964	1.1215	0.9933	1.0189	1.0215	0.9892	0.9457	0.9930	0.9892
2011	1.0011	0.9966	1.2519	0.9944	1.0174	1.0203	0.9907	0.9377	0.9941	0.9907
2012	1.0010	0.9969	1.1410	0.9951	1.0161	1.0193	0.9918	0.9284	0.9949	0.9919
2013	1.0009	0.9971	1.0928	0.9957	1.0150	1.0184	0.9927	0.9156	0.9955	0.9928
2014	1.0009	0.9972	1.0667	0.9962	1.0140	1.0175	0.9935	0.8987	0.9960	0.9935
2015	1.0008	0.9974	1.0543	0.9966	1.0132	1.0167	0.9940	0.8742	0.9963	0.9941

Figure 5 gives the national average of the substitution rates among the factors. It can be seen that the substitution between labor and energy is weaker in the central region and stronger in the northwest and southeast coastal regions, suggesting that increasing agricultural labor in these regions can reduce energy consumption. The substitution between labor and water resources is relatively smaller in the western region and stronger in the central and southeastern coastal regions, suggesting that increasing agricultural labor in these regions is more effective in conserving water resources. The substitution effect between labor and land is smaller in the eastern region and relatively stronger in most provinces in the northwest, suggesting that increasing labor input in the northwest can save land resources. Regarding the substitution between land and water, land and energy, and land and labor, unlike the substitution of capital for water, land, labor and energy, the substitution of land for water, energy and labor does not show obvious regional characteristics, and the elasticity values of most provinces are greater than 1, showing strong substitution characteristics, indicating that land has a strong substitution ability for these three factors. This indicates that land can effectively substitute for these three factors within the sample interval. Therefore, under the situation of land and water scarcity, increasing energy and labor inputs can effectively save land resources.

Previous studies rarely report specific values of the elasticity of substitution directly, and Table 7 shows the studies of different scholars on the elasticity of substitution in agriculture. Lin and Raza [40] find that the substitution elasticity of labor and energy consumption is the highest in Pakistan, which shows that energy consumption can be substituted by labor. Thus, they suggested that an efficient, modern and healthy physical, energy-efficient machines and technical labor are required in Pakistan's agriculture sector. Takeshima et al. [41] explored the substitution relationship between energy and labor in southern Nigeria, and found that the substitution relationship between them was beneficial to increasing farmers' income. Suh [42] found that energy-capital and energy-labor in U.S. agriculture exhibited substitutability between 2000 and 2011, with rising energy prices reducing their intensity of use and output contribution. This paper provides empirical research for studying the substitution relationships of production factors in Chinese agriculture.

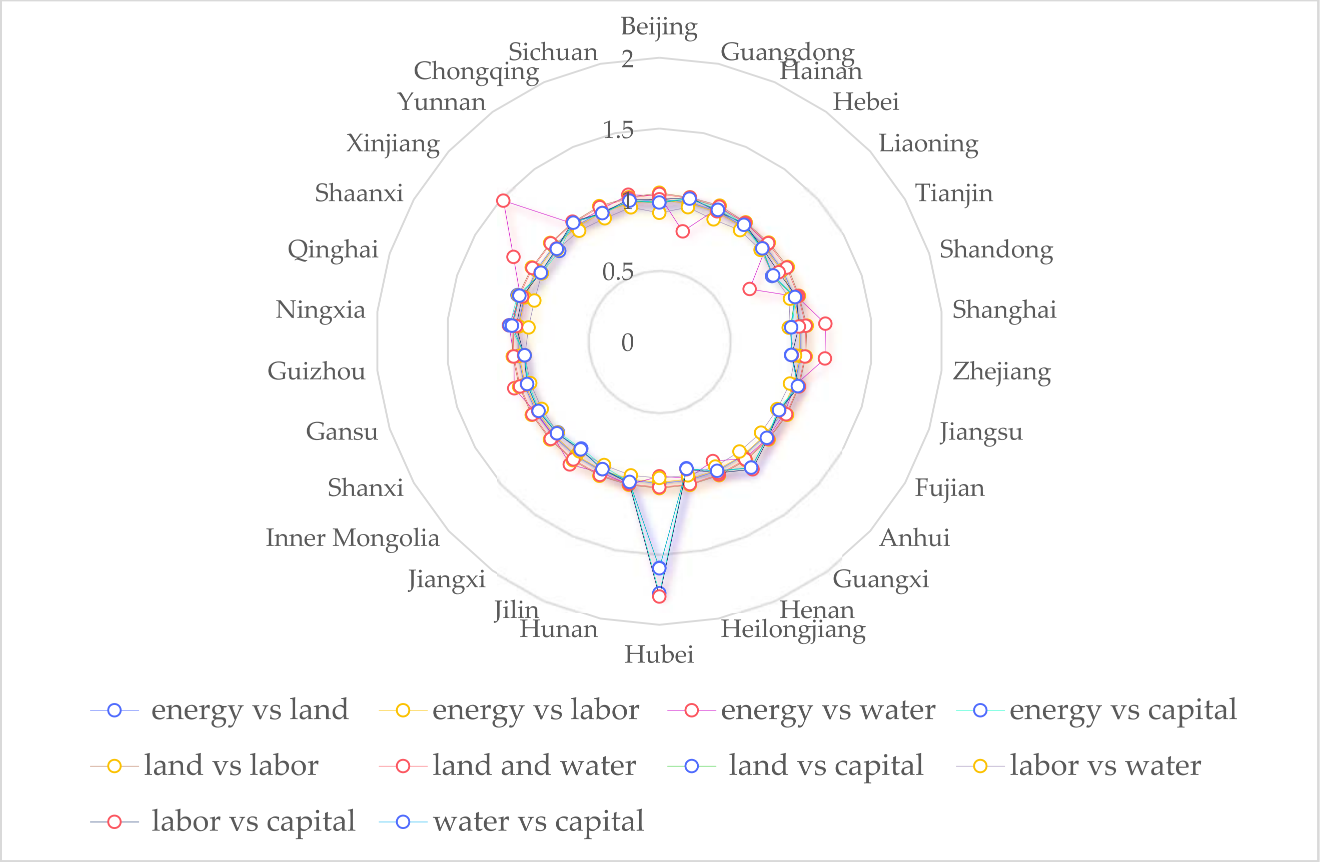

Figure 5. Elasticity of substitution between elements.

Table 7. Substitution relationships between different factors of production.

Author	Research Country	Research Time Period	Substitution Elasticities (Field of Agricultural Research)
Lin, B., Raza M. Y.	Pakistan	1980–2018	Capital vs. energy (1.34–2.06) Capital vs. labor (1.59–2.04) Labor vs. energy (1.74–2.44)
Takeshima, H., Nin-Pratt, A., Diao, X.	Nigeria	2010	Labor vs. energy
Suh, D. H.	America	1960–1964,2000–2004	Capital vs. energy Capital vs. labor Labor vs. energy

4.3. Differences in Technological Progress between Production Factors

The difference in technological progress between different factors of production will affect its contribution to economic growth. Therefore, we compare the technological progress in the area of energy, water and land, which are scarce resources in agricultural production, to analyze where China should increase the investment in technological progress to promote the balanced development of factors.

According to [43], the difference in technological progress among production factors can be expressed as $\text{Bias}_{ijT} = \frac{\beta_{iT}}{\delta_i} - \frac{\beta_{jT}}{\delta_j}$, where β_{iT} in the formula represents the cross-term between input factors and the time trend, and it is also the partial derivative of the output elasticity of corresponding factors to the time trend, reflecting the effects of technological progress alone on the output elasticity of factors. In the formula, if $\text{Bias}_{ij} > 0$, the technology of input factor i advances faster than that of factor j, and vice versa. Combined with the translog production function, this paper mainly analyzes the differences in the technological progress of capital, water resources and land. From the empirical results in Figure 6, it can be perceived that in the process of agricultural development, the order of technological progress speed is water resources > capital > land. According to the theory of induced technological transition, changes in agricultural technology respond to the relative scarcity of production factors. Combining the research conclusions in this chapter, it can be concluded that water resources are the scarcest element in agricultural activities because their technological progress is the fastest. As for capital and land, their speeds of differing technological progress are not much and show a trend of convergence.

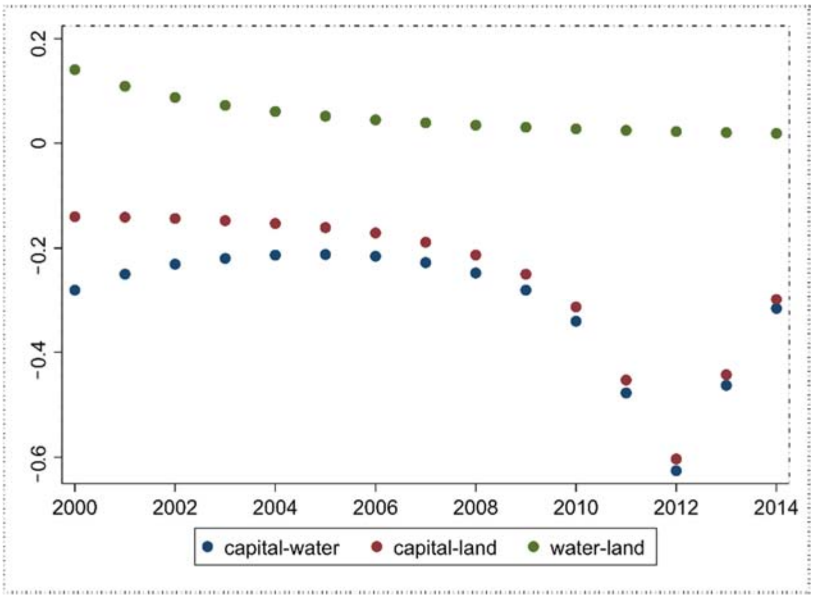

Figure 6. The difference of technical progress in water and land: 2000–2015.

4.4. Important Information for the Management of Agricultural Water, Energy and Land Resources

Based on the above analysis, it can be seen that China's agricultural production is mainly driven by capital, and the phenomenon of capital deepening has already appeared in agricultural sector. Hence, it is difficult to achieve sustained growth of the agricultural economy simply by accumulating capital. The labor force in agricultural production has shifted from surplus to scarcity. What needs more attention is that agricultural water resources and land are already the scarcest elements from the perspective of inductive technology change theory. The enlightenment about the management of water and land resources can be drawn based on the above research conclusions.

As for water resources, China is facing increasingly serious water resource security problems. The changes in demand, quantity, quality, availability, and spatial and temporal distribution patterns of water resources caused by climate change have aggravated the uncertainty of China's agricultural water resource security. Therefore, in order to maintain the sustainable development of agriculture, it is not feasible to exploit agricultural water resources in a short time, which can only be ameliorated from the perspective of production factor substitution. From the empirical results, the marginal output of water resources production is increasing, and water resources and other factors are substitutable. In order to reduce the impact of water resources on the sustainable development of agriculture, the following three measures can be actively promoted. Firstly, increase scientific and technological investment in agricultural water use and improve the efficiency of agricultural water resources. According to the literature, the use efficiency of agricultural water resources in China is about 0.4–0.5, which is much lower than the water use efficiency of 0.7–0.8 in developed countries. Additionally, the efficiency of agricultural water resources in different regions of China varies greatly. Therefore, it is indispensable to increase investment in R&D related to agricultural water resources. Secondly, establish an agricultural water rights trading market. At present, most provinces and cities in China do not have a unified agricultural water market. The low price of agricultural water has caused serious waste. The National Development and Reform Commission of China and the Ministry of Water Resources have issued guidance on the development of a comprehensive demonstration of water-saving agriculture in large and medium-sized irrigation districts. Full implementation of the irrigation area water intake permit system, the use of total water consumption control and quota management indicators play important roles as a basis for achieving the efficient use of agricultural water resources. Thirdly, reduce pollution of agricultural water resources. In this regard, it is necessary to strengthen the government's supervision and establishment of local environmental protection facilities and the management of companies' sewage. On the other hand, it is necessary to strengthen rural people's environmental protection awareness and establish a clear reward and punishment system.

In terms of energy output elasticity, energy efficiency is still at the stage of improvement, so China should ensure the input of agricultural energy and improve the quality of energy use in the agricultural sector. The following initiatives should be taken to improve the quality of agricultural energy: First, the government should cultivate a reasonable awareness of energy consumption among agricultural producers to ensure that agricultural energy can be coordinated with rural economic and social development. Secondly, the government should correctly handle the interrelationship between the agricultural economy and agricultural production machinery and energy to promote agricultural mechanization and modernization. Finally, the government must pay attention to the negative impact of the development process of agricultural mechanization on nature, human life and the social environment, and take reasonable initiatives to reduce the harm it causes to the national economy and society.

Likewise, the importance of cultivated land is undeniable because it not only has multiple functions in production, life and ecology, but also serves as the fundamental guarantee for national food security. From the perspective of the output elasticity of production factors, agricultural land is still in the improving stage of utilization efficiency. Therefore, some measures must be taken to reduce the loss of agricultural land. First, farmers should be given more bargaining power. In China, agricultural land is held in collective ownership. In fact, in the process of agricultural land transfer, farmers have no real independent decision-making power, and local governments often forcefully exchange it in the form of subsidies. In this way, the land does not actually reflect its scarcity in the agricultural economy, and this will accelerate its outflow from the agricultural sector. Secondly, it is necessary to increase the labor force of young and middle-aged people and eliminate the problem of the hollowing out of rural areas, which are characterized by the old and weak. At the same time, introduce high-tech agricultural talents to the agricultural production field. Because land and labor population are substitutable, increasing the input of labor force can alleviate the impact of land loss on agricultural development in the short term. Further, appropriate policies to encourage fertility can also be adopted in the long run.

5. Conclusions

This article examines the changing characteristics of Chinese agriculture from 2000 to 2015 from the perspective of production factors, especially energy, water and land resources. The study finds that the growth of China's agriculture in the sample interval is mainly dependent on capital drive, which is consistent with the hypothesis of weak agriculture in the existing literature. Excessive reliance on capital investment will eventually hinder the improvement of production efficiency. China's agricultural labor force has achieved full transfer to secondary and tertiary industries, and agricultural labor shows signs of scarcity. For agricultural water and land resources, their output elasticities are continuously increasing, and they are replaceable with capital and labor factors. According to the theory of induced technological change, water resources are currently the most important production factor restricting agricultural development in agricultural production, so the scientific management of water resources is imperative. At present, since agricultural mechanization in China is in the medium-term stage of development, energy input is unlikely to decrease in the short term. We call for much a higher input of the agricultural labor force considering the reality of agricultural hollowing out and the tension between of water and land resources in China. Hence, large-scale rural–urban population transfer is not recommended in China now, and policies to encourage fertility should also be put forward in the near future.

This article provides an idea of sustainable agricultural development from a short-term perspective, but it is only based on the analysis of desirable output and input elements. However, in the context of the low-carbon economy and green agriculture, the quality and efficiency of economic development is being and will be gradually paid more attention to. Therefore, the analysis of pollution emissions and comprehensive efficiency in agricultural economic system is an important direction for future research. In addition, how the global economic crisis caused by the epidemic affects the sustainable development of agriculture is also our key research direction in the future.

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References

1. Cao, X.C.; Wu, M.Y.; Guo, X.P.; Zheng, Y.L.; Gong, Y.; Wu, N.; Wang, W.G. Assessing water scarcity in agricultural production system based on the generalized water resources and water footprint framework. *Sci. Total Environ.* **2017**, *609*, 587–597.
2. Huang, Y.; Li, Y.P.; Chen, X.; Ma, Y.G. Optimization of the irrigation water resources for agricultural sustainability in Tarim River Basin, China. *Agric. Water Manag.* **2012**, *107*, 74–85. [CrossRef]
3. Mushtaq, S.; Khan, S.; Dawe, D.; Hanjra, M.A.; Hafeez, M.; Asghar, M.N. Evaluating the impact of Tax-for-Fee reform (Fei Gai Shui) on water resources and agriculture production in the Zhanghe Irrigation System, China. *Food Policy* **2008**, *33*, 576–586. [CrossRef]
4. Wang, F.T.; Yu, C.; Xiong, L.C.; Chang, Y. How can agricultural water use efficiency be promoted in China? A spatial-temporal analysis. *Resour. Conserv. Recycl.* **2019**, *145*, 411–418. [CrossRef]
5. Zhao, R.Q.; Liu, Y.; Tian, M.M.; Ding, M.L.; Cao, L.H.; Zhang, Z.P.; Chuai, X.W.; Xiao, L.G.; Yao, L.G. Impacts of water and land resources exploitation on agricultural carbon emissions: The water-land-energy-carbon nexus. *Land Use Policy* **2018**, *72*, 480–492. [CrossRef]
6. Geng, Q.L.; Ren, Q.F.; Nolan, R.H.; Wu, P.T.; Yu, Q. Assessing China's agricultural water use efficiency in a green-blue water perspective: A study based on data envelopment analysis. *Ecol. Indic.* **2019**, *96*, 329–335. [CrossRef]
7. Shen, X.B.; Lin, B.Q. The shadow prices and demand elasticities of agricultural water in China: A StoNED-based analysis. *Resour. Conserv. Recycl.* **2017**, *127*, 21–28. [CrossRef]
8. Smith, L.; Inman, A.; Xin, L.; Zhang, H.F.; Meng, F.Q.; Zhou, J.B.; Burke, S.; Rahn, C.; Siciliano, G.; Haygarth, P.M.; et al. Mitigation of diffuse water pollution from agriculture in England and China, and the scope for policy transfer. *Land Use Policy* **2017**, *61*, 208–219. [CrossRef]
9. Liao, L.W.; Long, H.L.; Gao, X.L.; Ma, E.P. Effects of land use transitions and rural aging on agricultural production in China's farming area: A perspective from changing labor employing quantity in the planting industry. *Land Use Policy* **2019**, *88*, 104152. [CrossRef]
10. Wang, C.; Siriwardana, M.; Meng, S. Effects of the Chinese arable land fallow system and land-use change on agricultural production and on the economy. *Econ. Model.* **2019**, *79*, 186–197. [CrossRef]
11. Johnston, B.F.; Mellor, J.W. The role of agriculture in economic development. *Am. Econ. Rev.* **1961**, *51*, 566–593.
12. Garciabarrios, R.; Garciabarrios, L. Environmental and technological degradation in peasant agriculture: A consequence of development in Mexico. *World Dev.* **1990**, *18*, 1569–1585. [CrossRef]

13. Kwan, F.; Wu, Y.R.; Zhuo, S.H. Surplus agricultural labour and China's Lewis turning point. *China Econ. Rev.* **2018**, *48*, 244–257. [CrossRef]
14. Zhang, X.B.; Yang, J.; Thomas, R. Mechanization outsourcing clusters and division of labor in Chinese agriculture. *China Econ. Rev.* **2017**, *43*, 184–195. [CrossRef]
15. Hayami, Y.; Ruttan, V.W. Factor prices and technical change in agricultural development: The United States and Japan, 1880–1960. *J. Political Econ.* **1970**, *78*, 1115–1141. [CrossRef]
16. Babin, F.G.; Willis, C.E.; Allen, P.G. Estimation of substitution possibilities between water and other production inputs. *Am. J. Agric. Econ.* **1982**, *64*, 148–151. [CrossRef]
17. Cai, X.M.; Ringler, C.; You, J.Y. Substitution between water and other agricultural inputs: Implications for water conservation in a River Basin context. *Ecol. Econ.* **2008**, *66*, 38–50. [CrossRef]
18. Edwards, B.K.; Howitt, R.E.; Flaim, S.J. Fuel, crop, and water substitution in irrigated agriculture. *Resour. Energy Econ.* **1996**, *18*, 311–331. [CrossRef]
19. Kirby, M.; Bark, R.; Connor, J.; Qureshi, M.E.; Keyworth, S. Sustainable irrigation: How did irrigated agriculture in Australia's Murray–Darling Basin adapt in the Millennium Drought. *Agric. Water Manag.* **2014**, *145*, 154–162. [CrossRef]
20. Shani, U.; Tsur, Y.; Zemel, A.; Zilberman, D. Irrigation production functions with water-capital substitution. *Agric. Econ.* **2009**, *40*, 55–66. [CrossRef]
21. Shao, S.; Yang, Z.B.; Yang, L.L.; Zhang, X.; Geng, Y. Synergetic conservation of water and energy in China's industrial sector: From the perspectives of output and substitution elasticities. *J. Environ. Manag.* **2020**, *259*, 110045. [CrossRef] [PubMed]
22. Wang, F.; Jiang, Y.J.; Zhang, W.L.; Yang, F. Elasticity of factor substitution and driving factors of energy intensity in China's industry. *Energy Environ.* **2019**, *30*, 385–407. [CrossRef]
23. Apostolakis, B.E. Energy-capital substitutability/complementarity: The dichotomy. *Energy Econ.* **1990**, *12*, 48–58. [CrossRef]
24. Blackorby, C.; Russell, R.R. Will the real elasticity of substitution please stand up? (A comparison of the Allen/Uzawa and Morishima elasticities). *Am. Econ. Rev.* **1989**, *79*, 882–888.
25. Griffin, J.M.; Gregory, P.R. An intercountry translog model of energy substitution responses. *Am. Econ. Rev.* **1976**, *66*, 845–857.
26. Thompson, P.; Taylor, T.G. The capital-energy substitutability debate: A new look. *Rev. Econ. Stat.* **1995**, *77*, 565–569. [CrossRef]
27. Arnberg, S.; Bjorner, T.B. Substitution between energy, capital and labour within industrial companies: A micro panel data analysis. *Resour. Energy Econ.* **2007**, *29*, 122–136. [CrossRef]
28. Christopoulos, D.K. The demand for energy in Greek manufacturing. *Energy Econ.* **2000**, *22*, 569–586. [CrossRef]
29. Solow, J.L. The capital-energy complementarity debate revisited. *Am. Econ. Rev.* **1987**, *77*, 605–614.
30. Anderson, K.; Hayami, Y.; Mulgan, A.G. *The Political Economy of Agricultural Protection: East Asia in International Perspective*; Allen & Unwin in Association with the Australia-Japan Research Centre, Australian National University: Sydney, Australia, 1986; pp. 169–176.
31. Christensen, L.R. Conjugate duality and the transcendental logarithmic prodcution function. *Econometrica* **1971**, *39*, 255–256.
32. Alizadeh, P.; Mohammadi, H.; Shahnoushi, N.; Saghaian, S.; Pooya, A. Evaluating Cost Structure and Economies of Scale of Beef Cattle Fattening Farms in Mashhad City. *J. Agric. Sci. Technol.* **2019**, *21*, 1753–1766.
33. Ashayeri, M.S.; Khaledian, M.R.; Kavoosi-Kalashami, M.; Rezaei, M. The economic value of irrigation water in paddy farms categorized according to mechanization levels in Guilan province, Iran. *Agric. Water Manag.* **2018**, *202*, 195–201. [CrossRef]
34. Lavee, D.; Bahar, S. Examining the economies of scale of water and sewage utilities in the urban sector: The case of Israel. *Water Policy* **2017**, *19*, 257–270. [CrossRef]
35. Lin, B.Q.; Luan, R.R. Are government subsidies effective in improving innovation efficiency? Based on the research of China's wind power industry. *Sci. Total Environ.* **2020**, *710*, 136339. [CrossRef] [PubMed]
36. Onumah, E.E.; Onumah, J.A.; Onumah, G.E. Production risk and technical efficiency of fish farms in Ghana. *Aquaculture* **2018**, *495*, 55–61. [CrossRef]
37. Rossi, F.R.; de Souza, H.M.; Miranda, B.V.; Carrer, M.J. The role of contracts in the adoption of irrigation by Brazilian orange growers. *Agric. Water Manag.* **2020**, *233*, 106078. [CrossRef]
38. Hoerl, A.E.; Kennard, R.W. Ridge regression: Biased estimation for nonorthogonal problems. *Technometrics* **1970**, *12*, 55–67. [CrossRef]
39. Wu, Y.R. China's capital stock series by region and sector. *Front. Econ. China* **2016**, *11*, 156–172.
40. Lin, B.; Raza, M.Y. Fuels substitution possibilities and the technical progress in Pakistan's agriculture sector. *J. Clean. Prod.* **2021**, *314*, 128021. [CrossRef]
41. Takeshima, H.; Nin-Pratt, A.; Diao, X. Mechanization and agricultural technology evolution, agricultural intensification in sub-Saharan Africa: Typology of agricultural mechanization in Nigeria. *Am. J. Agric. Econ.* **2013**, *95*, 1230–1236. [CrossRef]
42. Suh, D.H. Declining energy intensity in the US agricultural sector: Implications for factor substitution and technological change. *Sustainability* **2015**, *7*, 13192–13205. [CrossRef]
43. Smyth, R.; Narayan, P.K.; Shi, H.L. Inter-fuel substitution in the Chinese iron and steel sector. *Int. J. Prod. Econ.* **2012**, *139*, 525–532. [CrossRef]