How to Break the Bottleneck of Potato Production Sustainable Growth—A Survey from Potato Main Producing Areas in China

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Abstract: China is the world’s largest potato producer, and the potato’s role in ensuring food security and rural development is irreplaceable. Therefore, how to achieve sustainable growth in potato production has attracted widespread attention from academia. However, few existing studies have analyzed how to achieve sustainable growth in main potato-producing areas based on farmers’ micro perspectives in terms of both technical efficiency and output elasticity of input factor. This paper investigates the output elasticities of input factors, technical efficiency, and its influencing factors among 398 potato farmers from China’s main potato-producing regions in 2021 to fill this knowledge gap. The stochastic frontier production is applied to calculate the technical efficiency and elasticities of input factors in main potato-producing areas. The Tobit model is utilized to analyze influencing factors of technical efficiency. Our findings indicate that the technical efficiency of the main potato production regions is 0.67, with an efficiency loss of 0.33. And, the output elasticity of land input and labor input is negative, and the output elasticity of capital input is positive. Moreover, the factors that affect the technical efficiency in main potato-producing areas include age, whether to be a village leader, income from other crops, labor input, potato price, and disaster impact. Our findings suggest that the agricultural authorities should strengthen the cultivation of potato producers, control the scale of potato production, and optimize the allocation of input factors.

Keywords: potato production; production growth; technical efficiency; stochastic frontier production function; output elasticity of input factor; influencing factors

1. Introduction

The potato is the fourth-largest food product in the world and the fourth staple food in China, except for rice, wheat, and maize [1,2], and China is now the leading fresh potato producer in the world, accounting for 25.09% of the world’s total production and 31.89% of its cultivation area [3,4]. China’s potato production has increased from 30.405 million tons in 1991 to 88.895 million tons in 2019 [5]. Because of its resistance to drought and low-fertility conditions, high nutritional value, and multipurpose, potatoes can be consumed as a vegetable, fodder, and the major food grain [4,6]. The key to stabilizing the development of food production is to stabilize the development of potato production, and potato production sustainable growth plays a very crucial role in ensuring food security, increasing the incomes of farmers, and promoting rural revitalization in China [7–10].

China’s main potato-producing areas consist of five parts, namely, Northeast China’s main potato-producing area, North China’s main potato-producing area, Northwest China’s main potato-producing area, Southwest China’s main potato-producing area, and South China’s main potato-producing area, which occupy an important position in China’s potato production. Due to the overuse of agricultural production factors such as chemical fertilizers, chemical pesticides, and plastic films, environmental pollution is currently
one of the most prominent challenges to sustainable potato production growth in these regions [11–13]. The growth rate of potato per unit yield has shown a downward trend from 1991 to 2019 (Figure 1), although potato production continues to increase. Theoretically, potato production growth can be categorized as area driven and yield driven. Area driven means that growth in potato production is mainly attributable to an increase in planted areas with stable yields. Yield driven means that growth in potato production is mainly attributable to an increase in yield with stable planted areas. With the planting area of potatoes stabilized at 47 million hectares over the past five years, production growth has been attributed mainly to increases in yield growth. According to neoclassical economic theory, yield growth can be enhanced by improvements in the output elasticity of the input factor [14]. Input factors are the basic conditions for the growth of agricultural output. Land, labor, and capital are the most basic input factors in agricultural production, their input levels have a direct impact on the growth of agricultural output, and changes in the level of each factor input will have an impact on the level of the other two [15–17]. Technical efficiency is a key indicator of agricultural productivity; it refers to the efficiency of input factors such as land, labor, and capital utilization at a given level of technology, with higher technical efficiency representing higher agricultural output with fewer factor inputs [18–20]. Factors that influence technical efficiency can also have an indirect impact on agricultural output through technical efficiency. Theoretically, the rate of economic growth into a function of the growth rate of each input factor to analyze the degree of impact of each input factor on economic growth [21–23]. For agricultural production, the degree of impact of each input factor on production growth is the output elasticity of the input factor, and the higher the elasticity of the output of an input factor, the greater the production growth (Figure 2). Therefore, it is a top priority to analyze how to achieve sustainable growth of potato production from the perspective of technical efficiency and input factors in the main potato-producing areas.

In terms of agricultural production growth, the majority of studies have focused on grains, such as rice and maize, and cash crops, such as tobacco and grape, but little attention is paid to potato production growth, except for Sultana et al. [24]. Baffes and Gautam [25] identified that modern varieties are the source of rice production growth, and rising yields are also an important contributor to yield growth. Yang [26] analyzed the drivers of grain production growth from a regional perspective and found that technological innovations, opportunity costs, and storage and transportation facilities all had a significant impact. The findings of the above studies all indicate that technical efficiency has a major impact on production growth [27–29]. But, few studies have explained the growth of agricultural output from the angle of technical efficiency and elasticity output of input factors. Many scholars also focus on the technical efficiency of agricultural production [17,20,24,27–39]. Generally, there are two main methods to evaluate technical efficiency, namely, data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Compared to DEA, SFA can estimate the effects of technical efficiency and technological progress simultaneously while taking into account the effects of unavoidable random disturbances on technical efficiency, and the results are closer to reality. Thus, this study will employ SFA to calculate the technical efficiency of potato production [20]. Wilson et al. adopted SFA to explain technical efficiency in the UK [40]. Vlontzos et al. [41] found that technical efficiency can increase by adjusting input factor percentages. Tan et al. [42] revealed land fragmentation is an important factor in the technical efficiency of rice production. Some studies also provided the same evidence about this [27,32,43]. Several scholars have also explored the factors that influence the technical efficiency of many crops, including potatoes [17,20,23,24,29,30,33–35,44,45]. Some findings show that age and level of education, new varieties adoption, labor quality, off-farm employment, and farm size of farmer have a significant influence upon the technical efficiency of production [27,31–33,46], especially for farm size, some scholars have argued that farm size is positively correlated with technical efficiency, while others have argued for a negative correlation [17,22,23,28,30,45,47–52]. But, very few studies have considered...
some characteristics, production and management variables, socioeconomic variables, and natural environment variables.

Figure 1. Change in growth rate of potato yields in China, 1991–2019.

Figure 2. Conceptual framework.

Prior research has provided a solid theoretical and methodological foundation on production growth and technical efficiency for this study [8,17,18,20,30,45,53,54]. Nevertheless, most of the existing studies have focused on staple crops such as rice and maize, with a few studies focusing on multipurpose crops such as potatoes, and a few researchers have explored the factors driving production growth in terms of technical efficiency and output elasticity of input factors. Most studies focus on technical efficiency from the individual characteristics of farmers and socio-economic characteristics, while a few studies have paid attention to the impact of natural disaster factors and production and management factors. Thus, the representative data is used to analyze the factors contributing to output growth in terms of both technical efficiency and the output elasticity of input factors, and the list will be enriched with potential factors influencing technical efficiency.

This study attempts to investigate how to break the bottleneck of potato production sustainable growth. Specifically, this paper will first evaluate the level of potato sustainable production in main potato-producing areas in China. Second, this paper will identify the influencing factor of technical efficiency. Finally, this paper will discuss how to achieve potato production sustainable growth by improving technical efficiency based on the results.
The rest of this paper has been divided into three parts. Section 2 describes the data and methodology used in this paper, involving stochastic frontier production function and Tobit model. Section 3 presents the estimation results and discussion. Section 4 states the conclusions and implications.

2. Materials and Methods

2.1. Data Collection

The input–output cross-section data from potato farmers were collected from China’s main potato producing areas in 2020 conducted by China Agriculture Research System-Industrial Economics research group. According to the “China’s Main Potato Producing Areas Layout Plan (2008–2015)”, research areas include northeast China’s main potato-producing area, North China’s main potato-producing area, Northwest China’s main potato-producing area, Southwest China’s main potato-producing area and South China’s main potato-producing area. For the study, 131 villages from 28 counties (districts) were randomly selected using the random sampling method, and 398 potato farmers were randomly selected from all villages. The survey was based on a participatory approach, with one-on-one interviews with potato farmers. Therefore, the sample is well representative (Figure 3).

![Distribution of China’s main potato-producing areas](image)

**Figure 3.** Distribution of China’s main potato-producing areas.

2.2. Stochastic Frontier Model

For the technical efficiency, one of the popular indicators for exploring production growth is used in this study. Currently, data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are the two most used methods to measure technical efficiency. Compared to DEA, SFA can better fit the production reality when constructing production
equations, while considering the effect of stochastic disturbance terms. In 1957, the frontier production function was first proposed by Farrell et al. [55] and calculated the technical efficiency, which was then continuously developed by Aigner et al. [56], Meesien et al. [57], and Battese et al. [58]. The SFA model for measuring the technical efficiency of potato production is constructed as follows:

\[ Y_i = f(X_i; \beta) \exp(\varepsilon = V_i - U_i), \quad i = 1, 2, \ldots, N, \]  

(1)

taking both sides of Equation (1) simultaneously logarithmically, Equation (1) is as follows:

\[ \ln y_i = \ln f(x_i, \beta) + v_i - \mu_i, \quad i = 1, 2, \ldots, N, \]  

(2)

where \( y_i \) denotes the actual output of the farmer \( i \), \( f(x_i, \beta) \) denotes the determined part of the production possibility frontier, i.e., the optimal output of the farmer \( i \) given the available input combinations, \( x_i \) denotes the row vector consisting of each production input element, \( \beta \) denotes the column vector consisting of the parameters to be estimated, \( v_i \) denotes the observation error and random disturbance terms, which assumes to be \( v_i \sim N(0, \sigma^2_v) \), and \( \mu_i \) denotes the technical inefficiency term, which equals to \( 1 - TE_i \) and assumes to be the truncated normal distribution. \( v_i \) and \( \nu_i \) are independent of each other.

The technical efficiency loss function is as follows (3):

\[ \mu_i = \delta_0 + \sum_k \delta_k X_k + \omega_k, \]  

(3)

where \( \omega_k \) is an unobservable random variable, which assumes to be the truncated normal distribution; \( X_k \) represents exogenous variables that affect the technical efficiency of potato production; \( \delta_0 \) and \( \delta_k \) are all unknown parameters to be estimated; if \( \delta_k > 0 \), it shows that exogenous variables have a negative impact on technical efficiency, if \( \delta_k < 0 \), it shows that exogenous variables have a positive impact on technical efficiency. According to the stochastic frontier theory, Equations (2) and (3) do not satisfy the assumptions of the least squares method, so the equations should be estimated using the maximum likelihood estimation method. The variance parameters are as follows:

\[ \left\{ \begin{array}{l} \gamma = \sigma^2_\mu / (\sigma^2_\mu + \sigma^2_v) \\ \sigma^2 = \sigma^2_\mu + \sigma^2_v \end{array} \right. \]  

(4)

where \( \gamma \) indicates the proportion of the technical inefficiency term in the random error term, and \( \gamma \) is utilized to verify whether the model setting is reasonable or not. If \( \gamma \rightarrow 0 \), it means that the difference between the actual output and the production frontier is mainly caused by the statistical noise term, and the least squares method is applied for regression analysis; if \( \gamma \rightarrow 1 \), the technical inefficiency term is the main reason for the difference between the actual output and the production frontier, and in this case, it is appropriate to employ the stochastic frontier production model for analysis.

The technical efficiency of farmer \( i \) (\( TE_i \)) can be calculated by the following equation:

\[ TE_i = \frac{E(Y_i | \mu_i, X_i)}{E(Y_i | \mu_i = 0, X_i)} = \frac{\exp(x_i \beta + v_i - \mu_i)}{\exp(x_i \beta + v_i)} = \exp(-\mu_i). \]  

(5)

If \( TE_i = 1 \), it implies there is no loss of technical efficiency; in other words, it means production is technically efficient; if \( TE_i \rightarrow 1 \), it represents higher technical efficiency; if \( TE_i \rightarrow 0 \), it shows greater technical loss; if \( TE_i = 0 \), it represents technical inefficiency.

The stochastic frontier production function model has two popular forms of function settings, namely, the Cobb–Douglas (C–D) production function and the transcendental logarithm (Translog) production function. The assumption underlying the C–D production function is that the elasticity of substitution among the input factors is 0 or 1, but the elasticity of substitution among the input factors is not clear when establishing the form of
the production function. Transcendental logarithmic production function is regarded as a second-order approximation of the general production function, which can well fit the actual production situation, so it is more reasonable to choose the form of transcendental logarithmic production function when measuring the technical efficiency in main potato-producing areas. The transcendental logarithmic stochastic frontier production function is expressed as follows:

$$\ln Y_i = \beta_0 + \beta_1 \ln L_i + \beta_2 \ln W_i + \beta_3 \ln C_i + \frac{1}{2} \beta_4 (\ln L_i)^2 + \frac{1}{2} \beta_5 (\ln W_i)^2 + \frac{1}{2} \beta_6 (\ln C_i)^2 + \beta_7 \ln L_i^* \ln W_i + \beta_8 \ln L_i^* \ln C_i + \beta_9 \ln W_i^* \ln C_i + v_i - \mu_i, \quad (6)$$

where $Y_i$ represents the total potato production value of potato farmers, $L$ is the potato cultivation area of potato farmers, $W$ is the number of family and employed labors engaged in potato production, $C$ is the capital input of potato farmers, including seed cost, fertilizer costs, pesticides cost, agricultural film cost, machinery cost, irrigation costs and tools, materials cost, etc. The descriptive statistical analysis is shown in Table 1.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition</th>
<th>Statistics</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Standard-Error</td>
<td>Max</td>
</tr>
<tr>
<td>Age</td>
<td>age of respondents</td>
<td>51.13</td>
<td>8.83</td>
<td>76.00</td>
</tr>
<tr>
<td>Gender</td>
<td>1 = male, 0 = female</td>
<td>0.75</td>
<td>0.43</td>
<td>1.00</td>
</tr>
<tr>
<td>Education</td>
<td>years of education</td>
<td>11.04</td>
<td>3.29</td>
<td>19.00</td>
</tr>
<tr>
<td>Village leader</td>
<td>1 = yes, 0 = no</td>
<td>0.16</td>
<td>0.36</td>
<td>1.00</td>
</tr>
<tr>
<td>Technical training</td>
<td>1 = yes, 0 = no</td>
<td>0.78</td>
<td>0.42</td>
<td>1.00</td>
</tr>
<tr>
<td>Income from other crops</td>
<td>other crops gross revenue in 2020 (ten thousand yuan)</td>
<td>1.40</td>
<td>0.15</td>
<td>2.72</td>
</tr>
<tr>
<td>Farm size</td>
<td>farm size (hectare)</td>
<td>1.80</td>
<td>2.30</td>
<td>10.00</td>
</tr>
<tr>
<td>Labor</td>
<td>number of laborers</td>
<td>2.11</td>
<td>0.97</td>
<td>8.00</td>
</tr>
<tr>
<td>Off-farm employment</td>
<td>1 = yes, 0 = no</td>
<td>0.52</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>Potato price</td>
<td>yuan $^1$ per kg in 2020</td>
<td>1.62</td>
<td>0.53</td>
<td>3.60</td>
</tr>
<tr>
<td>Market distance</td>
<td>Distance from the field to the nearest market</td>
<td>7.92</td>
<td>0.77</td>
<td>101.49</td>
</tr>
<tr>
<td>Disaster Impact</td>
<td>percentage of affected area in 2020</td>
<td>0.14</td>
<td>0.15</td>
<td>0.70</td>
</tr>
</tbody>
</table>

1 yuan is Chinese currency ($1 USD = 7.14 yuan in 2023$).

Firstly, the maximum likelihood ratio test is first used to determine whether the setting form of the stochastic frontier production model is reasonable or not, and its test statistic is shown as below:

$$LR = -2 \{ \ln[L(H_0)] - \ln[L(H_1)] \}. \quad (7)$$

$\ln[L(H_0)]$ and $\ln[L(H_1)]$ represent the maximum log-likelihood function values of the C–D stochastic frontier production function and the maximum log-likelihood function values of the transcendental logarithmic stochastic frontier production function, respectively. The null hypothesis $H_0$ of this test is that the estimates of all quadratic coefficients are 0, and the alternative hypothesis $H_1$ is that at least one quadratic coefficient is not 0. If the $LR$ statistic is greater than the critical value, the null hypothesis $H_0$ is rejected and the transcendental logarithmic stochastic frontier production function should be selected; instead, the C–D stochastic frontier production function model should be used.

2.3. Tobit Model

Based on the results of SFA, the efficiency loss function can be used to investigate the factors affecting technical efficiency, while the stochastic frontier model measures between
[0, 1], and the regression analysis of the restricted variables as dependent variables requires the application of Maximum Likelihood Estimate (MLE) to achieve unbiased estimation. In this study, the Tobit model based on the method of maximum likelihood estimation (MLE) is employed for the analysis, and the equation is rewritten according to Equation (3):

$$TE_i = \delta_0 + \sum_k \delta_k X_k + \epsilon_k,$$

(8)

where $TE_i$ is the dependent variable; $\delta_0$ denotes the constant term, $\delta_k$ denotes the regression coefficient of the independent variable, $X_k$ is the independent variable affecting the loss of technical efficiency, and $\epsilon_k$ is the random error vector. According to the “rational man” assumption and rational choice theory, the factors influencing the technical efficiency of potato production by farmers can be broadly classified into four categories, namely, farmers’ individual characteristics, production and management conditions, socioeconomic factors, and natural environmental factors. When combined with the results of prior studies and the actual situation of production in main potato producing areas, the variables affecting the technical efficiency loss consist of four components in this study, including individual characteristics variables (age, gender, years of education, whether to be a village leader, and whether to participate in technical training), production and management variables (farm size, labor input, and income from other crops), socioeconomic variables (whether to participate in off-farm employment, potato unit price, and distance from the field to the nearest market), and natural environment variables (disaster impact) [59].

Farmers’ individual characteristics include age, gender, years of education, whether to be a village leader, and whether to participate in technical training. On the one hand, the older the farmers are, the more experience in potato production, which is more conducive to improving technical efficiency of potato production; on the other hand, the older the farmers are, the lower their learning ability, which is directly reflected in their ability to understand and apply new knowledge and technologies, and thus leads to a decline in technical efficiency of production, which is also under debate in the existing studies; in general, due to the difference in labor capacity, the technical efficiency of production of male farmers is higher than that of female farmers; the more education time the farmers have, the higher their acceptance of new technologies and information, which leads to the improvement of technical efficiency of production. As mediators linking farmers and agricultural authorities, village leaders pass on various types of agricultural technology information while also applying this information to production, which, in turn, affects technical efficiency. Agricultural technology training is an important channel for farmers to acquire technical and management knowledge, and farmers who participate in technical training may change their production methods, resulting in improvement of technical efficiency.

Farmers’ production and management variables include farm size, labor input, and income from other crops. The relationship between farm size and technical efficiency of production is currently controversial in academia, with some scholars arguing that the relationship is non-linear and that results may vary based on different regions and different crops. A certain amount of labor input can improve the technical efficiency of production, but the definition of “a certain amount” is tricky, so the relationship in potato production needs to be examined. Income from other crops may be related to the agricultural techniques and management methods of farmers. Farmers who apply advanced agricultural techniques and management practices from other crops to potato may be able to increase technical efficiency of potato production. At the same time, farmers with other incomes are more likely to invest more in potato production, facilitating the purchase of inputs for production and the level of management.

Socioeconomic variables include whether to participate in off-farm employment, potato price, and distance from the field to the nearest market. In general, farmers participating in off-farm employment are more likely to be exposed to new technologies and knowledge, which will have a positive impact on technical efficiency of potato production. If the price of potatoes rises, farmers will be motivated to produce and accordingly increase material inputs and strengthen management to enhance technical efficiency of...
potato production. The closer the field is to the nearest agricultural products market, the more channels the farmers have to obtain outside information, the easier it is to get timely, accurate and reliable information, which is conducive to making correct production decisions and subsequently improving technical efficiency.

Natural environmental variables include disaster impact. Potato production is often affected by natural disasters and pests and diseases, which can lead to reduced yields and lower quality and which has a negative impact on technical efficiency. The descriptive statistical analysis is provided in Table 1.

2.4. The Output Elasticity of Input Factors

Since transcendental logarithmic stochastic frontier production function cannot measure the degree of influence of each input factor on output, that is, the output elasticity of input factors to measure the output elasticity of each input factor, drawing on the theory of marginal product and production function, the elasticity of each input factor on output is calculated as follows:

\[ E_L = \frac{\partial \ln Y}{\partial \ln L} = \beta_1 + \beta_4 \ln L + \beta_7 \ln W + \beta_8 \ln C, \]  
\[ E_W = \frac{\partial \ln Y}{\partial \ln K} = \beta_2 + \beta_5 \ln W + \beta_7 \ln L + \beta_9 \ln C, \]  
\[ E_C = \frac{\partial \ln Y}{\partial \ln C} = \beta_3 + \beta_6 \ln C + \beta_8 \ln L + \beta_9 \ln W. \]

\( E_L, E_W, \) and \( E_C \) represent output elasticity of land input, labor input, and capital input, respectively.

3. Results

3.1. Descriptive Statistics

Statistics on the variables affecting the technical efficiency of potato production and the input–output variables (Table 1) show the following characteristics: the average potato production output of all samples in China’s main potato-producing areas is high, with an average value of CNY 36,689.01, but there are large differences between farmers, with a maximum value of CNY 274,700 and a minimum value of CNY 1550. The average farm size of all samples is small, only 1.8 hectares, and there are large differences between farmers, with a maximum value of 10 hectares and a minimum value of 0.2 hectares. The average labor input and capital input of all samples in China’s main potato-producing areas are CNY 6686.83 and CNY 11,716.55, respectively, and there are large within-group differences in these two sets of variables.

Potato farmers are relatively old, with an average age of 51.13 years. During the field survey, it was found that most of the respondents were between 50 and 65 years old, with the oldest farmer at 76 years old. Respondents were mostly male, accounting for 75% of all samples. Potato farmers generally have a low level of education; the average number of years of education is 11.04, which means that most of the potato farmers have not completed high school (it takes approximately 12 years to complete high school in China). Of the respondents, 16% are village leaders and 78% have participated in technical training, indicating the effectiveness of the work of public agricultural extension services. The mean value of farmers’ income from other crops is CNY 14,000, and the differences among the farmers are relatively small, implying that farmers in the main potato-producing areas commonly plant other crops. The mean value of labor input of farmers is 2.11, with a large variation among all potato farmers, which is consistent with the results of the analysis of farm size. More than half of potato farmers participate in off-farm employment, suggesting that off-farm income is also an important source of income for them. The average sale price of potatoes is 1.62 yuan/kg, with a difference of nearly five times between the maximum and minimum values. The mean value of the distance from the field to the nearest market...
is 7.92 km and varied widely among potato farmers. The mean value of planting areas affected by natural disasters and pests and diseases is 0.14, indicating that the impact of natural disasters, pests, and diseases on potato production cannot be ignored.

3.2. Technical Efficiency in Potato Main Producing Areas

The transcendental logarithmic stochastic frontier production function was estimated using Frontier 4.1 software (proposed by Tim Coelli) (Appendix A). The likelihood ratio (LR) statistic was 25.50 and the null hypothesis \( H_0 \) was rejected at the 1% significance level, so it is reasonable to employ the transcendental logarithmic stochastic frontier production function model to estimate the technical efficiency in the main potato-producing areas. As shown in Table 2, the technical inefficiency term \( \gamma \) accounted for 0.8365 and was significant at the 1% level, indicating that 83.65% of the variance in the mixture error came from the technical inefficiency term, which means that there is a general loss of technical efficiency in potato dominant area farmer production, while the model passed the LR one-sided test, indicating that the model has a good fit and it is suitable to use transcendental logarithmic stochastic frontier production model in this study.

Table 2. Estimation results of transcendental logarithmic stochastic frontier production model.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Standard-Error</th>
<th>t-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>16.8538 ***</td>
<td>3.5137</td>
<td>4.7965</td>
</tr>
<tr>
<td>( \ln L )</td>
<td>1.1013 **</td>
<td>0.4592</td>
<td>2.3982</td>
</tr>
<tr>
<td>( \ln W )</td>
<td>0.2680</td>
<td>0.6421</td>
<td>0.4174</td>
</tr>
<tr>
<td>( \ln C )</td>
<td>-0.3551 *</td>
<td>0.3415</td>
<td>-1.0399</td>
</tr>
<tr>
<td>( 0.5 \times \ln L \times \ln L )</td>
<td>0.2334 *</td>
<td>0.1647</td>
<td>1.4169</td>
</tr>
<tr>
<td>( 0.5 \times \ln W \times \ln W )</td>
<td>-0.4155</td>
<td>0.3452</td>
<td>-1.0238</td>
</tr>
<tr>
<td>( 0.5 \times \ln C \times \ln C )</td>
<td>0.1764 ***</td>
<td>0.0522</td>
<td>3.3801</td>
</tr>
<tr>
<td>( \ln L \times \ln W )</td>
<td>0.0630</td>
<td>0.2207</td>
<td>0.2854</td>
</tr>
<tr>
<td>( \ln W \times \ln C )</td>
<td>-0.1845 **</td>
<td>0.0869</td>
<td>-2.1236</td>
</tr>
<tr>
<td>( \ln C \times \ln L )</td>
<td>-0.0903</td>
<td>0.0964</td>
<td>-0.9368</td>
</tr>
<tr>
<td>( \sigma^2 )</td>
<td>0.4360 ***</td>
<td>0.0457</td>
<td>9.5391</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.8365 ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log Likelihood function value</td>
<td>-249.3850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LR one-sided test</td>
<td>50.9996</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively.

As shown in Table 3 and Figure 4, the technical efficiency of potato production in potato the main potato-producing areas is relatively low. The average technical efficiency is only 0.67, with a technical efficiency loss of 0.33, indicating that potato production still has huge room for growth.

3.3. Determinants of Potato Production Growth

From the estimation results in Table 4, the log-likelihood value is 87.7837 and the value of Prob > chi² is 0.0000, which passes the significance test of the model (Appendix A).

Table 3. Descriptive statistical of technical efficiency in main potato-producing areas.

<table>
<thead>
<tr>
<th>All Samples</th>
<th>Number of Samples</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10 ≤ TE &lt; 0.40</td>
<td>13</td>
<td>3.27</td>
</tr>
<tr>
<td>0.40 ≤ TE &lt; 0.66</td>
<td>217</td>
<td>54.52</td>
</tr>
<tr>
<td>0.67 ≤ TE ≤ 0.91</td>
<td>168</td>
<td>42.21</td>
</tr>
<tr>
<td>Mean</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Standard-Error</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>
which is likely to have a negative impact on technical efficiency and is not conducive which is in line with the findings [60]. Potato farmers who participated in technical training are more technically efficient than those who did not participate in technical training [17,33].

For production and management variables, the estimated coefficient of farm size is negative. The estimated coefficient of the labor force variable is negative, indicating that a larger labor force is detrimental to the technical efficiency of potato production. The existing labor force in main potato-producing areas is generally of low quality, and these laborers will struggle with the application of new varieties and agricultural technologies, which is likely to have a negative impact on technical efficiency and is not conducive to the sustainable growth of potato production. The estimated coefficient of the income from other crops variable is positive, which again provides evidence for the previous conclusion [44,61].

Figure 4. Descriptive statistical of technical efficiency in main potato producing areas.

Table 4. Estimation results of Tobit model.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficients</th>
<th>Standard-Error</th>
<th>t-Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>−0.0033 ***</td>
<td>0.0009</td>
<td>−3.5589</td>
<td>0.0004</td>
</tr>
<tr>
<td>Gender</td>
<td>−0.0097</td>
<td>0.0212</td>
<td>−0.4576</td>
<td>0.6475</td>
</tr>
<tr>
<td>Education</td>
<td>0.0068 **</td>
<td>0.0032</td>
<td>2.1275</td>
<td>0.0340</td>
</tr>
<tr>
<td>Village leader</td>
<td>0.0664 ***</td>
<td>0.0254</td>
<td>2.6147</td>
<td>0.0092</td>
</tr>
<tr>
<td>Technical training</td>
<td>0.0301</td>
<td>0.0111</td>
<td>2.7138</td>
<td>0.0097</td>
</tr>
<tr>
<td>Income from other crops</td>
<td>0.1964 ***</td>
<td>0.0619</td>
<td>3.1703</td>
<td>0.0016</td>
</tr>
<tr>
<td>Farm size</td>
<td>−0.0025</td>
<td>0.0015</td>
<td>−1.6667</td>
<td>0.1090</td>
</tr>
<tr>
<td>Labor</td>
<td>−0.0188 **</td>
<td>0.0089</td>
<td>−2.1152</td>
<td>0.0350</td>
</tr>
<tr>
<td>Off-farm employment</td>
<td>0.0132</td>
<td>0.0176</td>
<td>0.7495</td>
<td>0.4540</td>
</tr>
<tr>
<td>Potato price</td>
<td>0.2347 ***</td>
<td>0.0272</td>
<td>−8.6287</td>
<td>0.0000</td>
</tr>
<tr>
<td>Market distance</td>
<td>−0.0148</td>
<td>0.0116</td>
<td>−1.2760</td>
<td>0.2027</td>
</tr>
<tr>
<td>Disaster Impact</td>
<td>−0.3763 ***</td>
<td>0.0795</td>
<td>4.7333</td>
<td>0.1158</td>
</tr>
<tr>
<td>Constant</td>
<td>0.5085 ***</td>
<td>0.0774</td>
<td>6.5698</td>
<td>0.000</td>
</tr>
<tr>
<td>LR chi² (12)</td>
<td>177.81</td>
<td>—</td>
<td>—</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: *** *, ** indicate significance at the 1%, 5%, and 10% levels, respectively.

In terms of the variables of farmers’ individual characteristics, farmers’ age and gender both showed negative effects on technical efficiency, and the age variable was significant at the 1% level, which is consistent with existing studies [54] and contradicts the findings of some studies [32,33,45]. Years of education passed the test of significance, and theoretically, the longer the years of education, the greater the ability of farmers to learn to receive information and emerging technologies, which, in turn, will have a positive impact on technical efficiency, this finding is consistent with the prior study [28,51]. The variable of being a village leader has a positive effect on the technical efficiency of potato production, which is in line with the findings [60]. Potato farmers who participated in technical training are more technically efficient than those who did not participate in technical training [17,33].
In terms of socioeconomic variables, the coefficients for off-farm employment and potato price are both positive, but only potato prices pass the significance test. The higher the price, the more motivated the potato farmers are, and the more technically efficient potato production will be, which has a contribution to the growth of potato production. Distance from the field to the nearest market and technical efficiency are negatively correlated, the further the distance from the nearest market, the more closed the production and management environment, and the more unfavorable to the dissemination of information, which, in turn, affects the growth of potato production.

For the natural environment variable, the coefficient of natural disasters and pests and diseases is negative and significant at the 1% level, which is in line with [28,62].

3.4. The Elasticity of Different Input Factors

The output elasticities of each input factor are calculated according to Equations (9)–(11), and the results are shown in Table 5:

Table 5. Output elasticity of input factors in main potato-producing areas.

<table>
<thead>
<tr>
<th>Output Elasticity of Input Factors</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>−0.3608</td>
</tr>
<tr>
<td>Labor</td>
<td>−4.4090</td>
</tr>
<tr>
<td>Capital</td>
<td>0.8007</td>
</tr>
</tbody>
</table>

Firstly, in terms of the output elasticity of each input factor, the largest is the output elasticity of labor. With other conditions remaining unchanged; every increase of a unit of labor input will reduce the output by 4.4090 units.

Secondly, the positive output elasticity of capital illustrates that the marginal effect of this capital input is in the stage of increasing, every increase of a unit of capital input will increase the output by 0.8007 units.

Thirdly, the output elasticity of land is negative, which means that output decreases as potato farm size expands, every increase of a unit of land input will reduce the output by 0.3608 units.

4. Discussion and Conclusions

For the technical efficiency scores, there are 217 farmers whose technical efficiency is higher than 0.67, accounting for 54.52% of all samples. There are 168 farmers whose technical efficiency does not reach the average, accounting for 42.21% of all samples, which means that there is great potential to improve the technical efficiency of potato production for these farmers. Meanwhile, there are still 3.27% of all samples with technical efficiency that is less than 0.4, which has largely lowered the average level of technical efficiency of potato production in the main potato-producing regions.

The reason both age and gender have a negative effect is that China’s main potato-producing areas are distributed in the area on both sides of the Hu Huanyong line, middle-aged, and old-aged males and females become the main force of agricultural production. Males tend to be the production decisionmakers and females are usually the production executors, the estimated coefficient of the gender variable is negative indicating that the technical efficiency of female potato farmers is higher than that of males, so we cannot ignore the influence of females on potato production. According to the survey, more than 55% of the potato farmers are above 50 years old, and only 10% of the male potato farmers are below 40 years old. The older the potato farmers are, the lower their acceptance of high-quality seed potatoes and advanced production technology, and the lower their adaptability to changes in the external environment, which directly affects their production technology efficiency; it is consistent with existing studies [54].

The coefficient of being a village leader is in line with the findings [60]. The reason for the positive effect may be that village leaders have more resource allocation power and information channels, which are more helpful for them to engage in potato production,
that is why it leads to higher technical efficiency. Previous research showed the same finding about technical training [17,33]. This variable did not pass the test of significance, which may be related to the ineffectiveness of technical training to meet the needs of potato farmers.

The coefficient of farm size indicates that with the expansion of scale, the technical efficiency of potato production in main producing areas does not necessarily increase, but rather decreases, which also verifies the theory of optimum land management scale. In terms of income from other crops, farmers with higher income from other crops are more likely to invest more in potato production, facilitating the purchase of means of production and the level of operations, and apply advanced agricultural techniques and management practices from other crops to potato, which is beneficial to technical efficiency, which again provides evidence for the previous conclusion [44,61].

For off-farm employment, potato farmers participating in off-farm employment are more likely to be exposed to new technologies and knowledge, which will have a positive impact on the technical efficiency of potato production, which is in line with existing studies [32]. The coefficient of off-farm employment is not significant, suggesting that potato farmers are too distracted from agricultural production when they engage in off-farm employment.

For the natural environment variable, potato production is highly affected by weather and pests. The larger the planting area, the greater the impact on potato production output, leading to a greater negative impact on the growth of potato production [28,62].

The output elasticity of labor is negative for two possible reasons. On the one hand, it shows that the current labor input is excessive in the main potato-producing areas, in the stage of diminishing marginal effect, and the quality of labor is generally low, the more labor input, the greater the negative impact on output; on the other hand, it shows that potato production is gradually getting rid of labor-intensive production mode, and machinery in main potato-producing areas is gradually popularized, which brings about higher productivity and lower costs, and the traditional way of labor inputs cannot satisfy the growth of potato production.

According to the survey, capital inputs include seed and potato costs, fertilizer costs, agricultural film costs, mechanical operation costs, irrigation costs, tools and materials, other costs, etc. In this study, the seed and fertilizer inputs in the capital accounted for a larger proportion, and the potato farmers with larger capital inputs tend to choose high-quality seeds and high-efficiency fertilizers, which indicates that the increase of these two inputs can directly make the output increase, and positive elasticity illustrates that the marginal effect of this capital inputs is in the stage of increasing, and also implies that the potato production in the main potato-producing areas presents the characteristics of the capital-intensive type.

The output elasticity of land means that in the main potato-producing areas, the marginal effect of the expansion of the potato production scale is negative and the scale effect is absent, which also confirms the conclusion of previous studies, the “inverted U-shaped” relationship between farm size and technical efficiency [52,62].

This paper explores how to realize sustainable growth of potato production from the technical efficiency and output elasticity of input factor two aspects, using stochastic frontier production function to analyze the cross-sectional data of 398 potato growers in China’s main potato producing areas in 2020, found that the potato advantage area farmers production technical efficiency is relatively low, the average technical efficiency is 0.67, there is still a 0.33 loss of technical efficiency, which means there is a huge space for potato production growth; from the perspective of the output elasticity of various input factors, the output elasticity of land input and labor input is negative, and the output elasticity of capital input is positive, the path of potato production growth can be explored from three aspects: capital, land, and labor; the factors that affect the technical efficiency of potato production in main potato producing areas include age, whether to be a village leader,
income from other crops, labor input, potato price, and disaster impact, based on these findings the way of potato production growth can be explored from a micro perspective.

5. Policy Implications

The policy implications are as follows:

Firstly, sustainable growth in potato production is realized by strengthening the cultivation of potato producers. The previous analysis shows that the labor force quality is low, and the aging trend is prominent. Therefore, it is necessary to eliminate the "path dependence" in potato production, organize technical training and guidance from agricultural services based on farmers’ needs, comprehensively improve farmers’ knowledge level, play a better role of village leaders as information intermediaries, and promote the new technology of potato production and varieties in multiple directions to comprehensively improve the quality of the farmers’ labor force and accelerate the cultivation of new young professional farmers.

Secondly, realize sustainable growth in potato production by reasonably controlling the scale of potato production. Local governments should moderately control the expansion of potato planting areas, actively guide farmers to shift from non-moderate to moderate-scale potato planting, actively explore the optimal scale of potato production, avoid scales that are too small or too large, encourage the application of intensive production techniques and machinery, improve the level of intensive operation, and realize the effect of economies of scale.

Thirdly, achieve sustainable growth in potato production by optimizing the allocation of input factors. Encourage farmers to increase capital investment and actively promote the positive impact of high-quality seeds, organic fertilizers, green pesticides, and biodegradable agricultural films on sustainable production. Increase support for the potato market, stabilize prices, and motivate farmers to produce. Improve the mechanism for predicting and preventing natural disasters and pests to minimize farmers’ economic losses.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The program used in Frontier 4.1 software is as below:

1 1=ERROR COMPONENTS MODEL, 2=TE EFFECTS MODEL
te-dta.txt DATA FILE NAME
te-out.txt OUTPUT FILE NAME
1 1=PRODUCTION FUNCTION, 2=COST FUNCTION
y LOGGED DEPENDENT VARIABLE (Y/N)
398 NUMBER OF CROSS-SECTIONS
1 NUMBER OF TIME PERIODS
The program used in Stata 15 software is as below:

clear
use "D:\stata15\data\te.dta"
des
sum
tobit te age gender edu leader training income scale labor work price distance disaster, ll(0)
est store tobit1
esttab tobit1, star(* 0.1 ** 0.05 *** 0.01) b(%8.4f) se(%8.4f)
margins, dydx(*)
margins, dydx(*) predict(e(0,1))

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