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Investigation of the Contribution Rate of Agricultural Mechanization to Agricultural Production Using Cobb-douglas Model

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Abstract: This study utilizes the Cobb-douglas production function and regression analysis to establish a computing model for the contribution rate of agricultural mechanization to agricultural production. The agricultural mechanization and agricultural output data of the Shaanxi Province from 2001 to 2010 were used as examples for the estimation. The results demonstrate that the contribution of agricultural mechanization to agricultural output was 31.46%. A regression analysis of the various input factors revealed that the growth of agricultural output was primarily due to an increase in capital and agricultural machinery. Capital investment displayed the largest contribution to the output, followed, in descending order, by the investment in agricultural machinery and land investment; moreover, the labor investment did not significantly affect the output. With an increased agricultural machinery and capital investment, the agricultural output of the Shaanxi Province exhibited a trend of significant upward growth. This observation suggests that further investment in agricultural machinery and an increase in the mechanization level of agricultural production may extensively contribute to the growth of the agricultural output. The results of this study are relevant for future evaluations of the development level of agricultural mechanization and its potential contribution to the agricultural output.

Key words: Agricultural mechanization, agricultural output, contribution rate, shaanxi province, production function

INTRODUCTION

Socio-economic development depends primarily on developing productivity. Agricultural productivity predominantly consists of a means of production (land, fertilizers and farm machinery, etc.) and agricultural laborers. As a production tool, agricultural machinery plays important roles in improving labor productivity and land productivity, promoting the application and development of agricultural biotechnology, improving working conditions and adjusting the rural economic structure. An accurate quantitative analysis of the contribution rate of agricultural mechanization to agricultural output in a particular region facilitates the elucidation of the status and roles of agricultural mechanization in this region and of the overall development level and the agricultural mechanization trends and informs scientific decision-making. Models that calculate the contribution rate of agricultural mechanization and the related data processing methods have consistently garnered attention in this field.

Fulin (1998) derived the growth rate equation and subsequently obtained the computing model that measures the contribution of agricultural mechanization to the growth of agricultural output. Based on the analysis of domestic and international productivity theories and computing methods, Bang-Jie *et al*. (2000) proposed to use methods based on the Cobb-Douglas production function to calculate the contribution rate of agricultural mechanization to agriculture. Qing *et al*. (2000) performed a quantitative analysis of the contribution rates of agricultural mechanization to the agricultural production in the Shaanxi Province since 1980 and derived the computing equation for the contribution rate of agricultural mechanization to agricultural output and the gray sequence forecasting model. Li *et al*. (2006) investigated the distinction between the two key indicators (the agricultural mechanization level and the contribution rate) in evaluating the status and roles of agricultural mechanization in agricultural production. Weijun (2007) employed a Cobb-Douglas production function-based model and multiple regression analyses to

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establish the agricultural production function model of the Zhejiang Province from 1991 to 2004. Hongqi *et al*. (2009) using the Hunan Province as an example, used the "comparing with or without input" method to calculate the contribution rate of agricultural mechanization to agricultural output. Liang and Xiu-Juan (2010) applied the Cobb-Douglas production function to the study of the economic growth in the Guizhou Province and recommendations were proposed after analyzing the economic growth problems in the Guizhou Province. Rendong (2010) used a deformation of the Cobb-Douglas production function in a regression estimation and analyzed the economic growth factors in Beijing. Hongqi *et al.* (2011) used the gray prediction system to obtain the overall regression model of agricultural input and output and to predict the agricultural mechanization contribution rate. Han *et al.* (2012) established the corresponding model based on the Cobb-Douglas production function to measure the economic benefits of the Smart Power Grid. Md. Hossain *et al.* (2012) others measured the production levels of certain selected manufacturing sectors in Bangladesh via appropriate models based on the Cobb-Douglas production function. This study used a model based on the Cobb-Douglas production function and regression analysis to calculate the contribution rate of agricultural mechanization to agricultural production. The agricultural mechanization and agricultural output data of the Shaanxi Province from 2001 to 2010 were used as examples to quantitatively analyze the contribution of agricultural mechanization to agricultural output in the Shaanxi Province. The results of this study are relevant for future evaluations of the development level of agricultural mechanization and its potential contribution to the agricultural output.

MATERIALS AND METHODS

Cobb-Douglas production function and the computing method for the contribution rate: Agricultural production is a material production process and its output growth is the result of the combined effects between investment in various production factors, such as the land, labor and capital (material consumption) and technical progress. The agricultural machinery is reflected in the levels of capital investment and technological progress. If we isolate agriculture machinery as an independent production factor, the production factors in the agricultural production process could be divided into the following four main categories: agricultural machinery, capital, labor and land. The agricultural production function (the relationship between inputs and outputs) is:

$$Y = A(t)\, f\,(M, K, L, D) \tag{1}$$

where, Y is the agricultural output, A(t)- coefficient, generally known as the technical level at time t, M, K, L, D - agricultural machinery, capital, labor and land investments, respectively.

Agricultural output: The agricultural output can be represented by the total agricultural output value, total production or agricultural profits (Pingou, 2008). Given that the total production reflected in the statistics is a classification statistic and that it is difficult to accurately calculate the agricultural profit, which would be low or negative in numerous regions if the labor expenses were calculated in agricultural production, we used the total agricultural (farming) output value as the agricultural output.

Investment in agricultural machinery: The agricultural machinery investment refers to the tangible and intangible value loss of the agricultural machineries used in agricultural production. It is expressed as an annual depreciation value calculated from the original agricultural machinery value using the straight-line method of depreciation. The depreciable period is 8 years and the depreciation rate is 12.5% (Song *et al.*, 2010).

Capital investment: The capital investment is represented by the agricultural material consumption value of the year after the deduction of agricultural machinery depreciation (Hunan *et al.*, 2002).

Labor investment: The labor investment represents the number of people comprising the labor force involved in the agricultural production in the calculation period (Li, 2010). It is difficult to accurately determine the rural surplus labor or the labor utilization factor; therefore, we used the year-end agricultural labor number provided by the statistics as the labor investment.

Land investment: The land investment can be represented by the available arable land or the acreage of sown land. Given that the acreage of sown land can better explain the changes in the amount of agricultural machinery operation and output, we used the actual acreage of sown land in the same year as the land investment.

The production function can be represented by various forms. According to the literature, we selected the model based on the Cobb-Douglas production function (referred to as the C-D production function), which is frequently used in China and abroad. Thus, the formula 1 is transformed into:

$$Y = A(t)\, M^{\alpha}K^{\beta}L^{\gamma}D^{\theta} \quad (2)$$

where, α, β, γ and θ are the output elasticities of the agricultural machinery, capital, labor and land investments. The significances of α, β, γ and θ are set to reflect the scales among these four types of input factors (Camarena *et al*., 2004).

Formula 2 is a nonlinear function that must be transformed to a linear function by variable substitution. After taking the natural logarithm of both sides, we get:

$$\text{In } Y= \text{In } (A(t))+\alpha \text{In } M+\beta I \text{ In } K+\gamma \text{In } L+\theta \text{In } D \quad (3)$$

Given $Y' = \ln Y$ $C = \ln(A(t))$ $M' = \ln M$ $K' = \ln K$ $L' = \ln L$ $D' = \ln D$

$$Y' = C+\alpha M'+\beta K'+\gamma L'+\theta D' \quad (4)$$

where, C is a constant and the values of α, β, γ and θ can be determined using regression analysis.

The above processes first take logarithms of each variable, such as the total agricultural output value, material consumption, depreciation of the original value of the agricultural machinery, arable land and labor, to obtain the respective logarithmic variables. The logarithmic variables were then subject to multiple linear regression to obtain the corresponding coefficient values, which are the production flexibilities (elasticity coefficients) of the corresponding variables in the C-D production function. The regression model is:

$$Y = X\hat{\beta} \quad (5)$$

where, Y is the matrix composed of the logarithms of the total agricultural output values over the years. X is the matrix composed of the logarithms of the values of agricultural machinery, capital, labor and land investments over the years. $\hat{\beta}$ is the matrix composed of α, β, γ and θ from formula 2. Both sides are multiplied with X^T, the transpose matrix of observed value matrix X:

$$X^TY = X^TX\hat{\beta} \quad (6)$$

As X^TX is a square matrix, X^TX is a non-singular matrix and there is an inverse matrix of X^TX, $(X^TX)^{-1}$. Thus:

$$\hat{\beta} = (X^TX)^{-1} = X^TY \quad (7)$$

The respective components of the vector $\hat{\beta}$ are the values of α, β, γ and θ.

The contribution rate of agricultural mechanization to agricultural output is:

$$\delta = \alpha\frac{\Delta M}{M}\frac{Y}{\Delta Y}\times 100\% = \frac{\alpha m}{y}\times 100\% \quad (8)$$

where, ΔM-increment of the agricultural machinery investment, ΔY-agricultural output increment, M-agricultural machinery investment growth rate, Y-agricultural output growth rate.

Data acquisition and the pre-processing method: The total agricultural output value, original value of agricultural machinery, agricultural material consumption, agricultural labor and area of sown land used in the contribution rate computing formula were obtained from the "China Statistical Yearbook", "China Agricultural Yearbook" and the yearbooks of various regions.

To calculate the actual growth rate of the agricultural output and the investment values of various production factors expressed as monetary values, we must consider the impact of price changes and inflation factors by translating the above values into those calculated at constant prices. In addition, some production factors, such as the agricultural machinery and capital investment, exhibited time lags before the investment could be transformed into productivity or capital capable of serving the production process and different types of investments displayed different time lags. In other words, the invested funds were not completely converted into capital in the same year and instead, the funds were transformed into capital by a certain percentage over several years. Therefore, with the exception of the ability to calculate the value at constant prices for the total agricultural output value from the statistics, the constant price values for the other four categories could not be obtained and were difficult to convert accurately. To ensure that the data were more comparable laterally and relatively reasonable, all values were calculated based on the price in the same year as reflected in the statistics followed by an approximate calculation.

Some historical data were not collected or were not included in the statistical yearbooks and the statistical data in the year that the yearbooks were published were not yet published. Therefore, we frequently encountered the situation in which the statistical data obtained from various statistical yearbooks were incomplete (Xiaojie *et al*., 2000). For this reason, we had to first choose a reasonable prediction method to predict the missing data during its processing. Compared to the traditional method of mathematical statistics (such as regression analysis), the gray sequence prediction model (Qing *et al*., 2000) requires less data and its computation is simple, manually tenable and its speed can be increased by using computers. It generally does not need multi-factor data but only single-factor data of the predicting object itself. The gray sequence prediction model harbors a wider range of applications and could be used for both short-term and medium- or long-term predictions and it has high prediction accuracy with small errors and provides various inspection methods to determine whether the model is reliable and whether the predicted value is trustworthy. The gray sequence prediction method builds models by extrapolating the trend of a series and it is particularly suitable for ordered series (ascending or descending; generally back propagation) and provides good data prediction tools. Therefore, this study utilized the moving average formula of the gray sequence prediction method. The calculation was as follows:

$$X(t) = \frac{X(t-1) + 2X(t) + X(t+1)}{4} \quad (9)$$

Where:

X(t) = The index value in year t
X(t-1) = The index value in the year before year t
X(t +1) = The index value in the year after year t

The preprocessed data were added to the weight of the data in the current year and thus were more reasonable. The data at the two ends were processed using formula 10 and 11:

$$X(1) = \frac{3X(1) + X(2)}{4} \quad (10)$$

$$X(N) = \frac{X(N-1) + 3X(N)}{4} \quad (11)$$

where, X(1) is the index value of the beginning year, X(N) is the index value of the terminating year.

MODEL APPLICATION AND RESULT ANALYSIS

Basic information about the Shaanxi Province and its agricultural mechanization development history: The statistics of the Shaanxi Province were used as examples for the application of the model. We focused on the analysis of the contribution rate of agricultural mechanization in the Shaanxi Province to the agricultural production. Therefore, our study may further elucidate the field's understanding of the agricultural growth trend in the Shaanxi Province and facilitate scientific decision-making in agricultural development. The Shaanxi Province is located in the northwest of inland China, ranking first among the five northwestern provinces in agricultural production. Shaanxi Province abuts to China's economically developed southeast and connects to the four other resource-rich northwest provinces. It exhibits a unique geographical location. The capital city Xi'an is an ancient Chinese capital city. The province is in the hinterland of inland China, belongs to the middle reaches of the Yellow River and the upper reaches of the Yangtze River and is between the geographic coordinates of east longitude 105°29' to 111°15' and north latitude 31°42' to 39°35'. The province encompasses an area of approximately 210,000 km^2 and a population of 37.33 million. The Shaanxi Province exerts jurisdiction over one sub-provincial city of Xi'an, nine prefecture-level cities such as Baoji and one agriculture demonstration district. The main Shaanxi Province crops include wheat, corn, cotton, rapeseed, millet and rice.

The household contract responsibility system has been implemented in rural China since 1979. During this period, because large farming machinery could not adapt to small plots and were mostly unused, the amount of manual labor and animal power in farming increased. The fervor for agricultural mechanization started to surface after 1985. In particular, the agricultural machinery represented by small tractors started to rapidly grew around 1990. Since 1995, self-propelled combine harvesters have been used extensively with trans-regional operations and agricultural machinery entered a new stage of development. According to the statistics from 2004 to 2010, the state subsidies to the Shaanxi Province for the purchase of farming machinery increased from 2 million Yuan in 2004 to 601 million Yuan in 2010. In 2010, the province's total agricultural machinery power was 18.893 billion watts, revealing an increase of 44.6% compared with that of 2004 and the average annual growth rate was 6.3%. There were 78,300 large and medium tractors, an increase of 1.3-fold since 2004 and the average annual growth rate was 14.8%. There were 23,400 combine harvesters, revealing an increase of 76.3% compared with the harvesters in 2004 and the average annual growth rate was 9.9%. There were 174,700 small tractors units, a decrease of 3.4% compared to 2004. There were 2,078,600 hectares of arable land with mechanical tillage in the province, demonstrating an increase of 32.8% compared with 2004 and the average annual growth was 4.8%. The

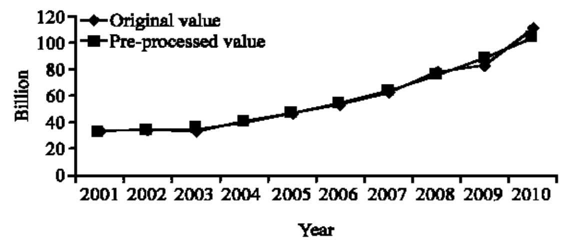

Fig. 1: Total agricultural output in the Shaanxi Province from 2001-2010

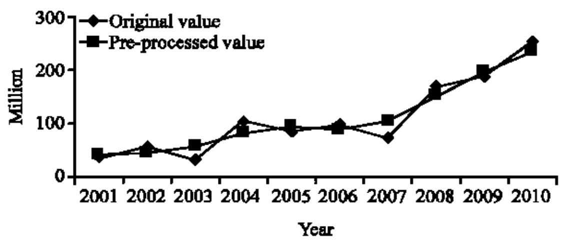

Fig. 2: Agricultural machinery investment in the Shaanxi Province from 2001-2010

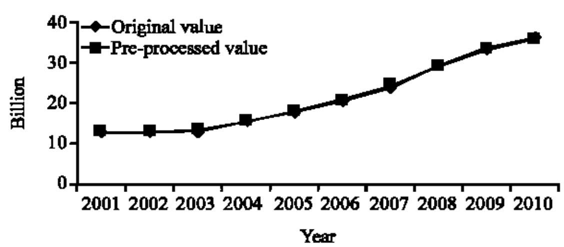

Fig. 3: Capital investment in the Shaanxi Province from 2001-2010

mechanical cultivation area accounted for 72.7% of the province's arable land commonly in use, revealing an increase of 16.7% compared with that of 2004.

Raw data and the pre-processed results: The raw data, including the total agricultural output value, the original value of agricultural machinery, agricultural material consumption, agricultural labor and the sown area, were obtained by searching the “China Statistical Yearbook”, “China Agricultural Yearbook”, “Statistical Yearbook of Shaanxi Province” and “China Agricultural Yearbook”. The moving average method was used for pre-processing and the results are displayed in Fig. 1 to 5. The total agricultural output value, agricultural machinery investment and capital investment presented in the figures were calculated based on the price in the same year.

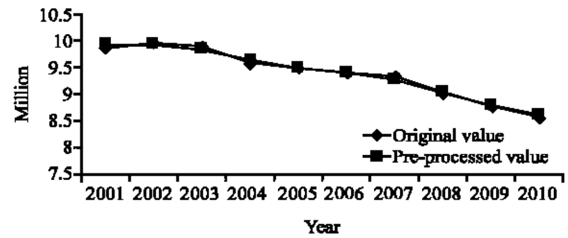

Fig. 4: Labor input in the Shaanxi Province from 2001-2010

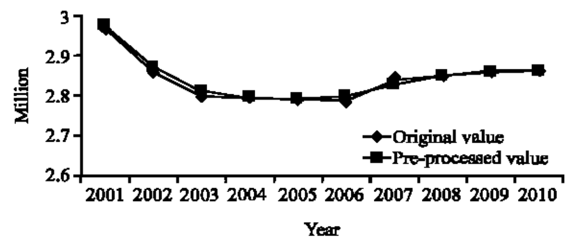

Fig. 5: Land investment in the Shaanxi Province from 2001-2010

Regression analysis of the agricultural production function and calculation of the contribution rate: Using formula 3 and the pre-processed data in the figures, natural logarithms of the agricultural total output Y, agricultural machinery M, capital K, labor L and land investment D values were taken. The fitting function was obtained by multiple linear regression analysis:

$$Y' = 60.08319-0.25491M'+0.57963K'-6.58587L' -0.9916D' \quad (12)$$

Formula 12 was transformed into the nonlinear equation:

$$Y = 1.142\times10^{26}\, M^{-0.2549}\, K^{0.57963}\, L^{-6.58587}\, D^{-0.9916} \quad (13)$$

Formula 13 was the regression model of the C-D agricultural production function for the Shaanxi Province from 2001 to 2010.

The regression results indicated that the regression coefficient of the agricultural machinery input factor α was -0.25491, the capital investment factor β was 0.57963.

The labor input factor γ was -6.58587 and the land input factor θ was -0.9916, where $\beta>\alpha>\theta>\gamma$. It indicated that among all of the input factors, the capital investment displayed the most significant effects on the output, followed in descending order by the agricultural machinery input and land investment, whereas the labor input did not significantly affect the output.

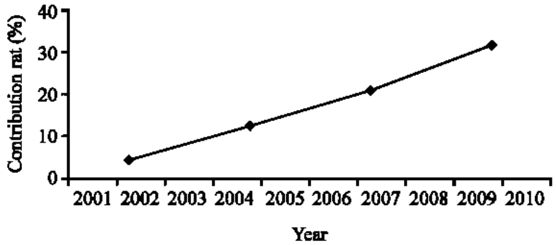

Fig. 6: The contribution rates of agricultural mechanization of Shaanxi Province in various time periods

The value of the input-output elasticity α of the agricultural machinery investment was derived based on the total agricultural output shown in Fig. 2, the average annual growth rate of the value of the agricultural machinery investment and regression. Using the formula 8, we calculated the contribution rate of agricultural mechanization to the agricultural output in the Shaanxi Province from 2001 to 2010 Δ to be 31.46%.

Figure 6 illustrates the distribution of the contribution rates of agricultural mechanization to agricultural production in different time periods in the Shaanxi Province. As demonstrated in the figure, the contribution rate of agricultural mechanization in agricultural output has been trending upwards for nearly three decades in the Shaanxi Province. This trend suggests that under the current agricultural production conditions, the role of agricultural mechanization in agricultural output is increasingly important. The contribution rate of agricultural mechanization was low during 1980-1985 due to the implementation of the household contract responsibility system in rural China since 1979. In this period, because large farming machinery could not adapt to small plots and were mostly unused, the amount of manual labor and animal power in farming increased, thus leading to a lower contribution rate of agricultural mechanization. The fervor for agricultural mechanization after 1985 is clearly demonstrated by the rapid growth of small tractors approximately 1990. Since 1995, self-propelled combine harvesters have been used extensively with trans-regional operations. Agricultural machinery entered a new stage of rapid development. Therefore, the contribution rate increased in this stage. Since 2004, the state has purchased agricultural machinery subsidies and the extent and variety of these subsidies increase every year. In addition, the appraisal of agricultural vocational skills has been promoted steadily. Moreover, "Agricultural Mechanization Promotion Law", "Road Traffic Safety Law", "Agricultural Machinery Safety Supervision and Management Regulations" and "Shaanxi Provincial Agricultural Machinery Management Ordinance" have provided a relatively complete legal system for the development of agricultural mechanization. Therefore, during this period, the contribution rate of agricultural machinery to agricultural output has greatly increased in the Shaanxi Province. As demonstrated in the Fig. 1-3, with increasing agricultural machinery and capital, the agricultural output of the Shaanxi Province exhibits a clear trend of upward growth. This observation suggests that further investment in agricultural machinery and an increase in the mechanization level of agricultural production may contribute to the growth of the agricultural output and increase the contribution rate of agricultural mechanization.

CONCLUSION

In this study, the Cobb-Douglas production function model was applied to estimate the contribution rate of agricultural mechanization to agricultural output. The following conclusions were obtained by analyzing the examples:

The methods of the Cobb-Douglas production function model and regression analysis could be used to estimate the contribution rate of agricultural mechanization to agricultural output. The time series forecasting model was used to pre-process the data required for the estimation, thus smoothing the data and solving the problem of insufficient statistical data.

The contribution of agricultural mechanization to the agricultural output was 31.46% in the Shaanxi Province during 2000-2010. Regression analyses of the various input factors demonstrated that the growth of agricultural output was primarily due to the increase in capital and agricultural machinery. The capital investment exhibited the largest contribution to the output, followed in descending order by the investment in agricultural machinery and land and labor input did not significantly affect the output.

In the Shaanxi Province, agricultural output revealed a significant upward growth trend for increased agricultural machinery and capital investment. This observation suggests that further investing in the agricultural machinery and increasing the mechanization level of agricultural production may contribute to the growth of agricultural output. The results of this study are relevant for future evaluations of the development level of agricultural mechanization and its potential contribution to the agricultural output.

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