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A Study on Grain Production Efficiency and Its Influencing Factors in Heilongjiang Province 'Based on Malmquist Index and Tobit Model' Based on the "COVID-19"

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Abstract: "COVID-19" led to the influence of food imports, safe and effective to improve the efficiency of food production is imminent. In recent years, many studies have been made on grain production efficiency in China and various regions by choosing different measurement methods from different perspectives. Based on the previous research, in this paper, judging from the reality of structural reform on the supply side of agriculture to the continuous advancement of urbanization and industrialization, the relevant urbanization and industrialization measurement indicators were finally selected based on the background of agricultural modernization development, and the grain structure and grain yield were included in the evaluation system, which expanded the research scope of production efficiency to some extent. Malmquist index and Tobit model were selected to analyze the grain production efficiency. Its influencing factors in Heilongjiang province based on panel data, so as to provide relevant suggestions for promoting the improvement of grain production efficiency and ensuring the stability and quality of grain production in Heilongjiang province. Pesticide consumption and urbanization rate had significant negative correlation with grain production efficiency, while the purity of chemical fertilizer, planting structure and grain yield had significant positive correlation with grain production efficiency.

1. Introduction

China is a big country with a population of 1.4 billion, where food production is still a hot topic even if it has a great scientist like Yuan Longping, who has solved the problem of Chinese people eating. Since 2004, China has successively promulgated eighteen No.1 documents of the Central Committee, which has always taken food security as the focus of agricultural work and provided policy guidance for China's food production [1].

Heilongjiang Province, which has one of the world's three black lands, has always been a major agricultural province. Its agricultural modernization level has been significantly improved by taking

advantage of China's rapid development of science and technology through the reform of modern agriculture supporting system, the improvement of agricultural investment, the use of new farming techniques, the strengthening of ecological protection, the protection of black soil quality, the reduction of pesticide and fertilizer consumption, the reduction of agricultural non-point source pollution, the improvement of resource utilization efficiency, and the development of efficient and sustainable agriculture.

2. Analysis of Total Factor Productivity in Heilongjiang Province

2.1. Model Selection

Malmquist index is mainly used to describe the production technology of multiple input-output variables in decision-making units, the remarkable feature of which is that they define the distance function through the output-input method without any explanation of the standard of specific behavior. With a given input variable matrix, the distance function of an output is defined as the optimal proportional term of the output index variable matrix. Similarly, given the output variable matrix, the output variable distance function can be regarded as the minimum proportional term of the input index variable matrix. Caves Christensen and Diewert (1982) proposed the Malmquist productivity index based on output index variables for a single technology, which is defined as:

$$M_{ac}^{t} = \frac{E^{t}(x^{t+1}, y^{t+1})}{E^{t}(x^{t}, y^{t})} \tag{1}$$

$$M_{ac}^{t+1} = \frac{E^{t}(x^{t+1}, y^{t+1})}{E^{t}(x^{t}, y^{t})} \tag{2}$$

Where, E_t (x_t, y_t) and E_{t+1} (x_{t+1}, y_{t+1}) are the output distance functions obtained by comparing the production points with the optimal production frontier foundation in the same time period (i.e. t period and t+1 period), respectively. E_t (x_t, y_t) and E_{t+1}(x_{t+1}, y_{t+1}) are respectively the output distance functions obtained by comparing the production point with the optimal frontier foundation during the mixing period.

The quantitative relationship among Malmquist index, efficiency change and technological change is MI=EC*TC, that is, Malmquist index mainly includes two parts, namely efficiency change and technological change [2].

$$\begin{aligned} M_{ac} &= \sqrt{\frac{E^{t}(x^{t+1}, y^{t+1})}{E^{t}(x^{t}, y^{t})} \frac{E^{t+1}(x^{t+1}, y^{t+1})}{E^{t+1}(x^{t}, y^{t})}} \\ &= \frac{E^{t+1}(x^{t+1}, y^{t+1})}{E^{t}(x^{t}, y^{t})} \sqrt{\frac{E^{t}(x^{t}, y^{t})}{E^{t+1}(x^{t}, y^{t})} \frac{E^{t}(x^{t+1}, y^{t+1})}{E^{t+1}(x^{t+1}, y^{t+1})}} \end{aligned} \tag{3}$$

2.2. Indicator Selection

In the process of analysis, by referring to the data from the Statistical Yearbook of Heilongjiang Province since 2001, and comparing the data on the statistical website of Heilongjiang Province for 20 years before and after, the total factor productivity calculation system of Heilongjiang Province was finally constructed by selecting five input indicators, namely, the sown area of grain crops, agricultural employees, the purity of chemical fertilizer, the amount of pesticides used and the total power of agricultural machinery, and one output indicator of grain output.

2.3. Analysis of Total Factor Productivity in Heilongjiang Province

Table 1: Calculation results of total factor productivity in Heilongjiang Province from 2001 to 2020

Years	Technical efficiency change (TECH)	Technical progress (TCH)	Pure technical efficiency change (PECH)	Scale efficiency change (SECH)	Total factor productivity change(TFPCH)
2001-2002	1.000	1.082	1.000	1.000	1.082
2002-2003	1.000	1.036	1.000	1.000	1.036
2003-2004	1.217	0.869	1.261	0.965	1.057
2004-2005	1.017	1.100	1.000	1.017	1.119
2005-2006	1.003	1.148	1.002	1.002	1.151
2006-2007	0.926	1.110	1.000	0.926	1.028
2007-2008	1.035	1.002	1.000	1.035	1.038
2008-2009	1.223	0.980	1.181	1.035	1.199
2009-2010	0.936	1.093	0.944	0.991	1.024
2010-2011	0.992	1.129	1.000	0.992	1.120
2011-2012	1.039	1.148	1.000	1.039	1.193
2012-2013	0.962	1.172	0.972	0.990	1.128
2013-2014	1.033	1.141	0.990	1.043	1.179
2014-2015	1.000	1.196	1.000	1.000	1.196
Mean	1.027	1.086	1.025	1.002	1.111

The total factor productivity of grain production in Heilongjiang Province from 2001 to 2020 was calculated by running DEAP2.1 software. The results showed that the average total factor productivity of grain in Heilongjiang Province was 1.111, which was on the rise, but the whole range was different in different stages. The average technical efficiency in the study period was 1.027, of which the pure technical efficiency was 1.025 and the scale efficiency was 1.002, indicating that the main driving force for the improvement of technical efficiency was the effective and reasonable input of various agricultural production in grain production, but the efficiency improvement brought by expanding grain planting scale was not obvious. The average value of technological progress was 1.086, that is, the benefits brought by technological progress were higher than the contribution of technical efficiency to grain production efficiency, indicating that Heilongjiang Province has improved grain production efficiency and ensured grain production level by improving grain planting and production technologies, including the use of new machinery, improvement of new production facilities, seed improvement and efficient and safe use of pesticides and fertilizers.(in table 1) In addition, the agricultural planting structure in Heilongjiang Province has been adjusted and optimized to promote the marketization of agriculture and to give full play to the role of the market in allocating various production resources to improve the efficiency of grain production [3].

The technical efficiency did not reach the best in 2006-2007, 2009 -2010, 2010 -2011 and 2012 -2013. The results of data show that technological progress has provided power support for the improvement of total factor productivity in Heilongjiang Province, and it has promoted the improvement of grain production efficiency by using new agricultural science and technology, improving agricultural production methods and using advanced management knowledge and experience.

The technological progress only failed to reach the best in 2003 -2004 and 2008 -2009. In these two periods, the power provided by technical efficiency supported the overall improvement of total factor productivity in Heilongjiang Province. From 2003 to 2004, the scale efficiency was 0.965, and the pure technical efficiency reached 1.265, which indicated that the improvement of total factor productivity could not be separated from the improvement of input and management of grain production factors and technical efficiency. From 2008 to 2009, the pure technical efficiency and

scale efficiency both exceeded 1, indicating that the scale of grain production and the input of grain production factors in that year both promoted grain production in Heilongjiang Province [4].

In recent three years, the total factor productivity of Heilongjiang Province has been continuously improved, mainly because of the improvement of the efficiency of research, development and popularization of new grain production technologies. The manpower, material resources and ideas need to be continuously innovated, effective and stable technology and knowledge should be put into food production, and farmers should be publicized and popularized to accept new things. Farmers who produce need to acquire enough knowledge to fully exert the advanced productivity of production technology [5]. Against the background of agricultural supply-side reform, Heilongjiang Province has been concentrating on the adjustment of agricultural planting structure, rational land circulation and prevention and control of agricultural non-point source pollution in recent years. Under the condition of ensuring the regional pure technical efficiency and scale efficiency to be stable at a certain level, the total factor productivity, driven by technological progress, has fundamentally guaranteed the quality and quantity of grain production in Heilongjiang Province [6].

2.4. Analysis of Total Factor Productivity of Cities in Heilongjiang Province

Table 2: Calculation results of total factor productivity of cities in Heilongjiang Province

Regions	Technical efficiency change (TECH)	Technical progress (TCH)	Pure technical efficiency change (PECH)	Scale efficiency change (SECH)	Total factor productivity change(TFPCH)
Harbin	0.998	1.117	1.000	0.998	1.115
Qiqihar	1.019	1.100	1.038	0.982	1.121
Jixi	1.000	1.102	1.000	1.000	1.102
Hegang	0.987	1.115	1.000	0.987	1.100
Shuangyashan	1.039	1.119	1.022	1.017	1.163
Daqing	1.044	1.112	1.033	1.010	1.160
Yichun	0.977	1.130	0.989	0.988	1.104
Jiamusi	0.995	1.098	1.000	0.995	1.092
Qitaihe	1.011	1.105	1.000	1.011	1.117
Mudanjiang	0.994	1.105	0.993	1.001	1.099
Heihe	1.015	1.111	1.025	0.990	1.127
Suihua	0.995	1.108	1.000	0.995	1.103
Great Khingan	1.000	1.134	1.000	1.000	1.134
Mean	1.005	1.112	1.008	0.998	1.118

On the whole, the grain productivity of each region from 2001 to 2020 was not significantly different and was mainly driven by technological progress, indicating that the radiation driving effect among each region was strong, and regional information exchange and resource sharing achieved common development to a certain extent. However, there were some differences between pure technical efficiency and scale efficiency. From the perspective of pure technical efficiency, Yichun and Mudanjiang did not reach the optimal level and declined slightly. The input of grain production factors was unreasonable, which to a certain extent caused the waste of resources or the shortage of certain input factors and had a negative impact on technical efficiency. From the perspective of scale efficiency, these problems are reflected to varying degrees in the provincial capital of Harbin, Qiqihar and Hegang, the forest city of Yichun, the coal city of Jiamusi, Heihe and Suihua. It means that there is blind expansion or insufficient area of food crops planting scale in these areas, and there is also the problem of high degree of land fragmentation, which makes the scale efficiency decline and affects regional food production.(in table 2)

3. Analysis of Influencing Factors of Grain Production Efficiency in Heilongjiang Province

3.1. Model Selection and Establishment

Under normal circumstances, the efficiency value can be regressed by the ordinary least square method (OLS). Nevertheless, the efficiency values calculated by DEA model are discrete, and if the least square method is still used, the estimated values of parameters will be deviated or inconsistent [1]. The Tobit regression model, a model (truncated regression model) with limited dependent variables was put forward by Tobit (1958). It follows the maximum likelihood method and can effectively solve the above-mentioned situation [2]. The basic model is:

$$Y = \begin{cases} Y^* = \beta X + \mu & Y^* > 0 \\ 0 & Y^* \le 0 \end{cases} \tag{4}$$

Where,
Y^*= the truncated dependent variable vector;
Y= the efficiency value vector;
X= the independent variable vector;
β=the regression parameter vector;
μ=the error term, and $\mu \sim (0, \delta^2)$.
Based on Tobit basic model, the calculation formula is set as follows:

$$Y = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \beta_8 X_{8i} + \beta_9 X_{9i} + \mu \tag{5}$$

Where,
β_0= a constant term, and β_1, β_2, β_3, …, β9 are the regression coefficients of each variable;
i= the year;
X_{1i} =the sown area of food crops in this area;
X_{2i} =the total power of agricultural machinery;
X_{3i} = the purity of fertilizer;
X_{4i} =the amount of pesticide used;
X_{5i} =the amount of mulch film used;
X_{6i}= the urbanization rate;
X_{7i} =the planting structure;
X_{8i}=the grain yield per unit area;
X_{9i} = the degree of industrialization.

3.2. Indicator Selection

As there are many factors that affect the efficiency of grain production, in order to comprehensively analyze the technical efficiency of grain production in Heilongjiang Province and considering the authenticity and accessibility of the data, various input factors of grain production were selected as measurement indicators, specifically: total power of agricultural machinery, sown area of grain crops, purity of chemical fertilizers, the amount of mulch film used, the amount of pesticide used, urbanization rate, planting structure, grain yield per unit area and degree of industrialization, a total of 9 input indicators.(in table 3)

Table 3: Description and statistics of influencing factors of grain production efficiency in Heilongjiang Province

Variables	Description	Min.	Max.	SD	Mean
Sown area of grain crops X_1	Unit:10,000 hectares	783.30	1432.77	259.04	1140.45
power of agricultural machinery X_2	Unit:10,000 KWH	1741.80	5442.73	1309.99	3265.99
Purity of chemical fertilizers X_3	Unit:10,000 tons	129.72	255.31	48.36	188.42
The amount of pesticide used X_4	Unit:10,000 tons	3.50	8.30	1.91	6.21
The amount of mulch film used X_5	Unit:10,000 tons	2.20	3.30	0.45	2.70
Urbanization rate X_6	Unit: %	52.57	58.80	2.18	55.00
Planting structure X_7	Unit: %	83.33	96.84	5.14	90.89
Grain yield per unit area X_8	Unit: kg/ha	3754.88	4413.79	382.03	3807.57
Degree of industrialization X_9	Unit: %	45.39	26.88	6.62	42.33

3.3. Analysis of Influencing Factors of Grain Production Efficiency in Heilongjiang Province

The model has a good overall fitting degree, as the fitting degree of the model reached 0.94 after calculation. FF test statistic is used to test the significance of the whole equation, that is, the sum of squares of interpretation divided by the sum of squares of residuals. The P value of F statistic was 0.014 less than 0.05, indicating that the original hypothesis was rejected and the regression model was effective.

The total power of agricultural machinery has a negative correlation with grain production efficiency instead of a positive correlation as some people think. Generally speaking, the input of agricultural machinery can greatly liberate productive forces and promote the improvement of grain production level, but the total power of agricultural machinery hinders the grain production efficiency in this study. According to the actual development situation, Heilongjiang Province as a large agricultural province with high level of mechanization, the impact of increasing mechanical input in a short period of time on grain production efficiency is not so obvious as in the past. In addition, the covid-19 outbreak has caused a large number of labor force shifts in Heilongjiang Province due to the employment environment, and the non-agriculturalization of labor force has become more and more prominent. Nowadays, most farmers in agricultural production are middle-aged and elderly. However the agricultural machinery needs high-quality and skilled talents to use because of its own characteristics, that is, the use of agricultural machinery requires farmers to have a certain level of education, but the education level of left-behind farmers is far from this requirement, which leads to the fact that even with the input of agricultural machinery, they can’t enter the actual production, which may result in a large number of idle agricultural machinery, which is not conducive to the improvement of food productivity. (in table 4)

The purity of chemical fertilizer has a significant positive effect on grain production efficiency. The input of chemical fertilizers plays an important role in increasing grain output. Agricultural technicians in each area guide farmers’ input of chemical fertilizers for grain production in the current year according to the actual production situation in each area, so as to ensure the utilization rate of chemical fertilizers and increase grain output. Moreover, the use of organic fertilizers such as farmyard manure, biogas manure, compost, and compost can better promote crop production, with long-lasting fertilizer effect, and can also conserve land, and the quality of soil is of great positive significance to the improvement of grain production efficiency [7].

Table 4: Calculation results of influencing factors of grain production efficiency in Heilongjiang Province

Explanatory variables	Coefficient	SE	Z value	P value
Sown area of grain crops X_1	-7.22E-06	0.000104	-0.069509	0.9446
Total power of agricultural machinery X_2	-0.000154	4.90E-05	-3.145605	0.0017
Purity of chemical fertilizers X_3	0.014362	0.003823	3.756808	0.0002
The amount of pesticide used X_4	-0.075907	0.011166	-6.798148	0.0000
The amount of mulch film used X_5	-0.025335	0.029530	-0.857929	0.3909
Urbanization rate X_6	-0.017084	0.008959	-1.906857	0.0565
Planting structure X_7	0.026304	0.004488	5.861083	0.0000
Grain yield per unit area X_8	0.000217	1.86E-05	11.64175	0.0000
Degree of industrialization X_9	0.002034	0.001798	1.131455	0.2579
C Constant	-1.022808	0.455974	-2.243128	0.0249
R-squared	0.940807			
Prob-(F-statistic)	0.013660			

The amount of pesticides used has a significant negative impact on grain production efficiency. Pesticide is very harmful to land, ecological environment, food quality, and has a serious impact on soil fertility [8] Moreover, they can enter the water body with runoff and evaporate into the atmosphere, and spread around to pollute water sources and the atmosphere. All kinds of elements produced by grain crops in this type of land will also enter plants, and the existence of such substances in the grown grain will affect the yield and quality of grain crops, which is not conducive to the improvement of grain productivity. Besides, there are still some problems, such as the difference of pesticide quality, the unscientific collocation of pesticide varieties and quantities, the unscientific use of pesticides, and the backward equipment for pesticide use. In addition, due to the farmers' knowledge level and lack of professional accomplishment, such as the lack of scientific knowledge and corresponding management measures for pesticide use and the farmers' anxious attitude to achieve success, the abuse of pesticides in pursuit of grain production and the random increase in the dosage of pesticides, a series of various pollution problems including pesticide pollution to soil have been caused. Therefore, pesticides should be strictly monitored, and measures should be taken to deal with the harmful substances left in the land, so as to ensure the soil quality and improve the grain productivity [9].

The urbanization rate has a significant negative impact on the food production efficiency, which is manifested in the large-scale transfer of young and middle-aged labor force in Heilongjiang Province to the cities. Only the old people, children and women who stay in the rural areas stick to agriculture, so the rural areas are gradually becoming "hollowed out" and "aging". Agricultural production and development are facing a severe situation of no successor, resulting in a decrease in the regional food production efficiency. Particularly, in Heilongjiang Province, although the grain output has increased continuously in recent years, the cost of farming for farmers is high, and the economic income of farmers has been impacted, which leads farmers to choose other industries such as working to ensure their living needs. The continuous advancement of urbanization leads to the decrease of rural population, and most of the left-behind farmers have a low level of education. And all kinds of new agricultural science and technology, new knowledge and technology are constantly used in the field of agricultural production. Limited by the educational level, it is self-evident whether these left-behind farmers have the consciousness and ability to apply new

technologies and knowledge to the subsequent agricultural production.

Planting structure has a significant positive impact on grain production efficiency. As a major grain-producing area in China, Heilongjiang is facing the ever-changing agricultural environment, increasingly tight environmental constraints, and increasingly prominent problems such as the impact of foreign grain on the Chinese market. Therefore, it is increasingly urgent to adjust the planting structure. Therefore, Heilongjiang should reduce the planting area of corn, stabilize the planting area of rice, increase the production area of soybean, potato and other crops, balance the proportion of grain crops and other agricultural crops, construct a reasonable rotation system, and promote the improvement of regional grain production efficiency by adjusting the structure to ensure food security.

Grain production efficiency is positively influenced by grain yield per unit area. The improvement of overall grain production efficiency also depends on the increase of grain yield per unit area. What is most important to improve the grain yield per unit area is to ensure that the input factors of grain production really act on the land per unit area. The rational allocation of fertilizer, pesticide, plastic film, mechanical power and other factors can maximize the benefits, and the utilization rate of resources per unit area can be improved by using irrigation techniques such as sprinkler irrigation and drip irrigation, thus improving the overall grain production efficiency and total grain output.

4. Conclusions and Suggestions

4.1. Conclusions

The analysis of grain production efficiency and influencing factors in Heilongjiang Province by using Malmquist index and Tobit model showed that the average total factor productivity of Heilongjiang Province and all cities could reach 1.111 in the 20 years from 2001, which was attributed to the technological progress. Food productivity of cities in Heilongjiang Province was similar and mainly driven by technological progress, which indicated that the radiation driving effect among regions is strong, and regional information exchange and resource sharing achieved common development to a certain extent. The analysis of influencing factors of grain production efficiency in Heilongjiang province based on Tobit model by selecting statistical yearbook data of Heilongjiang province in 2020 showed that the total power of agricultural machinery, pesticide consumption and urbanization rate had significant negative correlation with grain production efficiency, while the purity of chemical fertilizer, planting structure and grain yield had significant positive correlation with grain production efficiency.

4.2. Related Suggestions

Some methods to improve the problems found in the above analysis have been found. Firstly, strengthen the training of new professional farmers. At present, the main grain producers in Heilongjiang Province are middle-aged and elderly people, who have some difficulties in accepting new agricultural knowledge and technology, so they need to be trained. On the one hand, it is necessary to train farmers in a simple and clear way. Considering that middle-aged and elderly people are at a disadvantage physically and mentally, it is necessary to sort out the contents and teach them in the most direct way to make them easy to accept. On the other hand, young and middle-aged farmers should be encouraged to actively participate in training, so as to strengthen the construction of rural talents and lay a foundation for future agricultural development. Secondly, rationally plan the input of grain production materials, mainly chemical fertilizers, pesticides, mechanical power and other inputs. Organic fertilizers and biomass pesticides should be actively

promoted, and artificially synthesized pesticides and fertilizers containing high heavy metals should be reduced. Agricultural modernization is marked by the high level of agricultural mechanization. Therefore, it is necessary to put new machinery and technology into food production, and provide relevant technical personnel to guide farmers in production, so as to improve the utilization rate of machinery and promote the improvement of food production level. Thirdly, strengthen subsidies for grain production. On the one hand, the subsidies for grain production materials mainly refer to giving certain subsidies to farmers who use green fertilizers, pesticides and plastic films. Agricultural production cannot be separated from farmers, and no one is more eager than them to increase the output of grain by investing in the means of agricultural production, so as to ultimately increase their production income and improve their own lives. However, compared with synthetic materials, the input of organic fertilizer and other materials has the problems of longer production efficiency, higher cost and long return period, which leads to farmers' low willingness to use and psychological resistance. But with government subsidies, the significance is completely different, so that the cost of farmers' grain production will be reduced on the basis of subsidies. Through policy guidance, the original grain production factors will be changed into production mode, and the externality of this green production behavior will be weakened. On the other hand, it is subsidies for the adjustment of planting structure, mainly for corn, soybeans and other crops with relatively small planting areas in Heilongjiang Province. At this stage, due to the overcapacity and large stock of corn, farmers are not prepared for market-oriented sales of corn, and the price of corn is low, resulting in a large loss of farmers' income, which seriously affects the input of grain production factors in the second year and the grain production efficiency. The subsidy can encourage farmers to change the original planting structure and plant more food crops such as soybeans and potatoes. However, farmers who plant other crops know little about the growth environment and factor input ratio, so they need support from the state. At the same time, they also need support in technology popularization, production and processing, marketing and other aspects to ensure national food security and increase food output.

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