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Does the Expansion of Farmers' Operation Scale Improve the Efficiency of Agricultural Production in China? Implications for Environmental Sustainability

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China's agricultural development urgently needs dynamic transformation and green transformation, from a traditional extensive mode of production to a moderately intensive mode of production that meets the requirements of the new era, with efficiency improvement as the guide to promote green, low-carbon, and sustainable development. Based on the micro-data of farmers in Hunan province from 2015 to 2020, this paper uses the data envelopment analysis method to measure the cost efficiency of rapeseed production and then decompose the cost-efficiency. The Tobit model is used to analyze the influencing factors and cost-efficiency differentials. First, there is considerable room for improvement in the overall cost efficiency of Chinese rapeseed production. The technical efficiency (TE), allocation efficiency (AE), and cost efficiency (CE) of rapeseed production in the survey area are 0.869, 0.701, and 0.609, respectively. Second, allocative efficiency is an important factor affecting the improvement of cost efficiency. The expansion of farmers' operation scales does not necessarily improve their allocative efficiency, but increases their input of chemical fertilizer and other elements, which may lead to agricultural non-point source pollution. This is not conducive to sustainable environmental development. Third, the relationship between the cost efficiency of crop production and farmers' operation scale is of an "inverted U-type" curve. That is to say, with the expansion of farmer operation scale, cost-efficiency shows an "increasing first and decreasing later" trend peaking at (6.67,13.33) hm^2. Fourthly, the distinguishing factors which affect cost efficiency show obvious similarities while reserving differences. Finally, we also suggest countermeasures and suggestions from the perspective of R & D investment, industrial support, regional exchange and cooperation, reasonable input of resource factors, and awareness of agricultural green production to promote green and low-carbon development of the rapeseed industry in China.

Keywords: farm size, cost efficiency, rapeseed production, environmental sustainability, data envelopment analysis, China

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1 INTRODUCTION

Improving agricultural productivity and efficiency of production is crucial to ensuring the safe supply of food and oil crops, promoting green and low-carbon development, and reducing poverty in rural areas (Elahi et al., 2018; Zhang et al., 2022). However, with the acceleration of China's industrialization and urbanization process, the prices of the labor force, land, agricultural materials, and other production factors are increasing every year. The higher agricultural production costs weaken the market competitiveness of agriculture and agricultural products (Zhang et al., 2019). At the same time, the excessive input of factors has brought about many negative effects, resulting in serious agricultural non-point source pollution and water environment pollution (Hong et al., 2015; Zhang et al., 2013; Elahi et al., 2022a). Therefore, improving China's agricultural competitiveness and making the agricultural income sustainable has become an important policy goal of the Chinese government.

In China, agricultural land is collectively owned and distributed equally to each villager. The one-family small-scale farming method has faced a number of challenges, such as land management limitations, fragmentation of plots, and high production costs (He, 2016; Tan et al., 2008; Zhang and Zhong, 2017). Thus, it is often hailed as a good policy choice to promote agricultural modernization, improve agricultural production efficiency, reduce factor inputs, and increase farmers' income through large-scale agriculture (Chen et al., 2015; Mosheim and Lovell, 2009; Sumner, 2014). However, after the scale of operation changes, farmers may still invest too much fertilizer, pesticide and labor force in accordance with previous experience, resulting in unreasonable factor input structure (Fan et al., 2005; Cheng, 2015; Elahi et al., 2021b). Especially, with the rapid rise of agricultural production costs, it is necessary to conduct economic accounting of agricultural production for different scales of operation and improve farmers' awareness of efficiency improvement (Elahi et al., 2022b). To sum up, the analysis of cost efficiency is conducive to exploring the standard of appropriate operation scale, which will contribute to better achieving the established goals of reducing production costs, enhancing agricultural competitiveness, and improving farmers' income (Lund and Hill, 1979; Obi and Ayodeji, 2020).

Previous research has provided useful insights into the cost efficiency of agricultural production, which can be classified as follows: The first stream of literature is concerned with calculating and comparing the cost efficiency of agricultural production. For instance, Maurice et al. (2015) estimated the cost efficiency of food crop production in the Adamawa State of Nigeria by using the survey data of small farmers and found that the farms in the study area had 16% space for cost efficiency improvement. Thath (2014) used Cambodian socio-economic survey data to measure the cost efficiency of farmers' rice production and found that farmers still had a 20–30% efficiency loss in rice production. Paudel et al. (2009) used the stochastic frontier cost function to measure the cost efficiency of corn production of farmers in Chitwan, Nepal, and found that the cost efficiency of corn production by local farmers was 0.63. The second stream of literature is concerned with discussing the factors affecting the cost efficiency of agricultural production. For instance, Liu et al. (2017a) used the stochastic frontier method to analyze the impact of land operation scale on grain cost efficiency in China. They found that land operation scale and land fragmentation degree had a significant negative impact on grain cost efficiency. Wu et al. (2006) measured the cost efficiency of diversified farms and specialized farms by using the random frontier method based on the farm survey data in Missouri and found that the low-cost efficiency of these two farms was due to improper operation scale and improper input allocation. Third, some studies have systematically analyzed the influence of certain factors on the cost efficiency of agricultural production. For example, Liu et al. (2018) computed the cost efficiency of China's main rapeseed production provinces (or municipalities directly under the Central Government) by using provincial-level panel data. They found that excessive input of nitrogen fertilizer and insufficient input of potash fertilizer in rapeseed production had a significant negative impact on the cost efficiency. In another study, Liu et al. (2017b) conducted an empirical study based on the data of fixed observation points in China's rice industry technology system and found that agricultural production services can improve the cost efficiency of grain production in China. Zeng et al. (2015) used provincial macro data to study the saving effect of agricultural infrastructure on grain production cost in China and found that increasing investment in agricultural infrastructure could significantly reduce grain production costs. Zhao et al. (2021) used the data of fixed observation points in China's waterfowl industrial technology system for empirical analysis. They found that the relationship between the cost efficiency of duck breeding and the breeding scale was "inverted U-shaped". The efficiency was well achieved on a medium scale, with an annual production of duck breeding between 60,000 and 90,000.

The existing literature on environmental sustainability focuses on the following aspects. The first aspect is measuring agricultural green total factor productivity. Using panel data of Provinces in China from 2000 to 2019, Shen et al. (2022) studied the agricultural green total factor productivity from the perspective of carbon sinks and emissions, and found that the annual growth rate of agricultural green total factor productivity was 1.1% during the study period, and agricultural technological progress was the primary driver of its growth. The second perspective is agriculture's total factor productivity. Liu et al. (2022) analyzed data from 2003 to 2019 to determine how production factor mismatch affects environmental total factor productivity in four regions of China. In each region, the authors noted that both factor price distortion and factor allocation have a significant impact on environmental total factor productivity. The third aspect is reducing pesticide and fertilizer use. Schreinemachers and Tipraqsa (2012) examined FAO data for the period 1990–2009 and found that a 1% increase in crop yield was closely associated with an increase in pesticide use per hectare of 1.8%, but the increase in pesticide intensity leveled off with economic development.

Existing literature has also advanced fruitful discussions on the CE of agricultural production and environmental sustainability (Massarutto, 2003; Rosen et al., 2008; Zhang et al., 2012). Still, additional issues must be investigated further. First, the present research mostly assumes that farmers' operations are small-scale, scattered, and homogeneous. In contrast, very few studies have attempted to decompose the cost efficiency and analyze the differences in the impact of farmers of various sizes on technical, allocative, and cost efficiency. Second, in terms of research perspectives, most literatures focus on the total factor productivity of manufacturing or energy enterprises under environmental regulations, while few scholars discuss crop planting cost efficiency from the perspective of environmentally sustainable development. Third, in terms of the research subject, most of the literature focuses on food crops (Elahi et al., 2021a), but empirical research on the cost efficiency of oil crops production remains inadequate. On the other hand, Rapeseed is China's most important oilseed crop and one of the few crops that can successfully combine primary, secondary, and tertiary industries. Therefore, this paper used data envelopment analysis to measure the cost efficiency of rapeseed production and divided the cost efficiency into technical efficiency and allocation efficiency, from the perspective of environmental sustainability, based on micro-survey data from the fixed observation points of Hunan Provincial Development and Reform Commission from 2015 to 2020. In addition, the Tobit model was used to analyze the influencing factors and differences of the cost efficiency of crop production, to provide theoretical reference for ensuring the security of edible vegetable oil supply and promoting the green and low-carbon development of breeding, processing, and service industries in China.

2 MATERIALS AND METHODS

2.1 Data Collection

The Database of Agricultural Production Cost-Benefit used in this study is routinely updated by China's National Development and Reform Commission. This data set is in the form of cost accounting, which is filled in by farmers according to the actual expenditure each time. The data set covers the micro-survey data of farmers' agricultural production in seven prefecture-level cities by the Hunan Provincial Development and Reform Commission from 2015 to 2020. A three-stage stratified sampling method is adopted to determine sample counties, towns, and villages to improve the representativeness of samples. In addition, agricultural cost survey experts in Hunan check the data, and many experienced survey team members are well-trained, ensuring the data's quality Fan and Connie (2005).

In addition, to systematically investigate the relationship between the farmer operation scale and CE of rapeseed production, we classified the farmer operation scale into six intervals (0, 0.67), (0.67, 2), (2, 3.33) (3.33, 6.67), (6.67, 13.33, (13.33, +∞) following Zhang and Zhou (2019) for comparative study. In the original dataset, a total of 485 samples were obtained, among which the number of samples from 2015 to 2020 was 81, 81, 81, 81, 80, and 81, respectively.

2.2 Study Area

China is a major producer of rapeseed, with its sown area and total output ranking among the top globally, cultivating 6,583.09 thousand hectares and harvesting 13.4850 million tons in 2019, ranking second (after Canada) and third (after Canada and the European Union) globally (**Figure 1**). Rapeseed cultivation in China is strategically important for ensuring global food and oil security (He et al., 2015; Liu et al., 2017; Wang, 2018; Bureau of Statistics, 2020; FAO, 2020). Meanwhile, the winter rapeseed planting area in China accounts for approximately 90% of the total rapeseed area in China, primarily in provinces along the Yangtze River basin (Zhang et al., 2013).

In this paper, we use the case study method to select the study area. We specifically chose Hunan Province in China because it provides a suitable case for the cost efficiency study of rapeseed production and the green and low-carbon development of rapeseed industry (**Figure 2**).

Located in central China and the middle reaches of the Yangtze River, Hunan is a largely agricultural province with abundant agricultural resources. In Chinese history, it was known as "the granary of nine states" and "the land of fish and rice." After rice and vegetables, rapeseed is the third most important crop in Hunan province. In 2020, the province's rapeseed planting area was 1,326 thousand hectares, accounting for 18% of China's total planting area and ranking first in China since 2015. Rapeseed cultivation in the province is primarily based on "rice-oil seed" rotation, accounting for 42.46 percent of the total rapeseed area (China News Network, 2021).

2.3 Variable Description

The following variables are chosen in this study based on the current state of rapeseed planting and the basic requirements of the data envelopment analysis:

Total cost (RMB): It includes the cost of land, labor, machinery, seeds, fertilizers, pesticides, fertilizers, and other costs. Land costs include self-run land lease and land rent; labor costs include domestic and hired labor costs; machinery operation costs include own machinery and agricultural machinery service fees.

Price of input factors (RMB/ha or RMB/day): These include prices for seed, land, labor, machinery, seed, fertilizer, pesticide, and other costs. It is worth noting that China's diversified terrain features differentiate the mechanization rate of rapeseed planting, so the mechanical operation cost for some variables may reach 0.

Production (kg): It is expressed as the total yield of rapeseed planting.

The influencing factors of cost inefficiency selected in this study are as follows:

Scale of farmer operation: The operation scale of farmers is the key variable in this study. Following Li et al. (2010) and Wang et al. (2015), the sowing area of rapeseed is used to represent the operation scale of farmers, including the self-operated area and circulation area.

Age: It is expressed as the survey year minus the birth year of the rapeseed production decision-maker.

Gender: It is a dummy variable with 0 for females and1 for males.

Education: The following categories are considered for education: up to 6 years for primary school, up to 9 years for

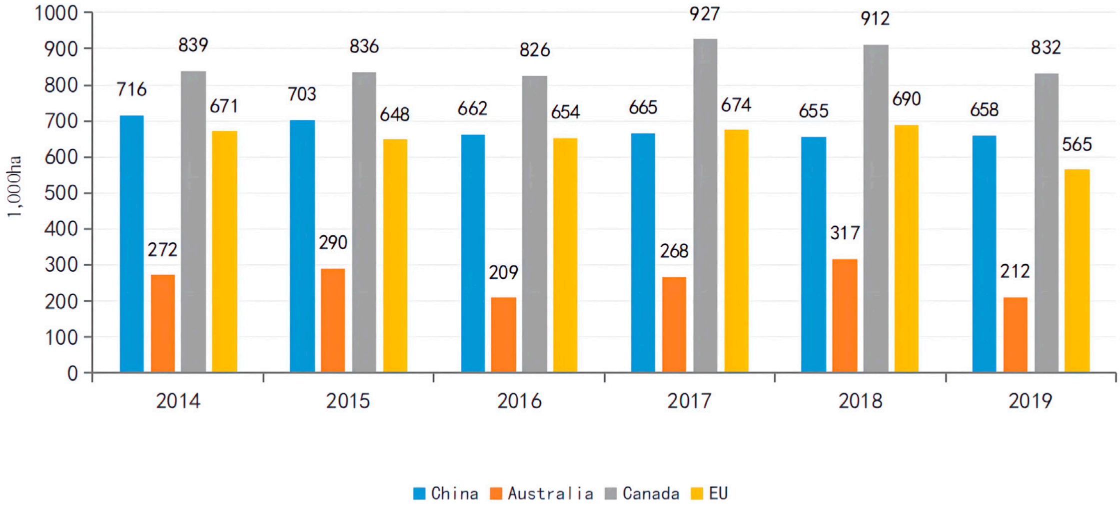

FIGURE 1 | Planting area of rapeseed in major producing countries from 2014 to 2019.

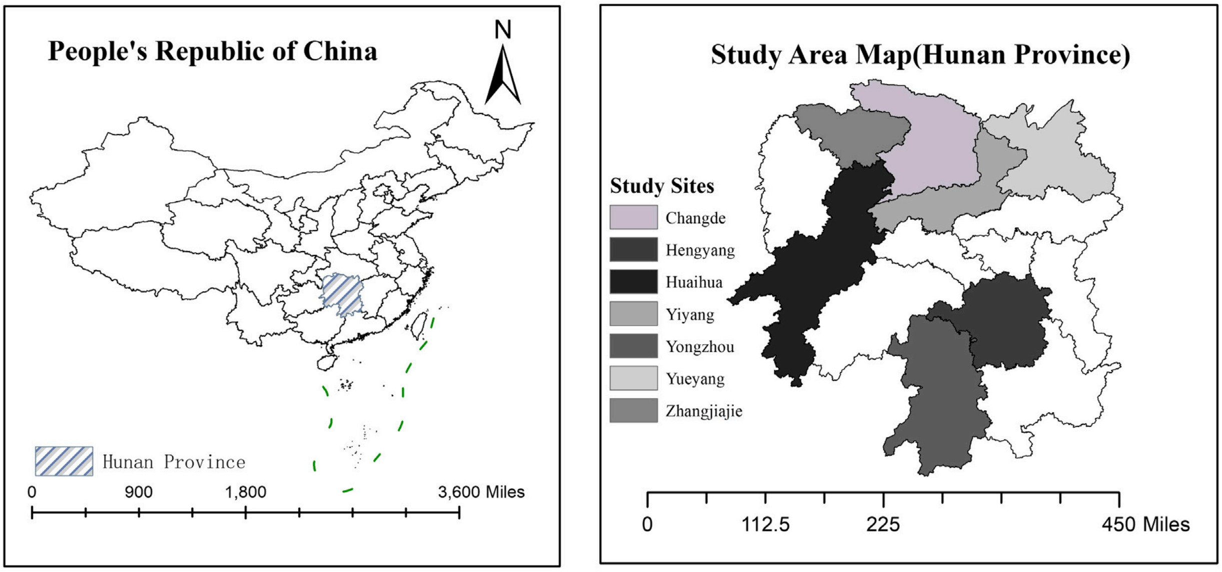

FIGURE 2 | Map of the study area.

middle school, up to 12 years for high school, up to 15 years for junior college, and up to 16 years for undergraduate.

Terrain: It is a dummy variable with 0 representing plain and 1 representing the hilly area.

Subsidies: It mainly refers to the land subsidies issued by the Chinese government and are calculated per the ratio of cotton + rapeseed or rice + rapeseed inter-planting.

Share of labor: It is expressed as the number of workers employed in rapeseed production divided by the total number of workers employed.

Rapeseed price: It is expressed as the quantity of rapeseed sold divided by rapeseed yield per unit area.

Area dummy variables: These variables reflect the regional differences in efficiency, with north Hunan as the base variable.

The variable description and the basic statistics are shown in **Table 1**.

2.4 Estimating Cost Efficiency Using Data Envelopment Analysis

Data envelopment analysis (DEA) mainly uses mathematical programming and statistical data to determine the relatively effective production frontier, projects each decision unit onto the DEA production frontier, and evaluates their relative

TABLE 1 | Variable definitions and descriptive statistics.

Function	Variable Name	Definition/Unit	Mean	Std. Dev	Min	Max
Cost function	Rapeseed yield	kg	12742.0	32199.0	600.0	347571.0
	Seed costs	RMB	2290.0	7793.0	120.0	91800.0
	Fertilizer costs	RMB	8508.0	24292.0	570.0	258638.0
	Pesticide costs	RMB	2431.0	6776.0	57.0	67500.0
	Mechanical operation costs	RMB	12447.0	40928.0	0.0	497250.0
	Fertilizer costs	RMB	9346.0	24268.0	825.0	258638.0
	Labor costs	RMB	11031.0	4074.0	3375.0	24750.0
	land charges	RMB	11510.0	32730.0	900.0	382500.0
	Other intermediate input costs	RMB	2280.0	6411.0	39.0	80190.0
	Seed price	RMB/hm^2	236.4	93.44	78	600
	Fertilizer price	RMB/hm^2	1,129	393.4	240	2340
	Pesticide price	RMB/hm^2	310.1	157.9	57	1,200
	Mechanical operation price	RMB/hm^2	1,321	927.6	0	4050
	Fertilizer price	RMB/hm^2	1,363	554.0	240	3840
	Labor price	RMB/work day	130.96	21.07	90.00	180.00
	Land price	RMB/hm^2	1,482	397.9	900	2438
	Other prices	RMB/hm^2	341.1	327.6	31.50	3166
Factors affecting the cost and non-efficiency items	Age of the head of household	year	58.05	8.86	26.00	79.00
	Sex	0 = Female, and 1 = male	0.93	0.26	0	1
	Education of the head of household	year	9.12	1.96	6.00	16.00
	Farm business scale	hm^2	0.813	2.472	0.0667	17
	Terrain	0 = Plain, 1 = hills	0.22	0.42	0	1
	Land turnover rate	%	12.61	7.90	5	25
	Subsidies	RMB	2.80	0.64	1.79	4.64
	Share of labor	%	2.84	10.63	0.00	88.06
	Quality category	0 = ordinary quality, 1 = superior quality	0.24	0.43	0	1
	Commodity rate	%	80.93	24.58	10.00	100.00
	Regional dummyvariables	1 for farmer located in Northern Hunan area, 0 otherwise	0.23	0.42	0	1
		1 for farmer located in Southern Hunan area,0 otherwise	0.33	0.47	0	1
		1 for farmer located in Western Hunan area,0 otherwise	0.22	0.41	0	1
		1 for farmer located in Central Hunan area,0 otherwise	0.22	0.42	0	1

effectiveness by comparing the degree of decision units deviating from the DEA frontier (Li and Chen, 2003; Li and Liu, 2021). This paper used the DEA analysis method to solve the DMU technical efficiency index with relative effective points (Min, 2012). Without any weight assumption, the comprehensive technical efficiency, allocation efficiency, and cost efficiency of rapeseed were obtained according to the input cost of rapeseed planting and the total output data of rapeseed planting to analyze the cost efficiency of different scales. Following Li et al. (2019), the model of DEA model estimated in this study is as follows:

$$\max h_{j0} = \frac{\sum_{r=1}^{s} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}} \tag{1}$$

$$s.t \begin{cases} \dfrac{\sum_{r=1}^{s} u_r y_{ij}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, 2, \cdots, n \\ u_r \geq 0, v_i \geq 0, r = 1, 2, \cdots, s; i = 1, 2, \cdots, m \end{cases}$$

In **Equation 1**, h_{j0} represents the efficiency index of the h_{j0} rapeseed farmer, while the constraint on the maximum efficiency index is $h_{j0} \leq 1$; x_{ij} is the total amount of different input factors 1) by the j^{th} rapeseed farmer; y_{rj} is the output data of the total planting yield (r) by the j^{th} rapeseed farmer, while x_{ij} and y_{rj} are both greater than zero. In addition, x_{ij0} and y_{rj0} are known quantities; v_i and ur represent the weight coefficients of input and output of rapeseed growers, respectively; m and s represent the number of input and output variables, respectively, and n represents the number of rapeseed growers.

Cost efficiency can be broken down into technical efficiency and allocative efficiency (Maietta, 2000). Technical efficiency refers to the minimization of factor input in a given output situation or the maximum output under a certain factor input. Allocative efficiency means that under a certain input, the optimal output can be obtained by optimizing the combination of various elements and realizing the optimal proportion (Coelli et al., 2005).

2.5 Estimating the Factors Influencing Cost Efficiency Using Tobit Model

Because the cost efficiency values of rapeseed production calculated by the DEA model lie in the range of 0–1, the

TABLE 2 | Cost efficiency of rapeseed production at different scales.

Efficiency	Operation Scale						Kruskal–Wallis Test
	(0,0.67)	(0.67,2)	(2,3.33)	(3.33,6.67)	(6.67,13.33)	(13, +∞)	
CE	0.606	0.615	0.620	0.702	0.820	0.493	0.047
TE	0.864	0.897	0.959	0.931	0.922	0.704	0.040
AE	0.701	0.685	0.646	0.754	0.889	0.700	0.0006

results may be biased if the traditional least square method (OLS) estimation is used. Therefore, Tobit regression model was constructed to conduct regression analysis on the rapeseed production cost efficiency values measured by DEA in Hunan Province to investigate the influencing factors of rapeseed production cost efficiency (Liu and Ouyang, 2021). The dependent variable is the cost efficiency value measured in this study, and 10 influencing factors, such as the characteristics of householders, sown area of rapeseed, terrain characteristics, subsidies, the proportion of employees, and commodity rate, are selected as independent variables. The following Tobit model is thus constructed:

$$CE_{it} = \begin{cases} \beta^T X_{it} + \varepsilon_{it}, & \beta^T X_{it} + \varepsilon_{it} > 0 \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

In **Equation 2**, CE_{it} is the measured cost efficiency of rapeseed production; Xit is the influencing factor vector of rapeseed cost efficiency; i is *i*th farmer; t is the time in *t*th year; βT is the regression coefficient vector of each variable; and εit the random error term.

3 RESULTS AND DISCUSSION

3.1 Efficiency Decomposition and Heterogeneity Analysis

Cost efficiency, technical efficiency, and allocation efficiency of rapeseed production was calculated using the DEA model (**Equation 1**). **Table 2** presents the estimation results and the classified descriptive characteristics according to the dimensions of the operation scale.

The results reveal a pretty low-cost efficiency (CE) for rapeseed farmers with the CE of 0.609. In fact, the actual CE rapeseed production deviates greatly from the frontier CE, with a considerable CE loss of 39.1%, compared with the minimum. These results indicate that there is still a large room for efficiency improvement in Hunan province. From the decomposition results of CE, we find that the average technical efficiency (TE) and allocative efficiency (AE) are 0.869 and 0.701, respectively. This result shows that allocative efficiency is an important factor affecting cost efficiency improvement.

From the perspective of scale dimension of CE, the results showed that with the increase of planting scale, CE of rapeseed production presented an "inverted U-shaped" curve of "first increasing and then decreasing" type, with cost efficiency reaching the highest value at the operation scale of (6.67, 13.33 hm^2]. This result is consistent with Liu (2017) and Zhao et al. (2021), suggesting that rapeseed production follows an optimal and moderate operation scale. The CE follows a "cliff-like" downward trend when the operation scale reaches a certain range and continues to increase. These findings show that excessive expansion of the operation scale may lead to non-optimal production of rapeseed, thus reducing the cost efficiency. This may be explained by the fact that when the operation scale reaches a critical value, so does the optimal value of the operation and management of the farmland. However, with further expansion of the operation scale, farmers may face a number of problems such as poor farmland infrastructure and lack of energy to manage their farmlands. In addition, agricultural technology training, personnel management and factor market reform may not be able to meet the requirements for further expansion. All these factors will undoubtedly affect the cost efficiency of rapeseed planting.

With the expansion of farmers' operation scale, the technical efficiency of rapeseed production also presents an "inverted u-shaped" trend of "first increasing and then decreasing" type and reaches the highest at 2,3.33 hm^2. However, no significant relationship was found between the operation scale and allocative efficiency. In other words, the expansion of farmers' business scale may improve the technical efficiency of rapeseed production, but not necessarily the allocative efficiency. Therefore, farmers should carry out moderate scale planting according to their local resource endowment and their own management skills.

Finally, we used the Kruskal–Wallis test to determine the significance of differences in CE between farm size groups. The results show that there are significant differences in cost efficiency, technical efficiency, and allocative efficiency among the farmers of the six operation scales.

Figure 3 shows the results of CE, TE, and AE of rapeseed production over the six-year period from 2015 to 2020. The cost efficiency in 2015, 2016, 2017, 2018, 2019 and 2020 is 0.603, 0.550, 0.602, 0.630, 0.607 and 0.657, respectively. It can be seen that the cost efficiency fluctuated greatly in 2016, because the government decided to cancel the policy of rapeseed temporary purchase and storage in May 2015, leading to a period of price adjustment. The fluctuations in technical efficiency also occurred in 2016 and 2020 partly for the same reason mentioned above and partly because of the outbreak of COVID-19 in the late 2019.

Another reason for CE fluctuations is that during the COVID-19 outbreak, the mechanization degree of rapeseed production was significantly higher than during the same period in previous years due to the implementation of the national policy of agricultural machinery subsidy. This finding is consistent with those of Zhang et al. (2021). These results indicate that improving

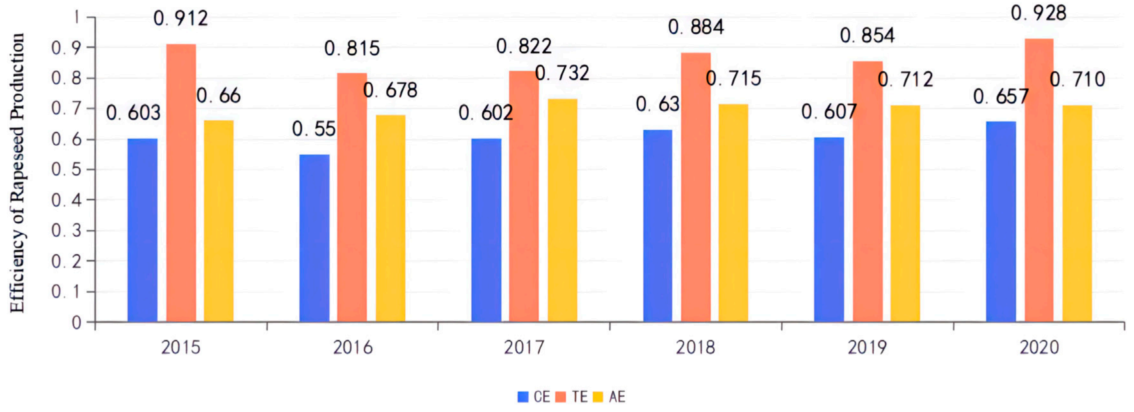

FIGURE 3 | Cost efficiency of rapeseed production in different periods.

TABLE 3 | Analysis of factors affecting cost efficiency of rapeseed production in Hunan.

Variable	Model 1	Model 2	Model 3
	TE	CE	AE
Gender	0.0194 (0.0201)	−0.0131 (0.0199)	−0.0318 (0.0196)
Age	-0.0003 (0.0006)	0.0002 (0.0006)	0.0006 (0.0005)
Education years	0.0025 (0.0026)	0.0022 (0.0026)	0.0009 (0.0026)
Farm business scale	−0.0431*** (0.0078)	−0.0326*** (0.0077)	0.0011 (0.0076)
Topography	−0.1864*** (0.0179)	−0.1511*** (0.0178)	−0.0200 (0.0175)
Land transfer rate	−0.0803*** (0.0110)	−0.1664*** (0.0108)	−0.1204*** (0.0107)
The proportion of hired workers	0.0021*** (0.0005)	0.0018*** (0.0005)	0.0001 (0.0005)
Subsidize revenue	0.0097 (0.0099)	−0.0360*** (0.0099)	−0.0466*** (0.0097)
Quality category	−0.0624*** (0.0162)	−0.0067 (0.0161)	0.0423*** (0.0158)
Commodity rate	0.1018*** (0.0119)	0.0614*** (0.0117)	−0.0179 (0.0116)
Southern Hunan area	0.0125 (0.0211)	−0.0150 (0.0208)	−0.0259 (0.0206)
Western Hunan area	0.1461*** (0.0188)	0.0881*** (0.0186)	−0.0138 (0.0183)
Central Hunan, area	−0.0653*** (0.0191)	0.0021 (0.0188)	0.0536*** (0.0186)
Constant	0.6591*** (0.0793)	0.8704*** (0.0786)	1.165*** (0.0776)

*Note: *** <0.01, ** <0.05, * <0.10. Standard errors are presented in parentheses. The reference region (base category) is Northern Hunan area.*

factor allocation is critical to increasing the cost efficiency of rapeseed production.

3.2 Analysis of the Factors Influencing Cost Efficiency of Rapeseed Production

Table 3 displays the results of the Tobit model, which was used to analyze the influencing factors of rapeseed production cost efficiency. We discover that the agricultural land operation scale, agricultural decision-maker characteristics, production characteristics, agricultural initial resource endowment, and other selected indicators significantly impact cost efficiency.

3.1.1 The Influence of Farmer's Characteristics on Cost Efficiency

There was not much difference in the age and gender among the surveyed farmers. They are of more or less the same age, and most of them are male. Moreover, the estimated coefficient of educational level of agricultural decision-makers was not significant, supporting Wang et al. (2019) that the education of farmers does not affect efficiency. This may be because although education level can reflect a person's learning ability, the education received by agricultural decision-makers may not include the knowledge of crop cultivation and agricultural production, so his/her education level may not be directly translated into agricultural production skills.

3.1.2 The Effect of the Initial Resource Endowment on the Cost Efficiency

Our results show that the expansion of business scale does not necessarily save costs, nor is it conducive to improving technical efficiency, which is consistent with the arguments of Fan et al. (2005), Wang et al. (2019), and Cheng (2019). Under normal circumstances, large-scale farmers have a higher cost of management and supervision. If resource allocation capacity cannot be improved correspondingly, the cost efficiency will be reduced. Therefore, the key to improving the cost efficiency of rapeseed production is to improve the farmers' ability to allocate resources. In addition, we find that the topographic characteristics of the surveyed farmland have a significant negative impact on both technical and cost efficiency. The sample area is mostly hilly, with rough terrain and small-scale farmlands, which does not fit large-scale mechanical operations.

Furthermore, the results show that the lands transfer rate also has a significant negative impact on cost efficiency, technical efficiency, and allocation efficiency, supporting the argument of Zhang et al. (2019). Therefore, given China's current rural situation, characterized by decentralized management, expanding the scale of farmland through farmland circulation and increasing the cost of inputs to improve agricultural production efficiency cannot effectively improve agricultural production cost-efficiency. Evidently, a more flexible approach should be adopted to enhance both production and cost efficiency, such as delegating power to the lower levels of agricultural land management and establishing price marketization mechanism while developing a variety of forms of moderate scale management--promoting family farms, farmer cooperatives and other new business entities (Wang and Lei, 2018).

3.1.3 Effects of Production Characteristics on Cost-Efficiency

We find that the proportion of hired workers has a significant positive impact on technical efficiency and cost efficiency. The possible reason is that agricultural employees have been involved in agricultural production for a long time, with extensive experience in agricultural production and rural practice. They can better grasp the application of new technology and new varieties, thus improving rapeseed production cost efficiency. Furthermore, the estimated coefficient of rapeseed production subsidies was significantly negative at the 1% significance level. This could be because local government subsidies for farmland fertility protection are constant and do not increase with increased production or different land allocation. Farmers may be tempted to engage in extensive production rather than diversification due to this. This conclusion is consistent with the findings of Serra et al. (2008). In addition, we find that the quality of rapeseed has a significant positive effect on allocative efficiency. Introduction and adoption of the new variety is a common type of technology. The older the farmer, the more experience they have in planting and the greater their willingness to adopt new varieties, confirming the findings of Kong (2004) and Li et al. (2018). New varieties with high yield and appropriate harvesting characteristics also save labor, which can greatly benefit the elderly labor force, improving the allocative efficiency of rapeseed production.

3.1.4 Effect of Sales Characteristics on Cost Efficiency

Commodity price had a significant effect on improving cost efficiency and the technical efficiency of rapeseed production. In other words, the more profit farmers can make from rapeseed; the more motivated they are to produce. This result implies that as profits rise, farmers are more likely to adopt new technological means to improve technical efficiency, lowering production costs.

3.1.5 Effects of Regional Characteristics on Cost-Efficiency

The results show that the region also affects cost efficiency, technical efficiency, and allocative efficiency. This conclusion is consistent with the research results of Zhou, (2019). Western Hunan has significantly higher cost efficiency and technical efficiency than northern Hunan because the natural conditions in the investigated area of Western Hunan are relatively superior to northern Hunan, with better infrastructure and more supporting facilities for rapeseed production. Furthermore, the allocative efficiency of Central Hunan is higher than that of Northern Hunan, though the technical efficiency is lower than that of northern Hunan. This is because Central Hunan is located in the south Dongting lake plain which is known for its natural endowments. In addition, the local government has been working hard for the past few years on the following projects: the introduction of efficient rapeseed varieties, fertilization after soil testing, timely seedling, directional fertilization, scientific management. As a result, it can produce 900–1,125 kg of rapeseed oil per hectare, with oil yield rate of nearly 30% higher than the general rapeseed (Tian et al., 2015).

4 CONCLUSION, POLICY IMPLICATIONS, AND FUTURE RESEARCH

4.1 Conclusion

Based on the farmer survey data of fixed observation points of Hunan Provincial Development and Reform Commission from 2015 to 2020, this study measured the cost efficiency of farmers' rapeseed production using DEA and decomposed the efficiency into technical efficiency and allocative efficiency. The study also explored the relationship between operation scale, cost efficiency and environmental sustainability. Furthermore, the Tobit model was used to analyze the impact of farmer operation scale, production characteristics, initial resource endowment, and farmer characteristics on cost efficiency.

The main conclusions of this study are given below.

First, the overall cost efficiency of rapeseed production in China needs to be improved. There is a considerable efficiency loss (39.1%) compared with the minimum cost and a great deviation from the frontier cost in the actual rapeseed production cost, suggesting space for cost efficiency improvement.

Second, allocative efficiency is an important factor affecting the improvement of cost efficiency. From the perspective of different scales, the expansion of farmer operation scale may improve the technical efficiency of rapeseed production, but not necessarily the allocative efficiency. This indicates that small-scale farmers may still follow the concept and mode of small-scale production and engage in more large-scale operations with lower allocative efficiency when expanding their operation scale. This is likely to increase the input of fertilizers and other elements, resulting in agricultural non-point source pollution, which is not conducive to sustainable environmental development.

Third, there is an "inverted U-shaped relationship between the rapeseed production cost efficiency and the farmer operation scale ". With the expansion of farmers' operation scale, there is often a "increasing first and decreasing afterward" trend. The cost efficiency reached the highest at (6.67, 13.33) hm^2. This is due to the fact that once a farmer's operation reaches a certain size, the cost efficiency of rapeseed production exhibits a "cliff-type" downward trend.

Fourth, the personal characteristics, family resource endowment, production characteristics and sales characteristics of rapeseed planting affect the cost efficiency of rapeseed production. Topographic characteristics, subsidies, land circulation rate and farmers' operating area were found to have a significant negative effect on the cost efficiency of rapeseed production. In contrast, commodity price and the proportion of employees showed a significant positive effect on the cost efficiency. In addition, we find that the regional difference is also an important factor affecting cost efficiency.

4.2 Policy Recommendations

4.2.1 Intensifying Land Consolidation and Technological Breakthroughs

According to the Development Report on Full-process Mechanization of rapeseed Production in 2019 released by the Ministry of Agriculture and Rural Affairs of China, the comprehensive mechanization rate of rapeseed production in China is 56%, especially in southern China, where terrain features are mostly hilly and land plots are scattered, which has a significant negative impact on improving the comprehensive mechanization level of rapeseed production. Therefore, in the face of such objective planting conditions, on the one hand, governments at all levels can reduce the degree of land fragmentation through land circulation and land consolidation, thus providing favorable conditions for appropriate large-scale planting of rapeseed. On the other hand, scientific research institutions should speed up the breeding of high yield, high resistance, and high oil varieties, research and promote the whole process of rapeseed mechanical, light and efficient production technology, to improve the adaptability of varieties to mechanized harvest.

4.2.2 Providing Financial and Technical Support

In order to maintain and increase farmers' enthusiasm for production and improve their comprehensive skills, financial and technical support must be provided. First, financial support can be offered to rapeseed farmers through various subsidies such as cultivated land protection subsidies and moderate scale management subsidies, grain production (oil) reward policy. Second, the government should provide agricultural technical guidance and training programs to the farmers. For example, the government can help build rapeseed information public platform, encourage farmers to join rapeseed industry association and participate in the technical training class.

4.2.3 Coordination and Symbiosis Between Regions

First, different regions should undertake different models of development. In other words, governments at all levels should provide targeted guidance based on local natural resources, topographic features, farmland infrastructure, and family endowments. Second, it is also important for the government to activate the radiating and driving ability of the production platform. Furthermore, it is pertinent to implement the responsibility system of the local government as the "chain leader" of the agricultural industry chain, thus forming a cooperative interest to create the sharing mechanism. This involves the government, experimental stations of the national industrial technology system, universities, research institutes, processing companies, farmers, and farmer cooperatives. Finally, the government should strengthen the exchange of rapeseed production experience between different regions and form a team atmosphere of mutual help among technical personnel of rapeseed production between different regions, so as to promote the healthy development of collaborative symbiosis between regions.

4.2.4 Rational Use of Resources in Rapeseed Production and Raising Awareness of Green Agricultural Production

Our results show that infinite expansion of the rapeseed planting scale does not necessarily improve cost efficiency, technical efficiency, and allocation efficiency. At the same time, there may be excessive input of fertilizers, pesticides and labor and other factors, resulting in serious agricultural non-point source pollution and water environment pollution. So, planting scale that best fits the local situation should be developed. For instance, the rapeseed planting area in southern China should be kept within (6.67, 13.33) hm^2 to optimize the reasonable ratio of input factors. In addition, while encouraging farmers to engage in moderate scale operation, governments at all levels should evaluate farmers' business qualifications, focusing on farmers' resource allocation ability, agricultural operation experience and ability, and the ability to accept new technologies, so as to promote the green, low-carbon and sustainable development of rapeseed industry.

4.3 Limitations of the Study and Future Research

Our research has provided compelling evidence for the need to improve the overall cost efficiency of Chinese rapeseed production. However, some limitations are worth noting. First, although we used the micro-survey data of the Hunan Provincial Development and Reform Commission from 2015 to 2020 for empirical analysis, the number of samples is not large enough to represent the whole picture of the country. The data used in this study only focused on the southern part of China, yet little is known about the rapeseed production situation in the eastern and western parts. Also, our study has only focused on one single cash crop - rapeseed, which may affect the width of the study. Future research needs to update the data to investigate the recent input-output of other cash crops in different regions of China.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Conceptualization: QZ and ZF Data curation: QZ and FY Formal analysis: QZ, AR, MX. Funding acquisition: ZF and QZ Investigation: QZ and ZF. Methodology: QZ and FY. Project administration: ZF Resources: QZ and ZF Supervision: ZF Validation: QZ, AR, FY, and MX. Visualization: QZ, AR, and FY. Writing—original draft: QZ Writing—review & editing: AR, JQ, FY, and MX.

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