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Efficiency Comparison and Influencing Factor Analysis of Dairy Farms over/at Different Scales: Based on the Survey Data of 263 Scale Farms in 22 Provinces of China

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Abstract China's dairy farming has presented a striking development in recent years. Under the dual constraints of environment and resources, it is of practical significance to increase the output of dairy farming and ensure the healthy and stable development of the dairy industry, by accurately comparing the differences in the farming efficiency of dairy farms at different scales and grasping key factors influencing the farming efficiency. This study, through the cost analysis of 263 scale farms across 23 provinces and regions of China in 2019, reaches a result that the cost of a single cow in a certain scale farm increases with the enlargement of the scale, and shows an inverted-U shaped curve with the relatively large scales (1 001 – 2 000 cows) at the highest point. It measures the farming efficiency of dairy farms at different scales through the data envelopment analysis and finds that the scale efficiency and allocation efficiency of scale farms in China are relatively high, while the technology efficiency and cost efficiency are relatively low. The efficiency of different scale farms is obviously different, where the cost efficiency, allocation efficiency and scale efficiency show a U-shaped curve as the scale enlarges (with the relatively large scale as the lowest point), while the technology efficiency gradually decreases as the scale expands. It is concluded that for the scale farms, feed conversion ratio and forage-to-concentrate ratio have a significantly negative impact on the scale efficiency, while the labor cost, number of employees, and depreciation of fixed assets are negatively correlated to the technology efficiency and cost efficiency of dairy farming.

Key words Data envelopment analysis, Farming efficiency, Influencing factor, Scale farm

1 Introduction

Since the food safety incident induced by "melamine" in 2008, Chinese government and the society have begun to pay great attention to the dairy farming of the upstream supply chain, rather than merely focusing on the processing and sales of dairy products[1-2]. Therefore, the large-scale farming policy has been promoted actively by the government at different levels, aiming to improve the quality and safety of raw milk effectively by changing the small-scale free-range production method[3]. Since 2013, the No. 1 central document has mentioned "supporting, cultivating, and promoting the development of Chinese family farms and encouraging large-scale farming" for eight consecutive years. The central and provincial governments have issued opinions or plans successively for revitalizing the dairy industry, and then China's dairy industry has undergone a production structure adjustment in a "sharp pain" and achieved some remarkable results. According to the statistics of the Ministry of Agriculture and Rural Affairs, the rate of large-scale farming of dairy cows with more than 100 dairy cows in China reached 64% in 2019, an increase of 45% over 2008; the annual benefit of dairy farming of scale farms reached 4 000 yuan/cow, while the annual income of farms with good farming management and high milk yield reached 6 000 yuan/cow. The efficiency of dairy farming has been greatly improved.

With the development of large-scale farming, Chinese dairy farming presents different organizational models such as family farming, small-scale farming, medium-scale farming, and large-scale farming. On the scale, scholars usually define them based on the number of cows, but so far there is no uniform classification standard. For example, in the *Compendium of National Agricultural Product Costs*, "51 – 500 cows" are medium-scale, and "more than 500 cows" are large-scale. In *China Dairy Industry Yearbook*, "more than 1 000 cows" are large-scale. Based on national conditions, different scales are represented as small-scale (100 – 500 cows), medium-scale (501 – 1 000 cows), relatively large-scale (1 001 – 2 000 cows), and large-scale (over 2 000 cows). The efficiency comparison of different dairy farming scales has also become a main focus of scholars. The research suggests that factors influencing the efficiency of dairy farming mainly include the capital, dairy cow quality, and farming scale[4]. The researches and other scholars suggest that the efficiency of large-scale dairy farming is higher[15-20], both at the provincial or the national level. However, we believe that the impact of natural conditions and management systems on the efficiency is greater than the scale of cow farms by measuring the efficiency of cow farms of different

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scales in Austria[5]. In addition, The research find that the efficiency difference among large-scale farms is smaller than that of small-scale farmers[12]. Wang Qiuyan concluded that the technology efficiency of large farms is higher than that of small farms through measuring the technology efficiency of Pennsylvania dairy farms[6]. Technology efficiency and allocation efficiency of intensive and large-scale dairy farms are higher, but their economic efficiency is lower than that of family farming by measuring the dairy farming efficiency under different organizational models in China[7-11]. Ma Yanli analyzed the technology efficiency of family farms and large-scale farms based on the DEA model of variable returns to scale, and found that the technology efficiency of family farms is significantly better than that of large-scale farms, and thinks that the production input of family farms is obviously insufficient considering from the output[13]. Consequently, the large-scale farming is the main trend for the future development of dairy farming in China, which is conducive to promoting the modernization of dairy farming in China.

However, despite the continuous advancement of large-scale dairy farming and the increasing regional concentration and intensification in China[21], there is still improvement room for China's milk yield per cow and production efficiency compared with that of the countries with developed dairy industry. According to existing studies, the farming cost of small-scale dairy farms is higher than that of large-scale dairy farms. It has an important impact on the policy to solve the large-scale farming problem by accurately judging whether the higher farming cost is due to technology shortage or low efficiency[22]. In the past, scholars have done extensive comparative studies on the farming efficiency of different farming modes in China, but there are few about the efficiency of different scales, particularly on the allocation efficiency and the cost efficiency. For countries with large-scale farming as the main model of the dairy industry, quantitatively analyzing the efficiency difference of different farming types of different farming scales has important practical significance for optimizing the structure of large-scale farming, increasing the output level, improving the farming efficiency, and promoting the healthy development of dairy farming.

Based on the above research background and purpose as well as the existing research experience, we set two research goals: the first is to measure and analyze the cost efficiency, scale efficiency, allocation efficiency and technology efficiency of dairy farming at different scales in China under large-scale farming conditions; the second is to analyze the influencing factors of farming efficiency. The rest of this paper is structured as follows: the first part introduces the data and research methods of this study; the second part explains the variables of the data envelopment analysis (DEA) and the Tobit model; the third part presents the analysis results of this study; and the last part discusses, analyzes and summarizes the results.

2 Data and research methods

2.1 Data We surveyed 266 scale farms in 24 provinces (regions or cities) (including Shanxi Province, Shandong Province, Hebei Province, Henan Province, Anhui Province, Jiangsu Province, Zhejiang Province, Hubei Province, Hunan Province, Guangdong Province, Guangxi Zhuang Autonomous Region, Sichuan Province, Fujian Province, Xinjiang Uyghur Autonomous Region, Gansu Province, Shaanxi Province, Ningxia Hui Autonomous Region, Beijing, Shanghai, Tianjin, Inner Mongolia Autonomous Region, Heilongjiang Province, Liaoning Province, and Jilin Province) in 2019. These data came from the research team randomly selecting different numbers of dairy farms in each province based on the number of dairy farms. After checking and filtering the cross-sectional data, it is found that there are 263 copies of effective sample data and the effective rate of the samples reaches 97.8%; 100% of the survey samples are scale farms, and the farm with the smallest herd size has 126 cows, while the farm with the largest herd size has 19 795 cows. According to the herd size, the research farms were divided into four types for research and analysis: small-scale (100-500 cows), medium-scale (501-1 000 cows), relatively large-scale (1 001-2 000 cows), and large-scale (over 2 000 cows). Among them, 59 are small-scale farms, 62 are medium-scale farms, 81 are relatively large-scale farms, and 61 are large-scale farms.

The questionnaire mainly contains the information such as the name of the dairy farm, the information of the farm manager, the scale of the farming, the price of raw milk, and the monthly milk production during the lactation period, disease conditions, monthly feed consumption and price, monthly labor costs, monthly depreciation of fixed assets and other cost data. The specific data processing method is as follows:

(i) Forage-to-concentrate ratio. In this paper, it is indicated by the ratio of the roughage forage consumption to the concentrated feed consumption of a cow in one month in the survey data, and the reasonable forage-to-concentrate ratio for a lactating dairy cow is 1.8. (ii) Feed conversion ratio, which is indicated by the ratio of the monthly feed consumption to the monthly milk production of a cow, and the ratio is lower, the feed conversion ratio will be higher. (iii) Labor cost, which is indicated by the balance of dividing the total monthly salary of the employees of each farm by the total cows. (iv) Depreciation of fixed assets; the fixed assets contained in the research mainly include the loader, forklift, mixer, submersible pump, refrigeration equipment of transformer box, spray equipment, calf hutch equipment, tractor, milk tanker, transporter, fan and other equipment, as well as the infrastructure facilities including cow house, power supply engineering, calf hutch, silage silo, feed storage, water wells, unloading shed and so on. The questionnaire contains the corresponding quantity, purchase/construction year, original value, service life and other information. Based on such information, the depreciation of fixed assets was calculated and averaged to each cow, which represents the level of facilities and equipment of the farms. (v) The cost of medical and epidemic prevention, which is numerically equal to the medical cost of each cow. (vi) Other costs are numerically expressed as the costs of each cow.

2.2 Research methods

2.2.1 DEA model. The Data Envelopment Analysis (DEA) method was proposed by Cooper, Channes and Rhodes in 1978. It uses the linear programming to construct a frontier with the production-possibility boundary[23], so as to evaluate the relative effectiveness of the decision-making unit (DMU) of the comparable similar type. Besides, DEA can handle the efficiency measurement of the multi-input and multi-output production system with no need to consider the specific form of the production frontier. It requires less information on the input-output data, and overcomes the skewness calculation problem resulting from that the input-output data does not conform to the model hypothesis, which is more in line with the actual production[24]. Thus, we used DEA model to measure the dairy farming efficiency at different scales of farms with variable returns to scale.

Under the parallel system, the technology efficiency, scale efficiency, allocation efficiency and cost efficiency of the dairy farming at different scales of farms will be measured. The parallel system indicates that there are "n" decision-making units (DMU_j), which means that for each farm, there are "p" different sub-units (*i.e.* SDMUp) in DMU_j ($j = 1, \cdots, n$), and the sub-units are homogeneous and in a parallel structure (Fig. 1). Besides, each SDMUp has "m" initial inputs X_{ij} ($i = 1, \cdots, m$) and "s" final outputs Y_{rj} ($r = 1, \cdots, s$), namely: $X_j = \sum_{k=1}^{p} X_j^k$, $Y_j = \sum_{k=1}^{p} Y_j^k$. The DMU_j administrator can allocate resources among the sub-units $SDMU_p$. In this paper, it was assumed that the farms at the same scale are homogeneous when measuring the efficiency at specific scale of farms, and all farms are homogeneous when calculating the overall efficiency. The production frontier of homogeneous $SDMU_p$ is composed of the parts with the highest marginal productivity of each unit, and the production frontier is constructed through the DMU theory of resource redistribution[25]. Its relative effectiveness is judged by comparing the effectiveness of each decision-making unit regarding the resource utilization.

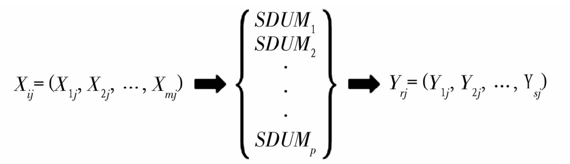

Fig. 1 DMU structure chart of parallel structure

In 1984, Banker, Charens and Cooper proposed the extension of DEA with constant returns to scale. They believed that in the case of variable returns to scale (VRS), the measurement of technology efficiency is affected by the returns to scale[26], so they improved the CCR model and obtained the BCC model, which can be expressed by the equation (1) as below:

$$E_{BCC} = \min\theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$
$$s.t. \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i0},\ i = 1, \cdots, m \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0},\ r = 1, \cdots, s \\ \lambda_j \geqslant 0,\ j = 1, \cdots, n \\ \sum_{j=1}^{n} \lambda_j = 1 \end{cases} \tag{1}$$

The expression introduced the non-Archimedean infinitesimal ε. λ_j represents the weight value of the effective decision-making unit constructed relative to the j^{th} decision unit; the output slack variable s_r^+ and the input slack variable s_i^-. x_{ij} and y_{rj} are known variables and represent the input and output of the decision-making unit. x_{i0} represents the total input of the i^{th} initial input of all decision-making units ($SDMU_p$) in the same parallel structure, while y_{r0} represents the r^{th} total final output of all decision-making units ($SDMU_p$) in the same parallel structure.

The technology efficiency (TE_j) and scale efficiency (SE_j) can be obtained through the BCC model. When the efficiency value equals to 1, the efficiency is completely effective; otherwise it is an invalid unit[27]. The technology efficiency (TE_j) measures whether dairy farmers have maximized the employee training, equipment and facilities, farming method and other technical input and whether the production is on the effective boundary.

The scale efficiency (SE_j) measures the degree of professionalization and intensive management of each farm and whether the farm reaches the appropriate scale of farming[28]. The calculation of the scale efficiency can be expressed by dividing the minimum total cost (CM_j^c) under constant returns to scale (CRS) by the minimum total cost (CM_j^v) under variable returns to scale (VRS), with the equation (2) as follows:

$$SE_j = \frac{CM_j^c}{CM_j^v} \tag{2}$$

The allocation efficiency (AE_{j0}) measures whether the farm adopts the best combination of inputs in the feeding process, with the equation (3) as follows:

$$AE_j = \frac{CM_j^c}{C_j TE_{j0}} \tag{3}$$

where C_j denotes the actual expenditure cost of the j^{th} farm.

The cost efficiency (CE_j) represents the extent to which the actual input cost of the decision-making unit is close to the frontier under the same external environment and output. Under the circumstance that the input of each production area does not increase, the cost efficiency equation (4) is as follows:

$$CE_j = \frac{CM_j^c}{C_j} \tag{4}$$

Under the condition of variable scale efficiency, $CE_j = AE_j \times TE_j$. It can be seen that the technology efficiency and the scale efficiency are determinative regarding the cost efficiency.

2.2.2 Tobit model. To measure the efficiency of different scales of farms, the research further explores the main factors influencing the farming efficiency and the influence degree. The dairy farming efficiency value measured through the BCC model is between 0 and 1. If the linear regression equation is used, the estimation result will be biased. On the contrary, the estimation result based on the Tobit model is unbiased and effective[29], so this study intends to use the Tobit model to perform the analysis of the factors influencing the dairy farming efficiency. The general expression of the Tobit model is formula (5):

$$\begin{cases} y_i^* = \beta^T X_i + \varepsilon_i \\ y_i = y_i^* \ if\ y_i^* > 0 \\ y_i = 0 \ if\ y_i^* \leqslant 0 \end{cases} \tag{5}$$

where y_i^* is the explained variable; β^T is the coefficient vector; X_i is the independent variable vector; ε_i is the error term, which is independent and conforms to the normal distribution: $\varepsilon_i \sim N(0, \sigma)$, y_i is the actual observation value; when $y^* \leqslant 0$, $y_i = 0$; when $y^* > 0$, $y_i = y^* > 0$.

3 Description of variables

3.1 Input and output variables in the DEA model In this study, the input variable of dairy farming is the consumption of roughage forage, the consumption of concentrated feed, the labor cost, the cost of medical and epidemic prevention, the total depreciation cost of fixed assets (infrastructure and equipment), the total cost, and the number of employees per cow for one month (30 d). The output variable is the monthly milk production per lactating cow (Table 1).

The output variable is expressed by the monthly milk production of each lactating cow. It can be seen that among the four scales, the average monthly yield per cow of large-scale farming is the highest, reaching 928.17 kg, and the average daily milk production per lactating cow is 31 kg; the average monthly yield per cow of the small-scale farm is 825.19 kg, which is the lowest. With the continuous expansion of scale, the yield per cow is higher and higher, but the growth rate slows down, which indicates that the advantage brought by the expansion of scale on yield per cow gradually shrinks and that it is necessary to further standardize farming and improve the farming efficiency, so as to enhance the level of yield per cow.

Table 1 Statistics of input and output indicators of dairy farming of scale farms

Indicator type	Indicator name	Unit	Mean			
			Small scale	Medium scale	Relatively large scale	Large scale
Output variable	Milk production	kg · (cow/month)	825.19	873.55	919.39	928.17
Input variables	Input cost of roughage forage	yuan · (cow/month)	325.59	400.24	434.96	350.76
	Input cost of concentrated feed	yuan · (cow/month)	492.33	558.94	590.10	557.74
	Labor cost	yuan · (cow/month)	138.29	149.80	144.03	114.95
	Cost of medical & epidemic prevention	yuan · (cow/month)	26.76	32.64	38.31	39.40
	Depreciation of fixed assets	yuan · (cow/month)	62.42	70.34	82.76	78.96
	Number of employees	employees/ cow	0.008	0.005	0.002	0.001
	Total cost	yuan · (cow/month)	1 313.50	1 510.01	1 555.31	1 513.01

Among the input variables, it can be seen from Fig. 2 that, except the cost of medical and epidemic prevention, the change trend of the other input cost variables from small scale to large scale shows an inverted-U shaped distribution with that of the relatively large scale as the highest point, which indicates that the cost input per cow in relatively large-scale farms (1 001 – 2 000 cows) is the highest, and the lowest in large-scale and small-scale farms. From the perspective of total cost changes, the total costs in small-scale farms are the lowest and the highest in relatively large-scale farms. The possible reason is that small-scale farming and large-scale farming are easier to take advantage of the scale advantages in China, while the relatively large-scale farming is not suitable for the farming conditions in the south on one hand, and is difficult to give play to the farming advantages of the north on the other hand.

The depreciation cost of fixed assets reflects the modernization of dairy farming. Small-scale and medium-scale farming have less depreciation of fixed assets. The other two types of farming have little difference in the depreciation of fixed assets, indicating that the relatively large-scale and large-scale farms pay more attention to the investment of facilities and equipment in the process of large-scale farming; in terms of the number of employees, as the scale enlarges, the number of employees for a cow continues to decrease, which also matches the fixed asset investment, since the more equipment and facilities are invested, the less employees will need. As for the cost of medical and epidemic prevention, as the scale expands, the probability of an epidemic increases, the requirements for epidemic prevention is higher, and the cost of medical and epidemic prevention also increases. The cost of medical and epidemic prevention per cow is increasing linearly.

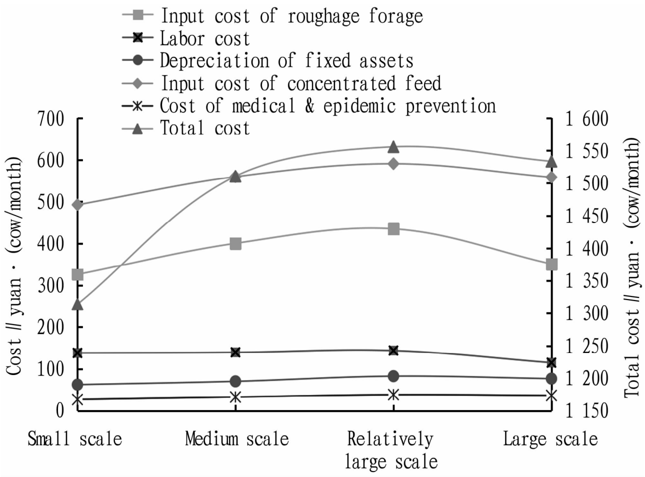

Fig. 2 Trends of input costs of dairy farming at different scales

3.2 Variable selection and basic situation of Tobit model Based on the previous research experience of scholars, we mainly explored the influence of the feed consumption, technical supply, supporting facilities, risk prevention and control and other variables of dairy farming on the efficiency of dairy farming, as well as the sensitivity of different scales and production areas to the efficiency of dairy farming[7-13]. The basic situation of each variable is shown in Table 2.

Table 2 Statistics of variables of Tobit model

Variable name	Unit	Mean			
		Small scale	Medium scale	Relatively large scale	Large scale
Forage-to-concentrate ratio	–	1.53	1.76	1.61	1.49
Feed conversion ratio	–	1.92	2.04	1.76	1.67
Number of technicians *	technicians/cow	0.008	0.007	0.007	0.006
Labor cost	yuan · (cow/month)	138.29	149.80	144.03	114.95
Cost of medical and epidemic prevention	yuan · (cow/month)	26.76	32.64	38.31	39.40
Depreciation of fixed assets	yuan · (cow/month)	62.42	70.34	82.76	78.96
Number of employees	employees/cow	0.008	0.005	0.002	0.001
Raw milk price	yuan/kg	3.56	3.67	3.78	3.78

Note: * Technicians mainly include the veterinarian, nutritionist, breeder, *etc.*

In respect of the feed consumption, the forage-to-concentrate ratio and feed conversion ratio represent the feed structure of farming. In the case of the roughage forage and concentrated feed respectively containing the same feed category, it is assumed that the content of nutritional ingredients contained in each unit of the roughage forage and concentrated feed fed by the sample farms to the dairy cows is the same. In the process of dairy farming, improper forage-to-concentrate ratio of feeding will cause damage to the rumen of dairy cows, lower digestibility, and decrease the production performance, which will affect milk production and even change the milk composition. Therefore, an appropriate forage-to-concentrate ratio is very important for dairy farming. While ensuring a reasonable forage-to-concentrate ratio, it is also necessary to ensure a low feed conversion ratio, that is, the ratio of monthly feed consumption to milk production, increase feed utilization, reduce input costs, and increase the enthusiasm of farming. As the scale expands, the forage-to-concentrate ratio and feed conversion ratio show a downward trend, which also indicates that the feed structure of large-scale farming is better than other scales.

In respect of human resources, we used the number of employees per cow to represent the basic distribution of human resources, and the number of technicians per cow in each farm represents the technical supply of dairy farming. In general, the more reasonable the ratio is, the more efficient the farm technical supply will be, the more standardized the dairy farming will be, and the less disease will occur and the higher the farming efficiency will be. Table 2 shows that the number of technicians and the number of employees decrease with the expansion of scale. Under the general trend of replacing manpower with machinery, it can be considered that the larger the scale is, the higher the degree of mechanization of the farm will be. And whether the monthly labor cost per cow increase or decrease the farming efficiency needs to be verified through further empirical tests.

In respect of hardware facilities, it is measured through the depreciation of fixed assets which mainly includes infrastructure construction and depreciation of mechanical equipment, to reflect the infrastructure and the scale of use of mechanical equipment in the farms. A modern large-scale dairy farm must invest in these two aspects. Reasonable investment in fixed assets can improve the farming efficiency and maximize the returns to scale of farming, while lower or excessive investment in fixed assets will reduce the efficiency of farming. We averaged the investment in this aspect to each cow in the farm, so as to make the relationship clear between the level of fixed asset investment and the efficiency of dairy farming of different scales.

The risk prevention and control mainly refer to the medical and epidemic prevention expenditure by each dairy cow during the dairy farming of the farm. For dairy farming, the larger the scale is, the higher the disease risk will have, and the greater the medical and epidemic prevention expenditure will occur. As the scale of farming expands, the cost on epidemic prevention and control will even greater.

4 Results and analysis

4.1 Efficiency of dairy farming With the aid of DEAP 2.1 software, we worked out the technology efficiency and scale efficiency of dairy farming, and obtained the allocation efficiency and cost efficiency through calculations. Among them, the cost efficiency, as an important evaluation indicator of dairy farming, is a comprehensive performance of the technology efficiency and allocation efficiency. Based on the specific results (Table 3), the overall technology efficiency of dairy farming of different scales is 0.82, the scale efficiency is 0.94, the allocation efficiency is 0.95, and the cost efficiency is 0.78, indicating that the scale efficiency and allocation efficiency are relatively high, but the technology efficiency and cost efficiency are relatively low in China's dairy farming. The cost efficiency of 0.78 means that only 78% of the total cost of the farm has been effectively used in the input-based DEA model, and there is still much room for improvement.

In terms of technology efficiency, that of small-scale farms is the highest. In the context of small-scale farming economy, the long-term free-range farming model has accumulated rich farming experience for small-scale farms, and the farming technology is more practical. In recent years, there is an intensive and large-scale development trend in China's dairy farming. However, farming technology is still in a continuous learning and exploration stage due to the lack of professional guide and the related experiences, thus the technology efficiency in large-scale and relatively large-scale dairy farming is relatively low.

On the scale efficiency, it is close to the optimal level where the lowest efficiency is above 0.93 at the relatively large scale, which means the farming can achieve better scale output with a smaller input. Among them, the scale efficiencies of small-scale farming and large-scale as well as relatively large-scale farming are higher than other types of large-scale farming.

In the aspect of allocation efficiency, the average allocation efficiency is close to 0.95, indicating that the combined efficiency of various infrastructure and machinery inputs is close to the optimal in the process of large-scale farming production; while, the allocation efficiency of the medium-scale and large-scale farming is the lowest, indicating that the investment in facilities and equipment is more effective and the degree of mechanization and automation is higher in the farming process for these two types of farming.

With regards to the cost efficiency, the cost efficiency of each type of farming is at a relatively low level. Nevertheless, compared with the relatively large-scale farming, the cost efficiencies of the small-scale and large-scale farming are higher.

Table 3 Efficiency calculation results of dairy farming of various production areas

Indicator	Overall	Small scale	Medium scale	Relatively large scale	Large scale
Technology efficiency	0.82	0.92	0.91	0.89	0.85
Scale efficiency	0.94	0.96	0.94	0.93	0.96
Allocation efficiency	0.95	0.95	0.93	0.92	0.98
Cost efficiency	0.78	0.87	0.85	0.82	0.83

Data source: obtained according to the calculation results of DEAP 2.1.

From the perspective of the dairy farming efficiency result of different scales (Fig. 3), the change trend of the farming efficiencies of the four scales in scale efficiency, allocation efficiency, and cost efficiency showed a "U"-shaped distribution with the relatively large-scale farming as the turning point. It shows that when the herd size is less than 1 000, the scale efficiency, allocation efficiency and cost efficiency gradually decrease as the farming scale enlarges; when the herd size is greater than 2 000, the scale efficiency, allocation efficiency and cost efficiency are on the rise as the farming scale enlarges. The allocative efficiencies, scale efficiencies and cost efficiencies of the small-scale and large-scale farming are higher than those of other scales. The technical efficiencies of the four scales of farming decrease as the scale of farming enlarges, which reflects that China's dairy farming technology and management in large-scale farms are not mature yet[30], and the technology efficiency is more efficient in developing small-scale farming.

4.2 Analysis of empirical results With the aid of the Stata 15.0 software, we analyzed the influencing factors of the technology efficiency, scale efficiency, allocation efficiency, and cost efficiency in the process of dairy farming of scale farms. Based on the regression results (Table 4), the overall fitting for the cross-sectional data model is good at the confidence level of 95%, which can explain the key problems to be solved in this study. The elastic coefficients of each explanatory variable have been worked out, to reflect the sensitivity of various factors to the farming efficiency.

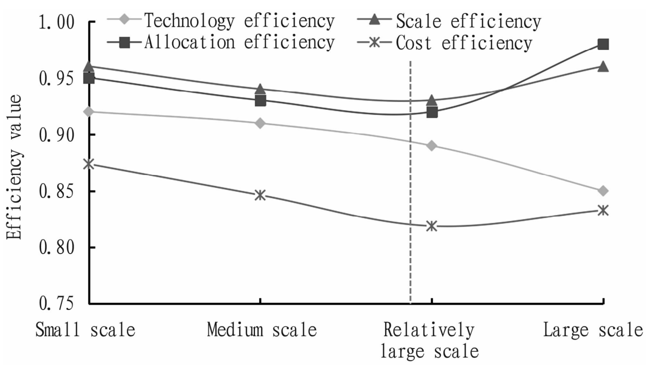

Fig. 3 Trends of farming efficiencies of four types of farm scales

Table 4 Tobit model results and elastic coefficients of related variables

Variable	Regression 1 Technology efficiency	Regression 2 Scale efficiency	Regression 3 Allocation efficiency	Regression 4 Cost efficiency
Constant term	1.164***	1.148***	1.106***	1.148***
Forage-to-concentrate ratio	0.012(0.009)	0.011**(0.008)	0.008(0.003)	0.013(0.011)
Feed conversion ratio	−0.072***(−0.056)	−0.081***(−0.055)	0.024(0.008)	−0.068***(−0.054)
Labor cost	−0.001***(0.002)	0.001(0.006)	−0.002(−0.0001)	−0.007***(−0.003)
Number of technicians	0.002***(0.001)	0.0013(0.001)	0.001(0.003)	0.002***(0.002)
Cost of medical and epidemic prevention	0.002***(0.002)	0.003**(0.002)	0.0004(0.0001)	0.002***(0.002)
Depreciation of fixed assets	−0.003***(−0.0002)	−0.001(−0.001)	−0.003***(−0.001)	−0.005***(−0.004)
Number of employees per cow	−0.172(−0.133)	−0.012(−0.008)	−0.500***(−0.159)	−0.427***(−0.344)
LR $chi^2(7)$	79.03	77.19	27.05	83.02

Note: The parenthetic values in represent the elastic coefficients of each explanatory variable, *, ** and *** represent the significance level of 10%, 5%, and 1% respectively, and LR $chi^2(7)$ represents the log likelihood ratio.

The forage-to-concentrate ratio has a significant positive effect on the scale efficiency of dairy farming. When the forage-to-concentrate ratio during lactation is 1.8, the milk production of dairy cows is the highest[31]. However, the forage-to-concentrate ratio of scale farm dairy farming in China is mostly lower than this indicator value. To this end, the amount of roughage forage and the forage-to-concentrate ratio should be increased to improve the scale efficiency of dairy farming in the process of large-scale farming in

China.

The feed conversion ratio has a significant negative impact on the technology efficiency, scale efficiency and cost efficiency at the confidence level of 5%. When other conditions remain unchanged, the higher the feed conversion ratio, the lower the feed conversion ratio in the dairy farming process, and the more feed will be used to produce the same amount of milk, which reduces the technology efficiency, scale efficiency and cost efficiency of dairy farming. Therefore, improving the feed conversion ratio will be an effective way to improve the efficiency of dairy farming.

The epidemic prevention and control is an important part in the process of dairy farming. The occurrence of epidemic diseases will cause great losses to farms and affect the technology efficiency, scale efficiency and cost efficiency of dairy farming. The medical and epidemic prevention expenditure is positively correlated with the technology efficiency and cost efficiency at the confidence level of 1%, and is positively correlated with the scale efficiency at the confidence level of 5%. That is, the output rate of the farm will increase as the epidemic prevention cost increasing, and with the increase of the intensive level and scale of dairy farming, the risk of disease is also increasing. Consequently, a reasonable increase in medical and epidemic prevention expenditure can effectively reduce the risk of disease caused by scale expansion.

The number of technicians, namely the number of technicians assigned to each cow, has a significantly positive impact on the technology efficiency and cost efficiency of dairy farming at the confidence level of 1%. The study shows that 7 technicians on average have been provided for every 1 000 cows in the researched farms. The main reason for the low technology efficiency may be that the related technologies of large-scale dairy farming in China are not mature enough and the promotion is insufficient, which is also the main reason for the low cost efficiency of dairy farms. Therefore, it is necessary to strengthen the large-scale dairy farming technology and management knowledge, improve the dairy farming technology and management level of scale farming, and strengthen the application and promotion of technology to improve the technology efficiency and cost efficiency of dairy farming.

The number of employees per cow and the depreciation of fixed assets have a significant negative impact on the allocation efficiency and cost efficiency of dairy farming. The depreciation of fixed assets represents the amount of investment in facilities and equipment, and the reason for the negative relationship may lie in the excessive investment in facilities and equipment during the large-scale farming process. The facilities and equipment have not been effectively utilized, which have affected the allocation efficiency and cost efficiency. Hence, it is necessary to strengthen the matching degree of facilities & equipment investment with the corresponding scale, increase the utilization rate, and arrange rational number of employees for large-scale farming. In this way, it can not only improve the farming standardization, but can also improve the farming efficiency.

5 Conclusions and discussion

5.1 Conclusions The measurement of the dairy farming efficiency in China's scale farms through the DEA model shows that the overall scale efficiency and allocation efficiency of the dairy farming in China are relatively high, but the problem of low cost-efficiency due to low technology efficiency needs to be resolved urgently. Through the efficiency value, which was also realized is that it is very necessary to improve the technology efficiency and cost efficiency to meet the objective of "improvement of quality and efficiencies" in dairy farming, rather than rely merely on the expansion of scale. And according to the results of this paper, the efficiencies of different scales of dairy farming is mixed, where the input costs of small-scale and large-scale farming are relatively low, while their scale efficiencies, allocative efficiencies and cost efficiencies are relatively high; the input costs of medium-scale and relatively large-scale farming are relatively high, but their scale efficiencies, allocative efficiencies and cost efficiencies are relatively low. Therefore, choosing small-scale or large-scale dairy farming is more conducive to improving farming efficiency according to the advantages of regional environment and resource endowments. In addition, the level of technology efficiency decreases with the expansion of scale, and thus it is necessary to strengthen the learning of dairy farming and management techniques in large scale farms, to improve the level of technology efficiency. Combining the trend of cost changes of different scales, it can be expected that the costs continue to increase with the expansion of the farm scale of China, which mainly results from low technology efficiency. Consequently, education and training methods should be adopted to make scale farms utilize technology more effectively.

The empirical analysis of dairy farming efficiency reveals that the feed conversion ratio and forage-to-concentrate ratio significantly affect the scale efficiency and cost efficiency of dairy farming. Reducing the consumption of concentrated feed and increasing the feed conversion ratio have a positive effect on the scale efficiency and cost efficiency. The labor costs, number of employees per cow, and depreciation of fixed assets are significantly negatively correlated with the technology efficiency and cost efficiency at the confidence level of 1%. The scale farms are encouraged to use machinery and information technology to replace labor, reduce the number of employees and labor costs; meanwhile, they should ensure the rationality of hardware and software configuration, avoid ineffective and redundant investment in facilities and equipment, so as to effectively improve the technology efficiency, scale efficiency and cost efficiency of dairy farming.

5.2 Discussion In the context of insufficient research on the dairy farming efficiencies over different scale farms in China, we have quantitatively studied the farming efficiencies of different scale farms based on the survey data of 266 scale farms in 23 provinces across the country. The trend chart of the dairy farming efficiencies shows that the scale efficiency and allocation efficiency of dairy farming in China's scale farms are relatively high, but the overall level of technology efficiency and cost efficiency is relatively low. Besides, according to the change trend chart of dairy farming costs, it can be seen that the small-scale (100 – 500 cows) and large-scale (more than 2 000 cows) farms have lower input costs per cow and higher scale efficiency, allocation efficiency and cost efficiency comparing with the medium-scale (501 – 100 cows) and relatively large-scale (1 001 – 2 000 cows) dairy farming. Moreover, as the scale expands, the level of technology efficiency decreases. The result will provide a theoretical reference for the structural adjustment of large-scale dairy farming in China. However, there are still limitations in this study. Further improvement should be made on the input indicators in the efficiency calculation, the scientific research investment cost indicators of farms, and the samples to enhance the representativeness of the results. The reasons for the farming efficiency difference over different farm scales should be further explored on the basis of this research in the future.

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