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Research on Technical Efficiency of Feed Use for Sustainable Beef Cattle Breeding in China: Evidence from 169 Beef Cattle Farmers

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Abstract: Sustainable green development, cost saving, and efficiency improvement have become the main theme of the high-quality development of China's animal husbandry and the problem of overuse of feed should be paid more attention. Based on the 3-year input–output data of 169 beef cattle farmers, a trans-logarithmic stochastic frontier function was used to study the relationship between feed utilization efficiency and beef cattle breeding scale. The results showed that the average technical efficiency of feed utilization was 0.56, and the technical efficiency of feed utilization increased year by year. Simultaneously, it showed that Chinese beef cattle farmers pay more attention to feed utilization efficiency at this stage; the feed utilization efficiency of retail and medium-sized beef cattle farmers was in the best state in 2015 and 2016. In 2017, the feed utilization efficiency of small-scale beef cattle farmers was the best; the technical efficiency of beef cattle breeding will increase with the expansion of scale. The technical efficiency of beef cattle breeding will increase with the expansion of the scale, and the feed utilization efficiency of large-scale farmers is also better than that of retail farmers, and the scale of beef cattle breeding can bring better benefits. However, from the perspective of feed utilization efficiency, it is not the largest scale that represents the best efficiency, and from the perspective of breeding technology efficiency, the gap between various scales is gradually narrowing. This should also prove that under the condition of hard resource constraints, the large-scale development of beef cattle breeding is in line with the basic national conditions of China at this stage.

Keywords: technical efficiency of breeding; technical efficiency of feed; scale beef cattle farming

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1. Introduction

With the increasing demand for livestock products and other high-protein foods in the food consumption of the population, the demand for feed grains in China is expanding, and the issue of food security in China is gradually focusing on feed safety, and the issue of feed cost saving and efficiency needs to be solved [1]. In 2020, the General Office of the State Council of China issued their opinions on promoting the high-quality development of animal husbandry, which pointed out that the feed formula structure should be adjusted and optimized to promote the reduction of corn and soybean meal substitution; in November 2021, the General Office of the Central Government of China and the General Office of the State Council of China jointly issued the Grain Conservation Action Plan issued the "food saving action plan", which proposed to strengthen the reduction of feed grain substitution, improve the utilization rate of protein feed, and increase the supply of high-quality forage while reducing the amount of concentrate feed in cattle and sheep breeding. How feed will be used efficiently will be a hot issue for animal husbandry research in the future.

Currently, two key challenges facing the livestock industry are: how to raise livestock at a low cost, and how to scientifically obtain high-quality feed [2]. Feed has become an important expense item in the cost of animal husbandry. The price of feed has been rising year by year, leading to an increase in the cost of animal husbandry, and it has gradually become a low-profit industry. Taking beef cattle as an example, the cost per head of free-range beef cattle in 2020, excluding the cost of litter, feed costs account for 94.53% of the total cost. In 2004, the cost of feed costs per head of beef cattle (free-range) in China was 483.92 yuan, and by 2020 the cost per head of feeding reached 2526.98 yuan, an increase of 5.22 times. Feed costs in beef cattle breeding have become an important influencing factor limiting the economic efficiency of farmers. Contrary to the high input of feed cost in the breeding industry is the low efficiency of domestic feed utilization. Currently, the average protein level in domestic feed is around 18%, but the actual utilization rate is only 50%. However, as a traditional beef cattle breeding country, the advantages of the United States (US) in feeding costs are mainly focused on three aspects. First, breeding technology and equipment are mature, and the intensive farms of US beef cattle have all achieved a series of scientific and automated processes such as feed farming, processing, scientific proportioning, etc. This guarantees product quality, production efficiency, management efficiency, and greatly reduces labor costs. Second, crop resources are abundant and corn cultivation cost is low, and the price of corn in the US was 1.5 yuan/kg at the end of 2021, while in China it reached 2.73 yuan/kg, which is only 54.95%. Third, the use of lean meat extract is allowed, which makes the feed conversion rate increase by about 10%. In contrast, traditional domestic beef cattle breeding has a low-feed utilization rate, which makes breeding costs higher while also causing eutrophication of excreta, which has a double impact on farmers' economy and social environment [3]. The real problems of high cost, low efficiency, and high pollution of feed inputs need to be given more attention.

Improving the use rate of feed efficiency in beef cattle breeding, scientifically planning feed input, and realizing the optimal allocation of resources for all input elements in the future will be an important realization path for the development of China's high-quality beef cattle industry. Forming a new situation of high-quality development of the beef cattle industry in parallel with resource conservation and output efficiency can achieve the development goal of improving the quality, efficiency, and competitiveness of China's beef cattle industry. This requires greater attention to feed utilization efficiency in the beef cattle industry. In addition, the research on this issue has important theoretical significance; it also, scientifically allocates resources from the perspective of farmers' input factors and finds that the feed utilization of different scale farmers. This is of great practical significance to promoting beef cattle farmers' income and reducing breeding risk.

Research on the economics of China's beef cattle industry has focused on moderate operation, subsidy policies [4], scientific and technological innovation, production efficiency [5], and industrial positioning [6]. The issue of feed use has only gradually gained the attention of Chinese scholars in recent years, and the main research focuses on the impact of feed prices on the Chinese beef cattle breeding industry. Bao [7] found that the feed cost per head of fattened cattle in the US is 47% less than that in China through a comparison of feed prices in China and the US, and cheap feed resources have become the main support for the development of the US beef cattle industry. Cao et al. [8] argued that under the impact of the "new crown epidemic", the price of raw materials for beef cattle breeding in China increased. Moreover, farmers paid more attention to the development of local low-quality and low-price feed resources and took the initiative to invest in technologies to improve quality, save costs, and increase efficiency. Although Chinese scholars have begun to focus on the efficiency and quality of feed inputs for beef cattle breeding, there has not been a more in-depth analysis of feed use by research samples of beef cattle farmers, especially from the perspective of factor inputs, since the farming industry lacks research on the efficiency of feed use by farmers.

According to Shi et al. [9], through the definition of agricultural production input factor (fertilizer) utilization efficiency, and combined with the theoretical experience of several scholars, feed use efficiency can be measured via two aspects: first, feed is an important input factor in the breeding process, how to use the same feed quantity or less to obtain higher carcass weight gain, but only measure the feed input and carcass output between. Second is the technical efficiency of feed use, which refers to the ratio of the smallest possible feed usage to the actual feed use under the condition that the carcass output and other input factors are certain. Focusing more on the management ability of the farmer's feed use rather than the feed quality itself. Since the second one takes more into account the multiple input structure is more in line with the factual requirements, and, thus, can better reflect the economic meaning of efficiency.

In other fields of agricultural production, many scholars have paid attention to single-factor input efficiency issues. Their research areas mainly focus on the rational use of agricultural resources and the improvement of environmental efficiency perspectives: for example, agricultural water irrigation [10–15] and the efficiency of input factors such as fertilizers and pesticide use [16,17] as well as measuring the efficiency of a substance harmful to the environment [18]. In terms of research methods, the Cobb–Douglas production function is mainly used as the research framework to surpass the variational super-efficient data envelopment analysis of the logit model. In other agriculture fields in China, Chinese scholars have performed a lot of useful single-factor input exploration, but there are still some limitations. Researchers mostly use micro-regional cross-sectional data and inter-provincial yearbook data, and the applicability of the model is not strong, but there are still some limitations in general: researchers mostly use micro-regional cross-sectional data and inter-provincial yearbook data. While the applicability of the model is not strictly tested, the use of the model lacks scientific rigor. The exploration of feed efficiency in China's beef cattle breeding industry will enrich the research on single-factor inputs in the beef cattle industry. Meanwhile, under the background of cost saving and efficiency enhancement and hard environmental constraints, large-scale beef cattle breeding is bound to become the development trend in the future. There is no uniform assumption on scale and efficiency in academic research, and single-factor input efficiency has an important influence on the change of comprehensive efficiency. The innovation of this paper is that the efficiency of beef cattle feed farming is measured by incorporating microdata into the model, and the efficiency of beef cattle feed use under different scales is discussed, which has important practical significance for the future policy formulation of the beef cattle industry and the development of farmers' farming scale.

The article is separated into five portions. After the introduction, Section 2 presents a literature review. Section 3 presents materials and methods. Section 4 describes the results and discussion of the study and, finally, Section 5 outlines the conclusion and recommendations of the study.

2. Review of Literature

Variations in the supply and demand of vegetables and food production have led to an upgrade in the structure of human food demand, resulting in a strong demand for animal-derived foods, for instance, eggs, meat, and milk, so transporting approximately the "animal husbandry revolution" that began at the end of the 20th century [19]. Beef has long been regarded by most Chinese as a health-improving meat for explanations associated with nutrition and traditional opinions [20]. Demand for beef is growing rapidly as their disposable income rises [21]. In 2021, China's beef consumption will be 9.81 million tons, second only to the United States (12.62 million tons). The annual per capita beef consumption of Chinese residents is 6.58 kg, 21 times that of 1978 [8]. China's beef cattle industry originated in the 1980s and has developed rapidly in recent years, especially in terms of beef production [20]. In 2021, China's beef production will be 6.83 million tons, accounting for 11.82% of the worldwide production of beef (57.78 million tons), positioned third after the United States (12.68 million tons) and Brazil (9.5 million tons). Over 30% (3 million tons) of the beef supply hole is filled by imports, making China the major beef importer, secretarial for 13.87% of worldwide beef trade [8,22]. The beef cattle industry conquers an important section of the agricultural industry in China.

Nevertheless, the regional attention to livestock and poultry farming leads to augmented farm, animal, and production intensity, with negative influences on air and water [23–25]. According to the Food and Agriculture Organization of the United Nations (FAO), agriculture accounts for 18% of all carbon emissions, and livestock and poultry production produces more carbon emissions than all human means of transportation (cars, ships, planes, etc.) [26]. According to the Intergovernmental Panel on Climate Change (IPCC), the EU emits 22 kg of CO2 for every kg of beef produced, which is more than the production of lamb, pork, and poultry [8,27]. Among livestock and poultry, beef cattle produce the largest amount of manure and urine as well, and its impact on the environment is 2–3 times that of pigs and 5–20 times that of chickens [28,29]. Animal manure and urine contain a large number of pollutants such as COD (chemical oxygen demand), N (nitrogen), and P (phosphorus), causing air and water pollution [30].

Several scholars have deliberated on the technical efficiency of the beef cattle industry from the outlook of environmental and ecological influence. It is significant to analyze technical efficiency while reflecting on the ecological and environmental impacts and influencing factors [31]. The eco-technological efficiency of beef cattle production not only has important regional differences [32] but, also due to positive externalities, the unit input of farms in areas with higher eco-efficiency has higher unit output compared with other areas [33]. Furthermore, eco-efficiency is more inclined by policy [34]. It is recommended to develop the acquaintance and services of beef cattle farmers to form the optimal mix of inputs [35]. Market services may not necessarily achieve sustainable growth in the livestock industry, and environmental regulations are significant. In the 1990s, Porter first proposed that suitable ecological regulations can inspire companies to conduct an investigation and guide the application of ecological innovation to form a competitive advantage and gain economic benefits in green markets. Empirical lessons on animal husbandry in existing years also display that ecological regulation can directly affect green total factor productivity [36].

3. Material and Methods

Feed, as the main input factor for the output efficiency of beef cattle, represents the ratio of feed inputs when maintaining a constant level of expected output to input, and feed use efficiency is a single-factor indicator of technical efficiency. Based on previous research experience by Haynes et al. [37,38], Reinhard et al. [39], and HU et al. [40], investigated feed use efficiency in two steps. Firstly, by calculating technical efficiency using transcendental log stochastic frontier analysis. Secondly, by using the results of technical efficiency to calculate feed use efficiency. Wang [41] measured single input efficiency (irrigation water) through microdata, and HU et al. [40] estimated the relationship between fertilizer use efficiency and scale through panel data.

3.1. Model Specifications

With a given technology and input factors, technical efficiency can be expressed as the ratio of observed output to the theoretical maximum output. Figure 1A shows the optimal production frontier F (.), which includes output Y, feed input F, other conventional inputs X, and $Y \leq (F, X)$, when Y_R is assumed to be the output value, $F_R(X_R)$ is the input value, and a is the observed production point. Then, we consider YR to be inefficient because it is below the frontier surface F (.). When there is no technical inefficiency, with constant input $FR(X_R)$, Y_F is the theoretical maximum output value that can be achieved, corresponding to a production point of b. Then, the formula for measuring technical efficiency can be understood as follows:

$$TE_R = \{\max[\delta\colon \delta\, Y_R \leq F(F_R, X_R)]\}^{-1} = |OY_R|/|OY_F| \quad (1)$$

when TE_R is expressed as the efficiency of feed utilization, δ is the reciprocal of TE_R. However, the standard radial measure cannot determine the single input efficiency problem because it treats the contribution of each input to the production efficiency as the same. The non-radial concept from the study of Kopp [42], and HU et al. [40] was used to define the efficiency of fertilizer use. The production frontier of fodder inputs is depicted in Figure 1B about other conventional inputs with constant output observations Y_R. It is assumed that the feed input is F_R, other conventional inputs are X_R, and a is the production point. The F^E point is the observed value of the frontier F(.) that can be reached with the least amount of feed input with no technical inefficiency and the production point b.

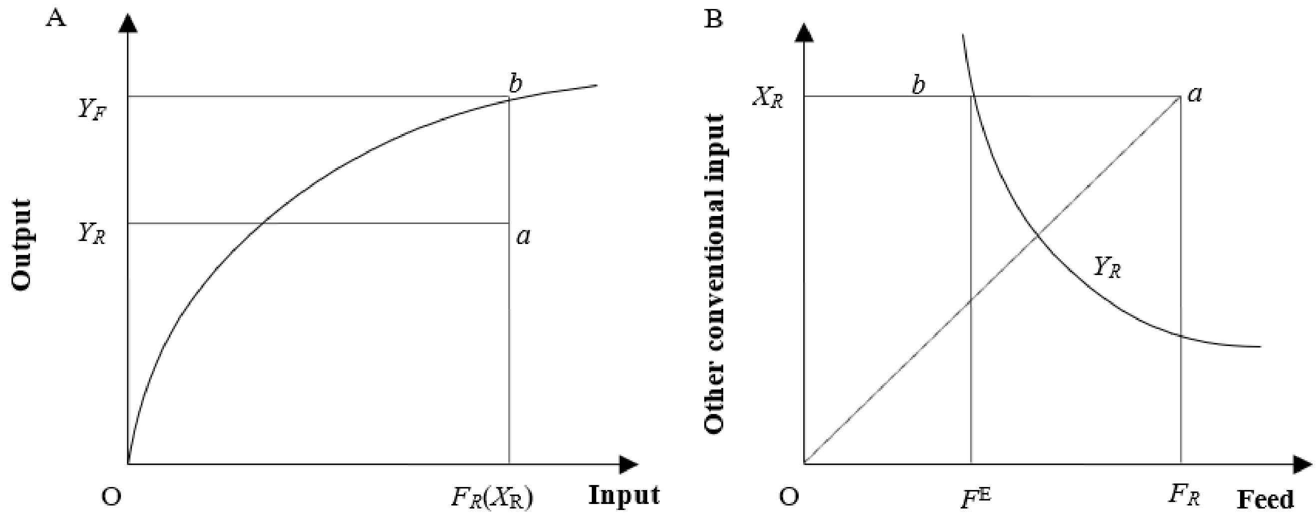

Figure 1. Measuring technical and feed use efficiency. (**A**) description of best practice production frontier. (**B**) description of given production frontier with feed input and other conventional input space.

So, the feed use efficiency can be expressed as:

$$FE_R = \{\min[\Phi: F(\Phi F_R, X_R) \geq Y_R]\} = |OF_E|/|OF_R| \quad (2)$$

FE_R represents feed use efficiency; Φ represents the ratio of minimum input feed to actual input feed. Agricultural output is usually considered a random variable and a stochastic frontier production function is used to measure the technical efficiency of beef cattle production as well as feed use efficiency in China. Its general stochastic frontier production form is:

$$Y_{it} = F(F_{it}, X_{it}; \beta) \exp(V_{it} - U_{it}) \quad (3)$$

where Y_{it} signifies the level of production; F_{it} indicates the feed; X_{it} is a vector of other conventional inputs, counting labor, newborn animals, and time trends; β is a vector of technical parameters to be assessed; V_{it} is a random error term that captures events outside the farmer's control (such as luck, climate, territory, etc.), independently and identically distributed as $N(0, \sigma_v^2)$; U_{it} captures technical inefficiency in production and it is a non-negative random error term, independently and identically distributed as $N+(\mu, \sigma_v^2)$. Rendering to the description of the radial technical efficiency measure, technical efficiency can be expressed as:

$$TE_{it} = Y_{it}/[F(F_{it}, X_{it}; \beta) \exp(V_{it})] \quad (4)$$

The previous formula introduces the basic production efficiency formula, but this study requires a more specific form of the production function. The study of panel data, used to observe the different years between farmers for inputs and farm size, are changing, which may lead to changes in the elasticity of substitution, and, so, in the next chapter, the use of a more flexible translog production function to study will be applied and we will also use a rigorous test of the scientific nature of the use of beyond log production function:

$$\ln Y_{it} = \beta_0 + \beta_f \ln F_{it} \sum_j \beta_j \ln X_{jit} + \beta_t T + \frac{1}{2}\beta_{ff}(\ln F_{it})^2 + \sum_j \beta_{fj} \ln F_{it} X_{jit} + \beta_{ft} \ln F_{it} T + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln X_{jit} \ln X_{kit} + \sum_j \beta_{jt} \ln X_{jit} T + \frac{1}{2}\beta_{tt} T^2 + V_{it} - U_{it} \tag{5}$$

In Equation (5), j represents the conventional input factors, labor, and newborn animal inputs, where F represents feed inputs, T represents the time trend, and the β coefficient subscript character represents the interaction term between different input factors (considering the Hicks neutrality problem). Assuming that feed inputs are efficiently utilized, F_{it} will be replaced by F^F_{it}, while there is no inefficiency with Uit = 0. The formula is:

$$\ln Y_{it} = \beta_0 + \beta_f \ln F^F_{it} \sum_j \beta j \ln X_{jit} + \beta_t T + \frac{1}{2}\beta_{ff}\left(\ln F^F_{it}\right)^2 + \sum_j \beta_{fj} \ln F^F_{it} X_{jit} + \beta_{ft} \ln F^F_{it} T + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln X_{jit} \ln X_{kit} + \sum_j \beta_{jt} \ln X_{jit} T + \frac{1}{2}\beta_{tt} T^2 + V_{it} \tag{6}$$

From the derivation of the basic equation above, the feed uses efficiency (FE_{it}) is equal to F^F_{it}/Fit according to its definition, and its logarithmic form is lnFEit = $F^F_{it}/F_{it} - \ln F_{it}$, Setting Equations (5) and (6) equal yields:

$$\frac{1}{2}\beta_{ff}\left(\ln F^F_{it} - \ln F_{it}\right)^2 - \left(\beta_f + \sum_j \beta_{fj} \ln X_{jit} + \beta_{ft} T + \beta_{ff} \ln F_{it}\right) \times \left(\ln F^F_{it} - \ln F_{it}\right) + U_{it} = 0 \tag{7}$$

According to Equation (7) feed use efficiency can be solved as:

$$\ln FE_{it} = \{ -\left(\beta_f + \sum_j \beta_{fj} \ln X_{jit} + \beta_{ft} T + \beta_{ff} \ln F_{it}\right) \pm \left[\left(\beta_f + \sum_j \beta_{fj} \ln X_{jit} + \beta_{ft} T + \beta_{ff} \ln F_{it}\right)^2 - 2\beta_{ff} U_{it}\right]^{0.5} \} / \beta_{ff} \tag{8}$$

Although there are two methods of solving (7) and (8) for feed use efficiency, Reinhard et al. [39] believe that Equation (8) + [.] 0.5 is more consistent with the assumption of feed use efficiency, more technically efficient feed use efficiency is also more efficient, so Equation (8) is used to derive the feed use efficiency.

3.2. Data Source

The data of this study were obtained from the tracking survey of individual microscopic beef cattle farmers in 2015–2017 by the Industrial Economics Research Office of China Beef Cattle Industry Technology System. The data were distributed in 18 provinces including Hebei, Jilin, Anhui, Jiangxi, Shandong, Sichuan, Yunnan, Tibet, Gansu, Qinghai, Ningxia, Xinjiang, Inner Mongolia, Guangdong, Henan, Hubei, Hunan, and Heilongjiang Figure 2. According to the definition of China's Compilation of Agricultural Cost Information Returns for retail beef cattle farmers, realistic research experience and sample distribution combined with retail (1–50 head) small-scale (51–100 head), medium-scale (101–500 head), and large-scale (more than 500 head), the total sample is 169 farmers' 3 years of observation data, a total of 507 observations, the observation sample in 2017 there were 22 retail households, 59 small-scale, 77 medium-scale, and 11 large-scale households. In the actual research, it is difficult for farmers to observe the quantity (pounds) as the main unit of measurement for feed input indicators, and the feed use cost (yuan) per head of beef cattle is usually used as the measurement indicator. Meanwhile, the sample was all large-scale farms, and there were no traditional beef cattle free-range farmers, whose farming mode was based on free-range eating roughage. The whole sample was understood to be relatively convergent in terms of fine and roughage feeding mode, so the feed uses cost (yuan) per head of cattle for beef cattle farmers was taken as the feed input variable. There is a period problem in the feed input elements, and this paper uses the price deflator to deflate the amount of fattened cattle sold and the feed use cost with 2015 as the base period.

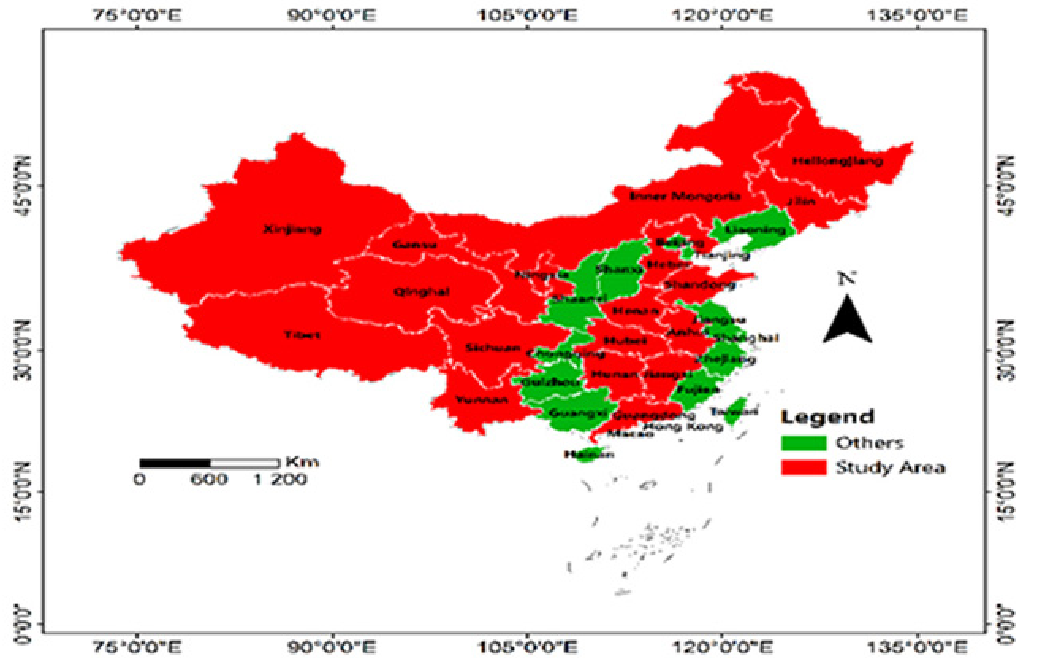

Figure 2. Map of the study area.

4. Results and Discussion

4.1. Basic Data Statistics and Model Applicability Analysis

The research data were organized in addition to key variables, and considering the applicability of model variables. We selected input–output variables from previous studies by Chinese scholars on the technical efficiency measurement of beef cattle and beef cattle feed feeding was divided into concentrate feed and roughage. However, due to data availability issues, the concentrate value and roughage feed for beef cattle farmers were summed up as an important variable for the examination of feed use efficiency. In Table 1 there is no observational data on the amount of feed used by beef cattle, according to the data from the beef cattle testing site, beef cattle need to be fed 5 kg of concentrate feed per day in the middle stage of fattening. While roughage needs to be fed 20 kg (silage), and although the cost of concentrate feed is the main expense of beef cattle fattening, the amount of roughage used in daily breeding is much higher than concentrate feed. Due to the differences in the breeding aspects of different beef cattle breeding types (fat and fattening) farmers, joint research may lead to distortion of technical efficiency. This paper selected farmers of 8–10 months as a sample. Feeding cattle carry out breeding efficiency research, and then focus on feed utilization efficiency under technical efficiency conversion. It can be seen that the key variable feed cost is increasing year by year, while the standard deviation between variables is large, and the variables are logarithmically standardized for more scientific measurement.

For the model selection of data after the stochastic frontier analysis needs to choose which model, when setting the functional form, the wrong form can lead to errors in the measured results [43]. According to previous scholars for stochastic frontier study to test the model rigorously: the first stochastic frontier model applicability test; the second production function form test is to see whether the quadratic and interaction terms in the model variables are zero and whether the Cobb–Douglas Production Function form is more applicable Table 2.

Table 1. Analysis of input–output elements in the past years.

Variables	Definitions	2015		2016		2017	
		Mean	Std	Mean	Std	Mean	Std
beef	The average selling price of beef cattle (head/yuan)	12,935.54	3714.31	14,005.57	3482.51	15,746.7	4191.52
cattle	newborn animal (kg)	253.18	84.89	255.43	83.25	258.01	84.94
labor	Number of laborers (man-days)	6.21	5.35	6.12	5.42	6.53	8.18
feed_total	Feed cost (yuan/head)	2158.34	1129.43	2435.033	1132.77	2750.01	1271.25
lny	Standardized processing (logarithmic)	9.42	0.33	9.51	0.30	9.62	0.32
lncattle		5.46	0.41	5.48	0.39	5.48	0.41
lnlabor		1.58	0.68	1.57	0.66	1.56	0.71
lnfeed_total		7.50	0.66	7.66	0.57	7.79	0.54

Table 2. The estimated results of the production function.

Variables	Coefficient	Model 1	Model 2
lncattle	β_1	2.891 ***	0.348 ***
		(0.40)	(0.02)
lnlabor	β_2	0.328	0.006
		(0.22)	(0.01)
lnfeed_total	β_3	1.547 ***	0.394 ***
		(0.23)	(0.01)
t	β_4	−0.058	−0.019
		(0.12)	(0.02)
lncattle2	β_{11}	0.014	
		(0.05)	
lnlabor2	β_{22}	−0.002	
		(0.02)	
lnf2	β_{33}	0.068 **	
		(0.03)	
t2	β_{44}	0.001	
		(0.01)	
lncattlelabor	β_{12}	−0.051	
		(0.03)	
lncattlef	β_{13}	−0.308 ***	
		(0.03)	
lncattlet	β_{14}	−0.003	
		(0.02)	
lnlaborf	β_{23}	−0.008	
		(0.02)	
lnlabort	β_{24}	0.011	
		(0.01)	
lnfeedt	β_{34}	0.007	
		(0.01)	
_cons	β_0	−6.832 ***	4.895 ***
		(1.61)	(0.16)
gamma		0.32 ***	0.36 ***
		(0.06)	(0.06)
log-likelihood function		275.91	186.99
N		507	507

Note: ** and *** represent the significance levels of 5, and 1%, respectively. Standard errors are in parentheses.

From model 1, the gamma value is 0.32, which indicates that there is an inefficiency term in the model, and it is reasonable to use the stochastic preamble production model setting. Model 2 is based on the equation:

$$LR = -2 \times [\ln L(H_0) \text{ - } \ln L(H_1)] \tag{9}$$

Check which is the more reasonable form of the production function. The LR = −2 × (186.99 − 275.91) = 177.84. It is greater than the mixed chi-square distribution critical value of 7.04 at the 5% level (degrees of freedom = 3) and 10.51 at its 1% level, still rejecting the original hypothesis and using the transcendental log production function model is more reasonable.

4.2. Technical Efficiency of Farmers and Efficiency of Feed Use

The technical efficiency of Chinese beef cattle was measured using frontier 4.1 software and the feed use efficiency of farmers was measured according to Equation (8), and its kernel density graph is shown in Figure 3. It can be seen through the image that the overall trend of technical efficiency is skewed to the right, indicating that the technical efficiency value is significantly higher than the feed users' efficiency value. Measured by the sample data, the technical efficiency of farmers in 2015–2017 ranged from 0.51–0.96, with an average value of 0.80. The data empirically proved that the technical efficiency of beef cattle breeding in China is high at this stage, and there is room for more output of about 20% with the established inputs. Feed use efficiency is between 0.19–0.88, with an average value of 0.56. Feed use efficiency is relatively low, and there is more room to improve feed utilization for Chinese beef cattle farmers at this stage.

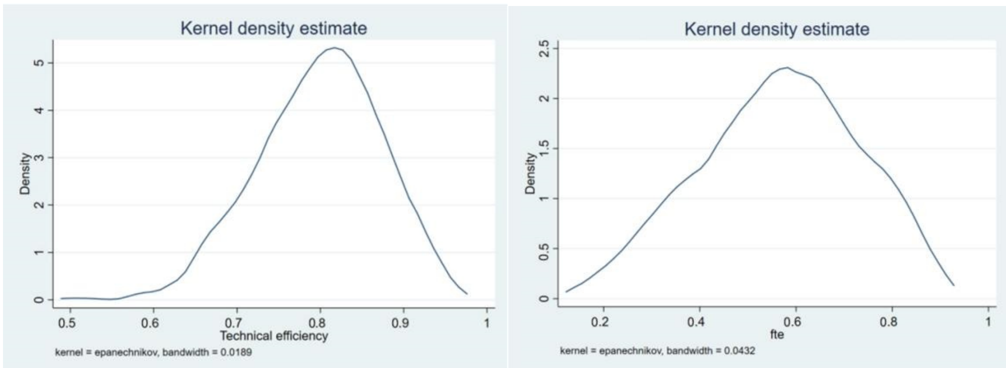

Figure 3. Kernel density estimates for technical efficiency and fertilizer use efficiency.

From the sample point of view, the technical efficiency of beef cattle farmers has improved year by year, and the feed utilization efficiency has also been gradually improved. In 2015, the feed utilization efficiency was only 0.48, indicating that a large part of the feed input by farmers was not effectively utilized. In 2017, the feed utilization efficiency was 0.64. Although some feeds were not used effectively, the overall trend was significantly improved compared with the previous two years, and the technical efficiency and feed utilization efficiency had the same changes.

There are several possible reasons for the rapid inter-annual growth in feed use efficiency. First, the prices of raw materials such as corn are rising, and feed companies are reducing the cost of raw materials using formula diversification, with more cost-effective feed. Second, the improvement of fattening cattle breeding technology, which has been improved in recent years through the "linear fattening method" and through the promotion and application of the "straight-line fattening method" and "racking cattle fattening method", feed efficiency can be continuously improved. The third is the improvement of breeding scale, cattle housing conditions, and management level, when promoting the behavior of beef cattle farmers to standardization and standardization guidance, improving the standardization of breeding, and improving the living environment of beef cattle are conducive to the improvement of feed efficiency. Fourth is the breeding feed is constantly in shortage and farmers are paying more and more attention to the issue of feed use efficiency. Table 3, imilarly, after 2015, the state carried out "grain to feed" pilot work in 629 counties and in 17 provinces and regions, and the main policy of the pilot is to reduce corn cultivation and develop clear corn, alfalfa, and other high-quality forage adapted to the needs of grass-fed animal husbandry.

Table 3. Inter-annual farming technical efficiency and feed use efficiency.

Year	Technical Efficiency	Feed Use Efficiency
2015	0.75	0.48
2016	0.80	0.56
2017	0.85	0.64

4.3. Beef Cattle Farmer Size and Feed Use Efficiency

Regarding the discussion of scale and efficiency, there has been no unified conclusion in academic circles. Through micro-empirical research, scholars have drawn three main conclusions. One is that scale expansion has a positive effect on improving production efficiency, and the other is that there is a moderate operating scale range within which production efficiency can be improved. Optimally, the third view holds that the expansion of the business scale will not bring about the improvement of production efficiency. There is no unified conclusion between scale and efficiency. It is mainly based on the advantages of factor input brought by scale, but, in turn, with the increase of supervision and other costs caused by scale expansion, there is a law of diminishing marginal returns between factors cost, and topic selection for different micro-research samples. From the results of the model, it can be seen that beef cattle breeding technology and feed utilization technology have the same trend and change rules, and are subdivided into different scales. From the model results of Table 4 showed that the beef cattle breeding technology and feed use technology have the same trend change law, then subdivided into different scales, China beef cattle feed use efficiency, is there a law to follow? The average annual slaughtering volume of beef cattle in the research sample is divided into scale, retail (1–50 head), small (51–100 head), medium (101–500 head), and large (more than 500 head), from the analysis of feed use efficiency according to different scale subjects.

Table 4. Technical efficiency of beef cattle farmers at different scales.

Breeding Scale	1–10 Heads	11–50 Heads	51–500 Heads	More than 501 Heads
2015	0.748	0.741	0.752	0.742
2016	0.795	0.802	0.805	0.803
2017	0.842	0.846	0.848	0.857

From the farming technical efficiency measured by the sample, the difference in farming technical efficiency between different scales is not significant, and the mean values of farming technical efficiency between years are 0.75, 0.8, and 0.85, indicating that the input and output of beef cattle breeding in China is relatively reasonable at this stage Table 5. From the inter-annual comparison, different scale farming subjects from the existence of change with time, and the technical efficiency of farming showed different degrees of increase. The development of medium-scale beef cattle breeding is very necessary for the development of beef cattle in China at this stage. Large-scale beef cattle breeding began in 2017. The technical efficiency of households is the highest, followed by the medium scale, indicating that the scope of the moderate scale is expanding, and scale and technical efficiency are gradually becoming a positive influence.

The feed use efficiency measured by the sample varies greatly from year to year, and retailers have a clear advantage in feed use efficiency in 2015 and 2016. However, the average feed utilization efficiency in 2017 ranked last among subjects of different sizes, indicating that the traditional experience advantage of retailers raising cattle is reduced as technology changes. In 2017, the efficiency of small-scale improved feed was faster and ranked first, but the efficiency value of the previous two years was relatively low. The comprehensive value of feed utilization efficiency of medium-scale is high, and the moderate-scale operation of beef cattle breeding is very effective for feed utilization. The feed utilization efficiency of large-scale groups has increased rapidly year by year, indicating that with the development of science and technology and the standardization of breeding enterprises, the feed use of large-scale groups is becoming more and more scientific. Compared with the technical efficiency of aquaculture, feed utilization efficiency varies greatly from year to year. From 2015 to 2017, the feed utilization efficiency of various breeding subjects showed an upward trend, and the overall increase in large-scale breeding groups increased by more than 10, year after year, while the overall feed efficiency of retail households only grows slowly at a speed of about 5 points, and gradually loses the comparative advantage between different entities. Small and medium-sized feed efficiency growth is relatively stable, with an average annual growth rate of about 0.9 and 0.7, respectively.

Table 5. The efficiency of feed use in different scales of beef cattle breeding.

Feed Use Efficiency	1–10 Heads	11–50 Heads	51–500 Heads	More than 501 Heads
2015	0.520	0.473	0.483	0.423
2016	0.568	0.550	0.562	0.524
2017	0.619	0.660	0.632	0.649

The relationship between different input elements and scale is described in Table 6, in which the elasticity of newborn animal input elements and feed input elements is greater. However, for newborn animal inputs as elements of the market buy for fattening farmers, its uncertainty is greater, and its overall trend is less elastic the larger the scale, and retail and small-scale households are more flexible for litter breeding, bringing higher yields than the scale. Feed input elasticity, retail households, small-scale and large-scale average elasticity is the largest, small-scale in 2017, such as a 1% reduction in feed inputs, will reduce the output by about 0.423%, from the average effect of which large-scale groups feed elasticity is the lowest, followed by medium-scale. The labor elasticity of each business entity has increased during the inter-annual period, but the growth rate is small, all around 0, indicating that the promotion effect of labor input on beef cattle production is not significant at this stage. In terms of technical flexibility, the annual growth rate is obvious, and the technological progress of each business entity is rapid.

Table 6. Input factor elasticity under different beef cattle breeding scales.

Elasticity	1–10 Heads	11–50 Heads	51–500 Heads	More than 501 Heads
newborn animal elasticity (2015)	0.454	0.52	0.361	0.387
newborn animal elasticity (2016)	0.336	0.431	0.345	0.363
newborn animal elasticity (2017)	0.339	0.374	0.298	0.312
Labor elasticity (2015)	0.002	0.002	−0.003	−0.004
Labor elasticity (2016)	0.008	0.01	0.007	0.002
Labor elasticity (2017)	0.015	0.023	0.013	0.015
Feed elasticity (2015)	0.39	0.365	0.381	0.364
Feed elasticity (2016)	0.405	0.382	0.393	0.346
Feed elasticity (2017)	0.386	0.423	0.383	0.39
Technology progress (2015)	−0.069	−0.074	−0.075	−0.081
Technology progress (2016)	−0.012	−0.017	−0.021	−0.026
Technology progress (2017)	0.042	0.038	0.035	0.031

5. Conclusions and Recommendations

5.1. Conclusions

This paper is based on the 3-year research data of 169 beef cattle farmers in the national beef cattle farmers' fixed observation sites from 2015–2017. The technical efficiency of Chinese beef cattle farming was measured using the transcendental logarithmic stochastic frontier function. The feed use efficiency of farmers was projected, and the relationship between feed use efficiency and farming scale was further discussed, and the basic results were as follows:

(1) In the research sample, the mean values of technical efficiency and feed use efficiency of beef cattle farmers are 0.80 and 0.56, respectively, and the technical efficiency and feed use efficiency of beef cattle breeding are increasing year by year. However, the feed use efficiency was 0.64 in 2017, which is a great improvement compared with 0.48 in 2015. Although the problem of feed being overused in beef cattle breeding still exists, with inter-annual variation this phenomenon is gradually decreasing.
(2) The technical efficiency of breeding and the efficiency of feed use both show an increasing trend between years, and the rate of increase of feed use efficiency is more obvious, with the development of China's beef cattle industry, feed use efficiency is being paid more attention by farmers.
(3) Scale-based farming will become a development trend, although the empirical results do not show that the larger the scale is, the higher the feed utilization efficiency. However, in recent years, the feed utilization efficiency of large-scale farmers is increasing year by year, which shows that large-scale farming is paying attention to and implementing more scientific feed utilization methods.
(4) Overall feed input elasticity is high, indicating that feed input has significant benefits for yield increase at this stage. However, when the scale of beef cattle breeding is expanded to medium scale, feed elasticity decreases, and although it still seems to be elastic overall, it is not as effective as small-scale and large-scale.

5.2. Recommendations

(1) Continue to expand the scale of beef cattle breeding, realize the transformation of traditional breeding from extensive to intensive, and continue to strengthen basic research on beef cattle feed nutrition and research and development of feed formula technology.
(2) Strengthen the publicity and training of feed and breeding technology for beef cattle farmers, and guide beef cattle farmers to focus on screening the eating characteristics of different stages of beef cattle breeding. Form seasonal feed eating habits, and at the same time, conduct scientific ratios of feed for different attributes of beef cattle breeding (fattening and breeding) to reduce the intake of excessive proportions of energy and protein materials.
(3) Strengthen policy supervision, more scientifically regulate the feed use behavior of beef cattle farmers, strive to balance feed grain resources and breeding production, and allow farmers to use feed more scientifically. For example, in 2020, the Ministry of Agriculture and Rural Affairs issued the Regulations on the Administration of Feed and Feed Additives, which regulates additives and feed raw materials, which has a significant impact on the supervision of beef cattle breeding and beef cattle breeding to expand the feed utilization efficiency.

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