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Changes in Livestock Grazing Efficiency Incorporating Grassland Productivity: The Case of Hulun Buir, China

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Received: 28 September 2020; Accepted: 10 November 2020; Published: 16 November 2020



Abstract: Recently, improving technical efficiency is an effective way to enhance the quality of grass-based livestock husbandry production and promote an increase in the income of herdsman, especially in the background of a continuing intensification of climate change processes. This paper, based on the survey data, constructs a stochastic frontier analysis (SFA) model, incorporates net primary productivity (NPP) into the production function as an ecological variable, refines it to the herdsman scale to investigate grassland quality and production capacity, and quantitatively evaluates the technical efficiency of grass-based livestock husbandry and identifies the key influencing factors. The results show that the maximum value of technical efficiency was up to 0.90, and the average value was around 0.53; the herdsman's production gap was large and the overall level was relatively low. Additionally, the lack of forage caused by drought was the key factor restricting the current grass-based livestock husbandry production level, and the herdsman's adaptive measures, mainly represented as "purchasing forage" and "selling livestock", had a positive significance for improving technical efficiency. Based on this, expanding the planting area of artificial grassland, improving the efficiency of resource utilization, and enhancing the supply capacity of livestock products while ensuring the ecological security of grassland are effective ways to increase the production level of grass-based livestock husbandry in Hulun Buir.

Keywords: grass-based livestock husbandry; technical efficiency; NPP; Hulun Buir

1. Introduction

Grassland is not only the largest terrestrial ecosystem but also an important green ecological barrier in China. Ecological function is always on the top of China's list, and the crucial role of the grassland ecosystem in maintaining national ecological security has become increasingly prominent [1–3]. For instance, in terms of water conservation, grassland accounts for nearly 40% of China's water conservation functional area; the grassland's ability to conserve water is 40–100 times that of cultivated land and 0.5–3 times that of woodland, the ability to block runoff is 58.5% higher than that of woodland, and the ability to reduce sand content is 88.5% higher than that of woodland [4,5]. In addition, grassland also plays an extremely important role in wind protection and sand fixation, soil and water conservation, biodiversity protection, and environmental beautification [6–8]. However, in recent

years, under the dual impacts of human activities and climate change, the ecological environment of grassland has faced great threats and challenges, such as the reduction of grassland area, an increase in land desertification, and a decrease in vegetation coverage [9–11]. Therefore, it is of great significance to carry out scientific and effective eco-management so as to achieve sustainable development of grassland resources.

Moreover, with the rapid development of China's economy, the diet structure of residents has also obviously changed, mainly manifested as a continuous decrease in demand for rations (rice, corn, wheat) and an increasing demand for livestock products (meat, milk, eggs) [12–14]. As grassland resource is the most basic input element for the production of livestock products, high-quality and sufficient forage supply has become a key factor for satisfying consumer demand, increasing herdsmen's income, and achieving sustainable development of pastoral areas [15–17]. However, as the main supply base of livestock products, pastoral areas occupy a relatively low proportion in the total output value of agriculture. The fragile supply capacity has difficulty meeting the market's consumer demand, resulting in a large number of livestock products being dependent on imports and seriously threatening national food security [18–21]. Therefore, the contradiction between ecological protection and increasing the supply capacity of livestock products has become more and more prominent [18].

From international experience, the existing patterns of developing animal husbandry in grassland areas among relatively developed countries, where the artificial grassland area accounts for a large proportion of the total grassland area, are essentially different from our country [5,18]. For example, the area of artificial grassland in New Zealand accounts for 70% of the total grassland area, and, in Europe, it also accounts for more than 50% [22]. However, the area of artificial grassland only accounts for 5% of the total grassland area in China [5], so that the production of livestock products mainly relies on forage supply from natural pastures, which is greatly affected by the natural environment, where grass production is low and unstable. Based on this context, the Central Committee Document No. 1 of 2015 proposed, for the first time, to accelerate the development of "grass-based livestock husbandry" so as to achieve a win-win situation of ecological benefits and economic benefits and finally meet major national strategic needs.

However, the existing research on grass-based livestock husbandry mainly focuses on the analysis of the influencing factors and causes of grassland ecological services and production functions degeneration [23–25] and the influence mechanism of grassland management policies such as "returning grazing to grassland" and "enclosure and grazing prohibition" on grassland ecological restoration and regional economic development [5,26]. The research perspectives are primarily based on the protection of ecological functions, equating the current status of the ecological environment with the level of sustainable development; however, few studies have analyzed the situation from the perspective of optimizing the allocation of grassland resources and improving grassland production efficiency [4,5]. In the background of resource constraints and increasing demand for livestock products, improving the level of production efficiency is undoubtedly helpful to meet consumer demand while maintaining the grassland's ecological environment [27]. Moreover, many studies had pointed out that the improvement of production efficiency comes mainly from technical efficiency and technical change. Furthermore, in the case of limited short-term technical change, technical efficiency improvement has become an effective way to enhance the level of production efficiency [28–30].

The concept of technical efficiency was firstly proposed by Farrell (1957) and considered as the ratio of ideal cost to actual cost [31]. Technical efficiency focuses on investigating the issue of how production and operation entities can maximize potential output through the existing inputs of production elements under the established production environment and technological level [32,33]. Subsequently, scholars carried out a wealth of research on technical efficiency. In recent years, they have gradually focused on investigating the coordination ability between the ecological and production functions of the economic system [27,34,35]. However, in the process of calculating technical efficiency, the existing research measures the environmental impact by taking the unexpected output of economic systems (wastewater, waste gas, solid waste) into account [36–38]. However, the environmental impact

in the production process of grass-based livestock husbandry mainly comes from the consumption of grassland resources; the unexpected output has less impact on it [39]. Therefore, the most relevant research focuses on industry or planting industry, while in the field of grass-based livestock husbandry, it usually takes grassland area as an input variable for analysis based on the traditional research paradigm [40,41]. However, it is difficult to accurately reflect the ecological level of grassland as the research ignores the significance of grassland quality (soil organic matter, grassland type, grassland net primary productivity) for grassland ecological and productive functions; most of the studies stay at the macro level, lacking micro-level research [27,39,42].

Based on this, in this paper, we combine survey data and construct a stochastic frontier analysis (SFA) model, which is the current mainstream model of measuring technical efficiency at the micro-level [43], to investigate the production status of herdsman's grass-based livestock husbandry production in Hulun Buir. Moreover, in order to calculate the grassland's ecological performance, we incorporate net primary productivity (NPP) into the production function as an ecological variable that characterizes grassland quality and productivity and refine it to the herdsman scale, according to the family pasture's grid position of the longitude and latitude, then we identify the key influencing factors of technical efficiency to clarify the main constraints in current grass-based livestock husbandry production and operation so as to provide policy recommendations for sustainable development.

2. Material and Methods

2.1. Study Area

Hulun Buir is located in the north part of Inner Mongolia, possessing typical semiarid grassland that is rich in resources and natural pastures (Figure 1). Grass-based livestock husbandry is the pillar industry there, which mainly relies on natural grasslands [8]. However, in recent years, 66% of all pastures have been degraded, which has resulted in a great impact on the market supply of livestock products and the regional ecological environment [44]. As an important national livestock production base, maintaining the national ecological environment and food security is an important task for grass-based livestock husbandry development. Therefore, it is of great significance to clarify the current efficiency level of grass-based livestock husbandry and explore the optimal path so as to achieve a win-win situation of ecological benefits and economic benefits in this region. Based on this, counties located in the pastoral area (including Xin Barag Right Banner, Xin Barag Left Banner, Prairie Chenbarhu Banner, Ewenki Autonomous Banner) and semirural and semipastoral areas (including Zhalan Tun, Daur Autonomous Banner of Morin Dawa, and Arun Banner) were chosen as the study areas.



Figure 1. Location of the study area and the sampled points for questionnaire data collection.

2.2. Experimental Design

2.2.1. Data Source

This paper selected the method of stratified random sampling to investigate the herdsman's grass-based livestock husbandry production and operation, covering 7 counties of Hulun Buir. A total

of 138 questionnaires were obtained, among which 126 were valid; the effective rate was 92%. The questionnaires included household population, labor force, grassland area, livestock quantity, livestock production, household grass-based livestock husbandry income, livestock product sales, and herdsmen's adaptive measures to climate change.

Additionally, the data of temperature, precipitation, and other climatic variables were all derived from China's meteorological data network [45], and the data of NPP was extracted from the MOD17A2 product, which can be downloaded for free [46]. Accordingly, we obtained MOD17A2 product data, covering two tiles (h25v05, h26v05) in Hulun Buir from 2001 to 2016; the image data band is 1 km. Then, the MODIS data were extracted and batch-stitched based on the MODIS data processing software MRT (MODIS Reprojection Tools) and the Cygwin platform to convert the source NPP data (in HDF format) to the GEOTIFF format, and, finally, we performed projection conversion and cropping on the spliced image by Python to obtain the NPP distribution of Hulun Buir. Moreover, learning from Huang et al. (2016), according to the grid location at the latitude and longitude of the family pastures, the NPP value at the grid location was extracted to characterize quality and productivity so that the NPP value was refined to the herdsmen scale.

2.2.2. Indicator System

This paper constructed an indicator system to evaluate the technical efficiency of herdsmen's grass-based livestock husbandry based on the scientific connotation of technical efficiency and the actual situations of local production and operation (Table 1). Most of the existing research take grassland as the land input element, together with the capital element and labor element, in the analysis of production function [27,47,48]. However, the influence of grassland quality on grassland production capacity and grass-based livestock husbandry production levels has been ignored [39]. As Hulun Buir is a vast area, the different conditions will inevitably lead to a different grassland quality in each region, as well as the corresponding production capacity, animal-carrying capacity, forage yield, and forage quality. Therefore, this paper took net primary productivity (NPP) as an ecological variable to investigate the quality of grassland on the technical efficiency evaluation system so as to scientifically and comprehensively estimate the production level of grass-based livestock husbandry. Thus, we specifically selected grassland area (x_1), labor (x_2), capital (x_3), and NPP (x_4) as input indicators and the output of total meat (Y) as output indicator. As for the key influencing factors of technical efficiency, the existing research mainly includes the aspects of herdsmen's age, household size, education level, income, and grazing capacity [49–51]. Additionally, related research has pointed out that climate factors (like temperature and precipitation) can also have a significant impact on technological efficiency. As the process of climate change intensifies, adaptive measures adopted by herdsmen to cope with climate change have increasingly highlighted their impact on technical efficiency [52]; purchasing forage and selling livestock are the most important adaptive measures at present, according to the survey data. Therefore, this paper specifically selected household size (z_1), livestock density (z_2), education level (z_3), precipitation (z_4), temperature (z_5), whether purchased forage (z_6), and whether sold livestock (z_7) as key influencing factors. Among them, household size (z_1) represents the population of each household; as for livestock density (z_2), learning from Bai et al. (2019), the equivalent unit was converted (1 pig = 5 sheep, 1 cow = 5 sheep) to the number of sheep carried on each hectare of grassland.

2.3. Data Analysis

2.3.1. Stochastic Frontier Analysis

Stochastic frontier analysis (SFA) mainly considers that the production frontier itself is in a state of random change in different production units [43]. This method can effectively distinguish various

controllable and uncontrollable factors that lead to production inefficiency and has become the current mainstream model of measuring technical efficiency [53], which can be shown as follows:

$$\ln Y_i = \beta_0 + \sum_n \beta_n \ln x_{n,1} + v_i - u_i \tag{1}$$

where Y_i represents the real output; x_i represents the input elements; v_i represents the random error term, which is an independent, identically distributed normal random variable with a mean of zero and a constant variance; u_i represents the inefficiencies of production, which is generally assumed to be an independent and identically distributed exponential random variable or a seminormal random quantity.

Table 1. Evaluation index and variable descriptions of the technical efficiency of grass-based livestock husbandry in light of herdsmen.

Type	Lable	Variable	Unit	Observations	Mean	Standard Deviation
Input	x_1	grassland area	hectare	126	201.40	202.49
	x_2	labor	herd	126	3.03	1.58
	x_3	capital	Yuan	126	80,641.43	123,313.90
	x_4	NPP	gC	126	198.65	32.02
Output	Y	output of total meat	kg	126	18,529.52	16,821.17
	z_1	household size	herd	126	3.32	0.99
Influencing factors	z_2	livestock density	sheep unit/hectare	126	6.75	11.1
	z_3	education level	-	126	0.15 0.74	0.35
	z_4	precipitation	mm	-	286.5	79.9
	z_5	temperature	°C	-	6.38	7.51
	z_6	whether purchased forage	-	126	0.43	0.46
	z_7	whether sold livestock	-	126	0.37	0.48

However, traditional SFA models are mostly based on the Cobb–Douglas (CD) production function, which contains the premise that the elasticity of substitution of all production inputs is 0 or 1. When constructing the production function of herdsmen’s grass-based livestock husbandry, it is difficult to determine the elasticity of demand substitution among various production inputs in advance [54,55]. Based on this, this paper selected the translog production function in a more flexible form, which can be approximated to any production function, and built an SFA model from the perspective of technical efficiency and combined it with the actual situations of local grass-based livestock husbandry production and operation [27,56], which can be shown as follows:

$$\begin{aligned} \ln Y_i = & \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + \beta_3 \ln x_{3i} + \beta_4 \ln x_{4i} + \beta_{12} \ln x_{1i} \ln x_{2i} \\ & + \beta_{13} \ln x_{1i} \ln x_{3i} + \beta_{14} \ln x_{1i} \ln x_{4i} + \beta_{23} \ln x_{2i} \ln x_{3i} + \beta_{24} \ln x_{2i} \ln x_{4i} \\ & + \beta_{34} \ln x_{3i} \ln x_{4i} + \frac{1}{2}\beta_{11}(\ln x_{1i})^2 + \frac{1}{2}\beta_{22}(\ln x_{2i})^2 + \frac{1}{2}\beta_{33}(\ln x_{3i})^2 \\ & + \frac{1}{2}\beta_{44}(\ln x_{4i})^2 + (v_i - u_i) \end{aligned} \tag{2}$$

where β represents the parameter vectors estimated by observation; Y_i represents the total output of the i -th herdsmen family; x represents the input value of production elements; u_i represents the non-negative random variable of technical efficiency loss of the i -th herdsmen family $u_i \sim iidN^+(m_i, \sigma_u^2)$; v_i represents the random error term $v_i \sim iidN(0, \sigma_v^2)$; u_i and v_i are independent of each other. Technical

efficiency is generally defined as the ratio of observed output at a given production frontier to the corresponding potential output, which can be shown as follows:

$$TE_i = \frac{f(x_i, \beta) \cdot \exp(v_i - u_i)}{f(x_i, \beta) \cdot \exp(v_i)} = \exp(-u_i) \quad (3)$$

2.3.2. Tobit Regression Model

Technical efficiency measured through the SFA model will not only be affected by the selected input–output variables but also by other exogenous variables. As the efficiency value is usually between 0 and 1, the Tobit regression model has advantages when it includes both continuous and discrete variables [57]. Thus, this paper selected the Tobit regression model, namely, the maximum likelihood method, to analyze the key factors influencing technical efficiency, which can be shown as follows:

$$y_i = \beta_0 + \sum_{j=1}^k \beta_j z_{ij} + \varepsilon_i \quad (4)$$

$$y_i = \begin{cases} 0, & \text{if } y_i^* \in (-\infty, 0] \\ y_i^*, & \text{if } y_i^* \in (0, 1] \\ 1, & \text{if } y_i^* \in (1, +\infty) \end{cases} \quad (5)$$

where y_i represents the technical efficiency of the i -th herdsman family; z_{ij} represents the factors influencing technical efficiency.

3. Results

3.1. Changes of NPP in Hulun Buir

We extracted the NPP data of Hulun Buir from the MOD17A2 product. Figure 2 shows the changes in NPP in the major years, indicating that the trend of “partial improvement, overall deterioration” has been quite obvious since 2001. In addition, although the NPP level in 2015 was lower than that in 2001, it had still improved compared with 2005 and 2010. On the whole, the ecological security of Hulun Buir grassland is still facing a severe threat.

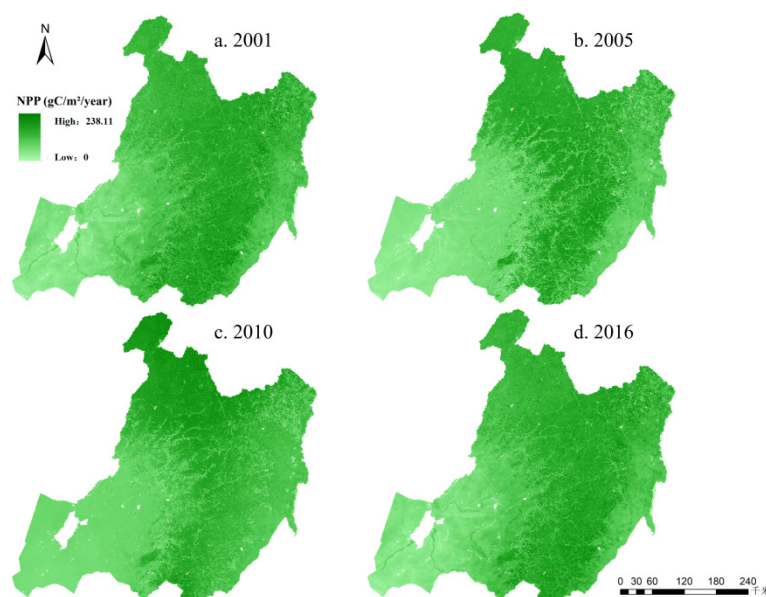


Figure 2. Changes of net primary productivity (NPP) in Hulun Buir.

3.2. Evaluation of Technical Efficiency of Grass-Based Livestock Husbandry

We constructed an SFA model to evaluate the technical efficiency of grass-based livestock husbandry based on survey data and Formulas (2) and (3). Table 2 shows the results of parameter estimation, where the model was significant at the 1% level, indicating that the overall fit was good and the independent variable had a high level of interpretation for the dependent variable. Among them, the coefficient of grassland area, labor, capital, and NPP were all positive, indicating that an increase of input elements would have a significant positive impact on total livestock output.

Table 2. Estimation results of the parameter-based test on the stochastic frontier analysis (SFA) model.

$\ln Y_1$	Coefficient	Standard Error	Z Value	P > z	95%
$\ln x_1$	0.266 ***	0.012	22.400	0.000	[0.242, 0.289]
$\ln x_2$	0.489 ***	0.063	7.760	0.000	[0.366, 0.623]
$\ln x_3$	0.165 ***	0.027	6.210	0.000	[0.113, 0.217]
$\ln x_4$	1.169 ***	0.180	6.480	0.000	[0.815, 1.522]
$\ln x_1 \times 2$	0.155 **	0.078	1.980	0.047	[0.002, 0.309]
$\ln x_1 x_3$	-0.220 ***	0.196	-11.220	0.000	[-0.259, -0.182]
$\ln x_1 x_4$	1.397 ***	0.133	10.490	0.000	[1.135, 1.658]
$\ln x_2 x_3$	0.043	0.046	0.940	0.349	[-0.047, 0.133]
$\ln x_2 x_4$	2.003 ***	0.206	9.730	0.000	[1.599, 2.406]
$\ln x_3 x_4$	-0.775 ***	0.150	-5.140	0.000	[-1.071, -0.479]
$\ln x^2$	0.316 ***	0.324	9.750	0.000	[0.253, 0.380]
$\ln x^2$	0.517 **	0.215	2.410	0.016	[0.096, 0.937]
$\ln x^3$	-0.033	0.025	-1.320	0.187	[-0.082, 0.015]
$\ln x^4$	8.185 **	3.156	2.590	0.011	[1.998, 13.37]
cons	0.526 ***	0.025	21.420	0.000	[0.477, 0.573]
Prob > chi2	0				
Number of obs = 126 Log likelihood = 37.66					

Note: **, *** represents 5%, 1% significance, respectively.

Subsequently, we evaluated the technical efficiency of grass-based livestock husbandry based on the SFA model. The results revealed that the level of grass-based livestock husbandry production was still quite low; the maximum value was 0.90, and the average value was 0.53. There was a large space for the development of grass-based livestock husbandry in the future. Moreover, it can be seen from the distribution that the overall distribution of technical efficiency is to the right, which meets the hypothesis of the SFA model (Figure 3).

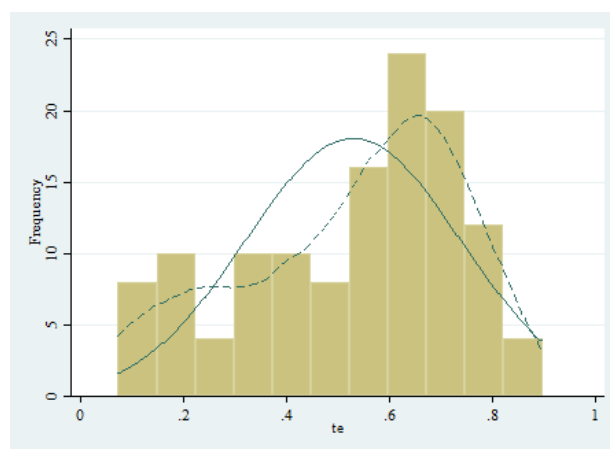


Figure 3. Distribution of technical efficiency of grass-based livestock husbandry on herdsmen.

3.3. Analysis of the Key Influencing Factors of Technical Efficiency

3.3.1. Data Validation

Before regression analysis, we also need to test the data of variables. In this paper, in order to avoid the distortion of model estimation results due to multicollinearity, we firstly selected the method of variance expansion factor (VIF) to test the multicollinearity of independent variables (Table 3). The results show that the variance expansion factors of each variable were less than 8, which indicated there was no strong correlation between the independent variables and no multicollinearity problem in the model.

Table 3. Results of the variance expansion factor (VIF) test.

Variables	VIF	1/VIF
household size	1.17	0.85
livestock density	1.26	0.79
education level	1.37	0.72
precipitation	3.94	0.25
temperature	4.06	0.24
whether purchased forage	2.07	0.48
whether sold livestock	2.35	0.42

Subsequently, in order to eliminate the error of the estimation results caused by the heteroscedasticity of the random interference term, we further selected the method of White to test the heteroscedasticity of the data (Table 4). The results showed that at the level of 5% significance, the adjoint probability of the R^2 statistic was around 0.323, which was greater than 0.05. Therefore, the original hypothesis of “the same variance of random error term” cannot be rejected as there was no heteroscedasticity in the regression equation, and the regression analysis can be further carried out.

Table 4. Results of White’s heteroscedasticity test.

R^2	Adjoint Probability	F Value
79.614	0.323	3.647

3.3.2. Analysis of the Key Influencing Factors

We identified the key influencing factors of technical efficiency based on the Tobit regression model (Table 5). The results showed that education level was significant at the 1% level, indicating that it had a positive impact on technical efficiency. In addition, skill training was an effective way to improve the production technology level of herdsmen as well. Among the climate variables, temperature and precipitation passed the significance test of 1% and 5%, respectively, indicating that climate change will also have an important impact on the production and operation levels of herdsmen’s grass-based livestock husbandry. Livestock density had not passed the significance test, but whether purchased forage and whether sold livestock both passed the significance test, indicating that the adaptive measures also played a positive role in improving technical efficiency and will be helpful in promoting grass-based livestock husbandry production by optimizing the management of adaptations to climate change.

Table 5. Regression results of the Tobit model.

Factors	Coefficient	Standard Error	Z-Value	P > z
household size	0.063	0.070	0.91	[−0.074, 0.200]
livestock density	0.223 ***	0.062	3.59	[0.100, 0.347]
education level	0.001	0.013	0.01	[−0.026, 0.026]
precipitation	0.329 **	0.120	2.73	[0.090, 0.567]
temperature	−0.093 ***	0.027	−3.40	[−0.147, 0.039]
whether purchased forage	0.146 **	0.058	2.53	[0.032, 0.260]
whether sold livestock	0.255 ***	0.063	4.05	[0.130, 0.379]
constant	0.592 ***	0.153	3.87	[0.289, 0.896]
LRchi2(7)	88.96			
Prob > chi2	0.00			

Note: **, *** represents 10%, 5%, 1% significance, respectively.

4. Discussion

As for NPP changes in Hulun Buir, the trend of “partial improvement, overall deterioration” was quite obvious. Areas with declining NPP were mainly concentrated in the east and west foothills of the Greater Khingan Range bordering the plain, specifically shown in the degradation from forest grassland to meadow and desert grassland. Many studies have pointed that NPP is an important indicator of the quality and productivity of grassland [39,44]; moreover, some scholars also believed that NPP can also represent ecological situations [13]. Based on this, in view of the overall deterioration of NPP, the security of grassland areas is still facing a severe threat. In addition, a series of grassland ecological protection policies, such as “Return Grazing to Grass” and “Forage–Livestock Balance”, implemented by national governments, may be the main reason causing the NPP increase in 2016.

As for the evaluation of technical efficiency, the increase in input elements had a significant positive impact on total livestock output. Furthermore, the coefficient of NPP (1.169) was obviously greater than grassland (0.266), labor (0.489), and capital (0.165), which means the quality of grassland had a more significant impact on grass-based livestock husbandry production. The results further illustrate that NPP plays a significant positive role in improving the supply capacity of livestock products. Moreover, one-third of the technical efficiency was between 0.4–0.7, one-third was more than 0.7, and one-third was less than 0.4, which indicated that the production and management levels of herdsmen were quite different.

As for key influencing factors, education level, climatic factors, and adaptive measures all had significant impacts on technical efficiency. Among them, education level had a positive impact on technical efficiency; this is mainly because the higher the cultural quality of herdsmen, the stronger the ability to understand and accept new things, new technologies, and new policies and the easier it is to have higher technical advantages. It also showed that skills training was an effective way to improve the production technology level of herdsmen as well. Mwalupaso et al. (2019) also pointed out that education level was helpful in improving the technical efficiency of households [58]. Moreover, climatic factors like temperature and precipitation also have important impacts on the production and operation levels of herdsmen’s grass-based livestock husbandry. In terms of the coefficient, the precipitation coefficient was positive, which indicated that in a certain range, the increase in precipitation promoted the growth of grassland vegetation, thus improving the forage yield. When the temperature was negative, which is indicated at a certain range, the temperature rise aggravated the evaporation of water in the soil and caused drought, which is not conducive to the growth of forage and, further, means that the lack of forage supply caused by drought will have a significant inhibitory effect on grass-based livestock husbandry production. Bai et al. (2019) also obtained a similar conclusion. Therefore, the lack of forage supply due to the mismatch between precipitation and evaporation is the main factor restricting the improvement of technical efficiency, as the natural pastures are the main supply sources of grass-based livestock husbandry production, which are significantly affected

by climate change. Hu et al. (2019) pointed out that artificial grassland can realize high yield and high-efficiency forage supply [5] and the construction of artificial grassland in a small area, with better water and heat conditions, can fully meet the needs of forage, so as to relieve the grazing pressure of a large area of natural grassland and restore ecological function [8,18]. Zhao et al. (2020) also found that through the construction of artificial grassland in areas with good water and heat conditions (at 10%), 100% of forage grass demand can be met if the planting scale is increased to 30%. The corresponding production scale can be increased by 1.7 times [44], which indicates that the construction of artificial grassland may be a key breakthrough to expand the supply of livestock products while protecting the ecological environment. Moreover, climate change adaptation measures, including whether purchased forage and whether sold livestock, also play a positive role in improving technical efficiency.

5. Conclusions

In this paper, we constructed an SFA model based on survey data while incorporating NPP into the production function as an ecological variable to investigate grassland quality and production capacity and refine it to the herdsman scale. Moreover, we further quantitatively evaluated the technical efficiency of grass-based livestock husbandry and identified the key influencing factors. We found that the maximum value of technical efficiency was up to 0.90, and the average value was around 0.53; the herdsman's production gap was large and the overall level was relatively low. Additionally, the lack of forage caused by drought was the key factor restricting the current grass-based livestock husbandry production level, and the herdsman's adaptive measures, mainly represented as "purchasing forage" and "selling livestock", had a positive significance for improving technical efficiency.

Therefore, the political implications of this study should include the following aspects: increasing the input of scientific research of grass-based livestock husbandry and improving the market competitiveness of livestock products; converting the production pattern of grass-based livestock husbandry and the dependence on grassland herding; optimizing the management pattern of grass-based livestock husbandry and realizing grassland ecosystem replacement; delimiting the red line between grassland resources and ecological protection and restoring the ecological function of grassland; increasing the compensatory input of the grassland ecosystem and advancing its ecological compensatory mechanism; intensifying supply-side reform in agriculture to achieve the optimization and upgrade of the industrial structure; establishing the industrial system of grass-based livestock husbandry and boosting the sustainable development of grassland areas.

Author Contributions: Conceptualization, X.D.; methodology, Y.B.; writing—original draft preparation, Z.Z.; writing—review and editing, J.C.; supervision, J.H.; project administration, Z.L. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financially supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA23070400).

Conflicts of Interest: The authors declare no conflict of interest.

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