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EDITED BY

Alexandre Rossetto Garcia,
Brazilian Agricultural Research Corporation
(EMBRAPA), Brazil

REVIEWED BY

Lu Wen,
Inner Mongolia University, China
Wang Mingli,
Chinese Academy of Agricultural Sciences,
China

*CORRESPONDENCE

Fulin Du
✉ fl_dimau@aliyun.com

[†]These authors have contributed equally to
this work and share first authorship

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The impact of the grassland ecological compensation policy on the modernization of grassland animal husbandry: evidence from Inner Mongolia

Mei Yong[†], Lili Xu[†], Chen Xue and Fulin Du*

College of Economics and Management, Inner Mongolia Agricultural University, Hohhot, China

Introduction: Against the background of China's modernization, which emphasizes harmonious coexistence between humans and nature, it is highly important to explore whether the grassland ecological compensation policy (GECP) can protect grassland ecosystems while promoting the modernization of grassland animal husbandry and whether it has spillover effects on rural revitalization.

Methods: On the basis of survey data from 475 herding households in Inner Mongolia, this study constructs an index system for the modernization of grassland animal husbandry, measures the level of modernization via factor analysis, and analyzes the impact of the GECP on the modernization of grassland animal husbandry.

Results and discussion: The conclusions are as follows: (1) Through ordinary least squares regression (OLS) and moderation effect models, the GECP can significantly promote the modernization level of grassland animal husbandry. For every 1% increase in the compensation amount, the level of modernization increases by 2.355%. The scale of livestock breeding positively moderates this relationship, with larger scales amplifying the policy's effect. (2) Threshold effect analysis reveals a dual-threshold effect on the basis of the compensation amount and grassland area. The relationship between the policy and modernization changes significantly as the threshold values vary. The dual-threshold values for the compensation amount are 6,450 and 11,517, and those for the grassland area are 279 and 4,900. (3) Heterogeneity analysis reveals that for households that practice captive breeding, a 1% increase in compensation increases the modernization level by 2.927%, whereas no significant impact is observed for households that practice year-round grazing.

KEYWORDS

herdsmen, grassland ecological compensation policy (GECP), animal husbandry modernization, livestock scale, pasture area

1 Introduction

The modernization of agriculture is an essential requirement for China's high-quality development, and the protection of the ecological environment is one of its key elements; thus, China has implemented several policies to protect the ecological environment. These policies play a key role in protecting the environment and are also important for the realization of agricultural modernization; grassland ecological protection policies are among the most important of these policies. China's grasslands cover 392.8 million hectares, accounting for

40.9% of the country's land area, constituting the largest land ecosystem in China (Zhang et al., 2017), and serving as an important ecological barrier in China. However, pastures are constantly degrading due to climate change and overgrazing, and the grassland ecosystem and herders' livelihoods are facing serious challenges. In 2011, China implemented the Grassland Ecological Compensation Policy (GECP) to reduce the pressure placed on pastureland, improve the grassland ecological environment, and increase the income of herders by providing certain subsidies to herdsman who reduce their livestock. The policy has been implemented in three rounds, spanning nearly 15 years, with a cumulative investment of more than 150 billion yuan; it has played an important role in improving the ecological environment and promoting the development of the animal husbandry industry. Within the context of the comprehensive implementation of the rural revitalization strategy, China has put forward the task goal of striving to make decisive progress in the comprehensive revitalization of the countryside and basically realizing the modernization of agriculture and rural areas by 2035. As grassland animal husbandry is an important part of agriculture, the modernization of grasslands and pastoral animal husbandry is related to the modernization of Chinese rural agriculture (Yu et al., 2021).

Farmers and herdsman, as the main entities of rural economic and social development, are important forces for promoting the modernization of agricultural and rural areas; thus, the degree of their modernization and development not only determines the speed and quality of the development of agricultural and rural areas but also restricts the pace of the modernization of agricultural and rural areas (Cao et al., 2023). At present, the production and management mode in rural and pastoral areas of China is still traditional family-based smallholder farming, with the total number of smallholders accounting for more than 98% of the overall agricultural business and 90% of the overall agricultural employees; thus, in the "big country, small farmers" context, promoting the integration of small farmers into the modern agricultural and animal husbandry development pattern has become a key link in the modernization of China's agriculture (Zhang and Zhang, 2021). The goals of the GECP are threefold. First, the policy aims to improve grassland ecology; second, it aims to transform the development mode of animal husbandry; and third, it aims to increase farmer and herdsman incomes (General Office of the Ministry of Agriculture of the People's Republic of China and General Office of the Ministry of Finance, 2016), which is an important target of agricultural modernization. Therefore, it is important to study whether the GECP can simultaneously promote the integration of small herders into the modernized production pattern of the livestock industry in the process of realizing the policy objectives and achieve the synergistic realization of the policy objectives and the objectives of the modernization of the livestock industry. Additionally, understanding both the role played by the GECP in promoting the modernization of the animal husbandry industry and its mechanism of action is highly important for realizing the goal of modernizing the animal husbandry industry and promoting a rural revitalization strategy.

The key to achieving agricultural modernization lies in building three major systems as quickly as possible, namely, the modern agricultural industrial system, production system, and management system (Luo, 2021), the same applies to the modernization of animal husbandry. Animal husbandry modernization is a relatively dynamic and connotative concept that can be understood as the process of arming and transforming the animal husbandry industry with modern production factors and management modes; it not only prompts

animal husbandry production technology, production methods, and production organizations to converge with the advanced level of today's world but also realizes the coordinated ecological, economic, and social development goals of pastoral areas that are highly efficient in production, income-enhancing for herdsman, resource saving, and environmentally friendly (Wang et al., 2018; Du, 2021). Grassland animal husbandry is an industry that uses grasslands as the production base and primarily employs a combination of grazing and captive breeding to utilize grassland forage resources for livestock breeding to obtain animal products. Therefore, the modernization of grassland animal husbandry can be understood as the modernization of animal husbandry to target grassland animal husbandry. Since the research area of this paper is the grassland pastoral area of Inner Mongolia, the modernization of animal husbandry referred to in this paper specifically refers to the modernization of grassland animal husbandry. In combination with the meaning of animal husbandry modernization and the contents covered by the above-mentioned three systems (Luo, 2021; Ji and Zeng, 2019) and considering that the research object of this paper is mainly the pastoral areas of "small-scale herdsman," the modernization of animal husbandry is achieved more through the integration of animal husbandry production. Therefore, the analysis of the modernization of animal husbandry in this paper is based mainly on the modernization of livestock production.

To analyze the role played by the GECP in the modernization of the animal husbandry industry and whether the policy can promote the integration of small herding households into the modernized production pattern of the animal husbandry industry, this paper constructs an indicator system for the modernization of the animal husbandry industry and conducts an empirical analysis via the OLS regression model, the moderating effect, and the threshold effect model on the basis of field research data from 475 herding households located in pastoral areas of Inner Mongolia. The results show that the implementation of the GECP can promote the modernization of animal husbandry, and the scale of livestock breeding plays a positive role in regulating the two. Moreover, there is a double threshold effect on the basis of the amount of subsidy and the area of pasture use, which is highly important for the stable implementation of the GECP, as well as for the realization of the goal of China's agricultural modernization.

2 Literature review and hypotheses

2.1 Literature review

A review and summary of the literature reveals that there are numerous studies on the policy effects of the GECP in academia, which are divided into two main aspects: ecological effects and economic effects.

In terms of economic effects, research has focused primarily on the impacts of the GECP on production efficiency, herder household income, and behavioral decision-making. The GECP is conducive to improving the production efficiency of herder households. The compensation funds have a positive effect on the enhancement of production efficiency, although the extent of this effect is limited (Wang et al., 2021). However, Guo and Zhang (2022) compared the livestock breeding efficiency of herder households with different grazing bans and concluded that livestock breeding efficiency decreases. Moreover, the longer the duration of the grazing ban was,

the greater the decline in breeding efficiency. The GECP has a positive effect on the income of herder households (Wang and Huang, 2018), and it particularly plays a significant role in increasing the income of middle- and low-income families (Zhi et al., 2022). However, its impact on high-income families is not significant (Ma et al., 2024). In addition, the GECP has exacerbated income inequality among herder households and suppressed the diversification of income sources for herders (Hou et al., 2021; Liu et al., 2023). In terms of its impact on production decision-making behavior, the GECP significantly suppresses herder households' behaviors related to grassland transfer and nonagricultural employment. However, it promotes their supplementary breeding behavior. This positive effect is weakened when herders face credit constraints (He et al., 2023; Feng et al., 2024).

In terms of ecological effects, after the implementation of grassland compensation policy, there has been a significant improvement in grassland ecology, with substantial increases in grassland cover and the area of usable grassland (Wei et al., 2022). The GECP has effectively guided herder households to reduce their livestock numbers, incentivizing large farms to decrease their total sheep population (Hu et al., 2019; Ding et al., 2022; Zhang et al., 2024). It has had a positive impact on the protection of grassland ecological environment (Zhou et al., 2023; Yang et al., 2022), promoting the recovery of grassland vegetation. The livestock carrying capacity has been reduced by 0.34 sheep units per hectare, and the grassland cover has increased by 2% (Zhao et al., 2019). Hou et al. (2021) analyzed grassland remote sensing data and herder household survey data from regions implementing the GECP nationwide. They reported that the overall grassland quality, measured by the Normalized Difference Vegetation Index (NDVI), slightly improved after the implementation of the policy. However, significant regional differences were observed. In addition, some scholars argue that grassland ecological compensation policy has not significantly improved the ecological environment. Deng and Ma (2024) analyzed geospatial data from the Qilian Mountain region from 2001 to 2020 and field survey data from 2021. They concluded that after the implementation of the policy, the NDVI of grasslands in both grazing prohibition areas and grass-livestock balance areas showed a downward trend. However, the decline in the NDVI in the grazing prohibition areas was smaller than that in the grass-livestock balance areas. These findings indicate that the ecological effects of grazing prohibition measures are greater than those of grass-livestock balance measures.

In recent years, research on the modernization of animal husbandry has focused mainly on high-quality development pathways, measurement of the level of modernization, and influencing factors. Wang et al. (2022) argued that high-quality development of animal husbandry in China requires prioritizing the development of medium-sized farms (households) while advancing the innovation and application of core breeding technologies, which will contribute to achieving high-quality development in animal husbandry (Zhang and Luo, 2023). Xiong et al. (2023) constructed an index system for the modernization of animal husbandry and measured and evaluated the development level of modernization in animal husbandry across 31 provinces in China. Song and Du (2020) argued that technological innovation plays a crucial role in the transformation and upgrading of traditional grassland animal husbandry to modern grassland animal husbandry. The sustainability of livestock production methods reflects the level of modernization in animal husbandry to a certain extent. Pan et al. (2020) argued that the GECP has promoted the transformation of

production methods in grassland animal husbandry, leading to a more diversified pattern of livestock production and management. The implementation of captive breeding shelters and artificial forage projects within the policy framework has significantly encouraged herders to shift from traditional grazing practices to captive breeding practices (Zhang et al., 2018). Moreover, the GECP has significantly influenced small-scale herders to increase supplementary breeding and large-scale herders to purchase insurance. These measures have provided positive incentives for the modernization of livestock development methods.

Existing studies have explored the effects of the GECP from multiple perspectives, including the ecological environment, livestock income, production efficiency, livestock reduction decisions, and herder behavior. However, they have not further considered linking these aspects to the modernization of grassland animal husbandry. In fact, the increase in production efficiency and income brought about by the use of science and technology, the reduction in grassland pressure and improvement in the ecological environment due to livestock reduction and the implementation of captive breeding shelters and artificial forage projects within the policy framework has significantly encouraged herders to shift from traditional grazing practices to captive breeding practices. The implementation of captive breeding shelters and artificial forage projects within the policy framework has significantly encouraged herders to shift from traditional grazing practices to captive breeding practices, which are manifestations of the modernization level of grassland animal husbandry. Together, they reflect the degree of modernization of grassland animal husbandry. In particular, the livestock reduction effect of the GECP directly leads herder households to compensate for the income loss caused by reduced livestock numbers by shifting toward intensive and modernized livestock production methods, thus embarking on a path of transformation and upgrading. In particular, the livestock reduction effect of the GECP directly leads herder households to compensate for the income loss caused by reduced livestock numbers by shifting toward intensive and modernized livestock production methods, thus embarking on a path of transformation and upgrading. In addition, most existing studies on the modernization of animal husbandry involve qualitative analyses. Quantitative research is also predominantly based on macrolevel data and examines the modernization of animal husbandry from the perspectives of provinces and counties. However, studies analyzing the modernization of grassland animal husbandry from the microlevel perspective of individual herder households are lacking. Therefore, this paper constructs an index system for the modernization of grassland animal husbandry on the basis of survey data from herder households, using multiple indicators that reflect the outcomes of modernization. It calculates a comprehensive score for the level of modernization in animal husbandry for herder households, proposes research hypotheses, and employs econometric models to analyze the impact of the GECP on the modernization of grassland animal husbandry. On the basis of these findings, this paper offers suggestions for improvement from the perspective of government policy design, aiming to provide empirical evidence for government decision-making.

2.2 Theoretical framework and hypotheses

Referring to the literature and combined with the research object of this paper, a theoretical framework of the influence mechanism of

the GECP on the modernization of animal husbandry is constructed, as shown in Figure 1.

The essence of livestock modernization is to support livestock development with modern technology and advanced management methods to create a green and efficient livestock production system and ecosystem (Cui et al., 2021). Animal husbandry modernization can be manifested through aspects such as improving livestock management practices, upgrading the modernization of livestock facilities and equipment, enhancing the professional competence of herdsman, and promoting the application of modern technologies in the field of animal husbandry, which depend on various types of production decisions made by herdsman. Agricultural policies affect farm household production decisions, and the mechanism of their impact is that agricultural policies usually provide income subsidies in the form of subsidies and price support and affect the rate of change in the structure of agricultural production, which further affects the production decisions of farm households (Chen, 2010; Gao et al., 2016; Breustedt and Glauben, 2007). The GECP provides corresponding supporting policies such as livestock breeding subsidies and animal husbandry infrastructure construction subsidies; grants grass–livestock balance subsidies; and supports and incentivizes the development of advantageous agricultural and animal husbandry industries by herdsman, who strictly follow the grazing ban and implement the grass–livestock balance system, such as through the creation of family ranches (Department of Agriculture and Animal Husbandry of Inner Mongolia Autonomous Region of People's Republic of China, 2023). Under the guidance of the policy and the role of the profit-seeking psychology of herdsman, herdsman can change their livestock production and management methods, which may affect the modernization level of the animal husbandry industry through the following channels.

First, modern technology is used. To reduce pasture pressure and increase herders' income, an increasing number of herders have

adopted herd optimization and breed structure optimization techniques. Moreover, under the economic incentives of the policy, herders also tend to raise improved and high-yielding livestock and adopt some efficient modern production technologies (Chen, 2010), and modern science and technology promote the transformation of animal husbandry toward technology-led modern grassland animal husbandry (Song and Du, 2020).

The second factor consists of facilities and equipment. Owing to the constraints of grass–livestock balance, grazing rest and grazing ban policies, herdsman's breeding methods have begun to gradually change from year-round grazing to intensive farming with captive breeding or semi captive breeding, which places higher requirements on livestock rearing conditions. Thus, herders tend to build standardized sheds, silage cellars and other facilities. To improve production efficiency, herders also use income from policy subsidies to invest in modern equipment.

The third factor is management style. To compensate for the loss of income caused by livestock reduction policies, herdsman are increasingly inclined to adopt modern management methods to improve their production efficiency and output. On the one hand, owing to the publicity and guidance of the policy, herdsman have the concept of green production, such as intensive culture and manure treatment. On the other hand, herdsman adopt standardized production methods, which are conducive to the safe and effective supply of livestock products and have also become a key link in the transformation of traditional animal husbandry to modern animal husbandry (Wang, 2018).

Fourth, the quality of labor is important. Herding households participate in the government's relevant technical training due to the policy, whereas increasingly highly educated laborers tend to stay in pastoral areas to engage in livestock production.

The fifth factor is output. With the above-mentioned modernization shift in production decisions, the income of herdsman has also further

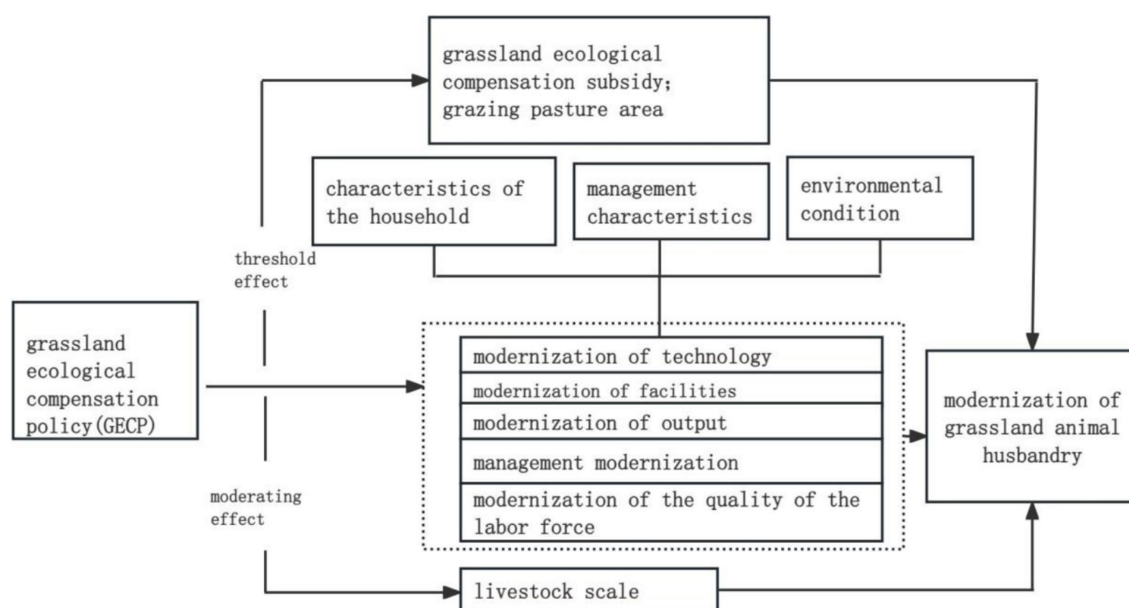


FIGURE 1

The mechanism of the impact of the GECP on the modernization of grassland animal husbandry.

improved. According to the above analysis, the modernization of animal husbandry can be embodied in five ways, namely, through technology modernization, facility and equipment modernization, management modernization, labor quality modernization and output modernization, and it is affected by the GECP.

Accordingly, research hypothesis 1 is proposed as follows:

H1: The GECP promotes the modernization of animal husbandry.

The scale of livestock breeding is one of the indicators for evaluating the modernization level of animal husbandry (Xiong et al., 2023). Scale operation can promote the high-quality development of animal husbandry (Wang et al., 2022); thus, the scale operation of agriculture is crucial for improving the level of agricultural mechanization and labor productivity, as well as the competitiveness of agricultural production (Xu, 2023b). The scale of livestock breeding also influences the modernization level of pastoral households. According to H1, the GECP can induce herders to modernize their livestock production methods through policy constraints and grants. Under the influence of the policy, herders increase their investment in technology, production facilities, equipment, labor and modern management methods, which in turn improves the efficiency and output of their livestock production, which are important indicators of the modernization level of the animal husbandry industry. In this process, herdsmen decide their inputs in animal husbandry modernization according to the scale of their livestock breeding; for example, they decide whether to buy or rent the corresponding mechanized equipment, whether to adopt the use of modern technology or the construction of sheds, etc., on the basis of the size of their breeding, which affects the degree of modernization of their animal husbandry industry.

On the basis of rational economic assumptions, herdsmen adopt different production factor configurations and production management methods, depending on their input–output ratios. Modern animal husbandry requires higher cost inputs, and when herdsmen are at a larger level of livestock breeding scale, the unit production cost of animal husbandry will be reduced due to economies of scale, and production efficiency will increase. However, higher livestock breeding scales also require larger capital inputs. Because of the need to improve returns and compensate for production costs, herdsmen are more inclined to invest the funds gained from the GECP in the modernization of livestock production, at which time the GECP can further promote the modernization of the livestock industry. Herdsmen with smaller livestock breeding scales tend to use subsidies for livestock modernization with less enthusiasm because the marginal cost of modernization inputs may be higher than the marginal output. At this point, the GECP plays a smaller role in promoting the modernization of the livestock industry.

Accordingly, research hypothesis 2 is proposed as follows:

H2: Livestock breeding scale plays a positive moderating role in the impact of the GECP on the modernization of animal husbandry.

The inputs, technologies, management methods and outputs of animal husbandry modernization may vary among different herdsmen depending on the amount of subsidies received and the area of pasture used. Therefore, the impact of the GECP on the modernization of

animal husbandry by herdsmen will also vary. On the one hand, if herdsmen's subsidy income is low or insufficient to cover the cost of modernized livestock production, then the promotion effect of the GECP on the modernization of the animal husbandry industry is limited. Only when the subsidy income is increased to a certain extent and the funds used by herdsmen for livestock production can compensate for their production costs will herdsmen improve their output through the adoption of modernized livestock production and management methods, thus improving the level of modernized livestock production of herdsmen. However, the promotion of modernization by subsidies is likely to be reduced if subsidies for herding households exceed a certain amount because more subsidy income will lead to a lack of motivation for herding households to improve their income by adopting modernized methods. On the other hand, when the pasture area used by herdsmen is relatively small, their production scale tends to be relatively small, which is not conducive to realizing economies of scale. At such times, herdsmen are more likely to be part-time herdsmen, and their investment in modernized production and management is often small, which is not conducive to improving the modernization level of the animal husbandry industry. In contrast, after the pasture area is expanded to a certain extent, economies of scale in terms of standardized production, technological inputs, and modern facilities and equipment will be more obvious, and the use of grassland ecological subsidies for animal husbandry production will currently have a more significant effect on enhancing the modernization level of the animal husbandry industry.

Accordingly, research hypothesis 3 is proposed as follows:

H3: There is a nonlinear effect of the GECP on the modernization of animal husbandry, with the amount of grassland ecological bonus and the area of pasture use serving as thresholds.

3 Data and methods

3.1 Sample data sources

The data for this study come from 2022 field research data pertaining to herding households, and the scope of the research includes 31 townships and 94 administrative villages located in 8 herding banners of Xilingol League and Chifeng city in Inner Mongolia (Supplementary Figure S1). The research combines stratified and random sampling to obtain livestock production and operation data from 504 herding households. After samples that included unclear records, missing important variables, and extreme outliers were eliminated, 475 valid questionnaires were finally obtained, with a sample validity rate of 94.2%. The survey included the situation of herding households, land utilization, assets, animal husbandry operations, income and expenditures, and the implementation of the GECP. Among these factors, this paper focuses on the individual and family characteristics of herders, livestock breeding and livestock product production, family income composition and production cost, input of livestock production facilities and equipment, grassland ecological subsidies, pasture utilization and adoption of modern production behaviors, all of which provide details for the measurement of the modernization level of livestock husbandry of herders and the verification of theoretical hypotheses, thereby providing good support for this study.

3.2 Indicator system for the modernization of the livestock industry and measurement of its level

On the basis of not only the definitions of the concepts of animal husbandry modernization and the animal husbandry modernization production system mentioned above but also the related literature (Zhai et al., 2020; Du, 2021; Xiong et al., 2023), 13 animal husbandry modernization indicators were determined from five dimensions: animal husbandry output modernization, technology modernization, facility modernization, labor quality modernization and production management modernization. The specific indexes are described and statistically described in Table 1.

In accordance with the research of Xu (2023a) and Sun et al. (2021), to accurately evaluate the level of animal husbandry modernization of herdsmen and overcome the inevitable problem of information overlap between the 13 selected indicators, the factor analysis method was adopted to downscale the indicator data and measure the index of the level of animal husbandry modernization. SPSS was used to standardize the data, after which a factor analysis applicability test was carried out. The results show that KMO = 0.678 and that the Bartlett sphericity test results are significant; thus, the data are suitable for factor analysis. According to the results of the total analysis of variance, the first five factors with eigenvalues greater than 1 were extracted as common factors; their explanatory power was 20.77, 13.6114, 13.53, 11.493 and 10.753%, with a total explanatory power of 70.157%, which indicated that the selected common factors had good representativeness. The maximum variance orthogonal rotation and regression method was used for factor analysis to obtain the rotated component matrix and component score coefficient matrix, from which the scores of each common factor were calculated. The variance contribution rate of each common factor was subsequently multiplied by the score of each common factor as the weight and weighted to obtain the composite score of the animal husbandry modernization level index.¹

3.3 Variable selection and description

Table 2 presents the variables used in the study, including their basic descriptions and statistics.

3.3.1 Dependent variable

The dependent variable is animal husbandry modernization, which is expressed by the index score of the animal husbandry modernization level of herdsmen derived from the factor analysis above. Since the comprehensive evaluation of the level of modernization of animal husbandry sY_i derived from factor analysis is a standardized value, to facilitate the regression analysis below, this paper refers to Wu et al. (2023) to transform it into a

percentage score Y_i , and the transformation formula is shown in Equation 1:

$$Y_i = \frac{sY_i - \min(sY_i)}{\max(sY_i) - \min(sY_i)} \times 100 \quad (1)$$

3.3.2 Core independent variables

In accordance with the existing research results (Gao et al., 2016; Wang et al., 2017; Zhou and Zhao, 2019), the amount of grassland ecological subsidy characterizing the GECP is selected as the core independent variable.

3.3.3 Control variables

To control for the differences in family and personal characteristics between different herding households, the characteristics of the household head, production and operation characteristics, and external environment characteristics, which are closely related to production decision making, were selected as control variables. The characteristics of the household head are the livestock experience of the head of the household, degree of education, and part-time operation; the characteristics of production and operation are the number of family laborers, the proportion of income from animal husbandry, whether it is a new type of business entity, and land productivity; and the characteristics of the external environment are the distance from the township government and the region in which it is located.

3.3.4 Threshold variable

On the basis of the previous section, pasture area is an important variable that constrains the effect of the GECP; thus, the threshold variable was chosen to be the pasture use area. The formula is as follows: pasture area = grassland contracted area + leasing area – leased area.

3.3.5 Moderator variable

The moderator variable is the livestock scale of the herding household, including the total stock of cattle, sheep, goats, horses, camels and other livestock of the family. The number of livestock in each category was converted into standard sheep units; i.e., one cow equals five sheep units, one horse equals six sheep units, and one camel equals seven sheep units for conversion. Definitions and descriptive statistics for each variable are shown in Table 2.

3.4 Modeling

3.4.1 Benchmark regression model

On the basis of the previous theoretical analysis, to further analyze the impact of the GECP on the modernization of the animal husbandry of herdsmen, a benchmark regression econometric model was constructed, as shown in Equation 2:

$$Y_i = \alpha_0 + \alpha_1 \text{sub}_i + \alpha_2 x_i + \varepsilon_i \quad (2)$$

¹ Due to space constraints, the specific calculation process of the factor analysis tabular data is not described herein; however, it has been kept for reference.

TABLE 1 Indicators for animal husbandry and descriptive statistics.

Dimensions	Indicator	Specification of indicator	Mean	Standard deviation
Output modernization	Average slaughter volume per labor (sheep unit)	Total number of livestock slaughtered/number of working labor	80.04	72.79
	Slaughter per square kilometer of pasture (sheep unit)	Total number of livestock slaughtered/Grazing pasture area	209.29	177.51
	Output value of animal husbandry per labor (RMB)	Animal husbandry production value/number of working labor	92233.72	9223.37
Facility modernization	Standardized shed area per animal (m ²)	Standardized total area of household livestock pens/livestock number	0.16	1.32
	Silage cellar volume per animal (m ³)	Total volume of silage cellar and number of cellars/livestock	0.21	0.64
Technology modernization	Livestock improvement rate (%)	The proportion of improved livestock in the total number of livestock	0.63	0.35
	Survival rate of young animals (%)	The number of breeding animals survived in the current year/the total number of breeding animals born	0.87	0.07
	Adoption of animal husbandry technology	Each adopted technology is assigned a value of 1, and multiple ones are cumulative; if none are adopted, they are assigned a value of 0	3.21	1.13
Labor quality modernization	Average number of animal husbandry training per year (times)	Herdsmen attends an average of several livestock training sessions per year	0.31	0.52
	Percentage of labor with lower secondary education or above	The number of laborers with junior high school education or above/the total number of laborers	0.81	0.23
Production management modernization	The degree of standardization of production management	2 = Very good, with production standards, strictly controlled; 1 = General, empirically, control part; 0 = Poor, no standard	0.85	0.59
	The degree of standardization of forage ratio	5 = Very high; 4 = Higher; 3 = Average; 2 = Lower; 1 = Very low	2.20	1.08
	The degree of green production management methods	Each green production management method adopted is assigned a value of 1, and numerous items are cumulatively added; the assignment is 0 if no method is adopted	0.99	0.85

(1) Animal husbandry technology specifically includes livestock disease prevention and control technology, combination planting and rearing technology, pasture improvement technology, intelligent grazing technology, and so on. (2) The index of the degree of standardization of production management is assigned a value on the basis of the answers of the herdsmen to the question of the degree of standardization of production management. (3) The degree of standardization of the forage ratio is assigned according to the answer to the question of the standardized degree of ratio of hay, silage corn, seeds, formula feed and other feeds. (4) Green production management methods include manure treatment, the use of green feed, less intensive breeding, and harmless treatment of sick and dead livestock. The livestock numbers in the indicator are in standard sheep units.

The dependent variable Y_i denotes the level of animal husbandry modernization of the i th herding household; sub_i is the core independent variable; x_i is a set of control variables; α_0 is the intercept; α_1 and α_2 are the parameters to be estimated; and ε_i is the random perturbation term.

3.4.2 Moderating effect model

To explore the role of the livestock scale of herdsmen in the impact of the GECP on the modernization of the animal husbandry of herdsmen, a moderating effect model was constructed by adding the moderating variables and the interaction terms of the core independent variables and moderating variables on the basis of Equation 2, as shown in Equation 3. In Equation 3, $scale_i$ is the livestock scale of the i th herdsman; $sub_i scale_i$ is the interaction term between the subsidy amount and the livestock scale; δ_0 is a constant term; $\delta_1, \delta_2, \delta_3, \delta_4$

represents the parameters to be estimated; and the other variables are the same as those described for Equation 2:

$$Y_i = \lambda_0 + \lambda_1 sub_i I(qit \leq \phi) + \lambda_2 sub_i I(qit > \phi) + \lambda_3 x_i + \varepsilon_i \quad (3)$$

3.4.3 Threshold effect modeling

To test the threshold effect of the subsidy amount and pasture area, following Hansen (2000), a threshold regression model was established, and the self-help method was adopted to test it, as shown in Equation 4:

$$Y_i = \lambda_0 + \lambda_1 sub_i I(qit \leq \phi) + \lambda_2 sub_i I(qit > \phi) + \lambda_3 x_i + \varepsilon_i \quad (4)$$

In Equation 4, qit is the threshold variable; ϕ represents the threshold value of the threshold variable; $I(\bullet)$ is the demonstrative

TABLE 2 Variable definitions and descriptive statistics.

Variable type	Variable	Description of the variable	Mean	Standard deviation
Dependent variable	Index score of animal husbandry modernization level	The results were calculated in above factor analysis	22.74	9.71
Core independent variable	Subsidy amount (RMB)	GECP subsidy fund	11573.61	11946.67
Moderator variables	Livestock Scale (Sheep Unit)	Livestock number	472.52	378.65
Control variables	Education level (years)	Number of years of education for the head of household	8.21	2.99
	Livestock experience (years)	Number of years of livestock	29.7	11.6
	Part-time employment	0 = Not part-time; 1 = Part-time	0.28	0.45
	Labor (Persons)	Number of labor	2.47	0.94
	Proportion of income from animal husbandry (%)	Annual income from animal husbandry/Annual household income	0.81	0.23
	New types of business entities	0 = No; 1 = Yes	0.32	0.46
	Land productivity (RMB/Mu)	Livestock production value/Pasture area	180.6	385.8
	Distance from Township Government (km)	The distance between the herdsman's home and the nearest township office	56.7	36.46
	Region	0 = Chi Feng; 1 = Xilingol League	0.53	0.49
Threshold variables	Pasture area (Mu)	Grassland contracted area + leasing in area – leasing out area	3317.57	4248.28

Due to the large differences in the data of the relevant variables of different herding households, to increase the comparability of the data, the core explanatory variables and moderating variables were logarithmic when the regression described below was conducted.

function, and the condition is assigned to be 1 if it is established and 0 otherwise; λ is the parameter to be estimated; and the meanings of the other variables are unchanged.

4 Empirical results and discussion

4.1 Benchmark regression model results

Before the model regression, the variables were first tested for multicollinearity, and the variance inflation factor of each variable was maximized at 1.78, which was much smaller than the empirical value of the variance inflation factor (VIF) of 10; thus, no multicollinearity problem was found.

The ordinary least squares method was used to regress the baseline model shown in Equation 2; the regression results are shown in Columns (1) and (2) of Table 3, which are the OLS regression results without and with control variables included, respectively. Regardless of whether the control variables were considered, the amount of subsidy was found to have a significant positive effect on the level of animal husbandry modernization of herdsman. For every 1% increase in the amount of grassland ecological bonus received by herding households, the index of their animal husbandry modernization level can be increased by 2.355%. Thus, the implementation of the GECP can promote the modernization level of the animal husbandry of herdsman.

These results occur because the GECP, through its policy transmission mechanism, changes the production behavior decisions of herder households in animal husbandry. This encourages them to increase their investment in modern production factors, thereby increasing the level of modernization in animal husbandry. On the one hand, on the basis of the theory of farmer behavior, herders are typical “rational economic agents” with rational economic thinking

and are pursuers of maximum profit. Therefore, they will increase their investment in modern production factors to obtain higher returns. The implementation of the GECP provides financial support to herders through the distribution of grazing prohibition and grass–livestock balance subsidies, as well as related subsidies for high-quality breeds and captive breeding shelters. This enables herders to invest in modern production factors.

On the other hand, due to measures such as grazing prohibition, grazing rest, and grass–livestock balance, the relative scarcity of grassland resources has increased. According to the theory of scarcity-induced technological progress, the increased scarcity of grassland resources leads to a relative price increase, which in turn raises the production costs for herders. This situation prompts herders to seek new methods and technologies to conserve scarce grassland resources. For example, they may actively adopt modern livestock breeding and reproduction techniques, production management methods, and modern facilities and equipment in animal husbandry. They may also enhance their own professional capabilities to achieve higher returns, thereby improving the level of modernization in animal husbandry. Therefore, in the future design and implementation of the GECP, it is necessary to further increase the intensity of financial compensation or innovate compensation methods. For example, herders could be guided to transform and upgrade toward modern animal husbandry through means such as technical subsidies, facility and equipment subsidies, and high-quality breed subsidies.

Among the control variables, part-time employment was found to significantly and negatively affect the dependent variable at the 5% level, indicating that the more a herding household is engaged in animal husbandry full-time, the higher the level of modernization of its animal husbandry is. The number of laborers was found to negatively and significantly affect the level of animal husbandry modernization of herdsman at the 5% level. Modernized animal husbandry production is intensive and efficient; thus, the greater the

TABLE 3 Benchmark model and moderating effect estimates.

Variable	(1)	(2)	(3)
The amount of subsidy	1.184** (0.469)	2.355*** (0.609)	0.906* (0.482)
Level of education		0.04 (0.142)	0.062 (0.128)
Livestock experience		−0.044 (0.031)	−0.034 (0.03)
Part-time employment		−4.290** (1.78)	−4.920*** (1.615)
Labor		−1.503** (0.598)	−1.975*** (0.628)
Proportion of income from animal husbandry		12.632*** (4.712)	7.509** (2.97)
New types of business entities		0.98 (1.012)	1.53 (1.184)
Land productivity		0.005*** (0.001)	0.005*** (0.001)
Distance from the township government		−0.013 (0.01)	0 (0.01)
Region		−2.703*** (0.945)	−3.421*** (0.983)
Livestock breeding scale			3.484** (1.439)
The amount of the bonus*Livestock breeding scale			2.499** (1.101)
Constant terms	12.161*** −4.176	−1.691 (8.217)	23.083*** (2.308)
Sample size	475	475	475
R ²	0.013	0.267	0.344

(1) ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. (2) Numbers in parentheses are the corresponding robust standard errors.

level of production is, the smaller the number of laborers needed at the same level of production. The proportion of income from animal husbandry was found to significantly and positively affect the dependent variable at the 1% level. Land productivity efficiency was found to significantly and positively affect the dependent variable at the 1% level, which is consistent with the results of Ma and Zhang (2021). The level of animal husbandry modernization is significantly different depending on the region where a herdsman is located. The level of animal husbandry modernization reported by herdsmen in the Chifeng city region is greater than that reported by herdsmen in Xilingol League, possibly because herding households in this region have greater locational advantages. Neither the distance of the herder's home from the township government, the level of the herder's education nor the herder's experience in animal husbandry were found to have a significant effect on the dependent variable. Furthermore, whether a herdsman represents a new type of business

entity was also found to have no significant effect on the level of animal husbandry modernization of herdsmen.

4.2 Moderation effect

According to the above-mentioned analysis and model, the livestock scale may play a moderating role in the impact of the GECP on the level of modernization of animal husbandry, and the impact of the GECP on the level of modernization of animal husbandry may vary depending on the size of the livestock scale. The regression of Equation 3 can verify the existence of this moderating effect. In accordance with Sun et al. (2023), to solve the problem of multicollinearity in the model, the two variables of subsidies and livestock scale were centered, and the product of the centered two variables was used to generate the turnover multiplier term; the regression results are shown in Column (3) of Table 3. The results show that the interaction term of the subsidy amount and livestock scale has a positive and significant effect on the level of animal husbandry modernization of herdsmen at the 5% level, which indicates that the livestock scale plays a significant moderating role in the effect of the GECP on the level of animal husbandry modernization of herdsmen. The coefficient of the interaction term is positive, which is consistent with the direction of the main effect of the subsidy amount on the level of modernization of animal husbandry, indicating that the scale of livestock can strengthen the promotion effect of the GECP on the level of modernization of the animal husbandry of herdsmen; i.e., the larger the scale of livestock is, the more prominent the promotion effect of the GECP on the level of modernization of the animal husbandry of herdsmen is, which verifies H2.

As indicated in the preceding text, the level of modernization in animal husbandry is influenced by the level of modern production factors. The introduction of modern production factors requires a significant investment in costs. Owing to economies of scale, herders with larger livestock breeding scales can better spread and compensate for the production costs incurred. Therefore, these herders are more likely to allocate the ecological compensation funds they receive toward investments in modern production technologies, facilities and equipment, human resources, and production management methods, thereby increasing the level of modernization in animal husbandry.

4.3 Threshold effect

In accordance with Hansen (2000), the bootstrap method was used to simulate the calculation of LM values by repeatedly sampling 500 times to test whether there was a threshold effect present in Equation 4; single and double threshold tests were conducted sequentially. The results of the threshold test are shown in Table 4; the *p* values of the single and double threshold tests of the threshold variables subsidy amount and pasture area are less than 0.05, indicating that both passed the single and double threshold tests.

The estimation results of the threshold effects are shown in Table 5. The first and second thresholds of the subsidy amount are 6,450 and 11,517, respectively. When the amount of grassland ecological compensation received by herders is less than or equal to 6,450 yuan, the policy has a positive but minimal impact on the modernization of animal husbandry, with an impact coefficient of

0.152. This is primarily because the compensation funds available for investment in modern production factors for animal husbandry are limited at this level, resulting in an inconspicuous promotion effect. When the amount of compensation exceeds the first threshold of 6,450 yuan but is less than 11,517 yuan, the impact coefficient increases to 0.501. This suggests that within this range, the policy's promoting effect on the modernization of animal husbandry has significantly increased. This may be because medium-sized compensation provides herders with sufficient financial support to make larger-scale modernization investments while also giving them the incentive to further increase their income through modernized production. When the amount of compensation exceeds the second threshold of 11,517 yuan, the impact coefficient decreases to 7.179. This indicates that when the compensation amount is too high, its promoting effect on the modernization of animal husbandry is somewhat weakened. The possible reason is that an excessively high compensation amount may lead to increased dependence on the policy among herders, reducing their motivation to drive modernization through their own efforts and resulting in a decline in the efficiency of their fund utilization. The promoting effect of the grassland ecological compensation policy on the modernization of grassland animal husbandry is nonlinear, with an initial increase followed by a decrease as the amount of compensation increases.

The first and second threshold values for the area of grassland use are 279 and 4,900, respectively. When the area of grassland use is less than or equal to 279 mu (a Chinese unit of area), the impact of the compensation policy on the modernization of animal husbandry is not significant. This may be because a smaller area of grassland use is unable to achieve economies of scale, and herders lack sufficient resources for modernization investments. When the area of grassland use is between 279 and 4,900 acres, the impact of the compensation

policy on the modernization of animal husbandry is significantly positive, with an impact coefficient of 1.153. This is because as the area of grassland increases, the amount of compensation received by herders also increases, providing them with more funds to invest in modern production, thereby increasing the level of modernization in animal husbandry. When the area of grassland use exceeds 4,900 acres, the impact coefficient increases sharply to 3.969. This suggests that as the area of grassland further increases, the positive effect of the compensation policy on the modernization of animal husbandry significantly strengthens. The use of large areas of grassland may generate economies of scale, enabling herders to more effectively utilize compensation funds for modernized production, thereby increasing the level of modernization in animal husbandry. The above results indicate that as the area of grassland use increases, the promoting effect of the GECP on the modernization of animal husbandry is also nonlinear. Thus, H3 is valid.

4.4 Heterogeneous effects

For herdsman with different breeding methods, heterogeneity analysis was used to determine whether the impact of the GECP on herdsman's animal husbandry modernization level varies according to the different breeding methods. The sample herdsman were divided into two groups according to whether they engaged in captive breeding; the regression results are shown in Table 6. Column (1) shows the estimation results of herdsman who graze year round; it can be seen that the subsidy amount does not have a significant effect on the level of modernization of the animal husbandry industry. Column (2) shows the estimation result of the herdsman who engage in captive breeding, and the subsidy amount has a significant and positive effect

TABLE 4 Threshold effect test results.

Threshold variables	Model type	LM test	Threshold value	p value	Number of BS	Trimming ratio
Subsidy amount	Single threshold	38.752	6,450	0	500	0.15
	Double threshold	27.592	11,517	0.008	500	0.15
Pasture area	Single threshold	39.691	279	0	500	0.15
	Double threshold	43.656	4,900	0	500	0.15

TABLE 5 Threshold effect regression results.

Threshold variables	Animal husbandry modernization level	Threshold variables	Animal husbandry modernization level
Subsidy amount $\leq 6,450$	3.203*** (1.203)	Pasture area ≤ 279	0.5923 (3.277)
	11.103** (4.377)		1.153 ** (0.565)
6,450 < Subsidy amount $\leq 11,517$	7.179*** (1.454)	279 < Pasture area $\leq 4,900$	3.969 *** (1.389)
Control variables	Controlled	Control variables	Controlled
Sample size	475	Sample size	475
R ²	0.226	R ²	0.226

(1) ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. (2) Numbers in parentheses are the corresponding robust standard errors.

TABLE 6 Heterogeneity analysis results.

Variable	(1)	(2)
Subsidy amount	0.789	2.927***
	(1.644)	(0.551)
Constant terms	16.914	−10.511*
	(20.291)	(5.392)
Control variables	Controlled	Controlled
Sample size	149	326
R ²	0.138	0.361

(1) ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. (2) Numbers in parentheses are the corresponding robust standard errors.

on the level of modernization of the animal husbandry industry of the herdsman at the level of 1%. Therefore, the GECP has a greater promotional effect on the animal husbandry modernization level of shepherd households that engage in captive breeding.

The breeding methods adopted by herdsman are constrained by pasture conditions and livestock breeds. Herdsman who do not captive their livestock are located in high-quality grasslands, and the advantages of natural conditions lead to their traditional concepts and behaviors. Strongly adapted native livestock require less refined and standardized management; thus, subsidies have a limited effect on these herders, who are positioned at the low modernization level of animal husbandry. In contrast, herders who practice captivity breeding generally have relatively poor pasture conditions and tend to breed improved breeds to earn more income. Because of the capital needs and management costs of improved breeds of livestock, these herdsman need to invest more in modernized production. Thus, these herdsman are more willing to invest the subsidies they receive in modernizing their animal husbandry production, which means that the GECP has a greater impact on their modernization level.

4.5 Robustness test

To ensure the robustness of the estimation results of the impact of the GECP on the level of modernization of the animal husbandry of herding households, the following methods were adopted to conduct a robustness test.

4.5.1 Endogeneity

Owing to the endogeneity problem caused by the possible mutual causation of dependent and independent variables and the omission of variables in the model, the instrumental variable method was adopted to address the endogeneity problem; the mean value of the subsidy amount in the area where the sample herding households are located was taken as an instrumental variable. The amount of subsidy issued by the government will fluctuate according to the implementation of the policy by herdsman, with the full amount being issued to those herdsman who fully implement the policy; conversely, the amount given to those who do not fully implement the policy will be reduced. Because the behavior of herdsman located in the same area affects each other, the behavior of other herdsman and the amount of subsidy they receive will indirectly affect the decision-making of the sample herdsman, which in turn will change the amount of subsidy they receive. However, the amount of subsidy

received by other herding households does not directly affect the animal husbandry production decisions of a certain herding household, which is in line with the requirement of instrumental variable correlation and exogeneity.

Two-stage least squares (2SLS) estimation was used to address the possible endogeneity problem. The test for the presence of endogeneity of the core independent variables was first conducted, and the *p* value of the Hausman test result was found to be 0.0876; this means that the GECP can be considered endogenous at the 5% level of significance. Therefore, the instrumental variables need to be used to address the endogeneity problem in the model. Second, an underidentification test for the instrumental variables was conducted. The results show that the LM (Kleibergen–Paap rk LM) test statistic passes the test at the 1% significance level. The C-D Wald F statistic for the underidentification test is 152.9, which is greater than 10. This indicates that there is no issue of underidentification or weak instrumental variables. Therefore, the selected instrumental variables are reasonable and exogenous.

Column (1) of Table 7 reports the first-stage estimation results of the 2SLS estimation; there is a significant correlation between the instrumental variable (IV) and the core independent variables, which satisfies the correlation requirement of instrumental variables. Moreover, the *F* value of the weak instrumental variable test of the first-stage regression is 159.579, which is much larger than the empirical value of 10, and the corresponding *p* value of 0.00 indicates that the original hypothesis that the instrumental variable is a weak instrumental variable can be rejected and that the instrumental variable has been appropriately selected and has strong explanatory power. Column (2) reports the results of the second-stage estimation of the 2SLS method. The effect of the subsidy amount on the level of modernization of herder households' animal husbandry after regression via instrumental variables is still positive and significant at the 1% level, which confirms the robustness of the previous estimation results and validates H1.

4.5.2 Replacing the variable evaluation method

The index of the animal husbandry modernization level of herdsman originally calculated via the factor analysis method was replaced with the result calculated via the entropy value method.² The regression results of the model after replacing the dependent variable are shown in Column (1) of Table 8; the results show that the effect of the subsidy amount on the level of animal husbandry modernization is still positive.

4.5.3 Quantile regression

This paper further verifies the robustness of the impact of the GECP on the level of animal husbandry modernization of herdsman via a quantile regression model. Since the quantile regression model is less susceptible to outliers, heteroskedasticity, and a skewed distribution of the dependent variable and is able to examine the difference in the effect of the independent variable on the dependent variable at different distribution levels of the latter, the estimation results are more robust to outliers and can more comprehensively

² Due to space constraints, the entropy value method calculation process is not described herein; however, it has been kept for reference.

characterize the relationship between the independent and dependent variables.

The regression results are shown in Columns (2), (3) and (4) of Table 8. In this work, the quantile points are set to 0.25, 0.5 and 0.75. The subsidy amount is positively related to the level of animal husbandry modernization of herdsman at all three quantile points, which further verifies the robustness of the main effect test results mentioned above. Among them, the GECP has the strongest impact on the animal husbandry modernization level at the 0.75 quantile, i.e., the higher modernization level of the herding households; this is probably because herding households with a higher level of animal husbandry modernization tend to have a stronger sense of modernization and are thus more willing to invest the amount of compensation in the modernization of animal husbandry production, thereby further improving their modernization level. For herdsman with a medium modernization level, the GECP has a relatively small effect on improving their animal husbandry modernization level. The stronger effect of the GECP on the level

of animal husbandry modernization at the 0.25 quantile may be explained by the fact that a low level of modernization of animal husbandry production is often caused by a lack of funds; thus, the subsidy provides more opportunities for animal husbandry households to adopt modernized production methods and improve their modernization level, which further reduces the modernization gap between animal husbandry households with different levels of modernization behavior.

5 Conclusions and policy implications

From the perspective of micro herdsman in Inner Mongolia's grassland pastoral areas, this paper constructs an index system of animal husbandry modernization, comprehensively measures the modernization level of its animal husbandry, empirically analyzes the impact of the GECP on the modernization level of its animal husbandry, and draws the following conclusions.

The analysis results revealed that (1) the GECP can promote further improvements in the animal husbandry modernization level of herding households, especially those with high modernization levels. For every 1% increase in the subsidy amount that herdsman receive, the modernization level of their animal husbandry can be increased by 2.355%. (2) The livestock breeding scale of herdsman plays a positive regulatory role in the relationship between the GECP and the modernization level of animal husbandry; i.e., the larger the livestock breeding scale is, the more obvious the promotion effect of the GECP on the modernization level is. (3) There is a double threshold effect of the subsidy amount and pasture area on the influence of the GECP on the modernization of the animal husbandry of herdsman. On the one hand, the promotion effect of the GECP on animal husbandry modernization shows a nonlinear effect of first increasing and then decreasing with increasing subsidy amount. On the other hand, the impact coefficient also significantly nonlinearly changes with the change in the two thresholds crossed by the pasture area. (4) Under different breeding methods, the promotion effect of the GECP on the level of animal husbandry modernization of herdsman significantly differs.

On the basis of the above research conclusions, this paper draws the following policy insights.

First, the government should play a guiding role in improving the level of awareness of the modernization of animal husbandry among herdsman. Given the background of the "big country, small farm" concept in China, herdsman are the main actors in pastoral modernization. From the perspective of herdsman's interests, the government should strengthen herdsman's animal husbandry production skills training and publicity, optimize the service system in pastoral areas, improve the corresponding supporting measures and infrastructure construction, strengthen the construction of animal husbandry science and technology promotion personnel, and establish a mechanism for communication among scientific research, education and promotion. Furthermore, the government should focus on improving the modernization of the animal husbandry production level of herders to promote the modernization of the animal husbandry level, for example, by promoting the publicity of typical cases of modern pastoral areas; providing scientific breeding, nutritional formula and livestock common disease prevention and

TABLE 7 2SLS regression results.

Variable	(1) First-stage	(2) Second-stage
The amount of subsidy		3.797*** (1.110)
Level of education	0.002 (0.012)	0.051 (0.142)
Livestock experience	0.006** (0.003)	−0.051* (0.030)
Part-time employment	−0.134 (0.085)	−3.945** (1.794)
Labor	0.141*** (0.034)	−1.798*** (0.634)
Proportion of income from animal husbandry	−0.128 (0.159)	13.232*** (4.748)
New types of business entities	0.167** (0.080)	0.807 (1.015)
Land productivity	−0.001*** (0)	0.006*** (0.001)
Distance from the township government	0.003*** (0.001)	−0.010 (0.010)
Region	0.010 (0.091)	−3.759*** (1.136)
Instrumental variable IV	0.974*** (0.077)	
Constant terms	−0.545 (0.731)	−13.996 (11.184)
Weak instrumental variable tests F value	159.579	
Sample size	475	475
R ²	0.452	0.253

(1) ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. (2) Numbers in parentheses are the corresponding robust standard errors.

TABLE 8 Robustness test results.

Variable	Change the variable evaluation method (1)	Quantile regression		
		(2)	(3)	(4)
The amount of subsidy	0.006*	1.786***	1.717***	2.861***
	(0.003)	(0.474)	(0.453)	(0.53)
Level of education	0.001	−0.04	0.024	0.124
	(0.001)	(0.143)	(0.136)	(0.16)
Livestock experience	0	−0.070**	−0.054	−0.064
	(0)	(0.035)	(0.034)	(0.039)
Part-time employment	0.042***	−3.223***	−3.090***	−3.399***
	(0.011)	(1.025)	(0.979)	(1.145)
Labor	−0.001	−1.294***	−1.220***	−1.624***
	(0.003)	(0.422)	(0.403)	(0.472)
Proportion of income from animal husbandry	0.01	16.053***	17.490***	15.870***
	(0.03)	(1.971)	(1.883)	(2.203)
New types of business entities	0.003	1.379	0.264	0.078
	(0.006)	(0.977)	(0.933)	(1.092)
Land productivity	0.00***	0.005***	0.005***	0.006***
	(0)	(0.001)	(0.001)	(0.001)
Distance from the township government	0	0.004	−0.009	−0.016
	(0)	(0.011)	(0.01)	(0.012)
Region	−0.015***	−4.034***	−2.556***	−3.117***
	(0.005)	(1.007)	(0.962)	(1.125)
Constant terms	0.049	−4.056	−1.668	−5.003
	(0.051)	(4.853)	(4.634)	(5.423)
Sample size	475	475	475	475
R ²	0.229			

(1) ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. (2) Numbers in parentheses are the corresponding robust standard errors.

treatment via thematic training; and comprehensively improving the professional quality of herders.

Second, the management and utilization efficiency of GECP funds should be enhanced. The GECP not only encourages herdsman to reduce the amount of pressure placed on pastures by reducing the number of livestock but also encourages herdsman to reduce the rate of carrying livestock in pastures through pasture transfer, pasture improvement, livestock breed improvement, foddering and other methods. Guiding herdsman to use the subsidy amount received in a reasonable manner is important so that the subsidy is more often used to develop and change the mode of production, thereby improving income and compensating for the loss of livestock.

Third, innovative incentive mechanisms for the GECP have been put in place to achieve an effective interface between small-scale herders and the modernization and development of the

animal husbandry industry. It is necessary not only to establish a diversified grassland ecological protection compensation mechanism, such as technical compensation, share compensation and other forms of compensation but also to promote the three-transformation reform of “resources change assets, funds change shares, and herdsman change shares.” Moreover, the green ecological value of the grassland animal husbandry industry chain should be explored and enhanced to better understand the path of modernization of pastoral areas where human beings live in harmony with nature.

6 Research contributions and future research directions

The primary contributions of this paper are as follows: (1) This study broadens the scope of evaluating the effects of the GECP. Previous studies have focused mainly on the separate impacts of the policy on the grassland ecological environment, livestock reduction behavior, herder satisfaction, income, and livelihoods. In contrast, this paper constructs a multidimensional index system for the modernization of animal husbandry to further explore the spillover effects of the policy in promoting livestock modernization while achieving its policy objectives. (2) This study enriches the research on the development of livestock modernization. Previous studies on livestock modernization have often focused on the broad concept of modernization and were mostly based on macrolevel data analysis. In contrast, this paper takes the modernization of grassland animal husbandry as its research object and conducts empirical research on the basis of microlevel survey data from 475 herder households. This is highly important for the modernization of animal husbandry in pastoral areas, where small-scale herders are the main operators. (3) This study provides empirical evidence for the formulation of relevant ecological protection policies. A literature review and empirical analysis revealed that the GECP can synergistically promote grassland ecological environment protection and animal husbandry modernization, which provides a reference for the formulation and implementation of future ecological protection and industrial development policies in grassland pastoral areas.

However, there are several limitations in this study. First, the research subjects of this paper are mainly small herding households in grassland pastoral areas. Considering that the integration point of their livestock operations with modern animal husbandry mainly lies in the production process, this study examines the impact of grassland ecological compensation and reward policy on the modernization of animal husbandry, mainly from the perspective of the livestock production system. Future research should further expand on the modernization of the livestock supply, marketing, and distribution systems. Second, owing to the vast and sparsely populated nature of grassland pastoral areas, there are practical difficulties in conducting surveys. The study area of this research is mainly concentrated in the eastern region of Inner Mongolia. Moreover, the survey data used in this study are cross-sectional, which means that they cannot capture the temporal changes in the sample households. In the future, we will expand the scope of the survey area and conduct continuous tracking surveys of sample households to obtain more comprehensive panel data, which will further enrich this study and increase its generalizability.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MY: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. LX: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. CX: Formal analysis, Investigation, Methodology, Software, Supervision, Visualization, Writing – original draft. FD: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2025.1532514/full#supplementary-material>

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