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Can non-pastoral employment alleviate grazing pressure among herding households?—Empirical evidence from the pastoral areas of Inner Mongolia, China

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Introduction: Overgrazing behavior has long constrained the sustainable development of livestock production in China's grasslands. In response to this challenge, the government has gradually implemented grassland ecological compensation policies and grazing monitoring systems. However, solely relying on government control is insufficient to fully reconcile the dual objectives of production development and ecological protection in pastoral areas. Against this backdrop, non-pastoral employment has increasingly become an important link in promoting labor transfer in pastoral areas and facilitating ecological restoration of grasslands. Participation in non-pastoral employment not only enhances the resilience of livelihoods in herding household, but also provides a feasible pathway for transforming traditional breeding methods and alleviating pressure on grasslands.

Methods: Therefore, this paper systematically studies the mechanisms through which non-pastoral employment empowers ecological protection of grasslands, aiming to provide scientific evidence and policy references for practices in this field, thereby contributing to achieving a win-win scenario for both economic and ecological outcomes in pastoral areas. Therefore, based on survey data from 1,030 herding households in Inner Mongolia, empirically analyzes the impact of non-pastoral employment on the grazing pressure of herding households, as well as the underlying mechanisms and heterogeneity.

Results: The findings indicate that: (1) Non-pastoral employment has a significant negative impact on the grazing pressure of herding households. (2) Mechanism analysis reveals that the non-pastoral employment time encourages herding households to adopt livestock reduction behavior (LRB) to alleviate grazing pressure; additionally, the non-pastoral employment income promotes herding households to adopt both livestock reduction and grazing substitution behaviors (GSB), further alleviating grazing pressure. (3) Heterogeneity analysis shows that the negative impact of non-pastoral employment time on grazing pressure is more pronounced in agro-pastoral ecoton.

Discussion: Based on these findings, it is recommended to strengthen vocational and technical training for herding households to assist them in achieving livelihood transformation, improve conditions for non-pastoral employment, thereby achieving the dual goals of improving livelihoods and ecological protection.

KEYWORDS
grazing pressure, grazing substitution behavior, herding households, livestock reduction behavior, non-pastoral employment

1 Introduction

In recent years, with global climate warming, extreme weather events such as droughts and snow disasters have become more frequent, posing a serious degradation risk to fragile grassland ecosystems (Feng et al., 2021). Meanwhile, the long-standing exploitative grazing practices by humans have further led to varying degrees of degradation in grasslands, resulting in a continuous decline in grassland productivity and severely hindering the development of the livestock economy (Gonzalez-Saldias et al., 2025; Feng et al., 2023). In response to this challenge, governments around the world have implemented measures to alleviate overgrazing. For instance, the United States has initiated the Conservation Reserve Program (CRP) to pay farmers and ranchers rent, encouraging them to retire environmentally sensitive pastures for ecological protection (Dunn et al., 1993); the European Union has introduced a cross-compliance mechanism in the Common Agricultural Policy (CAP), linking agricultural subsidies to environmental protection behaviors and strictly enforcing stocking rate standards to incentivize farmers and ranchers to participate in grassland conservation (Röder et al., 2024); the Kenyan government has issued grazing permits that specify grazing conditions, duration, and area, guiding herding households to adopt more scientific grazing practices (Scheetz et al., 2022). In order to strengthen the ecological protection of grasslands and alleviate overgrazing, China has implemented the Grassland Ecological Compensation Policy (GECP) in pastoral areas across the country since 2011. This policy aims to incentivize herding households to reduce livestock numbers through an economic compensation mechanism, thereby providing more ecological products and actively protecting the grassland ecosystem (Gao et al., 2016). As of 2025, the GECP has entered its third round, and there are preliminary signs of alleviating the trend of grassland ecological degradation nationwide. However, the current effects of livestock reduction under the policy deviate from the expected targets, with the actual overgrazing rate being severely underestimated (Zhang and Tan, 2022). The reasons for this include the universal and mandatory compensation policy that neglects the subjective willingness of herding households, as well as issues such as low compensation standards and a single compensation method (Wei and Qi, 2017; Hu et al., 2016). Deficiencies in institutional design have severely impacted the sustainable livelihoods of herding households, making it difficult to form an incentive-compatible policy intervention model (Zhou and Zhao, 2019; Xie et al., 2018). Against this backdrop, promoting the transfer of labor from pastoral to non-pastoral industries has become an important measure for national and local governments to alleviate the conflict between livestock and grassland and alleviate grazing pressure (Wang et al., 2024). Meanwhile, the non-pastoral transfer of labor in pastoral areas is expected to become a major trend in future development (Chang et al., 2022). Therefore, studying the impact of non-pastoral employment on alleviate grazing pressure is of great significance in improving the grassland ecological environment and ensuring the sustainability of herding households' livelihoods.

In terms of measures to alleviate grazing pressure, the academic community has proposed two primary solutions. The first solution is to directly reduce the number of livestock, known as livestock reduction behavior (LRB). The second approach is grazing substitution behaviors (GSB), such as cultivated pasture and barn-feeding. Currently, research on whether non-pastoral employment can alleviate grazing pressure primarily focuses on the livestock reduction effect of non-pastoral employment, specifically its impact on LRB. Some scholars argue that the emergence of non-pastoral employment opportunities has resulted in a decrease in the number of pastoral workers (Zhao et al., 2013). This has made it difficult for herding households, constrained by limited family labor resources and an incomplete labor hiring market, to invest sufficient labor into livestock production, thereby forcing them to adopt LRB (Huang et al., 2024). Additionally, income generated from non-pastoral employment reduces herding households' dependence on livestock production (Yin et al., 2018; Asfaw et al., 2017). Stable non-pastoral incomes can compensate for the loss of earnings of herding households due to the reduction of farming scale, thereby achieving a closed loop of "non-pastoral employment - LRB - grass-livestock balance" (Huang et al., 2023). However, some scholars have revealed through empirical research at the micro level of herding households that there exists a complex nonlinear relationship between non-pastoral income and breeding scale. When non-pastoral income exceeds a certain amount, it may significantly contribute to the farming scale of herding households, thus increasing the grazing pressure (Zhou et al., 2022). Furthermore, due to the low level of urbanization, employment barriers and biases, as well as the "attachment to land" phenomenon, herding households find it difficult to achieve effective livelihood transitions, and their production and life remain highly dependent on pastoral production (Chu et al., 2022; Luo et al., 2020). In this context, non-pastoral income, as a new source of financial capital, has not effectively promoted the diversification of herding households' livelihoods. Instead, it has reinforced the path dependence of existing production models, exacerbating the "involution" of their livelihood transformation and trapping them in a vicious cycle of "non-pastoral employment - reinvesting in pastoralism - overgrazing" (Zhou and Zhao, 2023). A review of the existing literature indicates that there is still considerable debate in academia regarding whether non-pastoral employment can facilitate the achievement of a balance between grass and livestock, thus necessitating further in-depth research on the relationship between the two.

With the rapid urbanization of pastoral area, the reduction in livestock due to non-pastoral employment is seen as a key factor in alleviating grazing pressure. However, the impact of non-pastoral employment on the LRB among different types of herding households varies significantly across regions. Relying solely on the reduction effect of non-pastoral employment is insufficient to alleviate grazing pressure and to achieve the policy goal of 'ecological protection and income generation for herders' (Feng et al., 2019). Therefore, to achieve a balance between grass and livestock, another approach that warrants attention is the grazing substitution behaviors (GSB) (Huang et al., 2025). Unlike the LRB, the core objective of GSB is to dynamically adjust the supply of forage to achieve a dynamic balance between the forage required by livestock and the total amount of natural grasslands and cultivated forage, thereby alleviating the supply pressure on natural grasslands. Existing studies indicate that artificial forage, cultivated pasture and pen breeding have become crucial for balancing economic and ecological effects (Chu et al., 2022). However, GSB require a high initial investment and feeding cost (Nicod et al., 2019), making it difficult for some herding households to protect grasslands by this way. In this context, external financial support plays a critical role in overcoming the production investment constraints faced by herding households, thereby creating conditions for achieving

Abbreviations: LRB, livestock reduction behavior; GSB, grazing substitution behavior; CMP, conditional mixed process; PSM, propensity score matching.

grass-livestock balance (Zhang et al., 2023). It is noteworthy that the income of non-pastoral employment can effectively improve the budget constraints of herding households, providing the necessary financial support for adopting GSB (Teng et al., 2025). However, existing research has only focused on the mechanisms through which non-pastoral employment affects LRB, neglecting the exploration of the transmission mechanisms of GSB. To this end, this paper asks the following questions: Can non-pastoral employment alleviate grazing pressure? Can non-pastoral employment promote herding households to adopt grazing substitution behavior (GSB), thereby achieving grassland ecological conservation? Furthermore, does the regional disparity in resource endowments have a heterogeneous impact on alleviating grazing pressure? An in-depth discussion of these issues holds profound significance for achieving the long-term goal of balancing grass and livestock.

Although existing research has significant support for this study, there are still several shortcomings: First, there is no consensus on the direction of the impact of non-pastoral employment on alleviating grazing pressure, and the underlying mechanisms lack systematic validation; Second, there is a scarcity of studies focusing on the mechanism of GSB in the context of non-pastoral employment's role in alleviating grazing pressure; Third, existing research has not sufficiently considered the spatial distribution heterogeneity of regional resource endowments, resulting in the heterogeneous mechanisms of non-pastoral employment's impact being inadequately revealed. The marginal contributions of this paper are as follows: (1) from the perspective of research, this paper attempts to explore the impact of non-pastoral employment on grazing pressure through the dimensions of "part-time effect" and "income effect," providing a clear theoretical explanation for the relationship between the two. (2) In terms of research content, this paper constructs a mediation model to discuss the pathway of "non-pastoral employment - LRB or GSB - alleviating grazing pressure." (3) It fully considers the spatial distribution differences in regional resource endowments, revealing the heterogeneity patterns of the effects of non-pastoral employment. Therefore, our research may provide new practical paths for global grassland ecological governance and share China's practical experiences to benefit other developing countries.

The remainder of this paper is organized as follows: Section 2 presents theoretical analysis and research hypotheses; Section 3 discusses data sources, model specifications, and variable descriptions; Section 4 offers empirical analysis; Section 5 includes discussions; and Section 6 concludes with relevant conclusions and policy recommendations.

2 Theoretical framework and research hypotheses

Overgrazing refers to the behavior in which the amount of forage required for livestock within a specific temporal and spatial range exceeds the supply of forage that grasslands and other sources can provide, thereby negatively impacting grassland ecology. Under the current ecological protection policy framework, livestock reduction behaviors and alternative grazing behavior are considered the core pathways to alleviate grazing pressure and curb overgrazing. The former reduces the scale of livestock farming, while the latter alleviates the grazing pressure on grasslands. In contrast to ecological protection policies, non-pastoral employment is a means through which rationally limited herders spontaneously optimize family resource allocation via the labor market, thereby adjusting the input structure of pastoral production factors. It is seen as a key factor that balances economic benefits with ecological effects. Therefore, this study is based on the increasingly normalized reality of non-pastoral employment and explores its ecological effects, theoretically analyzing how changes in this key factor promote herders to adopt livestock reduction and grazing substitution behaviors, thus achieving a balance between livestock and grass.

2.1 Theoretical analysis framework of non-pastoral employment impact on grazing pressure

Based on the Push-Pull Theory, the non-pastoral employment decisions of herding households are influenced by the push effects resulting from the constraints on grazing resources due to the implementation of ecological protection policies, as well as the pull effects arising from the relatively higher marginal returns of non-pastoral industries. Over the past decade, against the backdrop of deepening ecological protection policies and rapid urbanization, non-pastoral employment has become an important strategic choice for herding households to maintain their household livelihoods (Yin et al., 2019; Liu et al., 2020). As rational economic agents, herding households' decisions regarding non-pastoral employment adhere to the principle of maximizing household utility, with the expectation of enhancing economic returns through the reallocation of production factors. However, the "Eco-economic Man Hypothesis" from an ecological economics perspective further reveals that herding households' decision-making is influenced by both economic rationality and ecological rationality. Their production decision-making seeks to maximize their own economic benefits while also considering the protection and sustainable use of the ecological environment (Key and Roberts, 2009).

Non-pastoral employment serves as a crucial means for optimizing the allocation of household resources. It not only opens up new employment channels for idle labor within families, significantly enhancing overall household income, but also effectively alleviates the budget constraints of pastoral production caused by imperfections in the credit market by expanding the boundary of household income constraints (Huang et al., 2022; Xue et al., 2025). Essentially, non-pastoral employment addresses the livelihood limitations faced by herding households under resource constraints. However, when integrated into the institutional context of pastoral areas in China, it transcends the consideration of pastoral production and livelihood from a singular perspective, as it also relates to the sustainable development of grasslands. The labor transfer and income increase resulting from non-pastoral employment create realistic conditions for herding households to make ecologically rational decisions, prompting a shift in their pastoral production decisions from a sole focus on economic benefits to a balance between economic and ecological rationality, thereby profoundly impacting the achievement of grassland and livestock balance goals. Consequently, this paper explores the influence of non-pastoral employment on grazing pressure based on the logical framework of "non-pastoral employment—LRB or GSB—grazing pressure." Specifically, non-pastoral employment optimizes the allocation of household labor and resources such as grasslands, prompting households to adopt livestock reduction behaviors to alleviate ecological pressure on the grasslands; simultaneously, non-pastoral

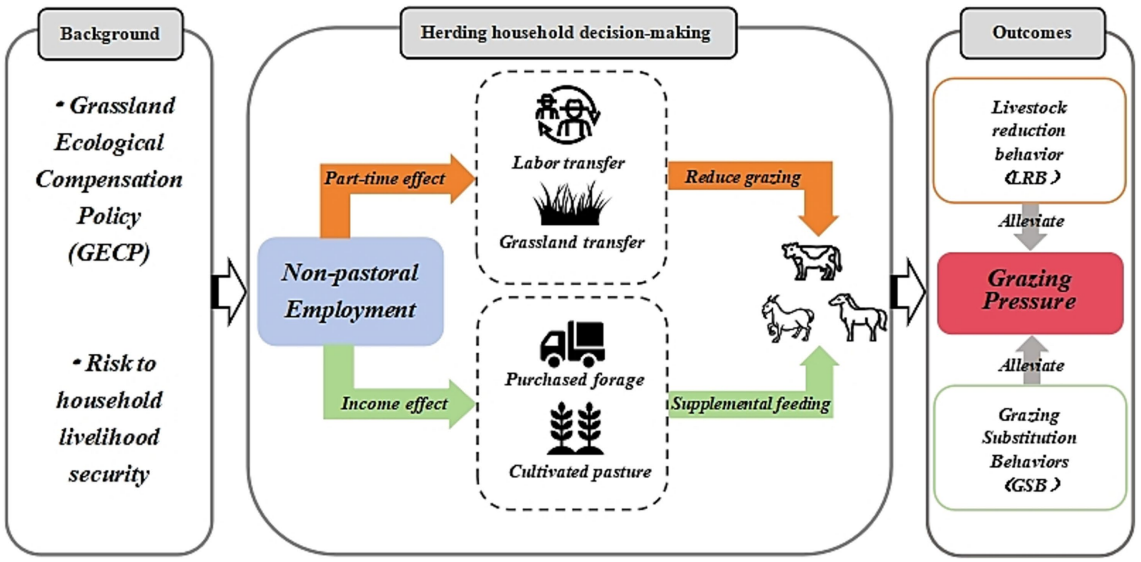

FIGURE 1
Theoretical analysis framework.

employment can mitigate the financial constraints faced by households when adopting alternative grazing behavior, thereby influencing grazing pressure (see Figure 1).

2.2 Research hypotheses

2.2.1 The effect of non-pastoral employment on the grazing pressure of herding households

The New Economics of Labor Migration posits that the non-pastoral employment of herding households is a rational choice made by their families to maximize household income (Zhu et al., 2019). The impact of non-pastoral employment on herding households is mainly in terms of pastoral labor and income structure. On one hand, non-pastoral employment can influence grazing pressure through the "part-time effect." Specifically, non-pastoral employment alters the original resource allocation methods of herding households, which in turn affects grazing pressure. In terms of labor resource allocation, animal husbandry is labor-intensive, requiring a significant amount of labor input, particularly from young and middle-aged workers (Wang D. et al., 2018; Wang J. et al., 2018). However, under the influence of ecological protection policies and the rapid development of the economy and society in pastoral areas, there is an increasingly significant trend of labor migration from pastoral to non-pastoral industries, leading to a shortage of labor for animal husbandry production within herding households (Zhou and Zhao, 2019; Wang et al., 2024). Furthermore, the main workforce being diverted to non-pastoral sectors often consists of high-quality young and middle-aged laborers, which contradicts the industry characteristic of animal husbandry that requires a certain number of young and middle-aged labor inputs (Gai et al., 2014). The supply–demand gap in pastoral labor ultimately forces herding households to reduce the scale of animal husbandry to re-balance family resource allocation, further weakening the pressure of grazing on grasslands. In terms of grassland resource allocation, herding households who engage in non-pastoral employment may choose to lease their grasslands for economic benefits due to their inability to continue managing the original scale of grassland operations (Guan et al., 2023). This process promotes the transfer of grassland resources to operating entities that possess abundant labor and production materials, which have comparative advantages in large-scale operations, forming a "allocation effect" of non-pastoralism on grassland resources in livestock production. Consequently, this alleviates the overall grazing pressure on the grasslands (Yu et al., 2025; Kong et al., 2016). Thus, it is evident that the non-pastoral employment can optimize the allocation of household labor and grassland resources among herding households, thereby alleviating grazing pressure.

On the other hand, non-pastoral employment can influence grazing pressure through the "income effect," as non-pastoral employment alters the original income structure of herding households. Specifically, non-pastoral employment impacts grazing pressure mainly through three aspects: reducing dependence on livestock production, alleviating budget constraints in pastoralism, and promoting the adoption of new technologies. Firstly, the increase in the degree of non-pastoral employment reduces the dependence of herding households on livestock production. Stable and substantial non-pastoral income not only mitigates the risk of income fluctuations within households but also effectively compensates for the economic losses incurred from reducing livestock scale or exiting livestock production (Su et al., 2024). In this context, herding households tend to regard non-pastoral employment as their primary source of income, thereby decreasing their capital and labor investment in livestock production and ultimately reducing the scale of livestock farming. Secondly, non-pastoral employment effectively alleviates the budget constraints faced by herding households. In China's pastoral areas, most herding households still rely primarily on livestock production for their livelihoods. To balance ecological protection of grasslands with family livelihood maintenance, herding households often adopt strategies such as stall-feeding, semi-stall feeding, purchasing feed supplements, or leasing grazing land to reduce the grazing pressure on natural grasslands (Teng et al., 2025). However, due to high initial investments and ongoing maintenance costs, the ecological effects of these strategies are relatively limited (Zhang et al., 2018). The increase in non-pastoral income effectively alleviates the investment constraints imposed by

resource endowments on the production decisions of herding households, facilitating the substitution and optimization of factors such as capital, labor, and land, thereby helping to alleviate grazing pressure. Thirdly, non-pastoral employment has a positive effect on herding households' adoption of new livestock production technologies. For herding households for whom animal husbandry remains the primary source of household income, income diversification significantly enhances their willingness and ability to adopt new breeding technologies, improve grazing methods, and implement advanced grass-livestock balance management strategies (Sun et al., 2018). This technological transformation not only increases the production efficiency of animal husbandry but also reduces grazing intensity while ensuring economic benefits.

In summary, this study posits that the employment choices of herders and the adjustments in their grazing behavior are rational decisions influenced by multiple logics. Firstly, due to the combined effects of ecological pressure as a "push" factor and non-pastoral income as a "pull" factor, herders tend to engage in non-pastoral employment to achieve livelihood transformation. Secondly, based on the hypothesis of the "ecological economic man," herders are likely to proactively adopt measures such as reducing livestock and alternative grazing practices under ecological constraints. This behavior not only serves ecological protection but also represents a rational response aimed at long-term livelihood security. Lastly, according to the new economics of migration theory, the "part-time effect" and "income effect" brought about by non-pastoral employment influence herders' production decisions through two pathways: the reallocation of labor resources and the alleviation of production constraints, ultimately leading to a reduction in grazing intensity. Based on this, the paper proposes the following hypothesis:

> Hypothesis 1: The "part-time effect" and the "income effect" of non-pastoral employment have a significant restraining effect on herding households' grazing pressure.

2.2.2 The mechanisms of non-pastoral employment on the grazing pressure of herding households

Based on the previous analysis, non-pastoral employment influences grazing pressure through the "part-time effect" and the "income effect" from two dimensions: employment structure and income level. Although both mechanisms restrain grazing pressure, there are significant differences in their underlying mechanisms. Reducing livestock behavior (LRB), as a direct means of lowering the number of livestock, is regarded as a core approach to alleviate grazing pressure within the framework of ecological compensation policies. However, existing ecological compensation policies face issues such as goal deviation and insufficient policy effectiveness during implementation, which stem from the livelihood dilemmas faced by herding households under resource constraints (Su et al., 2024). After adopting LRB, some herding households may experience surplus labor in their households. If the effective transfer of surplus labor is not realized, herding households, as rational decision-making agents, may engage in production behaviors that contradict policy objectives (Zhang et al., 2021). Therefore, the ability to achieve an effective transfer of surplus labor resulting from livestock reduction will impact herding households' decisions on LRB. The non-pastoral income alleviates the livelihood pressure on herding households caused by livestock reduction, thereby promoting the balance between grass and livestock. Specifically, the non-pastoral income can absorb the surplus labor issues arising from livestock reduction, facilitating the effective transfer of surplus labor within households, which better promotes LRB among herding households. Furthermore, they can gain additional income by renting out idle grasslands after engaging in non-pastoral employment, which further strengthens the positive incentive of non-pastoral employment on LRB. Based on the above analysis, this paper proposes hypothesis:

> Hypothesis 2: The "part-time effect" of non-pastoral employment is mainly to alleviate grazing pressure by promoting herding households to adopt livestock reduction behaviors (LRB).

While LRB is regarded as an effective means to alleviate grazing pressure, the marginal benefits of this approach have been diminishing year by year with the ongoing implementation of ecological protection policies (Han et al., 2024). Large-scale of LRB has not only improved the ecological environment but also triggered a livelihood crisis among herding households, leading to strategic overgrazing and secondary degradation of grasslands in some areas, ultimately undermining the effectiveness of policy implementation. It is evident that relying solely on LRB cannot serve as a long-term solution to alleviating grazing pressure, especially as it may incur certain losses for herding household (Huang et al., 2025). Against this backdrop, the practice of grazing substitution behavior (GSB) with purchased forage and cultivated pasture is gradually becoming an important measure to combat grazing pressure. However, the GSB faces a high initial investment threshold and ongoing operating costs (Liu et al., 2023), which makes it difficult for some herding households to protect grasslands through this method. In this context, external financial support plays a crucial role in overcoming the production investment constraints faced by herding households. The non-pastoral income can effectively improve the budget constraints of herding households, providing the necessary financial assurance for them to adopt GSB. Specifically, the increase in non-pastoral income helps herding households overcome the shortcomings of the local credit market, further alleviating their household budget constraints (Wang D. et al., 2018; Wang J. et al., 2018). This enables them to purchase more capital-intensive and labor-saving pastoral production materials or to increase the hiring of labor in pastoral activities, thereby adopting alternative grazing behaviors and reducing the intensity of grazing on grasslands. This financial support mechanism allows herding households to adopt scientific breeding methods more flexibly, forming a virtuous cycle of "ecological improvement - income growth." Based on the above analysis, this paper proposes hypothesis:

> Hypothesis 3: The "income effect" of non-pastoral employment mainly restrains grazing pressure by promoting herding households to adopt grazing substitution behavior (GSB).

The mechanism diagram of the impact of non-herding employment on herding pressure can be seen in Figure 2.

2.2.3 Heterogeneity in the impact of non-pastoral employment on the grazing pressure of herding households

In general, grazing pressure may be influenced by a combination of natural conditions, social factors, and policies. Compared to pure

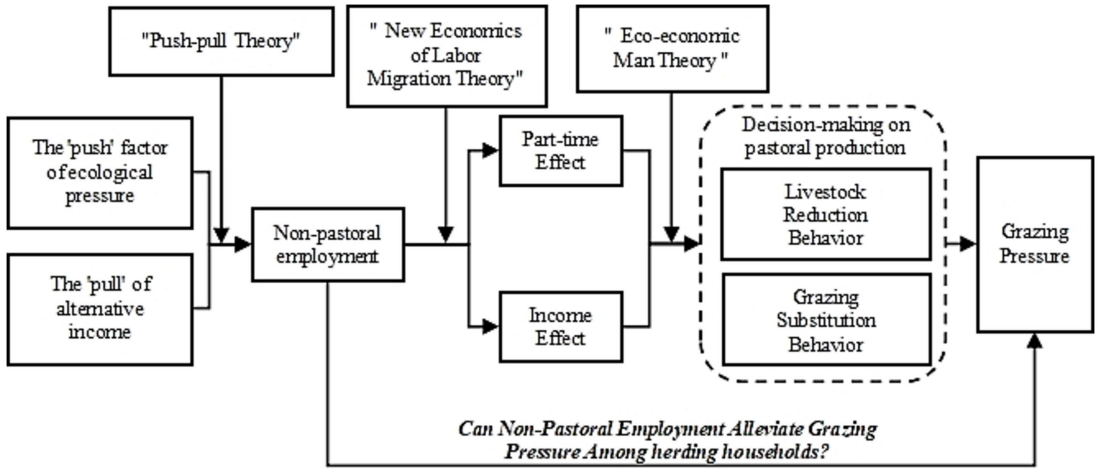

FIGURE 2
The mechanism diagram of the impact of non-herding employment on herding pressure.

pastoral areas, agro-pastoral ecotone exhibit a stronger potential for industrial transformation due to their diverse resource endowments and complex socio-economic structures. The mixed agricultural and pastoral economic model provides herding households with greater flexibility in labor resource allocation, production structure adjustment, and adoption of new technologies. This structural advantage enables herding households to respond more effectively to policy regulation and to timely adjust their production and management methods to reduce grazing intensity on grasslands. Moreover, the geographical proximity to agricultural areas offers convenient market circulation conditions and channels for technology diffusion, significantly lowering the opportunity cost of non-pastoral employment for herding households, thus facilitating their livelihood transformation and enhancing the role of non-pastoral employment in alleviating grazing pressure. Consequently, this inter-regional heterogeneity significantly influences the effect of non-pastoral employment on grazing pressure. Based on the above analysis, this paper proposes the hypothesis:

> Hypothesis 4: The impact of non-pastoral employment on grazing pressure varies due to differences in regional resource endowments.

3 Data sources and methodology

3.1 Study area

This study selects three representative pastoral areas in the Inner Mongolia Autonomous Region of China as research subjects: Hohhot City in the east, Xilin Gol League in the center, and Ordos City in the west. All three locations are significant livestock farming bases in China, possessing notable advantages for the development of animal husbandry, while also facing ecological pressures due to overgrazing. Specifically, Hohhot City (UMB, 47°05′—53°20′N, 115°31′—126°04′E) is located in eastern Inner Mongolia and includes the main portion of the Hulunbuir Grassland, one of the world's four major grasslands, which accounts for approximately 81% of the total area of natural grasslands in the city. The grasslands in this city are distributed in a strip from east to west, consisting of forest steppe, meadow steppe, and typical steppe. The total area of grasslands in the city is approximately 10.1 million acres, including 9.4082 million acres of natural grasslands, 283,000 acres of artificial grasslands, and 631,930 acres of other grasslands. This region has a temperate continental climate, with significant climate fluctuations throughout the year, and overall possesses natural conditions conducive to agricultural and pastoral development. Xilingol League (UMB, 42°32′—46°41′N, 111°08′—120°12′E) is situated in central Inner Mongolia and features the ecologically significant Xilingol Grassland, covering an area of approximately 179,600 square kilometers. It is one of the regions in China where the landscape of temperate grasslands is best preserved. The grassland types are diverse, including meadow steppe, typical steppe, and sandy shrub steppe, with high-quality pastures having a grass coverage exceeding 50%, providing a solid foundation for agricultural and pastoral development. Ordos City (UMB, 37°35′—40°51′N, 106°42′—111°31′E) is located in the western part of Inner Mongolia, with a total grassland resource area of approximately 76.2692 million acres, which includes 68.4994 million acres of natural grassland, 0.3906 million acres of artificial grassland, and 0.073792 million acres of other grasslands. Although the abundant grassland resources strongly support the local animal husbandry, the overall livestock carrying pressure in this region is more prominent than in other leagues and cities in Inner Mongolia due to the predominance of sandy and desert vegetation. The three aforementioned areas, characterized by typical grassland pastoral features, similar advantages in animal husbandry, and ecological pressures, provide a genuine research background for exploring the relationship between non-pastoral employment and grazing pressure. First, they possess comprehensive representativeness in terms of geography and ecological types. The grasslands of Inner Mongolia, as an important component of the Eurasian grassland, account for approximately 22% of the total grassland area in the country. The chosen three leagues and cities are distributed from east to west, covering major grassland types in Inner Mongolia, including meadow grasslands, typical grasslands, and desert grasslands, which can effectively reflect the characteristics of grassland ecology and pastoral production under different natural conditions across the region. Second, they are typical in terms of economic structural

transformation and the differentiation of herding households' livelihoods. With urbanization and regional economic development, these three areas have gradually formed differentiated industrial transformation paths, and the phenomenon of herding households participating in non-pastoral employment has become increasingly common.

3.2 Sampling and data collection

The data for this study was sourced from field research conducted in the pastoral areas of Inner Mongolia from January to May and in November 2024. The research areas include the Ewenki Autonomous Banner of Hulunbuir City; the Zhenglan Banner, Sunite Right Banner, and Xilin Hot City of Xilin Gol League; as well as the Hangjin Banner, Wushen Banner, Etuoke Banner, and Yijinhuoluo Banner of Ordos City. This survey primarily utilized a structured household questionnaire, supplemented by semi-structured interviews. The questionnaire covered various aspects including the demographic characteristics of herding households, family structure, livestock production conditions, and the utilization of grassland resources. Prior to the survey, researchers clearly explained the academic purpose and confidentiality policy to participants and obtained their informed consent before formally collecting data. The specific research steps are as follows: Firstly, stratified sampling was employed to select 2 to 4 banners (counties) from various leagues (cities) based on the per capita annual net income of the counties. Secondly, 1 to 3 sumu (townships) were selected from each banner (county) based on the per capita grassland area。 Thirdy, to avoid extracting ineffective samples, a typical sampling method was employed to select 2–3 gacha (villages) from each sumu, which exhibited higher levels of non-pastoral employment and a more severe phenomenon of overgrazing. Finally, a combination of simple random sampling and typical sampling methods was used to select 12 to 17 herding households as survey samples from each gacha (village). The specific operations for random sampling are as follows: (1) Establishing the sampling frame: Obtain a complete list of all herders from the village committee, including basic information such as household population, grassland area, and non-pastoral employment status, ensuring that the sampling frame is complete and without duplicates; (2) Randomly selecting samples: Based on a random number table, select 12 to 17 herder households from each village without any subjective screening criteria to ensure the randomness of the sample; (3) Sample supplementation and verification: For samples that refuse to participate or have incomplete information, replace them in the order of the random number table, ultimately obtaining 1,030 valid questionnaires. The distribution of samples is detailed in Table 1. As shown in Table 1, the proportion of herding households engaged in non-pastoral employment is relatively high across the three surveyed regions, with the highest proportion of part-time herding households in Hulunbuir City reaching 53.49%. This distribution characteristic further indicates that non-pastoral employment has become quite common in the pastoral areas of Inner Mongolia, providing a realistic data foundation for this study to explore the relationship between non-pastoral employment and grazing pressure.

3.3 Variable selection

3.3.1 Dependent variable

The dependent variable in this study is the herding households' grazing pressure. In measuring this variable, previous research has mostly compared the livestock inventory of herding households with the maximum carrying capacity that their managed grasslands can provide (Feng et al., 2023; Ma et al., 2025). However, with the transformation and upgrading of modern animal husbandry and the gradual improvement of the forage trading market, herding households' farming models have shifted from a single reliance on natural grassland grazing to a composite breeding model that combines barn-feeding and nature grazing. The traditional method for measuring the grazing pressure is solely based on the carrying capacity per unit area of grassland, failing to adequately consider the impact of external forage resource regulation, resulting in an underestimation of the theoretical grazing intensity standard and significant deviations in the measurement results. Therefore, this variable should comprehensively consider the potential forage supply space, that is, in addition to the traditional calculation of grassland carrying capacity, it should include supplementary forage obtained by herding households through cultivated pasture, purchased forage, and hay reserves to construct a more comprehensive grass-livestock balance evaluation system. Based on existing research (Shi et al., 2021; Teng et al., 2025), this paper calculates the reasonable carrying capacity for households based on the grazing area and the quantity of supplementary feeding. The supplementary feeding corresponds to the optimal breeding quantity of livestock achieved, which is determined based on the goal of maximizing livestock weight gain. This method draws on the theoretical calculations of carrying capacity for grasslands proposed by scholars such as Yan et al. (2022). Furthermore, survey results indicate that herders generally determine the livestock inventory at the beginning of the year and uniformly sell them at the end of the year, with the selling cycle typically maintained at around 12 months, and sheep are often sold as whole animals. Therefore, setting the feeding quantity with the aim of maximizing livestock weight

TABLE 1 Distribution of the survey sample.

League (city)	County (banner)	Sample size (households)	Sample proportion (%)	Pure herding household		Part-time herding household	
				(Households)	(%)	(Households)	(%)
Hulunbeier	Ewenki	387	37.57	180	46.51	207	53.49
Xilingol	Zhenglan; Sunite Right; Xilin Hot	296	28.73	216	72.97	80	27.02
Erdos	Hangjin; Wushen; Etuoke; Yijinhuoluo;	347	33.69	240	69.16	107	30.84

Field survey data.

gain aligns with the local actual breeding model. The specific calculation formula is as follows:

$$\text{Intensity}_i = N / N_T \quad (1)$$

$$N_T = \frac{\left(\text{land}_c + \text{land}_{in} - \text{land}_{out} - \text{land}_t\right)}{K} + \frac{\left(\sum \text{Grass}_i^b + \sum \text{Grass}_i^c + \sum \text{Grass}_i^d\right)}{S} \quad (2)$$

In Equation 1, Intensity represents the grazing pressure of herding households, N denotes the livestock inventory of herding households (the livestock inventory is calculated based on the conversion coefficients of sheep units corresponding to each representative species as outlined in the Ministry of Agriculture's "Calculation of Reasonable Livestock Carrying Capacity of Natural Grasslands (NY / T635—2015)," classified and totaled according to the different livestock species raised by herding households. The specific standard is as follows: 1 sheep = 1 sheep unit, 1 cow = 5 sheep units, 1 horse = 6 sheep units, and 1 peak camel = 7 sheep units. The young of sheep, goats, horses, cows, and camels are all equivalent to 0.5 of the corresponding adult livestock units. N_T is the theoretical livestock carrying capacity after summing all forage supply channels available to the herding households. Equation 2 provides the specific calculation formula for N_T, where land_c、land_{in}、land_{out} and land_t represent the contracted grassland area, rented grazing land area, leased grazing land area, and degraded grassland area, respectively; K is the standard acre coefficient stipulated by the government (The statistical basis for this coefficient originates from the official accounting coefficients published by the governments of various banners and counties). In calculating the carrying capacity obtained by herding households through supplementary feeding, it is considered that in actual production, herding households typically use a combination of various forage types for supplementary feeding, and there are significant differences in unit prices, weights, and nutritional values among different forages, resulting in varying carrying capacities. To ensure the accuracy of the calculation results, this paper unifies various types of forage into standard dry hay equivalents for computation (the conversion coefficients between different forages and standard dry hay are shown in Table 2). $\sum \text{Grass}_i^b$, $\sum \text{Grass}_i^c$ and $\sum \text{Grass}_i^d$ represent the total amount of forage purchased by herding households, the amount of grass cut from grasslands, and the yield of forage planted in grassland converted to standard dry hay, respectively. (It is important to note that the mowing field and the natural grazing field are two distinct pastures, with their purposes and accounting scopes strictly differentiated). The mowing field is solely used for artificial grass cutting, and its output is included in the reserve of manually harvested fodder. In contrast, the natural grazing field is exclusively designated for livestock free grazing, with its fodder yield corresponding to the supply from natural grazing. The accounting scopes of these two types of pastures are independent and non-overlapping, thereby eliminating any issues of double counting.). *S* denotes the annual feed intake of a standard sheep unit, calculated at 657 kilograms based on a daily intake of 1.8 kilograms per sheep unit. Ultimately, in conjunction with the relevant standards of the "Inner Mongolia Autonomous Region Grass-Livestock Balance and Grazing Ban Regulations," the grazing pressure of herding households' family grasslands is assessed. $\text{Intensity}_i \leq 1.1$ indicates that the herding households is not overgrazing; $1.1 \leq \text{Intensity}_i < 1.7$ indicates moderate overgrazing; $1.7 \leq \text{Intensity}_i < 2$ indicates severe overgrazing; $2 \leq \text{Intensity}_i$ indicates serious overgrazing. The grazing conditions of sample herding households are illustrated in Figure 3. Overall, the situation of overgrazing remains severe, with 59% of herding households still in a state of overgrazing. Among those herding households experiencing overgrazing, 35% are classified as being in a state of moderate to severe overstocking.

TABLE 2 Conversion coefficients between different forage materials and standard hay.

Forage type	Conversion factor
Green corn	0.33
Grasses	1.00
Other grasses	1.00
Alfalfa	2.00
Corn Pellets	2.50
Concentrates	2.50

The conversion coefficients in this table are referenced from the "Planning for the Protection, Construction, and Utilization of the Ertuoke Banner Grassland (2015–2020)" and the "Standards for Calculating Livestock Carrying Capacity and Grass-Livestock Balance in Natural Grasslands (DB51/T 1480-2012)." After aligning the conversion coefficients with the breeding experiences of multiple herding households surveyed, they have been fine-tuned. The hay harvested from the pasture is calculated based on the actual dry weight of the hay cut.

3.3.2 Core independent variables

This paper references existing studies (Wang et al., 2024; Hao et al., 2015) and selects the non-pastoral employment situation of herding households as the core explanatory variable, accurately characterizing its "part-time effect" and "income effect" through multiple indicators. The specific indicators are as follows: First, the "non-pastoral employment time" indicator is used to quantify the "part-time effect" of non-pastoral employment; second, the "non-pastoral employment income" indicator is chosen to measure the "income effect" of non-pastoral employment. The term "Non-pastoral employment time" refers to the total number of months that all labor forces in a pastoral household participate in non-pastoral employment. "Non-pastoral employment income" specifically denotes the total income earned by all labor forces in a pastoral household through economic activities outside of agriculture and animal husbandry, excluding transfer incomes such as ecological subsidies for grasslands. Its main components include: wage income (e.g., from migrant labor), business income (e.g., from commerce and transportation), and property income (e.g., from rent and interest). This dual indicator design can reflect the impact of non-pastoral employment on the household labor structure and also demonstrate its effect on the household income structure, thereby comprehensively assessing the impact mechanism of non-pastoral employment on grazing pressure.

3.3.3 Control variables

This study selects control variables including household head characteristics, family characteristics, external environmental characteristics, and regional characteristics (Tang et al., 2022; Lin et al., 2022). The household head characteristics include age, years of education, and health status; family characteristics encompass households loans, per capita annual income of households, total number of family members, whether to join a cooperative and total area of grazing land

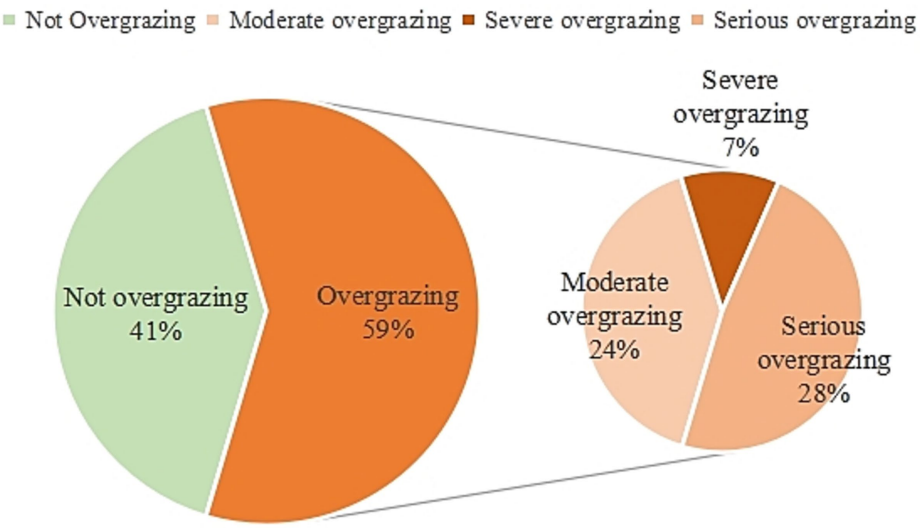

FIGURE 3
The grazing conditions of sample herding households.

managed. The external environmental characteristics consist of policy compensation amount, policy supervision, level of social services and fluctuation in livestock prices, regional characteristics include, distance from towns, number of livestock enterprises, regional dummy variables and types of grasslands dummy variables.

3.3.4 Mediating variable

Based on the different paths through which the core explanatory variables affect the explanatory variables, this paper selects the ways of alleviating grazing pressure as the mediating variable of non-pastoral employment, in order to investigate the mechanism of non-pastoral employment's influence on grazing pressure. Among them, the ways of alleviating grazing pressure mainly include "livestock reduction behavior (LRB)" and "Grazing substitution behavior (GSB)." The LRB is measured by asking herding households about their "willingness to reduce livestock in the coming year." This variable is an ordered categorical variable, assigned values as follows: 1 = very unwilling, 2 = somewhat unwilling, 3 = uncertain, 4 = somewhat willing, 5 = very willing. The selection of this indicator is primarily based on the Theory of Planned Behavior, which posits that behavioral intention is the most direct precursor to actual behavior. Using willingness as a proxy for behavior helps capture the key psychological mechanisms in the pathway of "non-pastoral employment—decision-making cognitive shift—future behavior adjustment," thereby revealing the internal logic of how external livelihood shocks influence herders' production decisions. Furthermore, existing studies often employ willingness to reduce livestock as a representation of the tendency to reduce livestock, a practice that has gained some academic recognition (Xie et al., 2018; Guan et al., 2021). The GSB is measured using the "proportion of labor time spent on barn-feeding." This indicator is derived by calculating the proportion of labor time that herding households allocate to barn-feeding management relative to the total labor time in livestock production, with a range of 0-1. Barn-feeding management activities mainly include daily feeding, preparation of feed, cleaning and maintenance of enclosures, and disease prevention within the stall. The reason for selecting this indicator is that "grazing substitution" essentially reflects the transfer of production factors (especially labor) from traditional grazing to barn-feeding management. The proportion of labor time allocation can objectively and directly reflect the intensity of resource reallocation by herders between different breeding methods, making it an effective indicator for measuring the shift in feeding methods. The definitions, assignments, and descriptive statistical analysis results of each variable can be found in Table 3.

3.4 Econometrics model

3.4.1 OLS model

Considering grazing pressure as a continuous variable, this paper establishes a multiple regression model, employing the least squares method for estimation. The specific model is as follows:

$$Intensity_i = a_0 + a_1 off_i + a_2 X_i + \varepsilon_i \quad (3)$$

In Equation 3, $Intensity_i$ represents the latent variable of the degree of herding households' grazing pressure; off_i indicates the status of household labor force transitioning to non-pastoral industries, which is measured in this paper by the number of months of non-pastoral employment and income; X_i denotes control variables that influence the grazing pressure; the random error term ε_i follows a standard normal distribution; α_1 is the estimated coefficient of the core explanatory variable.

3.4.2 Mediating effect model

In order to examine the impact mechanism of non-pastoral employment on the herding households' grazing pressure through the LRB and GSB. Referring to the study by Jiang (2022), a two-step regression method is employed to test the mechanism of mediating effects. Building on the model established earlier, appropriate mediating variables are selected, and existing theories and literature are fully utilized to demonstrate the correlation between mediating variables

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TABLE 3 Variable meaning and descriptive statistics.

Type	Specific indicators	Variable definition	Mean	Standard
Dependent variable	Grazing pressure	It is calculated through Equations 1 and 2	1.82	1.91
Independent variable	Non-pastoral employment time	Total non-pastoral time of pastoral households in 2023 (mouth).	5.11	7.96
	Non-pastoral employment income	Total non-pastoral income of pastoral households in 2023, in logarithmic form (10,000 yuan).	2.86	5.18
Control variables	Age	Age of head of herding household (years)	49.77	8.06
	Years of education	Years of education of herding household (years)	8.18	3.20
	Health state	Degree of physical health of the head of herding household, 1 = very bad; 2 = bad; 3 = fair; 4 = good; 5 = very good.	4.04	0.88
	Households loans	Total households loans of pastoral households in 2023, in logarithmic form (10,000 yuan).	6.98	10.81
	Per capita annual income of households	The amount of per capita annual income by herding households in the year 2023, in logarithmic form (10,000 yuan).	7.15	8.51
	Total number of family members	The total number of family members of the herding household.	3.51	1.05
	Whether to join a cooperative	Have herders joined rural cooperatives? 1 = Yes; 0 = No.	1.60	1.07
	Total area of grazing land managed	The area of grassland contracted and managed by herders' families(mu)	2448.31	5095.35
	The proportion of cattle	The proportion of cattle raised by herding household among all livestock in 2023	0.28	0.38
	Policy compensation amount	The amount of policy compensation amount by herding households in the year 2023, in logarithmic form, in logarithmic form (10,000 yuan).	1.13	1.88
	Policy supervision	Frequency of government monitoring of family pastures (times/year).	5.23	5.60
	Level of social services	Level of pastoral socialization services in the village where the herding household is located, 1 = No; 2 = Rather low; 3 = Average; 4 = Better; 5 = Very good.	3.46	0.93
	Fluctuation in livestock prices	Local livestock price volatility in 2022, 1 = very small; 2 = relatively small; 3 = average; 4 = relatively large; 5 = very large.	4.06	0.87
	Distance to townships	Distance of the heding households' home address from the nearest township (km)	68.84	55.37
	Number of livestock enterprises	Number of villages with livestock enterprises where herding households are located (number)	1.39	3.55
	Regional dummy variables 1	1 = Xilingol; 0 = Others	0.28	0.45
	Regional dummy variables 2	1 = Hulunbeier; 0 = Others	0.38	0.48
	Types of grasslands dummy variables 1	1 = desert grassland; 0 = Others	0.37	0.48
	Types of grasslands dummy variables 2	1 = typical grassland; 0 = Others	0.20	0.40
	Types of grasslands dummy variables 3	1 = meadow grassland; 0 = Others	0.32	0.46
Mediating variable	Livestock reduce behavior (LRB)	"willingness to reduce livestock in the coming year." This variable is an ordered categorical variable, assigned values as follows: 1 = very unwilling, 2 = somewhat unwilling, 3 = uncertain, 4 = somewhat willing, 5 = very willing	2.94	1.22
	Grazing substitute behavior (GSB)	The proportion of labor time spent on stall feeding in the total labor time of animal husbandry production	0.35	0.35

and the grazing pressure, thereby identifying potential mediating effects. The model is set as follows:

$$\mathrm{MID_i} = \beta_0 + \beta_1 off_i + \beta_3 X_i + \mu_i \quad (4)$$

$$\mathrm{Intensity_i} = \gamma_0 + \gamma_1 off_i + \gamma_2 \mathrm{MID_i} + \gamma_3 X_i + \theta_i \quad (5)$$

In Equations 4, 5 MID_i represents the mediating variable, while other variables remain the same. This study employs a two-step regression method to examine the mechanism of mediating effects, based on the following principle: if coefficients β_1 and γ_2 are both significant, it indicates that the mechanism test with MID_i as the mediating variable is validated. Furthermore, to determine whether it is a full or partial mediating effect, we can verify whether $\gamma_1$passes the significance test. If γ_1 is significant and its sign is consistent with $\beta_1 \times \gamma_1$, it demonstrates the existence of a partial mediating effect. If either β_1 or γ_2 is not significant, further validation through the Sobel test is required; if the results are significant, it indicates the presence of a mediating effect. If the mechanism test confirms that the mediating variable MID_i has a partial mediating effect, its contribution rate to the total effect can be calculated using Equation 6.

$$\varphi_i = \beta_1 \times \frac{\gamma_2}{\beta_1 \times \gamma_2 + \gamma_1} \quad (6)$$

4 Analysis of results

4.1 Basic regression results

Before conducting the model analysis, this study first performed a multicollinearity test. The results indicated that the maximum variance inflation factor (VIF) among the variables was 1.52, suggesting that the correlations among the variables were within a reasonable range and that there were no severe multicollinearity issues. Table 4 reports the estimation results of the impact of non-pastoral employment on grazing pressure before and after the inclusion of control variables in Models (1) to (4). Models (1) and (2) show that both the duration of non-pastoral employment and income have a negative impact on grazing pressure. The results of Models (3) and (4) indicate that the estimated coefficient for the duration of non-pastoral employment is −0.061, which is significant at the 1% level; the estimated coefficient for non-pastoral employment income is −0.103, also significant at the 1% level. This suggests that non-pastoral employment has a significant negative impact on grazing pressure. Considering that the cross-sectional data may be affected by heteroscedasticity, this study further conducted a White test on the OLS model. The results indicated that the null hypothesis of homoscedasticity could not be rejected. Additionally, the F-test results showed that the model fits well, further supporting the robustness of the above regression results. Thus, research hypothesis H1 is validated. Currently, the level of mechanization in animal husbandry production in most pastoral areas of China is relatively low, requiring substantial labor input, with a particularly high demand for young and middle-aged labor (Zhao et al., 2013). However, non-pastoral employment limits the labor input of herding households in animal husbandry production, which, to some extent, promotes a reduction in livestock numbers, thereby alleviating grazing pressure on grasslands. At the same time, the non-pastoral income generated from non-pastoral employment not only alleviates the livelihood pressures of herding households but also provides financial support for them to choose more scientifically and rationally grazing methods, thus contributing to the promotion of the grass-livestock balance. In this study, the data was grouped by county for regression analysis. The final results indicate that similar estimation results were obtained using data from each banner/county, suggesting that the baseline regression results possess a certain degree of robustness and universality. Detailed test results are reported in Supplementary Tables S1, S2.

The estimation results of the controlled variables indicate that the area of grazing land managed, the amount of ecological policy compensation, the intensity of policy supervision, and the fluctuations in livestock prices all have a significant negative impact on the grazing pressure. This conclusion is consistent with the findings of Qiu et al. (2020), Zhou et al. (2025), and Zhang and Tan (2022). Meanwhile, joining cooperatives also has a significant negative impact on the grazing pressure experienced. This may be due to the fact that cooperatives promote grassland consolidation, implement rotational grazing in designated areas, and supervise non-scientific grazing behaviors, thereby somewhat constraining unreasonable grazing practices by herding household, altering their methods of grassland utilization and accessibility, and ultimately alleviating grazing pressure. Additionally, factors such as years of education, distance from the town center, total household population, and the number of local private enterprises demonstrate a significant positive impact on the grazing pressure. These conclusions align with the research results of Teng et al. (2025) and Ma et al. (2025).

4.2 Endogeneity test

Baseline estimation results indicate that non-pastoral employment has a negative impact on grazing pressure. However, since both non-pastoral employment and grazing pressure are decision variables of herding households, there may be endogeneity issues between the two. On one hand, if herding households have a higher intensity of grazing, they need to invest more labor in grazing activities, which may suppress their choice of non-pastoral employment. On the other hand, due to limitations in the research design, there may be unobservable factors that influence both non-pastoral employment decisions and grazing behavior. To mitigate potential endogeneity bias, this paper employs the instrumental variable method for estimation. Following existing studies (Chang et al., 2021; Cheng et al., 2025; Liu et al., 2025), this paper selects "migration networks" (i.e., the average number of months of non-pastoral employment of other herding households in the same village, and the average income from non-pastoral employment of other herding households in the same village) as the instrumental variable for non-pastoral employment. Both variables satisfy the relevance and exogeneity conditions of instrumental variables. In terms of relevance, the non-pastoral employment decisions of herding households are often influenced by the employment choices of the labor force in the same village; the non-pastoral employment of other laborers in the village can promote the non-pastoral employment of the sampled herders through mechanisms such as information transmission, demonstration effect, and collaborative support. In terms of exogeneity, the grazing pressure of herding households is primarily determined by their internal household resources and decisions, and is generally not directly influenced by the non-pastoral employment situation of other herding households. Based on the aforementioned

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TABLE 4 The influence of non-pastoral employment on the grazing pressure of herding households.

Variables	OLS			
	Model (1)	Model (2)	Model (3)	Model (4)
Non-pastoral employment time	−0.072***	—	−0.061***	—
	(0.007)	—	(0.007)	—
Non-pastoral employment income	—	−0.124***	—	−0.103***
	—	(0.010)	—	(0.011)
Age	—	—	0.006	0.006
	—	—	(0.008)	(0.007)
Years of education	—	—	0.073***	0.074***
	—	—	(0.018)	(0.018)
Health state	—	—	0.021	0.008
	—	—	(0.061)	(0.060)
Households loans	—	—	−0.008	−0.008*
	—	—	(0.005)	(0.005)
Per capita annual income of households	—	—	−0.005	−0.009
	—	—	(0.070)	(0.070)
Total number of family members	—	—	0.223***	0.231***
	—	—	(0.054)	(0.053)
Whether to join a cooperative	—	—	−0.265**	−0.293**
	—	—	(0.134)	(0.133)
Total area of grazing land managed	—	—	−0.000***	−0.000***
	—	—	(0.000)	(0.000)
The proportion of cattle	—	—	0.203	0.204
	—	—	(0.138)	(0.137)
Policy compensation amount	—	—	−0.206***	−0.185***
	—	—	(0.045)	(0.044)
Policy supervision	—	—	−0.064***	−0.059***
	—	—	(0.010)	(0.010)
Level of social services	—	—	−0.021	−0.026
	—	—	(0.058)	(0.057)
Fluctuation in livestock prices	—	—	−0.141**	−0.140**
	—	—	(0.065)	(0.064)
Distance to townships	—	—	0.002*	0.002*
	—	—	(0.001)	(0.001)
Number of livestock enterprises	—	—	0.042**	0.041**
	—	—	(0.016)	(0.016)
Regional dummy variables	No		Yes	
Types of grasslands dummy variables	No		Yes	
F-value	100.50	140.80	15.61	16.73
Prob>F	0.0000	0.0000	0.0000	0.0000
R^2	0.089	0.120	0.245	0.258
Observations	1,030	1,030	1,030	1,030

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

instrumental variables, this paper employs the Two-Stage Least Squares (2SLS) method for estimation, with the results reported in Table 5.

The regression results from models (5) and (6) indicate that the estimated coefficients of the instrumental variables (the average non-pastoral employment time and income) are significantly

positive at the 1% statistical level, suggesting a strong correlation between the instrumental variables and the endogenous explanatory variables. The F-statistics from the first-stage regression are 115.029 and 108.453, both of which are significantly above the critical value of 16.38 at the 10% significance level, effectively ruling out the weak instrument problem. The second-stage estimation results show that both non-pastoral employment time and income have a significant negative impact on grazing pressure, further validating the research hypothesis that non-agricultural employment helps reduce grazing pressure. The Wald χ^2 statistics for the two models are 265.43 and 263.80, with corresponding p-values less than 0.01, indicating that the models are highly significant at the 1% level. In summary, the use of instrumental variable methods effectively alleviates the endogeneity issue between non-pastoral employment and grazing pressure, enhancing the credibility and robustness of the estimation results. Hypothesis H1 is further validated.

4.3 Robustness test

4.3.1 Propensity score matching

This paper employs propensity score matching (PSM) to construct a counterfactual framework aimed at correcting potential selection bias, thereby validating the robustness of the benchmark regression results. This method, proposed by Rosenbaum and Rubin in 1983, has been widely applied in fields such as medicine and economics to enhance the causal inference power in observational studies. The basic implementation steps include: first, calculating the propensity score for each individual in the sample, which is the predicted probability of receiving treatment given observable characteristics; second, matching individuals in the treatment group with those in the control group who have similar propensity scores; third, assessing the quality of the matches through balance tests; and finally, estimating the average difference in outcome variables between the treatment and control groups based on the matched sample.

Specifically, in this study, the propensity score matching method is applied to analyze the impact of non-pastoral employment on grazing pressure, with the following steps: first, dividing the sample into a treatment group (participte in non-pastrol emploment) and a control group (not participte in non-pastrol emploment) based on whether the herding households engage in non-pastoral employment; second, estimating a Logit model based on observable covariates (such as the age of the household head, education level, family labor force, etc.) to calculate the propensity scores for each herding households; next, using nearest neighbor matching to match each individual in the treatment group with the closest counterpart in the control group; and finally, comparing the mean differences in grazing pressure between the two matched groups to estimate the average treatment effect of non-pastoral employment.

To ensure the validity of the matching results, it is necessary to examine the common support conditions and evaluate the balance after matching. The common support condition requires that the propensity score distributions of the treatment group and the control group have sufficient overlap to ensure effective matching. As shown in Figure 4, the propensity score distributions of the two groups become closer after matching, with a broad overlapping area. Only a few samples were excluded due to scores exceeding the common range, indicating that this study meets the common support hypothesis.

The results of the balance test (see Table 6) show that the pseudo R^2 decreased from 0.122 to 0.020, the likelihood ratio statistic dropped from 167.67 to 21.73, and the average bias reduced from 17.3% to 6.0%. This indicates that matching significantly reduced the systematic differences in the distribution of covariates between the two groups, effectively alleviating sample selection bias. The estimates in Table 7 indicate that after controlling for selection bias, non-pastoral employment still has a significant negative impact on grazing pressure at the 1% level, with an average treatment effect of −1.1218. This means that compared to herders who do not engage in non-pastoral employment, those who do experience an average reduction in grazing pressure of approximately 1.1218 units. Furthermore, robustness checks using kernel

TABLE 5 Considers the regression results of endogeneity.

Variables	Model (5) (2SLS)		Model (6) (2SLS)	
	First stage	Second stage	First stage	Second stage
Non-pastoral employment time	—	−0.058***	—	—
	—	(0.022)	—	—
Average non-pastoral employment time	0.754***	—	—	—
	(0.070)	—	—	—
Non-pastoral employment income	—	—	—	−0.066*
	—	—	—	(0.034)
Average non-pastoral employment income	—	—	1.942***	—
	—	—	(0.186)	—
Control variables	Yes	Yes	Yes	Yes
F value	115.029***	—	108.453***	—
Wald chi^2	265.43***	—	263.80***	—
Observations	1,030	1,030	1,030	1,030

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

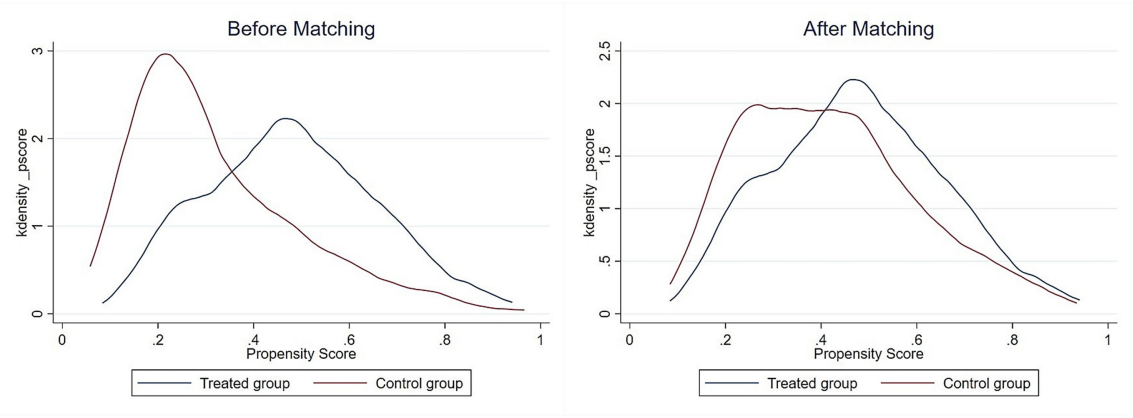

FIGURE 4
Probability distribution of propensity score values for the treatment and control groups before and after matching.

TABLE 6 The results of balance test.

Sample	Pseudo R-squared	Likelihood ratio statistic	$p > chi^2$	Mean bias	Med bias
Unmatched	0.122	167.67	0.000	17.3	11.5
Matched	0.020	21.73	0.355	6.0	5.8

TABLE 7 The results of matching scores for different tendencies.

Matching methods	Treatment group	Control group	ATT	Sta error	*T* value
Nearest neighbor matching ($K = 1$)	0.9788	2.1006	−1.1218***	0.2020	−5.55
Matching (0.01)	0.9869	2.0476	−1.0606***	0.1421	−7.47
Kerneltype matching	0.9788	2.0012	−1.0223***	0.1298	−7.87

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

matching and radius matching methods also support the conclusion that non-pastoral employment has a significant negative effect on grazing pressure, providing further validation for hypothesis H1.

4.3.2 Replacing the explained variables

To further examine the robustness of the baseline estimation results, this paper refers to existing research (Shi et al., 2022) and uses "whether overgrazed" as the dependent variable. A Probit model is employed for regression to estimate the impact of non-pastoral employment on herding households' grazing pressure. Specifically, when the livestock count of herding households at the beginning of 2023 exceeds the government's stipulated reasonable carrying capacity, it indicates that the herding household is overgrazed, with a value of 1; conversely, it indicates no overgrazing, with a value of 0. The results in Table 8 show that after changing the dependent variable, both the non-pastoral employment time and non-pastoral employment income positively alleviate the overgrazing behavior, which is consistent with the conclusions in Table 8, further confirming the robustness of the previous results.

4.3.3 The result of tail-trimming test

To mitigate the impact of extreme values on empirical results, a 1% winsorization was applied to all continuous variables. After winsorization, a regression analysis was conducted again, with the results presented in Table 9. The findings indicate that, at the 1% significance

TABLE 8 Replacement of explanatory variables.

Variables	Probit model	
	Model (7)	Model (8)
Non-pastoral employment time	−0.071***	—
	(0.006)	—
Non-pastoral employment income	—	−0.098***
	—	(0.009)
Control Variables	Yes	Yes
Pseudo R^2	0.2783	0.2670
Observations	1,030	1,030

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

level, the coefficients for non-pastoral employment duration and income have a significantly negative impact on grazing pressure, thereby demonstrating the robustness of the regression results.

4.4 Mechanism testing

This paper examines the mechanism by which non-pastoral employment affects herding households' adoption of LRB or GSB, thereby influencing grazing pressure, through the construction of a mediation effect model. Models (11) to (13) in Table 10 test the

mechanism by which non-pastoral employment duration impacts herding households' adoption of LRB and GSB, subsequently affecting their grazing intensity. Models (14) to (17) investigate how non-pastoral employment income influences herding households' adoption of LRB and GSB, again affecting their grazing pressure. The results indicate that the non-pastoral employment time has a significant positive impact on herding households' adoption of LRB at the 1% level, with a coefficient of 0.0801, while its impact on herding households' adoption of GSB is not significant. This suggests that the non-pastoral employment time significantly promotes herding households' LRB but does not significantly promote GSB. Additionally, from Model (13), it can be observed that the coefficient for the impact of LRB on herding households' grazing pressure is −0.0369. The significance test at the 1% level indicates that the greater the probability of herding households adopting LRB, the lower the grazing pressure on their household pastures. The coefficient for the impact of non-pastoral employment duration on herding households' grazing pressure is −0.3021, which is significantly negative at the 1% level and consistent with the sign of $\beta_1 \times \gamma_2$. This indicates that LRB play a partial mediating role in the pathway through which non-pastoral employment affects herding households' grazing intensity, thus validating hypothesis H2.

Similarly, The models (14) and (16) indicate that non-pastoral employment income significantly promotes the adoption of GSB among herding households. This suggests that GSB plays a mediating role in the pathway through which non-pastoral employment income impacts herding households' grazing pressure, thereby validating hypothesis H3. The regression results of the above mediation effect analysis have passed both the Sobel test and the Bootstrap test, confirming the mediating effect of the mediating variable in the influence of non-pastoral employment on grazing pressure. Furthermore, using Equation 6, the contribution rates of the mediating effects of LRB and GSB to the total effect are calculated to be 39.59% and 5.79%, respectively. It is noteworthy that the regression results from models (15) and (17) reveal that non-pastoral employment income can also influence the grazing pressure by affecting herding households' decisions to reduce livestock. A possible reason for this is that as non-pastoral employment income increases, herding households gradually decrease their reliance on livestock production, leading to decisions to reduce their farming scale.

4.5 Heterogeneity analysis

According to China's classification standards for pastoral and agro-pastoral ecoton, this study categorizes the samples into pure pastoral groups and agro-pastoral groups to analyze the heterogeneous impact of non-pastoral employment on the grazing pressure among herding households. The results in Table 10 indicate that the negative impact of non-pastoral employment income on grazing pressure shows significant differences between the two groups, while the effect of non-pastoral employment duration does not exhibit significant differences, thus partially validating hypothesis H4. This discrepancy can be explained by the following mechanisms: compared to pure pastoral areas, agro-pastoral ecoton offer relatively abundant non-pastoral employment opportunities, leading to more diversified livelihood strategies among pastoral households, who generally adopt a mixed operation model and rely less on pastoral labor (Zhou and Zhao, 2023). The increase in non-pastoral income also weakens pastoral households' identification with their pastoral identity. In this context, non-pastoral employment encourages herding households to shift their focus of resource allocation towards non-pastoral areas, actively

TABLE 9 Replacement of explanatory variables.

Variables	Tail-trimming test	
	Model (9)	Model (10)
Non-pastoral employment time	−0.060***	—
	(0.007)	—
Non-pastoral employment income	—	−0.099***
	—	(0.010)
Control variables	Yes	Yes
R^2	0.270	0.281
Observations	1,030	1,030

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

reducing the scale of pastoral production, thereby effectively lowering the pressure of grazing. In pure pastoral areas, although some household labor participates in non-pastoral employment, their income still primarily derives from pastoral activities, and the overall impact of non-pastoral income on pastoral production is relatively limited. At the same time, herding households tend to reinvest non-pastoral income back into the pastoral reproduction process, such as purchasing fodder, constructing barns, or leasing pastures (Wang D. et al., 2018; Wang J. et al., 2018). While these investments alleviate local grazing pressure to some extent, they do not fundamentally alter the family production structure dominated by pastoralism. Therefore, the inhibitory effect of non-pastoral employment income on grazing pressure is more pronounced in agro-pastoral ecoton (see Table 11).

5 Discussion

5.1 How does non-pastoral employment affect the grazing pressure among herding household?

Developing countries, represented by China, are striving to promote the transition of rural labor to non-pastoral industries through multiple avenues, aiming to increase farmers' income and advance the urbanization process. Pastoral areas not only fulfill significant ecological functions but also play a crucial role in ensuring the livelihoods of herding household and maintaining the national supply of livestock products. In the context where the transfer of labor from pastoral areas to non-pastoral industries has become an inevitable trend, a deep understanding of the impact of non-pastoral employment on the grazing pressure among herding households, as well as a systematic identification of its mechanisms, holds important decision-making reference value for the formulation of relevant policies. Based on this, this study relies on the New Economics of Labor Migration theory, utilizing micro-survey data to systematically analyze the impact effects and intrinsic mechanisms of non-pastoral employment on the grazing pressure among herding households. The research finds that non-pastoral employment significantly alleviate the grazing pressure of herding households, demonstrating positive ecological effects. This conclusion is consistent with some existing studies (Wang et al., 2024; Huang et al., 2024).

Unlike previous studies that primarily focus on the effects of non-pastoral employment on reducing livestock numbers, this paper also emphasizes the promoting effect of non-pastoral employment on GSB. As analyzed earlier, practices such as barn-feeding, cultivated

TABLE 10 Mechanisms of the role of non-pastoral employment on the grazing pressure.

Variables	Livestock reduction behavior	Grazing substitution behavior	Grazing pressure	Livestock reduction behavior	Grazing substitution behavior	Grazing pressure	Grazing pressure
	Model (11)	Model (12)	Model (13)	Model (14)	Model (15)	Model (16)	Model (17)
Non-pastoral employment time	0.0801***	0.0008	−0.3021***	—	—	—	—
	(0.0041)	(0.0014)	(0.0523)	—	—	—	—
Non-pastoral employment income	—	—	—	0.1076***	0.0158***	−0.2842***	−0.0777**
	—	—	—	(0.0065)	(0.0020)	(0.0501)	(0.0063)
Livestock reduction behavior	—	—	−0.0369***	—	—	−0.0720***	—
	—	—	(0.0081)	—	—	(0.0117)	—
Grazing substitution behavior	—	—	—	—	—	—	−0.3755**
	—	—	—	—	—	—	(0.1625)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.3546	0.0916	0.2695	0.3047	0.1420	0.2814	0.2623
Sobel test	−0.0043***	—	—	−0.0305***	−0.0059**	—	—
	(0.0023)	—	—	(0.0057)	(0.0026)	—	—
Bootstrap test	−0.0242***	—	—	−0.0305***	−0.0059**	—	—
	(0.0046)	—	—	(0.0060)	(0.0024)	—	—
Observations	1,030	1,030	1,030	1,030	1,030	1,030	1,030

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The values in parentheses under the Sobel and Bootstrap tests represent the corresponding *p*-values. The 95% confidence interval obtained from the Bootstrap mediation effect test does not include "0", indicating that the mediation effect is significantly present.

TABLE 11 Heterogeneity analysis: pastoral and agro-pastoral ecotone.

Variables	Pure pastoral areas	Agro-pastoral ecotone	Pure pastoral areas	Agro-pastoral ecotone.
	Model (16)	Model (17)	Model (18)	Model (19)
Non-pastoral employment time	−0.0669***	−0.0786***	—	—
	(0.0102)	(0.0098)	—	—
Non-pastoral employment income	—	—	−0.1106***	−0.1903***
	—	—	(0.0151)	(0.0159)
Control variables	Yes	Yes	Yes	Yes
R^2	0.2629	0.3950	0.2745	0.4928
Test for differences in coefficients between groups	−0.012		−0.080***	
Observations	665	365	665	365

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

pasture and purchased forage have become important measures to reduce overgrazing on grasslands and ensure the livelihoods of herding households. However, existing research indicates that due to high initial investment thresholds and ongoing operational costs (Guan et al., 2021), along with issues such as high idle rates of pen-feeding facilities and delays in the construction of silage pits, the actual effectiveness of pen feeding in alleviating grazing pressure on grasslands is limited. Most herding households, facing severe financial constraints, have not fundamentally changed their overgrazing behaviors (Zhang et al., 2018). In this context, external funding support plays a significant role in the production of pastoral livestock (Wang D. et al., 2018; Wang J. et al., 2018). The "income effect" brought about by non-pastoral employment can effectively alleviate family budget constraints, providing the necessary financial support for herding households to adopt GSB. This enables them to transition more flexibly to scientific breeding methods, thereby promoting the formation of a virtuous cycle of "ecological improvement - income enhancement." Previous studies have emphasized that non-pastoral employment reduces reliance on pastoralism to alleviate grazing pressure. Similarly, scholars such as Ghazali have pointed out through their

research on the livelihood strategies of pastoral nomads in southwestern Iran that as the level of non-pastoral employment increases, the dependence of herders on animal husbandry gradually diminishes. Livelihood diversification not only helps reduce the risk of poverty but also contributes to the restoration of grassland ecology. At this stage, the "part-time effect" outweighs the "income effect," as labor outflow and rising farming costs inhibit the likelihood of herders adopting GSB (Ghazali et al., 2023). However, Chinese herding households still predominantly rely on livestock farming as their main source of livelihood, and relying solely on non-pastoral income often fails to fully compensate for the income losses caused by livestock reduction. As rational decision-makers, herding households typically do not view livestock reduction as a long-term sustainable strategy; instead, they tend to reinvest non-pastoral earnings back into livestock production, thereby adopting GSB. This approach not only maintains or even expands the scale of breeding but also reduces dependence on natural grasslands. This finding supports the view that an increase in financial capital may, in fact, reinforce the "involution" of herding households "livelihoods" (Zhou and Zhao, 2023), thus clarifying why non-pastoral employment may contribute to a decrease in grazing intensity While simultaneously promoting an increase in breeding scale.

5.2 How to leverage non-pastoral employment to reduce the grazing pressure on herding households?

The grassland ecological protection policy is a mandatory administrative measure that serves as a core "push" factor influencing the non-pastoral employment of herders in the area of emigration. There are various theories regarding labor transfer, among which the dual economy theory by Lewis, the Ranis-Fei model, the Todaro model, the Schultz human capital investment model, and Stark's hypothesis on changes in relative economic status are particularly influential. These theories, from the perspective of development economics, emphasize the role of economic factors in population migration. In contrast, the push-pull theory considers economic factors while also integrating demographic, sociological, and other elements, providing a broader explanation for the motivations and barriers of labor transfer. Although the "push" of livestock reduction policies and the "pull" of alternative income jointly create certain external conditions for non-pastoral employment among herding households, they still face multiple structural obstacles in practice. The current obstacles are primarily reflected in three aspects: First, non-pastoral employment exhibits significant characteristics of part-time engagement and incompleteness. The vast majority of the labor force in pastoral areas has not completely detached from pastoral activities; instead, they display a seasonal migratory pattern akin to "migratory birds"—working in pastoral activities during busy seasons and seeking employment during slack periods. This mode of part-time non-pastoral employment maintains a somewhat tenuous relationship between pastoral households and non-pastoral jobs, as they remain engaged with pastoral activities. Due to the low level of urbanization in pastoral areas, limited local non-pastoral job opportunities, and uncompetitive wages, coupled with an inadequate social security system, pastoral households generally regard pastoralism as the "last line of defense" against the risks associated with non-pastoral employment. This part-time dominant non-pastoral employment model not only makes it difficult for herders to become a stable force in the urban labor market but also hinders the process of large-scale and modern transformation in pastoral areas to some extent. Second, pastoral labor faces significant employment barriers and social exclusion in the non-pastoral job market. During the process of working across regions and industries, herders often encounter prejudice and discrimination due to language and ethnic cultural differences, as well as the stigma associated with the label "farmers and herders," leading to their marginalization in social status. This is especially prevalent in informal employment sectors such as private enterprises and individual businesses, where violations of the legal rights of herding workers are common (Cui, 2012). These institutional and social barriers severely undermine the willingness and sustainability of pastoral households to participate in non-pastoral employment. Thirdly, herders have a deep emotional attachment and dependence on property rights related to the grasslands, forming a unique "land attachment" phenomenon. The long-established symbiotic relationship among people, grass, and livestock has led to a strong sense of personified property awareness and psychological ownership among herders regarding the grasslands. The grasslands are not only means of production but also serve as carriers of cultural identity and emotional support. In recent years, the issuance of grassland leasing rights certificates has further reinforced this consciousness of property control and emotional connection. At the same time, the development of the grassland circulation market in pastoral areas is underdeveloped, and the risks associated with circulation are high, making it difficult for herders to effectively obtain financial support for transformation and development through channels such as grassland mortgages. This further strengthens their tendency to cling to pastoralism and be cautious in transitioning.

To more effectively leverage non-pastoral employment in alleviating grazing pressure, the government should focus on removing various barriers that hinder herders from participating in non-pastoral employment, systematically enhancing their capabilities for non-pastoral employment and livelihood transformation. Specifically, building upon the continued implementation of grassland ecological compensation policies, it is essential to strengthen the promotion and guidance of non-pastoral employment channels, helping herders conceptually reduce their singular reliance on grassland resources and traditional pastoralism. Additionally, by developing vocational education targeted at pastoral areas and cultivating new types of professional herders, efforts should be concentrated on improving herders' skills for non-pastoral employment and their capacity for livelihood transformation. Furthermore, there should be an active development of characteristic industries such as deep processing of livestock products and grassland cultural tourism, extending the industrial and value chains to create more local non-pastoral employment opportunities that allow herders to remain in their hometowns while engaging in non-pastoral work. For herders with a lower willingness to engage in livestock production but stronger non-pastoral employment capabilities, organized guidance should facilitate their orderly transition to livelihoods through avenues such as external labor, promoting the rational flow of labor in agro-pastoral transition zones and gradually increasing the proportion of non-pastoral employment in herder households, thereby systematically enhancing the practical impact of non-pastoral employment in alleviating ecological pressure on grasslands.

5.3 Research deficiency

This study aims to contribute Chinese experiences to the global governance of grassland ecological environments; however, it still has

the following limitations: First, the research area focuses on Inner Mongolia, China, which has unique socio-economic and ecological conditions. Therefore, the conclusions and recommendations drawn are primarily applicable to similar pastoral areas in China. For broader promotion and application on a global scale, localized validation with data from a wider range of regions is necessary. Second, due to the limitations of the survey conditions, this study is based solely on cross-sectional questionnaire survey data. Such data may not fully represent the overall situation of pastoral areas, and its reliability requires further verification. Additionally, single-point data cannot capture the dynamic processes of variables over time, which limits the in-depth revelation of the longitudinal evolution patterns and causal mechanisms between non-pastoral employment and grazing intensity. Future research could incorporate more representative pastoral areas in China, such as Qinghai, Tibet, and Xinjiang, for comparison. By expanding the data coverage and employing panel data methods, the universality and explanatory power of the research can be enhanced, thereby providing a more systematic and dynamic explanation of the complex relationship between non-pastoral employment and sustainable governance of grasslands.

6 Conclusion

This study is based on survey data from 1,030 herding households in the Inner Mongolia pastoral region, employing an OLS model and a mediation effect model to empirically analyze the impact of non-pastoral employment on grazing pressure among pastoral households. Furthermore, it explores the heterogeneity of this impact across different regions. The conclusions are as follows:

(1) The "part-time effect" and "income effect" resulting from non-pastoral employment have a significant negative impact on the grazing pressure faced by herding households.
(2) Mechanism analysis indicates that non-pastoral employment time reduces grazing pressure by encouraging herding households to adopt livestock reduction behaviors. Meanwhile, non-pastoral employment income leads herding households to implement both livestock reduction and grazing substitution behaviors, thereby achieving a decrease in grazing pressure.
(3) Heterogeneity analysis indicates that the negative impact of non-pastoral employment time on grazing pressure is more pronounced in agro-pastoral ecoton.

7 Recommendations

(1) It is essential to emphasize the cultivation of non-pastoral employment capabilities among herders and to establish a long-term employment support system. This can be achieved by broadening employment channels and strengthening policy guidance to facilitate the orderly transition of labor from pastoral to non-pastoral sectors, while also improving the construction of the employment market to ensure the steady growth of non-pastoral income for herders. In implementation, attention must be paid to aligning training content with market demand to enhance the participation of herders, and a continuous tracking service mechanism should be established to avoid training becoming merely a formality. Additionally, proactive measures should be taken to address the potential risks of large-scale labor return due to fluctuations in the external job market, accompanied by corresponding employment placement and social stability plans.
(2) Promoting a systematic transformation of livestock production systems centered on "grazing alternative behaviors" is essential. Emphasis should be placed on supporting the construction of infrastructure such as forage bases, ecological pens, and storage and transportation of forage materials. These complementary measures will help reduce the farming costs for herders and provide support for large-scale and intensive breeding. In suitable areas such as agro-pastoral transition zones, the forage industry can be vigorously developed, and seasonal rest grazing and rotational grazing practices should be promoted to gradually reduce the grazing intensity on natural grasslands. During the implementation process, it is necessary to simultaneously improve supporting measures such as disease prevention and control, resource utilization of manure, and water-saving management, systematically addressing the ecological and health risks that concentrated breeding may pose, and steadily promoting the transformation of grazing methods towards housed feeding and semi-housed feeding.
(3) The employment promotion strategies for non-pastoral jobs should be differentiated by region and dynamically adjusted. In purely pastoral areas, in response to the characteristics of sparse populations and dispersed employment, it is essential to provide nearby services such as employment information, skills training, and contract signing, thereby reducing employment costs for pastoral households and enhancing participation rates in non-pastoral employment. In semi-agricultural and semi-pastoral areas, leveraging their industrial composite advantages, the focus should be on developing high-value-added industries such as livestock product processing and cold chain logistics, which will improve the quality of non-pastoral employment and income stability. During policy implementation, a regional collaboration and dynamic evaluation mechanism should be established, allowing for flexible adjustments based on actual conditions. This will help avoid issues of industrial homogenization and unsustainable employment, ensuring that differentiated policies are effectively implemented and yield tangible results.

Data availability statement

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

Author contributions

FJ: Conceptualization, Writing – review & editing, Data curation, Writing – original draft, Investigation, Formal analysis. WO:

Methodology, Investigation, Writing – review & editing, Formal analysis, Writing – original draft, Software, Data curation. NZ: Writing – review & editing, Software, Investigation, Methodology, Data curation. RX: Methodology, Software, Writing – review & editing, Data curation, Investigation. JZ: Supervision, Writing – review & editing, Project administration, Methodology, Conceptualization.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SUPPLEMENTARY FILE S1
Original data.

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