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# The impact of digital financial inclusion on the high-quality development of pastoral economy in China's minority regions

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**Introduction:** In the pursuit of high-quality development in the pastoral economy, digital financial inclusion (DFI) plays an indispensable role in driving progress. The system of DFI constructed through "digital technology + inclusive finance" has gradually extended various financial services, such as lending and financing, to the pastoral areas of ethnic minorities, significantly reducing the barriers and costs for herdsmen to access financial services.

**Methods:** Based on the panel data of 26 prefecture-level cities in the 9 main pastoral provinces of ethnic minorities in China from 2011 to 2022, this paper employs the entropy weight method to construct a High-Quality Development Index for animal husbandry. Utilizing fixed-effects and mediation-effect models, we analyze and elucidate the pivotal role of DFI in promoting the high-quality development of animal husbandry in impoverished regions, with particular emphasis on its underlying mechanisms.

**Results:** (1) DFI has a significant positive effect on the high-quality development of the pastoral economy in China's ethnic minority pastoral areas. Mechanism tests reveal that DFI promotes high-quality development in these regions through increased output value and income. (2) Structural heterogeneity analysis reveals that the coverage and usage depth of DFI have a significant positive effect on the high-quality development of the pastoral economy in ethnic minority pastoral areas. (3) Mediation effect tests indicate that DFI can further promote the highquality development of the pastoral economy through the trickle-down effect of non-agricultural employment and the optimization of the pastoral industry structure.

**Discussion:** This study provides theoretical support and empirical evidence for promoting the high-quality development of the pastoral economy through DFI. It also offers micro-level evidence for alleviating the funding constraints of herdsmen in remote areas without collateral through DFI.

#### KEYWORDS

digital financial inclusion, pastoral economy, high-quality development, fixed-effects model, ethnic minority pastoral areas

# **1** Introduction

Digital financial inclusion (DFI) is an extension and expansion of microcredit and microfinance, primarily providing financial services to impoverished populations and remote areas. This concept originated from the United Nations' (UN) global initiative during the "International Year of Microcredit," established through Resolution 53/197 by the UN General Assembly, which designated 2005 as the "International Year of Microcredit" to advance poverty reduction and inclusive economic growth through credit services. Subsequently, collaborative efforts between the UN and World Bank evolved this framework into an internationally recognized financial inclusion paradigm (United Nations General Assembly, 1998). By 2014, the World Bank had partnered with public and private stakeholders to implement financial inclusion programs in over 70 countries and territories, with more than 50 nations establishing explicit goals to improve financial inclusion (The World Bank, 2014). The Global Findex Report reveals that 3.8 billion adults (69% of the global population) now hold accounts with banks or mobile money providers (The World Bank, 2021); thus, it is essentially a manifestation of financial equity (Kernecker et al., 2021). The efficiency-enhancement, fairness, and sustainable-development connotations of DFI align with the goals of high-quality development in the pastoral economy (Véronique et al., 2022). In the pursuit of high-quality development in the pastoral economy, DFI is playing an indispensable role in driving progress (Thomas et al., 2022).

Currently, the development momentum of China's pastoral economy is strong. The main pastoral areas cover more than 50% of the country's total land area, and the number of livestock accounts for 22% of the total number of livestock nationwide. Moreover, the value of the pastoral economy constitutes about 30% of the total agricultural output value and is the main source of economic development and income for herdsmen in ethnic minority pastoral areas (Si et al., 2025). In recent years, with the rapid improvement of the scale level of the pastoral economy, the industry's quality has been significantly enhanced. However, the problem of financial repression in the pastoral economy remains prominent (Zhao and Guo, 2024; Wang, 2018). In ethnic minority pastoral areas, the traditional nomadic lifestyle of herdsmen, lack of suitable collateral, and vulnerability of livestock to diseases and disasters make the financing difficulties for developing the pastoral economy more widespread and prominent (Jared, 2022).

Theoretically, as the "lifeblood" of the real economy, the financial industry is not only a core element of a modern economic system but also an important component of regional industrial development. High-quality development of the pastoral economy cannot be achieved without the effective support of financial capital (Thomas et al., 2022). For a long time, traditional financial institutions have relied on physical branches to provide inclusive financial services. The high cost of operations has made attracting the favor of financial institutions difficult for remote and economically disadvantaged pastoral areas, leading to a threshold effect of missing and insufficient inclusive financial services (Yao et al., 2022). At the same time, the information asymmetry in financial markets also makes serving small and micro enterprises and people in remote areas difficult for traditional financial institutions (Bjorn, 2022). Moreover, the lack of a sound credit reporting system in remote pastoral areas often leads financial institutions to implement financial exclusion behaviors, such as increasing risk assessment requirements and reducing the types of financial products, to reduce risks (Carter, 2022).

The DFI system constructed through "digital technology + inclusive finance" has gradually extended various financial services, such as lending and financing, to the pastoral areas of ethnic minorities, significantly reducing the barriers and costs for herdsmen to access financial services. The economic development potential of these pastoral areas is being continuously activated (Deichmann et al., 2016; Dhanya et al., 2022). DFI, relying on its low barriers and wide coverage, has prompted the breakeven point to shift toward the right end of the long-tail boundary, incorporating the herdsman group originally outside the financial service field (Jared, 2022). By breaking through geographical and physical branch limitations with its "inclusiveness," digital finance can effectively alleviate the problem of information asymmetry (Melanie et al., 2023), and expand the scope and reach of financial services (María et al., 2022; Sjaak et al., 2023), not only promoting the efficient operation of financial services but also playing an important role in lowering service barriers and alleviating financial exclusion (Madhu et al., 2022; Bruno et al., 2021). To a certain extent, it has effectively solved the financial support problems of vulnerable groups in ethnic minority areas, enhanced the resilience of the pastoral industry chain, and provided "intelligence" and efficiency for the high-quality development of the pastoral economy in ethnic minority areas (Ekramul et al., 2022; Osinga et al., 2022).

Owing to the information asymmetry and high transaction costs inherent in traditional inclusive finance, herdsmen have long been impeded from accessing formal financial services, which in turn has hindered the possibility of high-quality development of the pastoral economy in remote pastoral areas (Pan et al., 2018; Si et al., 2025). DFI, leveraging its digital technology advantages, can effectively reduce information asymmetry between the supply and demand sides of various factors, providing strong support for the efficient flow of these factors and thereby facilitating enhanced efficiency in their allocation (David et al., 2021; Abdul-Salam and Phimister, 2017). On one hand, DFI can further streamline credit business processes, improve the efficiency of capital allocation, and enhance the convenience, feasibility, and security of financing. This helps to resolve the financial exclusion issues within the traditional financial system and provides sustainable financial services to economically underdeveloped areas. Thus, herdsmen and vulnerable enterprises can expand their production scale and improve production efficiency, promoting their benign development (Zheng et al., 2021; Du et al., 2023; Orsolin et al., 2022). On the other hand, DFI can overcome geographical exclusion, enabling low-income groups in pastoral areas to more conveniently access various financial services, such as loans, wealth management, and insurance. The channels for financial services become more unobstructed, thereby providing them with the possibility to use financial resources for entrepreneurship (Sekabira and Qaim, 2017), which can indirectly promote the high-quality development of the pastoral economy through the "trickle-down effect" (Wang and Fu, 2022; Pallavi and Matin, 2022). Moreover, DFI, with its unique advantages, can also significantly promote the optimization and upgrading of industrial structures. By skillfully integrating cutting-edge technologies such as artificial intelligence and big data, DFI not only reduces the difficulty of obtaining financial products and services but also greatly stimulates the intrinsic motivation and vitality of regional innovation entities, paving a solid

path for transforming and upgrading industrial structures (Jin and Chen, 2024). At the same time, DFI can expand the coverage and depth of financial services, injecting more abundant funds into the expansion of pastoral scale and technological iteration. This accelerates the transformation of the industrial structure in remote pastoral areas of ethnic minorities toward higher-level and more rational forms, promoting the high-quality development of the pastoral economy (Wang and Yu, 2024). However, the latest provincial-level research on DFI in China also shows that while it has a significant promoting effect on the development of more developed rural areas in China, its impact on the income of farmers in less developed areas is not significant (Lin and Peng, 2025). Provincial-level studies have obscured the heterogeneous contributions of disaggregated digital finance sectors and regional variations. Only when data from pastoral counties are aligned with county-level digital financial development can the true impact of digital finance on high-quality development of animal husbandry in impoverished regions be accurately reflected. Although the existing literature has conducted in-depth analyses of DFI's influence on pastoral development, all these studies have relied on provincial-level data for empirical testing. Given China's vast provincial geographical scales, substantial disparities exist in DFI development and socioeconomic conditions across cities and counties within the same province. As counties-the critical link between urban and rural areas-serve as the main arena for advancing highquality animal husbandry development, county-level analyses offer greater practical and theoretical value. The impact of DFI on the development of ethnic minority pastoral areas in China has not yet reached a consensus. On one hand, existing research has been constrained by the availability of data. On the other hand, few studies have closely integrated DFI with real industries at the prefecture-level city level—especially research on the high-quality development of the pastoral economy in ethnic minority areas closely combined with DFI. Therefore, this paper focuses on the impact of high-quality development of the pastoral economy in ethnic minority areas and adopts the "Digital Financial Inclusion Index of China" data released by the Institute of Digital Finance, Peking University. It explores the impact of DFI on the high-quality development of the pastoral economy in ethnic minority pastoral areas and investigates the transmission mechanism from the two paths of growth of the pastoral output value and income increase of herdsmen. Further, it constructs a mediating effect model to examine the role of DFI in non-agricultural employment and industrial structure upgrading in ethnic minority pastoral areas, which is conducive for the government departments to formulate policy tools for the deep integration of DFI and high-quality development of the pastoral economy. Compared with existing research, the marginal contributions of this paper are reflected in the following three aspects: (1) using prefecture-level city data as the data source, constructing a high-quality development index of the pastoral economy, exploring the impact mechanism of DFI on the high-quality development of ethnic minority pastoral areas combined with the real economy, and making up for the shortcomings of existing research that has mainly focused on provincial data; (2) elaborating on the mechanism of DFI's impact on the high-quality development of the pastoral economy, examining the impact of DFI on the high-quality development of the pastoral economy in ethnic minority pastoral areas from multiple dimensions, and empirically measuring the impact of the three dimensions of DFI coverage breadth, usage depth, and digital degree on the high-quality development of the pastoral

economy; (3) constructing a mediating effect model to explore the important role of DFI in non-agricultural employment and industrial structure upgrading in influencing the high-quality development of the pastoral economy.

# 2 Theoretical analysis and research hypotheses

DFI optimizes traditional financial systems through the internet and big-data technologies, substantially reducing intermediary service costs and transaction expenses for financial institutions while lowering access barriers for herders. This enables pastoral communities to more conveniently obtain financial products, effectively alleviating financial exclusion faced under traditional financial frameworks. In driving the high-quality development of animal husbandry, unlike the limited financial products and services offered by traditional institutions, DFI leverages big data and internet-based credit systems to enhance access to diversified financial services-including loans, payments, and insurance-via microcredit mechanisms. By accurately tracking pastoral payment behaviors and mitigating credit risks caused by information asymmetry, it reduces service barriers and facilitates herders' utilization of comprehensive digital financial services, boosting output and income growth in pastoral economies. Building on innovations in digital finance theory and practice, this study integrates long-tail theory and inclusive finance principles into a unified DFI framework. We systematically reveal its impact mechanisms on high-quality animal husbandry development in impoverished pastoral regions through direct and indirect effects. With advancements in digital and information technologies, financial inclusion no longer depends on physical branch networks, but it delivers services to remote pastoral areas through digital channels. Utilizing big-data analytics and user profiling, the system identifies individual preferences, risk profiles, and investment needs to provide personalized financial solutions. The long-tail theory reinvigorates traditional inclusive finance by emphasizing its inclusive nature and low-threshold design, enabling effective service delivery to underserved populations. This approach has considerable potential for advancing sustainable animal husbandry development in povertystricken regions. Our conceptual framework synthesizing these elements is illustrated in Table 1. The high-quality development of the pastoral economy requires sufficient financial support, yet many herdsmen are excluded from traditional financial services (Joseph et al., 2022). DFI, as a comprehensive, efficient, and low-cost new financial service model, offers a potential opportunity to address the shortcomings of traditional financial development (Oyakhilomen et al., 2021; Weersink et al., 2018). Compared to traditional finance, DFI, through the integration of digital means and financial services, can optimize resource allocation and reduce transaction costs (Kaila and Tarp, 2019; Linmei et al., 2021). These advantages play an important role in promoting the high-quality development of the pastoral economy. This paper categorizes the process by which DFI promotes the high-quality development of the pastoral economy into direct and indirect channels (Figure 1).

In terms of the direct channel, this study posits that DFI not only retains the basic financing functions of traditional inclusive finance, but it also lowers the barriers to financial services and expands the financial supply in pastoral areas. On one hand, DFI can break free

#### TABLE 1 The high-quality development index for the pastoral economy.

Variables	Secondary indicators	Content	Measurement	Nature
	Fundamental aspects of growth in the economic benefits of the pastoral economy	Meat production (tons)	Total Meat Production Data for Each Region	+
High-quality development index for the pastoral economy ( <i>Y</i> )		Proportion of pastoral economy (%)	Measured by the proportion of added value of the pastoral economy to the added value of the primary industry	+
		Labor productivity in pastoral economy (%)	Total meat production in the pastoral economy / Number of people engaged in pastoral labor	+
	Fundamental aspects of social and ecological benefits of the pastoral economy	Rural afforestation rate (%)	Rural green space area / Planned land area for village construction	+
		Comprehensive utilization rate of livestock and poultry manure (%)	(Manure treatment volume + Biogas electricity generation + Biofertilizer production + Other utilization volume) / Livestock and poultry manure generation volume × 100%	+
		<i>Per capita</i> disposable income in pastoral areas (RMB yuan)	(Total income of rural residents in pastoral areas - Household operating expenses - Tax expenditure - Depreciation of productive fixed assets - Property expenditure - Transfer expenditure) / Permanent household population	+



from the reliance on traditional physical offline institutions or financial products, embedding digital channels into various business scenarios to provide herdsmen with instant, barrier-free, and contextspecific financial services that meet the needs of different levels and fields, empowering the high-quality development of the pastoral economy (Liu et al., 2021; Rada and Jean-Christophe, 2021). On the other hand, it possesses greater geographical penetration and a low-cost advantage, increasing the coverage density of financial institutions in remote ethnic minority areas and significantly enhancing the accessibility of financial services for "long-tail customers" (Wang and Fu, 2022). By driving technological innovation, reducing transaction costs, and improving the accessibility of financial services, it can significantly enhance the financial environment of pastoral areas, providing crucial support for the high-quality development of the pastoral economy and helping to address the "last mile' issue of financial services in ethnic minority pastoral areas (Jared, 2022; Matthew et al., 2021). DFI has significantly improved the convenience of accessing financial services and reduced costs and product prices through the convenience, inclusiveness, and "affordability" of digital services; this has enabled people in remote areas to easily obtain low-cost and precise financial services and thus helped the pastoral economy to advance to a higher level of quality (Dhanya et al., 2022).

Regarding the indirect channels, DFI can promote the highquality development of the pastoral economy through non-agricultural employment and industrial structure upgrading. First, in terms of non-agricultural employment, DFI has given rise to new business models such as "Internet + Agriculture," leading to the emergence of new professions like e-commerce sales and smart agriculture, while also driving the development of related industries such as agricultural and livestock product processing and logistics transportation. This has provided herdsmen with more employment opportunities and entrepreneurial space, increased their non-agricultural income, narrowed the urban-rural income gap, and thus promoted the highquality development of the pastoral economy (Wang and Fu, 2022). Second, DFI helps financial institutions in pastoral areas enhance their digital risk management capabilities, significantly improve financial regulatory standards, continuously strengthen the entire process of credit supervision and financial support for agriculture, meet the needs of small and micro enterprises for technological innovation and market expansion, create more non-agricultural employment opportunities, and drive the high-quality development of the pastoral economy through the "trickle-down effect" (Sekabira and Qaim, 2017). Third, in terms of industrial structure upgrading, DFI can promote the high-quality development of the pastoral economy through industrial structure upgrading. DFI increases the willingness and ability of financial institutions to allocate credit funds to remote areas, significantly boosts the flow of credit funds in these regions, injects a key financial driving force into industrial structure upgrading, supports the construction of infrastructure and technological innovation in pastoral areas, and improves the economic operation efficiency and growth vitality of ethnic minority pastoral areas,

achieving high-quality development of the pastoral economy (Wang and Yu, 2024).

Therefore, DFI has played an important role in promoting the high-quality development of the pastoral economy. On one hand, by expanding coverage, increasing usage depth, and deepening the degree of digitalization, it enhances the accessibility of financial services and reduces transaction costs in remote ethnic minority pastoral areas while providing personalized products and services to promote the high-quality development of the pastoral economy, which is the direct channel. On the other hand, DFI promotes the high-quality development of the pastoral economy through the trickle-down effect by increasing the proportion of non-agricultural employment and upgrading the industrial structure, enhancing the level of regional economic development, which is the indirect channel. In summary, this paper proposes the following hypotheses:

Hypothesis 1: The development of DFI directly affects the highquality development of the pastoral economy in ethnic minority areas, and it has a significant positive impact on the growth of the pastoral output value and herdsmen's income increase.

Hypothesis 2: The three dimensions of DFI-coverage, usage depth, and digital degree affect the high-quality development of the pastoral economy, with varying degrees of influence.

Hypothesis 3: DFI can indirectly promote the high-quality development of the pastoral economy in ethnic minority areas by increasing non-agricultural employment and driving industrial structure upgrading.

# 3 Research design

## 3.1 Model specification

#### 3.1.1 Benchmark regression model

DFI empowers the high-quality development of the pastoral economy. To test Hypothesis 1, this paper analyzes the relationship between the high-quality development of the pastoral economy (Y) and the level of DFI by constructing the following econometric model to examine the impact of the development level of DFI on the high-quality development of the pastoral economy (Equation 1).

$$Y_{it} = \alpha + \beta \ln DFI_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
<sup>(1)</sup>

Further expanding the mechanism analysis, this paper explores how DFI affects the high-quality development of the pastoral economy in ethnic minority areas and sets up a mechanism model from two aspects: the output value of the pastoral industry and the income level of herdsmen. The output value level of the pastoral industry is represented by the added value of the pastoral industry (*LVA*) (Equation 2), and the income level of herdsmen is measured by the per capita disposable income of herdsmen (*DPI*) (Equation 3).

$$\ln LVA_{it} = \alpha + \beta \ln DFI_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
(2)

$$\ln DPI_{it} = \alpha + \beta \ln DFI_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
(3)

#### 3.1.2 Mediation effect model

To examine the indirect impact of DFI on the high-quality development of the pastoral economy through non-agricultural employment and industrial structure upgrading, the mediation effect model is established based on Model (1) as follows (Lin and Peng, 2025):

(1) Trickle-Down Effect Test.

To further investigate how the growth of the Digital Financial Inclusion Index affects the empowerment role in the high-quality development of the pastoral economy, the non-agricultural employment (*NFP*) indicator is introduced (Equations 4, 5):

$$NFP_{it} = \alpha + \beta \ln DFI_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
(4)

$$Y_{\rm it} = \alpha + \beta \ln DFI_{\rm it} + \lambda_1 NFP_{\rm it} + \gamma Con_{\rm it} + \mu_{\rm i} + \varepsilon_{\rm it}$$
(5)

(2) Industrial Structure Upgrading Effect Test.

Introducing the indicator of Advanced Industrial Structure (*AIS*) (Equations 6, 7):

$$AIS_{it} = \alpha + \beta \ln DFI_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
(6)

$$Y_{it} = \alpha + \beta \ln DFI_{it} + \lambda_2 AIS_{it} + \gamma Con_{it} + \mu_i + \varepsilon_{it}$$
(7)

Among them, the explained variable is the level of high-quality development of the pastoral economy in region  $i(Y_{it})$ , and the core explanatory variable is the level of digital financial inclusion (lnDFI<sub>it</sub>). If the level of DFI has a positive impact on the high-quality development of the pastoral economy in ethnic minority areas, then the coefficient of impact,  $\beta$ , in Model (1) will be significantly positive. Conversely, if the impact is negative, the coefficient will be significantly negative, or it may not be significant at all. Con<sub>it</sub> represents other variables that affect the high-quality development of the pastoral economy in ethnic minority areas, including regional environmental regulations, traditional financial development, regional population density, human capital level, and the degree of government intervention. t denotes the tth year,  $\mu$  represents the individual effect term,  $\mu_i$  indicates the cross-sectional individual differences of each province and city that do not vary over time, and  $\varepsilon_{it}$  represents the random disturbance term.

# 3.2 Measurement methods and indicator system design for high-quality development of animal husbandry

#### 3.2.1 Entropy weight method

The high-quality development of the pastoral economy is a multidimensional concept that advocates the organic combination of green ecology, high efficiency, high output, and high benefits. Existing evaluations and measurements of the high-quality development of the pastoral economy typically employ research methods such as the entropy weight method, comprehensive evaluation model with multiple indicators, coupling coordination degree model, and barrier factor diagnosis model to measure the level of high-quality development in the livestock industry. Among these, the entropy weight method is a technique that assigns weights to indicators based on their information entropy utility, which can avoid information loss associated with principal component analysis and effectively enhance the integrity and stability of data. Based on this, drawing on existing research findings and considering the essential requirements of the development of the pastoral economy in ethnic minority pastoral areas as well as the availability of key indicators at the county level, the entropy weight method is used to measure the degree of high-quality development of the pastoral economy, dividing the high-quality development index of the pastoral economy into two fundamental aspects: the growth of the pastoral economy and the social benefits of the pastoral industry (Shi and Ren, 2018).

#### (1) Data Standardization

Considering the differences in dimension and magnitude among the indicators in the high-quality development evaluation system of pastoral county economies, it is necessary to standardize the raw data using the min-max normalization method to ensure the indicators' practicability and comparability. The selected indicators include both positive and negative indicators (robustness test), which are standardized according to Equations 8, 9, respectively. The specific steps and formulas are as follows:

The calculation formula for the normalization of positive indicators is:

$$x_{ijt}^{*} = \frac{a_{ijt} - min\{a_{ijt}\}}{max\{a_{ijt}\} - min\{a_{ijt}\}}$$

$$(i = 1, 2, \dots, m; j = 1, 2, \dots, n; t = 1, 2, \dots, 12)$$
(8)

The calculation formula for the normalization of negative indicators is:

$$\begin{aligned} x_{ijt}^{*} &= \frac{\max\left\{a_{ijt}\right\} - a_{ijt}}{\max\left\{a_{ijt}\right\} - \min\left\{a_{ijt}\right\}} \\ &\left(i = 1, 2, \dots, m; j = 1, 2, \dots, n; t = 1, 2, \dots, 12\right) \end{aligned} \tag{9}$$

where  $\mathbf{x}_{ijt}^{*}$  represents the initial data of the j-th indicator for the i-th county in year t.

(2) Calculation of Entropy Values.

Calculate the proportion  $p_{ijt}$  of the i-th county in the j-th indicator in year t (Equation 10):

$$p_{ijt} = \frac{x_{ijt}^{*}}{\sum_{i=1}^{m} \sum_{t=1}^{12} x_{ijt}^{*}}$$
(10)

Calculate the information entropy  $e_j$  of the j-th indicator  $(e_i \in [0,1])$  (Equation 11):

$$e_{j} = -\frac{1}{\ln(12*m)} \sum_{i=1}^{m} \sum_{t=1}^{12} \left( p_{ijt} \times \ln p_{ijt} \right)$$
(11)

(3) Determination of Indicator Weights.

Calculate the coefficient of variation, i.e., the redundancy value  $g_j$  for the j-th indicator (Equation 12):

$$g_j = 1 - e_j \tag{12}$$

Thus, the weight w<sub>j</sub> of the j-th indicator is calculated (Equation 13):

$$w_{j} = \frac{g_{j}}{\sum_{j=1}^{n} g_{j}}$$
(13)

(4) Computation of Composite Scores.

Based on the weight values, the comprehensive score S<sub>it</sub> for each indicator is calculated (Equation 14):

$$s_{it} = \sum_{j=1}^{n} \left( w_j \times x_{ijt}^{*} \right)$$
(14)

According to Equation 14, the comprehensive index of highquality development of the pastoral economy for different counties and years is calculated, which serves as the dependent variable.

#### 3.2.2 Construction of the indicator system

Investigating the high-quality development of animal husbandry in China's ethnic minority pastoral areas constitutes a critical research priority. This study establishes a two-tiered evaluation framework, with primary indicators focusing on economic growth in animal husbandry and social benefits in pastoral areas, further subdivided into six secondary indicators. The entropy weight method is applied to assess development levels. Departing from traditional development paradigms that prioritize singular output growth, highquality animal husbandry development integrates multifaceted objectives, including enhanced food production, social welfare functions (e.g., employment), and ecological security responsibilities. Consequently, our index transitions toward a multidimensional framework encompassing output expansion, ecological sustainability, and social welfare. To assess the core outputs and structural characteristics of economic growth in animal husbandry, three indicators are employed: meat output, proportion of animal husbandry, and labor productivity in animal husbandry. Meat output refers to the total meat production at the county level, reflecting the scale of production and material output capacity, which serves as a foundational metric for evaluating the pastoral sector's economic base. The proportion of animal husbandry is defined as the ratio of value-added in animal husbandry to that of the primary industry, measuring the sector's significance within the agricultural economy; a higher proportion indicates stronger regional economic contributions from animal husbandry. Labor productivity in animal husbandry, calculated as the ratio of total output to the number of engaged laborers, quantifies the efficiency of labor input relative to output, with higher ratios signifying more efficient production systems. Furthermore, the assessment of social benefits in pastoral areas incorporates three indicators: rural greening rate, comprehensive utilization rate of livestock waste, and per capita disposable income in pastoral areas, which collectively evaluate the coordination between regional development, ecological preservation, and residents' quality of life. The rural greening rate, defined as the proportion of green space to planned rural construction land area,

measures the level of ecological conservation and sustainable development in pastoral regions. A higher greening rate directly contributes to mitigating land desertification and maintaining biodiversity. The comprehensive utilization rate of livestock waste reflects the efficiency of resource recycling and pollution control, with elevated rates indicating the adoption of environmentally sustainable production practices. Last, per capita disposable income in pastoral areas serves as a direct metric of herders' economic wellbeing and stands as a core livelihood indicator for evaluating developmental outcomes in these regions. The specific indicator construction is shown in Table 1.

### 3.2.3 Construction of robustness indicators for high-quality development

This study conducts robustness tests by replacing the dependent variable. Using the entropy weight method in objective weighting methods to measure the level of common prosperity, we reconstruct a new indicator for high-quality development of the pastoral economy (Y1) to replace the original dependent variable (Y). Retaining the meat output, labor productivity, and per capita disposable income in pastoral areas from Table 2, this approach verifies the model's sensitivity to quantitative measures, assesses its reliance on efficiencydriven growth rather than pure scale expansion, and evaluates the stability of income distribution equity's impact on high-quality development. The Engel coefficient-defined as the proportion of food expenditure to total consumption expenditure-is introduced as a new social benefit dimension variable that inversely measures residents' living standards. This metric validates whether economic growth aligns with consumption structure optimization, thereby strengthening the model's explanatory power, as shown in Table 2.

### 3.3 Explanatory variable description

Given the increasingly prominent trend of the integration between inclusive finance practices and innovative digital finance, DFI, represented by internet-based financial services, has become an important driving force and growth point for social financial development (Thomas et al., 2022). Considering the scientific and comprehensive nature of the study, this research selects the Digital Financial Inclusion Index compiled by the Research Center for Internet Finance at Peking University as the core explanatory variable.

#### 3.3.1 Digital financial inclusion index

In recent years, China's DFI has achieved remarkable progress, exerting substantial global influence. This study adopts the Digital Financial Inclusion Index developed by Peking University's Institute of Digital Finance, which constructs a comprehensive measurement system comprising three dimensions—coverage breadth, usage depth, and digitalization degree—based on the aggregate index. This framework incorporates 33 specific indicators. Coverage breadth includes metrics such as the number of digital payment accounts and the proportion of card-binding users; usage depth evaluates financial service penetration across payment, credit, insurance, investment, and credit-related activities; and digitalization degree assesses mobile adoption, affordability, credit accessibility, and service convenience. By employing this index, our analysis achieves both longitudinal and cross-sectional comparability, enabling precise and holistic measurement of DFI development at the county level in China.

The DFI system is a comprehensive summary based on the connotations and characteristics of digital finance, with each indicator and dimension reflecting a specific aspect of the overall DFI. To truly reflect the inclusive value of digital finance, considering not only its population and geographical coverage but also its usage depth is essential. Moreover, the digital and mobile nature of financial services significantly enhances the reach of financial services and effectively reduces their costs, which should also be reflected in the Digital Financial Inclusion Index.

### 3.3.2 Control variables

To maximize the control of various factors affecting the high-quality development of the pastoral economy and prevent potential endogeneity issues, based on previous research, this paper selects the following control variables for analysis: (1) Traditional Financial Development. DFI is a new financial model formed by integrating modern digital information technology based on traditional finance. Therefore, traditional financial development is an essential sub-variable in this study. Traditional financial development is measured by the ratio of the

Variable	Secondary indicators	Contents	Measurements	Sign
High-quality development of the pastoral economy $(Y_i)$	Destandance de la distance	Meat production (tonnes)	Total meat production data for each region	+
	Pastoral growth indicator	Pastoral labor productivity (%)	Total pastoral output / Number of people engaged in pastoral labor	+
	Economic benefit indicator	Engel's coefficient (%)	(Food expenditure / Total consumption expenditure) × 100%	_
		Per capita disposable income in rural areas (RMB yuan)	(Total income of rural residents - Household business expenses - Tax and fee expenditure - Depreciation of productive fixed assets - Property expenditure - Transfer expenditure) / Number of permanent household residents	÷

TABLE 2 Indicators for robustness tests.

Control variables	Unit	Description of control variables
Traditional Financial Development ( <i>TFI</i> )	%	The year-end balance of deposits and loans of financial institutions in various regions / local GDP
Environmental Regulation( <i>ER</i> )	10, 000 yuan / square kilometer	Regional economic development level / regional area
Rural Internet Penetration Rate( <i>Com</i> )	%	Proportion of Internet users in the region to the permanent resident population
Number of Financial Industry Employees(FP)	Persons	Average number of employees in the financial industry in the region at the end of the year
Regional Population Scale( <i>DOP</i> )	Person / square kilometers	Population of prefecture-level cities / area of prefecture-level cities
Urban–Rural Income Gap( <i>URID</i> )	%	Per capita disposable income of urban residents / per capita disposable income of rural residents
Human Capital Level(EDU)	year	The average years of education of rural residents
Government Intervention Degree(GOVN)	Billion yuan	General government fiscal expenditure / regional gross product
Transportation Convenience( <i>ROAD</i> )	Kilometers / square kilometers	Total kilometers of highways / area of prefecture-level cities

#### TABLE 3 Selection of control variables.

year-end deposit and loan balances of financial institutions to local GDP. (2) Environmental Regulation. Environmental regulation is an important norm for monitoring regional environmental pollution and reflects carbon-emission levels. This indicator can be used to reflect the carbon-emission situation of ethnic minority pastoral development. Considering that pastoral areas with better economic development levels have higher environmental quality requirements, when the environmental regulatory capacity is certain and the regulatory intensity greater, the smaller the regional area, the higher the environmental regulatory level, and the stronger the environmental regulation. Therefore, this paper uses the ratio of regional economic development level to city area to measure the environmental regulation indicator (Li et al., 2021). (3) Rural Internet Penetration Rate. Measured by the proportion of internet users in the region to the permanent population. (4) Number of Financial Industry Employees. The number of financial industry employees is related to the scale of regional financial institutions and is an important indicator affecting the level of regional financial development. This indicator is represented by the average number of employees in the financial industry at the end of the year in the region. (5) Regional Population Scale. Measured by the population density indicator, which is the ratio of the permanent population in the region to the city area. (6) Urban-Rural Income Gap. The urban-rural income gap is measured by the ratio of per capita disposable income of urban residents to that of rural residents. The smaller the ratio, the smaller the urban-rural income gap. This indicator has good intuitiveness and availability. (7) Human Capital Level. Represented by the average years of education. The level of human capital reflects the impact of labor quality on the high-quality development of the pastoral economy. (8) Government Intervention Degree. Based on the proportion of general government fiscal expenditure to regional GDP. (9) Transportation Convenience. Measured by the ratio of the total kilometers of roads to the area of the prefecture-level city. Below is the selection and explanation of control variables for this study (see Table 3).

# 3.4 Sources of data and descriptive statistical analysis

Combining the practice of livestock development in pastoral areas and based on data availability, this paper selects the sample period from 2011 to 2022, focusing on the panel data of 26 prefecture-level cities in nine major pastoral provinces of China, which results in 312 observations as shown in Table 4.

The study examines the impact of DFI on the high-quality development of the pastoral economy and its mechanisms of action across different dimensions, as well as the potential "trickle-down effect" and industrial structure upgrading effect of DFI on livestock development in ethnic minority pastoral areas. Data on DFI come from the Digital Financial Inclusion Index compiled by the research team of the Institute of Digital Finance at Peking University. The data for the remaining research variables are all sourced from the China Statistical Yearbook, China Rural Statistical Yearbook, China County Statistical Yearbook, and relevant pastoral province statistical data during the period of 2012 to 2023. For missing and omitted data, linear interpolation and ARIMA imputation methods are used to fill in the gaps to ensure data integrity. Additionally, to eliminate heteroscedasticity in the data, logarithmic transformation is applied to some variable data. According to the descriptive statistics of the sample data, the Digital Financial Inclusion Index and other indicators of the 26 prefecture-level cities in the nine major ethnic minority pastoral provinces in China, which serve as the research objects for DFI development levels, show significant differences across regions, with a minimum value of 18.910 and a maximum value of 304.091, indicating a large disparity between the two. The dependent variable-the high-quality development of the pastoral economy-also exhibits noticeable differences across regions, generally ranging between 0.088 and 0.968. Similar significant differences between the minimum and maximum values are observed for other indicators, reflecting the imbalanced development among different regions.

Variables	Abbr	Obs	Mean	S.D	Min	Max
High-quality development of the pastoral economy	Y	312	0.356	0.226	0.088	0.968
Digital Financial Inclusion	DFI	312	178.999	73.729	18.910	304.091
Coverage breadth of digital finance	COV	312	173.664	83.228	1.750	347.617
Usage depth of digital finance	DEP	312	161.739	67.849	13.950	271.057
Digitization degree of digital finance	DIG	312	227.460	74.408	6.150	402.499
Traditional Finance Index	TFI	312	2.786	1.318	0.732	7.446
Environmental regulation	ER	312	154.404	223.639	1.033	892.608
Rural Internet Penetration Rate	Com	312	8.409	5.981	2.759	24.003
Number of Financial Industry Employees (person)	FP	312	4335.962	3311.852	10.000	12700.000
Population density (persons/square kilometers)	PD	312	151.519	130.111	5.000	363.000
Urban–Rural Income Gap	URID	312	2.749	0.618	1.497	3.688
Human Capital Level	EDU	312	1.221	0.872	0.375	3.409
Government Intervention Degree	GOVN	312	0.483	0.475	0.079	2.673
Transportation Convenience	ROAD	312	0.403	0.393	0.024	1.902

#### TABLE 4 Descriptive analysis results.

# 4 Analysis of empirical results

# 4.1 Test of direct effects

# 4.1.1 Benchmark regression: digital financial inclusion empowers high-quality development of the pastoral economy

Based on a fixed-effects model (Kaila and Tarp, 2019), this paper systematically assesses the mechanisms through which the DFI level affects the high-quality development of the pastoral economy. It conducts a Hausman test and rejects the hypothesis of using a random-effects model, indicating that the fixed-effects model is more appropriate for this study.

Table 5 presents the estimation results of the impact of DFI on the high-quality development of the pastoral economy. In Models (1)–(4) of Table 5, the coefficient estimates of DFI are all significantly positive, which suggests that DFI has a significant positive effect on promoting the high-quality development of the pastoral economy, thereby validating Hypothesis H1. In fact, with the development of financial technology and the new quality of productive forces, as well as the continuous improvement of the DFI level, prefecture-level cities in China have gradually changed the situation where traditional finance is concentrated in urban areas. Digital finance has increasingly benefited low-income groups and remote and vulnerable populations. It has provided more diversified financial services to people in pastoral

areas, reduced the credit constraints and costs of enjoying financial services for vulnerable groups in pastoral areas, and effectively alleviated the financing constraints faced by herdsmen due to the lack of credit. Ultimately, as the DFI level increases, the level of highquality development of the pastoral economy also continues to rise.

Judging from the impact coefficients of the control variables, in Model (3) of Table 5, the regression coefficient of the Traditional Finance Index (TFI) is significantly positive at the 5% level. The possible reason is that an increase in the TFI often indicates the prosperity and stability of the financial market, which can provide more financing opportunities and financial support for pastoral areas. This not only helps to alleviate the shortage of funds in pastoral areas but also promotes the upgrading and transformation of the pastoral industry. The regression coefficient of Environmental Regulation (ER) is significantly positive at the 1% level, indicating that the region has a higher environmental carrying capacity, which is an important foundation for promoting the high-quality development of the pastoral economy. According to the "green paradox" theory, environmental regulation may produce results contrary to policy intentions. On one hand, environmental regulation increases herdsmen's production costs by internalizing the negative externalities of energy consumption and pollution emissions caused by livestock production, namely the "compliance cost effect" (Sinn, 2008). On the other hand, the "pollution haven hypothesis" suggests that environmental regulation may prompt

#### TABLE 5 Regression results.

Variable	High-quality development of the pastoral economy				
	Model (1) FE	Model x (2) RE	Model (3) FE	Model (4) RE	
	0.074***	0.074***	0.011**	0.019***	
InDFI	(14.03)	(14.03)	(2.27)	(5.23)	
TFI			0.007**	0.002	
			(2.01)	(0.63)	
lnER			0.029***	0.001	
			(2.65)	(0.20)	
lnCom			0.024	0.025	
			(1.11)	(1.14)	
lnFP			-0.007	0.001	
			(-0.35)	(0.09)	
lnPD			0.019	0.005	
			(0.58)	(0.68)	
MP			-0.048**	-0.039*	
			(-2.14)	(-1.78)	
EDU			0.189***	0.205***	
			(15.05)	(19.41)	
GOVN			-0.001	0.006	
			(-0.02)	(0.40)	
ROAD			0.002	0.011	
			(0.14)	(0.81)	
cons	-0.019	-0.019	-0.021	0.024	
	(-0.70)	(-0.36)	(-0.09)	(0.024)	
Ν	312	312	312	312	
R <sup>2</sup>	0.4084	0.0229	0.8678	0.9667	
	chi2(1)	) = 0.10	chi2(10) = 17.36		
Hausman test	0.7	539	0.0668		

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

pollution-intensive herdsmen to move to regions with weaker environmental regulation, forming a "pollution haven" (Lanoie et al., 2011), thereby shifting livestock farming to areas with less environmental pressure. The regression coefficient of the Urban-Rural Income Gap (URID) is -0.048, which is significantly negative at the 5% level. This may be due to the significant differences among regions in terms of the ownership, application, and innovation capabilities of information and network technologies. The development of digital technology may further widen the information gap and exacerbate the wealth disparity, leading to the so-called "digital divide" issue (Adams, 2000), which is not conducive to the sustainable development of the pastoral economy. The Human Capital Level (EDU) is significantly positive at the 1% level. An increase in the level of human capital can promote the quality of financial services and innovation of financial products, enhancing the financial inclusion of herdsmen and popularization of financial services. In turn, the popularization and improvement of financial services can further promote the level of human capital. With the support and incentives of financial services, herdsmen are encouraged to invest in education and training to improve their knowledge and skills, which ultimately contributes to the highquality development of the pastoral economy.

# 4.1.2 Further discussion: testing the three dimensions of digital financial inclusion

The Digital Financial Inclusion Index is a comprehensive indicator that measures the extent of financial service inclusion in the digital age. This index reflects the development of DFI through three dimensions: Coverage breadth (COV), Usage depth (DEP), and Digitalization degree (DIG). To enhance the accuracy and depth of this study, the impact of each of these dimensions on the high-quality development of the pastoral economy was tested separately, with the results presented in Table 6.

As shown in Models (5) and (6) of Table 6, both the coverage breadth and usage depth of DFI have a significantly positive impact on the high-quality development of the pastoral economy at the 1% level. This indicates that the widespread dissemination and in-depth development of financial services are more conducive to promoting the high-quality development of the pastoral economy. However, the digitalization degree does not have a substantial impact on the highquality development of the pastoral economy. This may be due to the fact that ethnic minority pastoral areas are geographically remote and vast, with scattered herdsman populations, which makes laying wired networks difficult and results in low network coverage. This severely restricts the popularization and application of digital services in

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TABLE 6 Regression results of dimensional tests.

Variable	COV	DEP	DIG
	Model (5)	Model (6)	Model (7)
Y	0.023***	0.018***	0.005
1	(6.09)	(5.23)	(1.49)
TFI	-0.019	0.383	0.941***
	(-0.05)	(1.14)	(2.71)
lnER	-0.508	1.749*	3.721***
	(-0.44)	(1.77)	(3.54)
lnCom	23.543	2.717	2.745
	(1.16)	(1.32)	(1.27)
lnFP	-0.374	-0.679	-0.450
	(-0.21)	(-0.37)	(-0.23)
lnPD	1.787	2.745	2.411
	(0.55)	(0.83)	(0.69)
МР	-3.550*	-3.882*	-4.761**
	(-1.66)	(-1.79)	(-2.09)
EDU	19.019***	18.716***	18.855***
	(16.00)	(15.51)	(14.91)
GOVN	1.224	1.139	-0.930
	(0.87)	(0.79)	(-0.65)
ROAD	-0.720	0.699	0.384
	(-0.44)	(0.43)	(0.22)
	10.281	-0.639	-5.041
cons	(0.47)	(-0.03)	(-0.22)
Ν	312	312	312
R <sup>2</sup>	0.8813	0.8774	0.8664

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

pastoral areas. The relatively backward development of digital customer, digital product, and digital technology indices in pastoral areas indicates that commercial banks in these areas still have certain shortcomings in the "hard" behavioral aspects of acquiring and maintaining digital customers, designing and implementing personalized, differentiated, and customized digital products, and innovating and applying digital technologies. In terms of coverage breadth, DFI has a substantial impact on the agglomeration of beef cattle industry at the 1% level. For every 1% increase in coverage breadth, the level of high-quality development of the pastoral economy increases by 0.023%.

In terms of usage depth, for every 1% increase in usage depth, the level of high-quality development of the pastoral economy increases by 0.018%. These results suggest that in the process of promoting the development of DFI, greater emphasis should be placed on ensuring accessibility of financial services for herdsmen, expanding the scope of financial coverage, and paying attention to the actual usage depth and frequency of financial services by herdsmen, to maximize the role of DFI in promoting the high-quality development of the pastoral economy. While digitalization levels in impoverished pastoral regions exhibit a positive impact, the effect remains statistically insignificant. Currently, lower digitalization levels in pastoral and underdeveloped areas—attributable to infrastructure limitations and herders' digital literacy gaps—partially hinder their ability to fully benefit from DFI.

#### TABLE 7 Analysis of mechanism test.

Variable	lnLVA	lnDPI	
	Model (8)	Model (9)	
LDF	0.243***	0.398***	
INDIF	(4.00)	(16.49)	
Control variables	Y	Y	
Fixed effects	Y	Y	
Ν	312	312	
R <sup>2</sup>	0.3824	0.1644	

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

# 4.1.3 Mechanism test of the impact of digital financial inclusion on high-quality development of the pastoral economy

To further explore the mechanisms through which DFI affects the high-quality development of the pastoral economy, this paper examines the impact of DFI on changes in pastoral output and herdsmen's income from the perspective of the components of highquality development of the pastoral economy, as shown in Table 6.

(1) From the Perspective of Output Changes.

The added value of the pastoral industry is the most direct reflection of changes in pastoral output. The mechanism through which DFI promotes high-quality development of the pastoral economy by optimizing the industrial structure is reflected in the increase in output. The results show that in Model (8) of Table 7, DFI has a significantly positive impact on the added value of the pastoral industry at the 1% level. This result is consistent with the theoretical part discussed earlier. DFI continuously optimizes the industrial structure of the pastoral economy through its effect on industrial structure upgrading, fully leveraging the economies of scale in the industry, and indirectly promoting an increase in pastoral output, thereby enhancing the level of high-quality development of the pastoral economy.

(2) From the Perspective of Income.

As discussed in the theoretical section, DFI promotes non-agricultural employment, which in turn drives the high-quality development of the pastoral economy, primarily reflected in income growth. The results show that in Model (9) of Table 7, after relevant control variables are controlled for, the estimated coefficient of DFI is significantly positive at the 1% level. This indicates that DFI can benefit low-income herders in ethnic minority regions through a "trickle-down effect," indirectly promoting their development and prosperity and thereby enhancing the confidence of herders, as the main body of pastoral areas, in driving the high-quality development of the pastoral economy.

## 4.2 Mediation effects tests

#### 4.2.1 Trickle-down effect

Regarding the measurement of non-agricultural employment, this paper selects the proportion of employees in the primary industry (in reverse) to measure the non-agricultural employment indicator. This is because a decline in the proportion of employees in the primary

#### TABLE 8 Results of mediation effects tests.

Variable	Y	NFP	Y	AIS	Y
	Model (10)	Model (11)	Model (12)	Model (13)	Model (14)
LDEI	0.0111**	-3.3562***	0.0055	0.3672***	0.0068
mDF1	(2.27)	(-6.49)	(1.06)	(6.08)	(1.31)
NED			-0.0017***		
NFF			(-2.99)		
415					0.0118**
A15					(2.44)
TFI	0.0073**	0.4120	0.0080**	0.0642	0.0066*
	(2.01)	(1.07)	(2.23)	(1.43)	(1.82)
lnER	0.0297***	3.0264**	0.0348***	-0.0236	0.0300***
	(2.65)	(2.56)	(3.11)	(-0.17)	(2.70)
lnCom	0.0239	-0.6989	0.0227	-0.0620	0.0246
	(1.11)	(-0.31)	(1.07)	(-0.23)	(1.16)
lnFP	-0.0067	-1.5251	-0.0093	0.2737	-0.0100
	(-0.35)	(-0.75)	(-0.49)	(1.16)	(-0.52)
lnPD	0.0199	-11.8719***	-0.0000	0.7793*	0.0107
	(0.58)	(-3.26)	(-0.00)	(1.84)	(0.31)
MP	-0.0481**	0.4495	-0.0473**	0.2082	-0.0505**
	(-2.14)	(0.19)	(-2.13)	(0.75)	(-2.27)
EDU	0.1892***	-0.0026	0.1892***	0.5016***	0.1832***
	(15.05)	(-0.00)	(15.26)	(3.24)	(14.43)
GOVN	-0.0002	-3.4139**	-0.0060	-0.0398	0.0002
	(-0.02)	(-2.14)	(-0.40)	(-0.21)	(0.02)
ROAD	0.0024	-0.4343	0.0016	0.0379	0.0019
	(0.14)	(-0.24)	(0.10)	(0.18)	(0.11)
	-0.0210	74.8930	0.1047	-7.5532	0.0682
cons	(-0.09)	(3.12)	(0.46)	(-2.70)	(0.30)
Ν	312	312	312	312	312
R <sup>2</sup>	0.8678	0.2575	0.8719	0.4221	0.8706

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

industry typically indicates that labor is shifting toward non-agricultural industries. Moreover, changes in the proportion of employees in the primary industry also reflect adjustments in the industrial structure. When the proportion of employees in the primary industry decreases, it usually means that the proportion of employees in the secondary and tertiary industries is increasing, which reflects the optimization and upgrading of the regional economic structure and is conducive to accelerating the process of achieving the highquality development of the pastoral economy. The specific empirical results are shown in Table 8. Models (11) and (12) in Table 8 reflect the full mediating effect of the non-agricultural employment indicator in the process of DFI promoting the high-quality development of the pastoral economy. In Model (11), the regression coefficient of DFI is significantly negative, indicating that the DFI level has a negative impact on the non-agricultural employment indicator (proportion of employees in the primary industry), which is consistent with the expectations discussed earlier. Combining the data analysis of Models (10) and (12) shows that DFI can promote the high-quality development of the pastoral economy through its negative impact on the non-agricultural employment indicator.

In fact, the "income-increasing and poverty-reducing" effect of DFI can be achieved by increasing non-agricultural employment in a "non-migrant" manner. With the relaxation of institutional factors such as household registration and social security, as well as the gradual improvement of transportation, logistics, and communication technologies, the long-standing problem of traditional financial exclusion in pastoral areas has been alleviated. Herders in ethnic minority regions can conveniently access low-cost credit and various other financial services through DFI. This helps promote the development of secondary and tertiary industries in pastoral areas, such as processing, sales, and distribution of agricultural and livestock products, thereby releasing pastoral labor and redirecting surplus labor to non-agricultural sectors in pastoral areas. This increases the proportion of non-agricultural employment in pastoral areas and raises the income of local herders. Meanwhile, the development of secondary and tertiary industries in pastoral towns also gradually drives the development of new business forms and scenarios such as rural e-commerce and leisure tourism. According to the "trickle-down effect" theory, the economic growth brought about by the development of DFI can benefit low-income groups by promoting employment,

indirectly optimizing the employment structure in pastoral areas and promoting the prosperity of herders' lives, thereby promoting the high-quality development of the pastoral economy.

#### 4.2.2 Industrial structure upgrading effect

DFI development can promote the optimization and upgrading of the pastoral industrial structure, driving the pastoral industry toward high value-added, high-efficiency, and low-carbon directions. This paper measures the upgrading of the industrial structure using an indicator of industrial structure sophistication, which refers to the shift of industrial focus from lower to higher levels of industry, specifically measured by the ratio of the added value of the tertiary industry to that of the secondary industry. The empirical results are shown in Table 8. In Model (13), the regression coefficient of DFI is 0.367 and significant at the 1% level, which confirms that DFI can promote regional industrial structure sophistication. Combining the data analysis of Models (10) and (14) shows that DFI can promote the high-quality development of the pastoral economy by optimizing the industrial structure.

Currently, the deep integration of DFI with traditional pastoral industries is becoming an important driving force for the high-quality development of the pastoral economy. Digital elements in DFI possess important characteristics such as non-rivalry and positive externalities, which traditional factors do not have, and these characteristics will have a substantial impact on the transformation of production methods and the upgrading of industrial structures. In the process of promoting the rapid development of the pastoral economy and the transformation and upgrading of animal husbandry, DFI guides the main flow and overall distribution of social funds through differentiated credit policies and threshold restrictions. It encourages financial capital to flow toward industries in pastoral areas with high capital demand and high efficiency, while simultaneously raising the financing thresholds for livestock enterprises with high energy consumption and poor performance. This optimizes the allocation of resources and the structure of animal husbandry, continuously enhances the economies of scale in animal husbandry, significantly improves the efficiency of economic operations and vitality of economic growth, creates a favorable economic environment for industrial structure upgrading, and drives the industrial structure to shift toward a more advanced and rational direction.

Under the condition of constant control variables, this study employs a mediation effect model and applies the Bootstrap non-parametric percentile method with 5,000 replications to test the mediating roles of the proportion of primary industry employment and industrial structure upgrading in the relationship between the Digital Financial Inclusion Index and high-quality development of animal husbandry. The test results are presented in Table 9. Specifically, the direct effect of the proportion of primary industry employment falls within a 95% confidence interval that excludes zero, indicating a partial mediation effect of primary industry employment between DFI and high-quality development of animal husbandry. Regression results reveal a mediation effect estimate of -0.0017 for primary industry employment, implying that changes in the number of primary industry workers exert a 0.17% influence on the high-quality development of animal husbandry. For industrial structure upgrading, the adjusted indirect effect also resides within a 95% confidence interval excluding zero, which confirms its mediating role between DFI and high-quality pastoral development. The estimated mediation effect is 0.0118, which suggests that DFI enhances high-quality development of animal husbandry by 1.18% through industrial structure upgrading. This outcome can be interpreted as the proportion of primary industry employment exhibiting an inverse relationship with non-agricultural employment. The negative coefficient estimate for primary industry employment implies that increased non-agricultural employment positively impacts highquality pastoral development. This demonstrates that DFI can elevate the proportion of non-agricultural employment among pastoral workers, driving high-quality development. Simultaneously, DFI is closely linked to industrial structure optimization, facilitating advanced industrial restructuring and promoting sustainable, highquality growth in animal husbandry.

## 4.3 Robustness tests

This paper mainly employs the following methods to test the robustness of the empirical results. First, high-quality development of the pastoral economy (Y1) serves as a robustness test indicator for measuring the level of high-quality development of the pastoral economy in this paper, and its expected direction is consistent with that of high-quality development of the pastoral economy (Y). The regression analysis results are presented in Model (15) of Table 10, and the conclusions drawn are consistent with those of the benchmark model, indicating the robustness of the research findings.

Second, the robustness test was conducted by excluding some prefecture-level cities that do not primarily rely on the pastoral economy for their income. The results are shown in Model (16) of Table 10. The regression results indicate that the effect of DFI on the high-quality development of the pastoral economy remains significantly positive. The coefficients and significance levels of the core explanatory variables did not change substantially, which suggests that the benchmark regression results are highly reliable.

# 4.4 Endogeneity tests

Empirical results demonstrate that DFI significantly enhances the high-quality development of animal husbandry. However, the impact of the current level of DFI on pastoral development may exhibit temporal lag effects, meaning its facilitating effects might not manifest immediately. To address this potential endogeneity, we employ Instrumental Variable (IV) approaches and Generalized Method of Moments (GMM) estimation. The study utilizes the one-period lagged term of the core explanatory variable, DFI (L1.DIF), as the instrumental variable. As shown in Table 11, after endogeneity is controlled for, the coefficient of the instrumental variable (L1.DIF) on the explained variable (Y) remains significantly positive at the 1% level, with L1.DIF passing identification tests. The first-stage F-statistic of 496.33 confirms a strong correlation between the instrumental variable and DFI, ruling out weak instrument concerns. The secondstage regression yields an estimated coefficient of 0.044 for highquality pastoral development, further validating the facilitating role of DFI. System GMM estimation results, reported in Table 11 (Model 19), show that the sign and significance of core explanatory variables align with baseline regression findings. Both endogeneity-related tests confirm the validity of panel regression results.

Variable	Effect	Pathway	Coefficient	Std. Err.	LLCL	ULCL
Employment in the primary sector Indirect ef	Direct effect	Digital Financial Inclusion → High- Quality Development of Animal Husbandry	0.0296	0.0045	0.0208	0.0384
	Indirect effect	Digital Financial Inclusion → Employment in the Primary Sector → High- Quality Development of Animal Husbandry	0.0002	0.0005	-0.0008	0.0012
	Direct effect	Digital Financial Inclusion → High- Quality Development of Animal Husbandry	0.0243	0.0047	0.0152	0.0334
Industrial structure Upgrading	Indirect effect	Digital Financial Inclusion → Industrial Structure Upgrading → High-Quality Development of Animal Husbandry	0.0054	0.0017	0.0021	0.0088

#### TABLE 9 Model bootstrap results.

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

#### TABLE 10 Results of robustness tests.

Variable	Alternative dependent variables	Reduced sample	
	Model (15)	Model (16)	
DIF	0.017*** (4.43)	0.011** (2.31)	
Control variables	Yes	Yes	
Fixed effects	Yes	Yes	
Ν	312	288	
R <sup>2</sup>	0.9123	0.8779	

\*, \*\* and \*\*\* denote statistical significance at 10, 5 and 1%, respectively. Figures in parentheses represent t values.

#### TABLE 11 Results of endogeneity tests.

Variable	25	GMM	
	Model (17)	Model (18)	Model (19)
	lnDIF	Y	
In DIE		0.044***	0.044***
InDIF		(6.72)	(6.64)
I 1 InDIE	0.687 ***		
L1.mDII	(60.10)		
Control variable	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes
Ν	312	312	312
Adj. R <sup>2</sup>	0.9475	0.9721	0.9721

# 5 Research conclusions and strategy implications

## 5.1 Research conclusions

Inclusive finance is a global challenge, and the development of digital and financial technology has injected new vitality and momentum into it. Whether DFI can truly promote the high-quality development of the pastoral economy has become a hot topic in academia. This paper selected 26 prefecture-level cities in 9 pastoral provinces in China from 2011 to 2022 as the research objects to deeply explore the relationship between DFI and the high-quality development of the pastoral economy. The following research conclusions were drawn through empirical tests. First, DFI has a significantly positive impact on the high-quality development of the pastoral economy in economically underdeveloped regions, which is different from the existing research conclusion that DFI has no impact on regions with lower levels of economic development. In fact, only by combining DFI with specific real industries can we better reveal the internal laws of DFI's role in promoting the high-quality development of the pastoral economy in poor areas. Second, DFI has a direct effect on the high-quality development of the pastoral economy. We constructed an index for the high-quality development of the pastoral economy in ethnic minority areas and revealed the mechanism through which DFI affects the high-quality development of the pastoral economy in underdeveloped regions through empirical simulation. Among the three sub-dimensions of DFI, mainly coverage breadth and usage depth play a role, while the impact of the digitalization degree is not significant. Third, mechanism testing revealed that DFI promotes the high-quality development of the pastoral economy mainly in two aspects: herdsmen's income growth and the increase in the output value of the

pastoral industry. DFI can promote the high-quality development of the pastoral economy in ethnic minority areas by promoting non-agricultural employment of herdsmen in pastoral areas and upgrading the industrial structure. This paper provides theoretical references for further deepening the understanding of the development patterns of DFI in the new development stage and for scientifically and reasonably promoting the high-quality development of the pastoral economy.

## 5.2 Strategy implications

The core function of DFI lies in serving the real economy, with particular emphasis on advancing high-quality development of animal husbandry in impoverished regions. By strengthening its support for the pastoral sector, DFI ensures herders' access to essential funding and resources. This study expands the research scope on DFI's economic impacts in pastoral areas, providing quantitative evidence and multidimensional analytical arguments. Currently, low digitalization levels in pastoral and underdeveloped regions-driven by infrastructure gaps and herders' limited digital literacy-restrict their ability to fully benefit from DFI. Therefore, policymakers must strengthen infrastructure development and related initiatives to enable DFI to serve herders better and more deeply. To further enhance the efficacy of DFI, all regions should accelerate the construction and optimization of digital infrastructure, comprehensively expand its coverage breadth, usage depth, and particularly, its digitalization level in rural areas. Given the indirect effects, coordinated development of DFI across regions should be prioritized, with policy tilts toward underdeveloped areas to intensify support for the animal husbandry sector, creating a more favorable environment for its high-quality development. Simultaneously, financial regulation must be reinforced to ensure the accessibility and security of financial services for herders, further advancing the progress of high-quality animal husbandry. Specific recommendations are as follows.

First, DFI is an important driving force for promoting the highquality development of the pastoral economy. The positive role of DFI in driving the high-quality development of the pastoral economy must be fully leveraged. Enhancing the application capabilities of vulnerable groups in utilizing DFI and accelerating the penetration of DFI into low-income populations and underdeveloped regions are critical steps. Improving the access efficiency of new types of infrastructure, such as cloud computing, big data, blockchain, and internet platforms, is also necessary. In particular, in ethnic minority pastoral areas, greater investment should be made in constructing new financial infrastructure. By achieving a comprehensive integration of payments, credit, and digital technologies, the inclusiveness of DFI can be fully utilized. This will help to release the "digital dividend" of DFI to the greatest extent and actively promote the sharing of development outcomes among people in pastoral areas, making DFI an important driving force for achieving high-quality development of the pastoral economy.

Second, to promote the breadth and depth of DFI in ethnic minority areas, financial institutions should regularly conduct financial literacy campaigns targeting herdsmen and provide specialized training on the operation of financial service platforms. This will enhance herdsmen's awareness and operational capabilities regarding DFI, mitigate the invisible financial exclusion caused by difficulties in using financial service platforms, and help herdsmen bridge the "digital divide." By doing so, herdsmen can fully utilize digital financial resources to serve the pastoral industry, promoting the high-quality development of the pastoral economy.

Third, considering the positive moderating role of the industrial structure upgrading effect in promoting the high-quality development of the pastoral economy through DFI, the government should guide the scientific layout of the pastoral industry and enhance policy support for pastoral production processes and sectors. Continuously optimizing the allocation structure of data elements and other production factors, improving the efficiency of factor allocation, and accelerating the transformation and upgrading of the industrial structure as well as the increase in productivity is essential. The advantages of DFI should be fully utilized to support the development of small and medium-sized enterprises in pastoral areas by improving financing efficiency, optimizing the allocation of financial resources, and accelerating technological innovation, among other means, and to guide them toward high value-added, high-tech-intensive industries. The ultimate goal is to achieve sustainable socioeconomic development.

Fourth, given the significant differences in economic development levels, geographical conditions, and the current state of rural areas across different regions, establishing inclusive mechanisms for DFI at the micro level based on local resource endowments is essential. This approach aims to break the "threshold effect" that traditional finance imposes on low-income rural groups and alleviate the income-increasing pressure on herdsmen. By employing financial education and training, the digital financial literacy of low-income groups in pastoral areas can be enhanced, mitigating their "digital exclusion" and "self-exclusion." Ultimately, this will achieve the inclusiveness and universality of DFI in ethnic minority pastoral areas, continuously coordinate regional economic development levels, and promote the high-quality development of the pastoral economy.

# 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

JW: Conceptualization, Methodology, Writing – original draft. XZ: Investigation, Supervision, Writing – review & editing. YuD: Project administration, Writing – review & editing. YiD: Methodology, Project administration, Writing – original draft. JC: Funding acquisition, Resources, Writing – review & editing. YL: Conceptualization, Investigation, Software, Writing – original draft.

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The authors declare that the research 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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