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Do Differences in Modes of Production Affect the Ability of Ecological Restoration Projects to Improve Local Livelihoods?

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Abstract: Large ecological restoration projects have been widely implemented across the world since the 20th century, yielding complex ecological, economic, and social results. Today, balancing ecological restoration with local people's livelihoods is a key issue. Based on the existing literature, this study proposes a "shock adaptation" mechanism to describe the response of rural residents' livelihoods to the impact of ecological restoration projects. We hypothesize that adaptability varies across the modes of production. To verify our hypothesis, we used the machine-learning-based local projection (LP) method to analyze China's Three-North Shelter Forest Program (TNSFP), with data for 596 counties from 2001 to 2020. After the TNSFP started, rural residents' income dropped, rose, and then exceeded the starting point over 8 years. Moreover, significant heterogeneity exists between agricultural and pastoral areas. Agricultural areas recover faster and improve livelihoods, while pastoral areas take longer to bounce back. The results confirmed the "shock adaptation" mechanism and suggested the importance of the mode of production. Policymakers should add more social–ecological indicators to their evaluation systems, allow local communities more self-management, and offer extra help to those struggling to recover from shocks.

Keywords: ecological restoration projects in China; mode of production; rural livelihood improvements; agricultural and pastoral areas; Three-North Shelter Forest Program

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1. Introduction

Ecological restoration is the process of assisting in the recovery of degraded, damaged, or destroyed ecosystems to restore valued characteristics inherent to that ecosystem and to provide goods and services that people value [1]. Since the mid-twentieth century, the United States, the former Soviet Union, Japan, India, and other economies have implemented ecological restoration programs at the national level, aiming to simultaneously improve the environment, promote employment, and boost demand. In 1978, China started the Three-North Shelter Forest Program (TNSFP), the largest ecological restoration project in the world. It aims to boost greenery and fight land degradation in the northwest, north, and northeast regions of China through various measures, including afforestation and mountain closure. According to data released by the Chinese government, the TNSFP achieved a cumulative afforestation and preservation area of 30,142,700 hectares from 1978 to 2018. The forest coverage rate of the project area increased from 5.05% in 1977 to 13.57% in 2017. Approximately 15 million people have relied on specialty fruit and the forestry industry in this area to achieve stable poverty alleviation [2] (p. 1). However, incompatible with the above goals, the TNSFP still suffers from problems, including a singular forest structure and the mismanagement of resources [2] (pp. 68–70). There is still a conflict between ecological construction and livelihood needs [3,4]. Some observers have found that, because the greening rate occupies an important position in performance assessment, some local governments blindly implement ecological restoration projects. These not only fail to improve the ecological environment but also affect the normal production activities and lives of residents, exacerbating tensions between people and nature [5]. In this study, we will take the TNSFP as an example to examine the relationship between ecological restoration projects and rural livelihoods, exploring the key factors that affect the effectiveness of ecological restoration projects. However, it is first necessary to review the literature.

Researchers have carried out many studies on the relationship between ecological restoration projects and resident welfare. Ecological restoration projects can impact welfare in three main ways: (1) by boosting output and employment through public investment; (2) by enhancing socioeconomic benefits from project outcomes; and (3) by incurring costs and losses for various reasons.

Shropshire and Wagner (2009) and Weinerman et al. (2012) pointed out that ecological restoration projects can stimulate local economies and employment by favoring local labor and materials [6,7], akin to a Keynesian economic stimulus strategy. This means that an increase in demand in one sector can set off a chain reaction throughout the industry chain. Therefore, the economic impact of ecological restoration should be seen as a comprehensive outcome that includes both direct and indirect benefits to the local community and economy. In an empirical study, Baker (2004) first used the multiplier approach to estimate the impact of ecological restoration projects on new employment and the corresponding industrial value added in Humboldt County, California, USA [8]. This method has been widely used and provided evidence of the economic benefits of ecological restoration projects [9]. However, some researchers have pointed out that the stimulus effects of projects can significantly vary across scales, regions, and types. Employment multipliers also do not describe the quality of jobs. This makes it difficult to accurately measure the impacts of ecological restoration projects on the well-being level [10]. To avoid such omissions, later researchers have sought to examine the socioeconomic benefits of ecological restoration projects from a more integrated perspective. They have shown that the consequences of implementing ecological restoration projects—primarily, improving ecosystems and related facilities—must be taken into account.

Modern ecological researchers have pointed out that healthy ecosystems offer many things we need, including climate regulation and hydrologic regulation, which are called ecosystem services [11–15]. These services can be translated into social benefits in various ways, including increasing property values, increasing incomes associated with tourism and outdoor activities [16], increasing income from fishing and hunting [17], and reducing the environmental costs of production and living [17,18]. Evaluating ecosystem services usually takes two approaches: a physical quality assessment and a value quantity assessment. The former examines the actual quality of ecosystem services, using methods like on-site experiments, remote sensing, geographic information systems, and surveys. The latter tries to put a monetary value on these services to account for differences in their tangible measurements. It uses methods like the market value, opportunity cost, shadow pricing, and willingness to pay surveys. The above techniques and methods have also been widely used in a Chinese context. Zhao et al. [19] adopted an improved ecological project–benefit dynamic assessment method, and they found that the annual net benefit increases in the TNSFP, Natural Forest Protection Project, and Grain-for-Green Project were CNY 461.7 billion, 2930.5 billion, and 530.1 billion, with a rate of return of 29.3%, 328.9%, and 77.0%, respectively.

In addition to impacts on ecosystem services, attention has also been paid to the micro-mechanisms by which ecological restoration projects improve the livelihoods of residents. Researchers have found that ecological restoration projects may lead to the construction of farmland and water conservancy infrastructure, which helps in industrial restructuring [20]. These projects also promote local economic development by increasing the human capital in the project area [21] or, more directly, raising resident incomes, thus promoting poverty alleviation and prosperity through policy subsidies [22]. Many studies have shown that ecological restoration has a significant positive impact on absolute poverty alleviation [23–25]. In the rocky desertification area of Guizhou Province, the industrialized poverty alleviation model of pasture pastoralism achieved a win–win situation, leading to poverty reduction and ecological improvement by synergistically operating multiple resources and elements [26]. Forestry-based ecological poverty alleviation in Western China has not only increased farmer income but has also proven to have long-term effects [27].

However, ecological restoration projects do not necessarily improve the local population's livelihood and are accompanied by many unforeseen costs and losses. For example, insufficiently developing alternative industries leads to economic shrinkage and a decline in incomes. Other issues include weak laws, poor government action against illegal land grabs, not enough public involvement, and no solid plan to ensure fairness and social gains from the project's irrational construction design. Additionally, plantation forests can consist of monocultures, be poorly resistant, and consume excessive groundwater resources, representing further issues [28,29]. These factors can potentially weaken or even subvert the effects of ecological restoration.

Notably, traditional pastoral communities may be less likely than agricultural areas to gain livelihood improvements from ecological restoration projects. Over the past few decades, the pastoral lifestyle has been increasingly confronted with various global pressures, including modernization processes, insecure land tenures, and the integration of market economies [30]. Researchers have observed that pastoral residents exhibit insufficient adaptability to ecological restoration projects in economic, institutional, and cultural terms [31,32]. In economic terms, the local industrial structure is singular, the industrial support capacity is insufficient, and the sustainable development capacity is weak [33]. In institutional terms, there are deviations in the cognitive concepts, formulation, and implementation process of ecological restoration projects [34,35]. For example, some radical ecological restoration projects require herders to dispose of a large quantity of livestock in a short period, greatly lowering market prices and inflicting significant losses on their livelihoods [36] (p. 2). In cultural terms, ecological restoration projects have often overlooked the unique "local knowledge" of pastoral areas [37,38].

Some environmental sociology and ecological anthropology studies have pointed out that grassland herders have created special rules for living with nature, like moving animals, sharing pastures, reciprocal cooperation, and caring for the environment. Externally imported ecological restoration projects can easily ignore this uniqueness and blindly promote standardized and homogenized engineering measures, resulting in tensions between human beings and nature [38–40]. This reality specifically manifests in two problems. The first is planting trees and grasses instead of employing natural restoration, which results in "planting trees every year and dying every year". Consequently, the project becomes a fight for financial support and fails to effectively improve livelihoods [41]. Secondly, employing simple closure and relocation policies, rather than organized use, increases costs for herders and disrupts the natural cycle, leading to pasture degradation. [36,41–43]. Thus, compared with other areas, communities where pastoralism is the main mode of production may be more impacted during ecological restoration projects, and it is more difficult to enjoy the gains provided.

The literature discusses the ways ecological restoration projects affect people's livelihoods and the related evaluation methods, providing useful policy lessons for public administrators. However, most studies have focused only on the three main ways ecological restoration projects affect livelihoods, lacking a holistic view of the structural changes in society, particularly ignoring the counterproductive effects of heterogeneity in production patterns on the impacts of ecological restoration projects. Exploring heterogeneity in the modes of production is not only innovative but can also, to some extent, consider the key point of sustainable ecological governance, which is particularly important for a developing country like China, with a vast territory and diverse modes of production. It is thus worth asking to what extent the differences in the modes of production affect the ability of ecological restoration projects to improve people's livelihoods. Are the results statistically significant?

Based on the existing research, this study aims to examine the relationship between ecological restoration projects and the livelihoods of rural residents, exploring the key factors that influence the effectiveness of ecological restoration projects. Generally speaking, this study provides contributions through two aspects. First, it proposes a "shock adaptation" mechanism to describe how residents respond to ecological restoration projects, including three hypotheses:

Hypothesis 1. *With the passage of time, the impact of ecological restoration projects on local livelihoods will turn from negative to positive.*

Hypothesis 2. *Compared with pastoral areas, agricultural areas can obtain more positive benefits from ecological restoration projects.*

Hypothesis 3. *In areas where initial natural conditions are extremely harsh, ecological restoration projects can always improve local livelihoods better than average.*

Second, based on the machine-learning-based local projection (LP) method, this study builds panel data including 596 counties in the TNSFP and then estimates the long-term response of rural residents' per capita disposable income to this ecological restoration project. The regression results cannot reject Hypotheses 1 to 3 at a significant level, confirming the existence of the "shock adaptation" mechanism and demonstrating that heterogeneity in modes of production can affect the ability of ecological restoration projects to improve livelihoods.

2. Theoretical Mechanisms and Research Hypotheses

Before discussing the heterogeneity of the modes of production, it is necessary to obtain a holistic understanding of the ways ecological restoration projects impact local livelihoods. Instead of purely considering the pull effect of project investments, this study focuses on the structural changes that such projects bring to local communities and how residents respond to these changes. Based on the literature, this study uses the term "shock adaptation" to summarize this process and explains it in both ecological and socioeconomic terms.

The theory of social–ecological system integration holds that there is a dynamic coupling relationship between human society and the natural world. The two are closely connected, forming a complex adaptive social ecological system. This system is influenced and driven by its own and external factors, and it has characteristics such as unpredictability, self-organization, complexity, historical dependence, multi-stability, and system resilience [44,45]. Adaptability is an important attribute that characterizes the trajectory of social–ecological system evolution and describes how this system responds to external disturbances. However, there is currently no unified definition. According to the definition provided by the Intergovernmental Panel on Climate Change (IPCC), adaptive capacity refers to the ability of a system to adapt to climate change in order to reduce potential losses. It is mainly used to analyze the adaptability of communities, countries, and regions to external disturbances caused by climate change and natural disasters [46,47]. Maldonado and Moreno-Sánchez (2014) believe that adaptability refers to the ability of a household to predict and respond to natural or human-induced disturbances, minimize them, and recover from the results of these disturbances [48]. Engle (2011) believes that adaptability is a potential characteristic of individuals, communities, and social ecosystems in responding to threats and opportunities [49]. Generally, adaptability is defined as the ability to cope with disturbances and take advantage of new opportunities.

In this study, "shock" represents various economic, ecological, and cultural impacts caused by ecological restoration projects, while "adaptation" means that residents adjust their labor, capital, and technology to maintain or improve their livelihood levels in response to those impacts. In the beginning, implementing ecological restoration projects may prevent residents from utilizing natural resources, leading to economic contraction and decreasing income when alternative industries are insufficiently developed [36]. Subsequently, as the ecosystem stabilizes and the supply of ecosystem services increases [50], residents adjust their livelihood strategies, utilize new resources and infrastructure to arrange production activities, and strive to maintain or even increase household income [51,52]. However, given the difficulty of directly applying existing technologies, experiences, and production materials to new livelihood activities, adaptation can only be gradually completed. Therefore, ecological restoration projects have a gradual effect on local livelihoods over time. In the beginning, these shocks may have negative impacts. With the ecosystem service supply's improvement and the transformation of the modes of production, these negative impacts will gradually dissipate, and improvements in livelihoods can be achieved.

Based on the mechanism analysis above, this study proposes Hypothesis 1:

Hypothesis 1. *With the passage of time, the impact of ecological restoration projects on local livelihoods will turn from negative to positive.*

Communities may have significant differences in adaptability regarding production methods, leading to differing performance when dealing with the impact of ecological restoration projects. As we discussed in the literature review, pastoral residents have insufficiently adapted to ecological restoration projects in several ways [31,32]. By contrast, agricultural production allows farmers to develop diversified businesses, such as by incorporating construction, manufacturing, and trade, opening up sources of income and enabling them to hone various livelihood skills [53]. Thus, when an ecological restoration project occurs as an external shock, farmers are more likely to adapt to changes in a relatively short period.

Considering the heterogeneity of these two modes of production—traditional agriculture and traditional pastoralism—we propose Hypothesis 2:

Hypothesis 2. *Compared with pastoral areas, agricultural areas can obtain more positive benefits from ecological restoration projects.*

Based on Hypothesis 2, we continue to consider adaptability under different initial natural conditions. Much evidence suggests that ecological restoration projects play an important role in both ecology and livelihood improvements in China's arid and semi-arid areas [54–56]. Zhou et al. (2020) summarized the current research status of China's desertification control models [57], which can be divided into five types: (1) comprehensive management modes such as grassland protection and construction in the completed fenced pasture areas of Uxin Banner, Inner Mongolia [58]; (2) combination modes such as ecological sand fixation projects and water-saving irrigation technology, for example, mulched drip irrigation on rice in Ningxia [59]; (3) integrated development modes such as the characteristic sand, forest, and fruit industries in the Kubuqi Desert in Ordos, Inner Mongolia [60]; (4) multi-compound ecological industrial modes such as agriculture–forest–herding–grass, for example, grassland pastoralism in Bashang area, Hebei [61,62]; and (5) development modes such as the ecological economy and ecological manor economy, for example, the ecological manor economy in Tailai, Heilongjiang [63]. Therefore, it can be inferred that both agricultural and pastoral areas can benefit from environmental improvements brought about by ecological restoration projects.

Based on the above analysis, this study derives Hypothesis 3:

Hypothesis 3. *In areas where initial natural conditions are extremely harsh, ecological restoration projects can always improve local livelihoods better than average.*

3. Materials and Methods

Our analysis shows that ecological restoration projects can restore the ecological environment, increase the supply of ecosystem services, and increase production and income for local populations by improving the natural environment. Appropriate ecological restoration projects that match the local production conditions can achieve the desired policy effects, whereas policies that do not match these production conditions are less effective and may even have the opposite effect. To test the above hypotheses, in the next section, we will use the LP method to investigate the effectiveness of policies for implementing ecological restoration projects in communities with different modes of production. We will present some basic information about the study area, provide a brief description of the methodology, and describe the sources and processing of the empirical data.

3.1. Study Area

On 25 November 1978, the State Council approved the "Plan for the Construction of Large-Scale Protective Forests in the Key Areas of Sand Hazard and Soil Erosion in the Three Norths", officially launching the TNSFP. The scope of the project covers 13 provinces, including Beijing, Tianjin, Hebei, Shaanxi, Shanxi, Inner Mongolia, Ningxia, Gansu, Qinghai, Xinjiang, Jilin, Liaoning, and Heilongjiang, as presented in Figure 1. The construction period is from 1978 to 2050, divided into three phases and eight stages. The first phase is 1978–2000, divided into phase one (1978–1985), phase two (1986–1995), and phase three (1996–2000). The second phase is 2001–2020, divided into phase four (2001–2010) and phase five (2011–2020). The third phase is 2021–2050, divided into phase six (2021–2030), phase seven (2031–2040), and phase eight (2041–2050). Owing to missing data from before 2000, we choose 2000–2020 as the study object, encompassing the fourth and fifth phases of the project. Considering that some areas added during the fifth phase of the project were not included in the fourth, we take the scope defined in the "Planning for the Fourth Phase of the Construction of the Three-North Shelterbelt Forest Program System" [46] as the target to ensure that the regression can achieve a sufficiently long lag period. The fourth phase covered 600 county-level units; excluding administrative division merging, 596 county-level units can be taken as the full sample, including 460 agricultural areas, 70 pastoral areas, and 66 semi-agricultural and semi-pastoral areas.

Figure 1. The 13 provinces involved in the TNSFP (the green part), based on the standard map offered by the Ministry of Natural Resources of the People's Republic of China.

3.2. Model Setting

Since Jordà first proposed the local projection method [64], it has become a popular econometric analysis tool in the field of macro policy analysis [65]. According to Jordà (2005), the general form of local projection can be written as [64]

$$y_{t+h} = \beta^h z_t + \gamma^h \boldsymbol{X_t} \quad (1)$$

z_t is the policy variable that researchers are interested in, and $\boldsymbol{X_t} = \{1, z_{t-1}, \cdots, z_{t-l}, y_t, \cdots, y_{t-l}, x_t, \cdots, x_{t-l}\}'$ is the control vector, including the intercept term, y_t, z_{t-1}, and other covariables (x_t) that need to be controlled and their respective lag terms. It is easy to see that the local projection method allows the researcher to estimate the effect of a policy on the economic variables of the h period after the policy happened during the t period. To eliminate endogeneity, we need to control some necessary control variables, such as those that may impact the economy and policymaking, as well as the respective L-order lags of these covariables, policy variables, and outcome variables. Jordà (2023) points out that, under the Rubin causal framework, the above equation can be viewed as a comparison between two potential outcomes [65]. In other words, the key prerequisite for the local projection method to obtain accurate estimation is that the information before t can be used to predict the t + h period's variables, and the shock should have sufficient externality compared with other covariables. Based on this idea, we decided to add a machine-learning model to better estimate the potential outcomes, and, on this basis, we obtained an estimate of the effect of policy processing.

Athey et al. (2021) and Mullainathan and Spiess (2017) point out that estimating potential outcomes is essentially a matter of compensating for missing data, thus leveraging the high accuracy of machine-learning methods in forecasting [66,67]. From this perspective, we set the general form of the model in this study as follows:

$$y_{t+h} = \beta^h z_t + f^h(\boldsymbol{X_t}) \tag{2}$$

$f^h(\cdot)$ is a nonlinear model constructed using machine-learning methods to accommodate higher-dimensional data and avoid model error problems that may be caused by the linear assumptions of the original model.

Overfitting should also be avoided when using machine-learning methods for fitting. We used the method suggested by Chernozhukov et al. (2018) to eliminate the influence of overfitting on the estimator for the β^h parameter [68], that is, by (1) using Neyman-orthogonal moments to reduce the regularization deviation and (2) using cross-fitting. This is not the focus of our study, so readers interested in the specific operation of this method may refer to the excellent discussion in Chernozhukov et al. (2018) [68].

For the algorithm, we selected the random forest model to construct $f^h(\cdot)$. There are two reasons: First, random forest models generally have very good prediction accuracy and have been widely used in many research scenarios [69]. Grinsztajn et al. (2022) pointed out that, in tabular data involved in social science research, tree-based models such as random forest outperform other methods, such as deep-learning models [70]. Secondly, the random forest method comprises many mutually independent learners (learners) and linear combinations, allowing the algorithm to reduce the prediction bias overall and be robust to noise in the data [71]. In their empirical studies, Li Bin et al. (2019) and Chen Xiaoliang et al. (2021) found that integrated learning algorithms such as random forest perform better in predicting economic variables [72,73]. To compare the prediction performance of this method, we compared the performance of random forest with some popular methods (including the least-squares method, multilayer perceptron, XGBOOST, and support vector regression) in predicting outcome variables and policy variables based on the whole sample[1]. The results show that, with the whole sample, the random forest is better than the other methods for out-of-sample prediction. Therefore, we will use random forest to fit the nonlinear part of the regression equation.

To sum up, the local projection method can reveal the dynamic effects of policy shocks on resident incomes, aligning with our research question. At the same time, compared with traditional vector autoregressive models, the local projection method is more flexible in terms of the regression form and can mitigate the interference from confounding and unobservable variables by adding control terms and fixed effects [64]. Since the impulse response function obtained via the local projection method is a regression coefficient, it enables simple and intuitive interpretation. Moreover, since the standard error formula can be adapted for simple linear regression derivation, serial correlation in the regression residuals can be adjusted, making it more suitable for time series analysis.

3.3. Data Description and Processing

We use the per capita disposable annual income variable of rural residents ($\Delta PCDI_{t+h}$) to measure improvements in their livelihoods caused by ecological restoration policies. This variable is the explained variable in this study. We use the Normalized Difference

Vegetation Index (NDVI) as a proxy variable for the government's investment in ecological restoration in a region, the main explanatory variable in this study. The NDVI data were obtained from the NASA MODIS database. We also controlled for some covariates related to the above two, including year; rainfall ($RAIN$); per capita gross domestic product (GDP); the per capita general public budget expenditure of the local financial sector (EXP); the urbanization rate (URB); the per capita power of agricultural machinery (MECH); and some dummy variables (***Dummy***) representing individual characteristics, including provinces; cities; counties; years; and agricultural, pastoral, and desert regions. The rainfall data were obtained from the Global Surface Summary of the Day—GSOD—and the county data were obtained from the China Statistical Yearbook for Regional Economy and the China Statistical Yearbook (county level). For counties with missing data in some years, we use the K-neighborhood algorithm for supplementation. The following is a detailed explanation of the data.

Explained variable ($\Delta PCDI_{t+h}$): This is the change in rural residents' disposable income during period h. In the regression, we use the change in the per capita disposable income (CNY) of rural residents in period h to represent this variable. Previous analyses show that ecological restoration projects can transform the natural landscape while also impacting local, traditional modes of production, impacting the livelihoods of rural residents. Presumably, if the rural disposable income per capita increases as the restoration project advances, ecological restoration is compatible with the community's modes of production. Meanwhile, if income decreases, the ecological restoration project is poorly adapted to the production mode, and the ecosystem restoration results do not support resident livelihoods. In the regression, we logarithmically treat $PCDI_t$ so that $\Delta PCDI_{t+h}$ represents the approximate percentage change in $PCDI_{t+h}$ relative to $PCDI_t$.

Core explanatory variable ($NDVI_t$): This is the implementation of ecological restoration projects. We use the Normalized Vegetation Index, $NDVI_t$, to represent this variable. The physical meaning of the NDVI is the result of calculating the reflectance in two bands, the near-infrared band and the red light band, calculated as follows: $NDVI = (NIR - R)/(NIR + R)$. It is generally believed that a higher NDVI indicates a higher degree of vegetation cover in the target area. The NDVI is an instrumental variable that can successfully characterize the implementation of ecological restoration projects, and many studies have used this variable for this purpose [74–76].

Control variables ($RAIN_t, RAIN_{t-1}, GDP_{t-1}, EXP_{t-1}, URB_{t-1}, MECH_{t-1}$, and ***Dummy***): Here, $RAIN_t, RAIN_{t-1}, GDP_{t-1}, EXP_{t-1}, URB_{t-1}$, and $MECH_{t-1}$ denote the annual precipitation (mm); the per capita gross domestic product (CNY); the per capita general public budget expenditure of the local financial sector (CNY); the urbanization rate; and the per capita power of agricultural machinery (kW) in period t or period t − 1, respectively. The first variable, abundant precipitation, can increase agricultural and pastoral outputs and, thus, incomes. It is also an important driver of vegetation cover changes in ecological restoration projects [77,78]. The second variable is the level of regional economic development, where developed regions may have more opportunities to increase their incomes and are more capable of organizing public projects [79,80]. We use the GDP per capita and urbanization rate to control for the level of regional economic development [81]. The third variable is the fiscal capacity of local governments. Generally, the stronger the fiscal capacity, the more capable local governments are of developing their economies and providing public services [82]. We use the per capita general public budget expenditure to denote this. Finally, there is the technology level. Advanced technology can make activities such as agriculture, pastoralism, and reforestation more efficient [83]. We use per capita agricultural machinery power to express this. These variables, except for the urbanization rate, are also logarithmically treated in this study.

In addition to the above control variables, fixed effect variables affect the explanatory variables and core explanatory variables, such as the year factor; whether the area is desert/sand; and the fixed effects of provinces, cities, and counties. We use ***Dummy*** to denote the above fixed effect variables controlled for in the regression. This includes the level value of the year and the respective dummy variables for each year; a dummy variable representing agricultural/pastoral/semi-agricultural/semi-pastoral areas; a dummy variable representing desertification areas (including the Hulunbeier Sandy Land, Horqin Sandy Land, Hunshandak Sandy Land, Maowusu Sandy Land, Kubuqi Desert, and the deserts of the Alxa Plateau); and a dummy variable representing the province, city, and county/flag. The agricultural, pastoral, semi-agricultural, and semi-pastoral attributes of counties/flags and the attributes of the deserts and sandy areas they belong to are taken from the "List of counties and flags in pastoral, semi-agricultural and semi-pastoral areas of China" [84] and the "National Plan for Sand Control and Prevention (2021–2030)" [85], respectively.

The descriptive statistics of the data sample used in our regressions are shown in Table 1.

Table 1. Descriptive statistics of the full sample.

Variable	Obs.	Ave.	Std.	Min.	Max.
$PCDI$	11,920	8.6501	0.7511	6.3630	10.3845
$NDVI$	11,920	7.6838	0.6210	4.4085	8.6753
$RAIN$	11,920	5.9014	0.6805	2.4563	7.3774
GDP	11,920	9.7431	0.9594	6.0913	12.8040
EXP	11,920	8.1739	1.1772	5.0641	12.0696
URB	11,920	0.6740	0.1859	0	1
$MECH$	11,920	0.6370	0.3212	0	2.2900

3.4. Estimation Process

Based on Equation (2), we set the regression model as follows:

$$\Delta PCDI_{t+h} = \alpha^h + \beta^h NDVI_t + f^h(\boldsymbol{info}_t) \tag{3}$$

Here, the explanatory variable $\Delta PCDI_{t+h} = PCDI_{t+h} - PCDI_t$ denotes the difference between rural resident incomes in periods t + h and t. $NDVI_t$ is the core explanatory variable of interest, i.e., the shock of the ecological restoration project. $f^h(\cdot)$ denotes the function fitted using a machine-learning method, and $\boldsymbol{info}_t$ denotes the set of control variables used in the regression.

Since this study is only concerned with the impact of $NDVI_t$ on $\Delta PCDI_{t+h}$, the estimation process of the core variable, β^h, is summarized as follows, as suggested by Chernozhukov et al. [49]. Here, we summarize the regression process as follows:

Firstly, $\Delta PCDI_{t+h}$ and $NDVI_t$ are fitted with respective random forest models based on the control variables to obtain their residuals, $\Delta \widetilde{PCDI}_{t+h}$ and $\widetilde{NDVI}_t$:

$$\begin{cases} \Delta \widetilde{PCDI}_{t+h} = \Delta PCDI_{t+h} - m^h(\boldsymbol{info}_t) \\ \widetilde{NDVI}_t = NDVI_t - n^h(\boldsymbol{info}_t) \end{cases} \tag{4}$$

$$where\ m^h(\boldsymbol{info}_t) = E(\Delta PCDI_{t+h} | \boldsymbol{info}_t),\ n^h(\boldsymbol{info}_t) = E(NDVI_t | \boldsymbol{info}_t),$$

$$\boldsymbol{info} = \{RAIN_t, RAIN_{t-1}, GDP_{t-1}, EXP_{t-1}, URB_{t-1}, MECH_{t-1}, \boldsymbol{Dummy}\}$$

Second, we regress $\Delta \widetilde{PCDI}_{t+h}$ on $\widetilde{NDVI}_t$ to estimate the core variable, β^h:

$$\Delta \widetilde{PCDI}_{t+h} = \beta^h \widetilde{NDVI}_t \tag{5}$$

This method is similar to the nonlinear version of the FWL theorem, which uses nonlinear functions to debias $\Delta PCDI_{t+h}$ and $NDVI_t$. The core idea is to use machine-learning algorithms to predict $\Delta PCDI_{t+h}$ and $NDVI_t$ based on the information set of the control variables, $\boldsymbol{info}$. Then, the residuals of $\Delta PCDI_{t+h}$ are regressed based on the residuals of $NDVI_t$.

4. Results

To test our hypotheses, this section analyzes the impacts of implementing ecological restoration projects on the livelihoods of people living in areas that have adopted different modes of production in farming and pastoralism, as well as differences in the natural environment, using the empirical methodology and data set out in Section 3. The theoretical analyses show that, after implementing the project, the adaptive adjustment of the regional modes of production; the different modes of production in agricultural and pastoral regions; and the regional differences in the natural environment all impact the results of the project. Specifically, based on the theoretical analyses, this study presents three hypotheses to be tested.

Before formally discussing the results, it is necessary to acknowledge several limitations. Firstly, the time span of the data used in this study is too limited. Because of availability issues, this study only captures data from the TNSFP spanning 20 years, from 2001 to 2020. This restricts our ability to select a longer lag period and observe the performance of ecological restoration projects over an extended period. Secondly, the sample size is insufficient. In the full sample consisting of 596 county-level administrative regions, pastoral areas only account for 70, somewhat reducing the significance of the regression results for these areas. Finally, this case has inherent limitations. Although we endeavor to discuss the regression results on a broader literature basis, considering the differences in economy, politics, and culture among various countries and regions, readers must be cautious when considering the universality of the relevant conclusions.

4.1. Shock Adaptation Processes Induced by Ecological Restoration Projects

According to the previous analysis, there is a "shock adaptation" process in which residents gradually adjust their modes of production according to an improving ecology, from the initial stage consisting of relearning and paying the corresponding costs to later adapting to it. Lastly, residents can transform their modes of production and improve their welfare levels.

In Figure 2, we present the full-sample regression results, with the shaded area from the outside to the inside denoting the 90% and 68% confidence intervals (CIs). Figure 2 shows the shocks to the local livelihoods caused by implementing ecological restoration projects, as well as the process through which local communities adapt to these shocks and gradually experience the benefits of ecological restoration. Figure 2 shows that the per capita disposable income of rural residents decreases and then increases after implementing the project. The increased income effect is still relatively significant in the eighth year, indicating that there is indeed a long-term impact mechanism. This is consistent with Hypothesis 1; i.e., the ecological restoration project initially not only fails to effectively increase the incomes of the residents but also disturbs the community's original mode of production and restricts the residents' rights to use the ecosystem. However, as the ecosystem evolves and the community gradually adapts, the supply of ecosystem services increases, and new modes of production are established. The people can enjoy lasting livelihood improvement effects, which, in this case, manifest as increased disposable income per capita. As discussed in the literature review, ecological restoration projects possess various mechanisms to enhance the livelihoods of rural residents. These include providing ecological services, boosting property income, and lowering production and living costs [16–18], thus facilitating the construction of agricultural water conservancy infrastructure and subsequently aiding in adjusting industrial structures [20]. Alternatively, they can promote local economic development by augmenting human capital in the project area [21].

Notably, the impact of ecological restoration on residents' livelihoods starts to transition from negative to positive after the third year and stabilizes after the sixth. This aligns with the real-world implementation context. According to the Chinese national standard, "Technical Regulations for Setting Apart Hills Including Sand Area for Tree Growing" (GB/T 15163-2018) [86], a general closure period of 10 years or less is sufficient, and shorter-term measures—such as the shrub-and-grass-type closure of unforested and sparsely forested land in the northern region—require only 4 to 6 years (Table 2). After the ecosystem has been restored to a certain degree, residents can carry out appropriate production activities, such as woodcutting, grazing, medicine collection, or processing other forest by-products. This output from the ecosystem is stable and sustainable as long as the anthropogenic disturbances are controlled within a certain range. Evidence suggests that the height, cover, and above-ground biomass of grassland vegetation rapidly increase over three years after sealing. These indicators decline after re-grazing but are still significantly higher than in continuously grazed grassland, and they eventually reach a steady state [87].

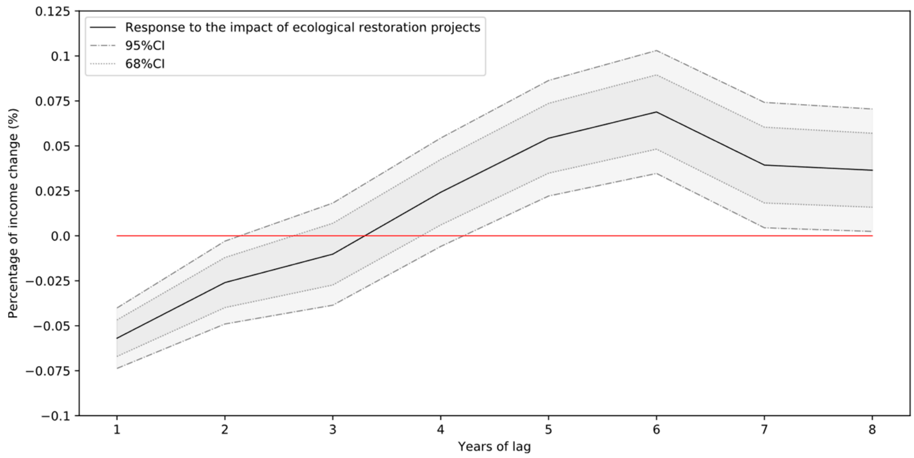

Figure 2. The response of rural residents' per capita disposable income to the TNSFP over 8 years.

Table 2. Years of forest closure in the northern region of China [1].

Forest Type of Closure		Closed Years
Closure of unforested and sparse land	Trees	8–10
	Trees–shrubs	6–8
	Shrubs	5–6
	Shrubs–herbs	4–6
Closure of forested land and shrubland		4–7

[1] Data source: Technical regulations for setting apart hills including sand area for tree growing (GB/T 15163-2018).

4.2. Heterogeneity of the Two Modes of Production: Agriculture and Pastoralism

The full-sample regression verifies Hypothesis 1 at a relatively significant level, but the empirical results diverge significantly after accounting for the differences between the two modes of production, agriculture and pastoralism. We will split the full sample according to the difference between agricultural and pastoral areas and perform separate regressions on the respective subsamples. The regression results are displayed in Figures 3 and 4, with the shaded area from the outside to the inside denoting the 90% and 68% CIs.

Figure 3 depicts the project's impact on the per capita disposable income of the residents in the agricultural areas. The trend is similar to that of the full sample: The pattern is first negative and then positive, with the improvement effect gradually stabilizing at a certain level. As analyzed earlier, residents in agricultural areas experience a certain degree of negative impact in the short term. However, in the long term, after adjusting their modes of production, they can gradually adapt to the changes and achieve sustainable livelihood improvements through ecosystem services. Considering that individuals from agricultural areas comprise most of the full sample, the full results likely mainly reflect the agricultural areas.

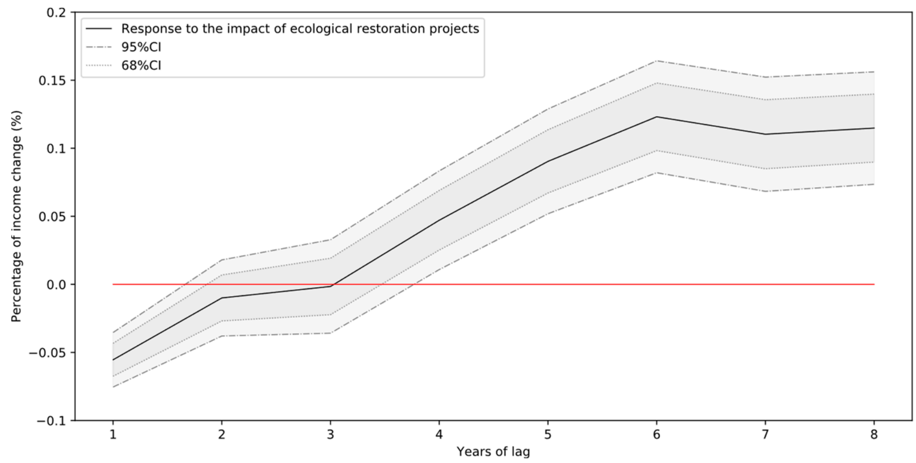

Figure 3. Response of rural residents' per capita disposable income to the TNSFP in agricultural areas over 8 years.

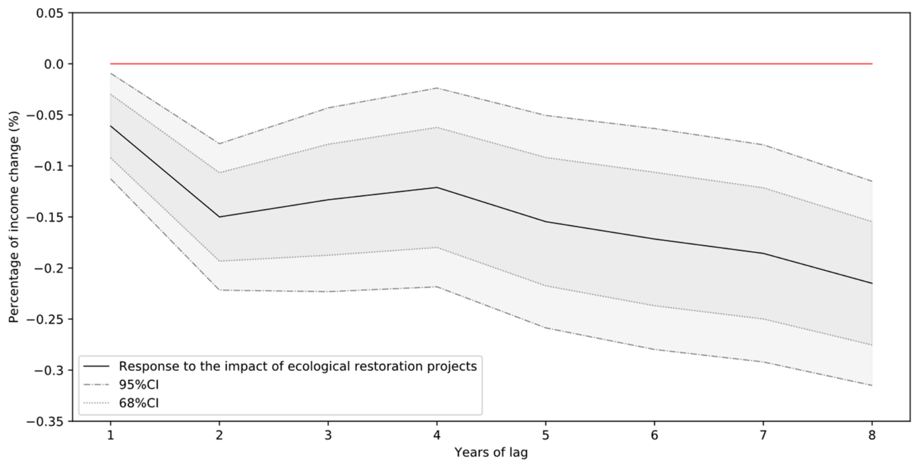

Figure 4. Response of rural residents' per capita disposable income to the TNSFP in pastoral areas over 8 years.

However, Figure 4 shows that pastoral areas are significantly different. The impact of ecological restoration projects on per capita disposable income has been negative for a long period, suggesting that pastoral communities have poor adaptability to these projects. Why is the adaptability of pastoral areas so poor? In the section on theoretical mechanisms, we provided a literature foundation from three perspectives: the economy, institutions, and culture [31,34,35,37,88,89]. Here, we can further discuss these perspectives based on the regression results and real-life details. From the perspective of evolving production methods, traditional pastoralism production requires producers to make decisions based on seasonal, weather, soil, and vegetation conditions and move grazing on large grassland areas to avoid natural disasters and fully utilize grass resources [38]. Because of market-oriented reforms and grassland-contracting reforms, traditional production methods are no longer sustainable, and new methods are not yet mature, greatly weakening the adaptability of pastoral societies. Firstly, market-oriented reforms have increased the cost of living for herders in areas such as education, healthcare, and elderly care, stimulating them to actively pursue monetary benefits [43]. Overgrazing on grasslands can seriously damage the effectiveness of ecological restoration projects [36]. Secondly, after grasslands were contracted to households, nomadism shifted to captivity, and a large quantity of livestock frequently trampled the land, accelerating the speed of grassland desertification [90]. Furthermore, with the atomization of interpersonal relationships, the tradition of mutual assistance among herders has also disintegrated, weakening the ability of individual families to withstand external shocks. Despite these difficulties, many herders still struggle to adapt to urban life and agricultural production owing to language and cultural differences. They have chosen to resist the ecological restoration policy, insisting on returning to closed areas or secretly rearing their livestock during the grazing prohibition, creating a cat-and-mouse game with public administrators [91].

Although similar issues have arisen in rural areas, such as the loss of traditional culture, weakened social capital, and rising living costs, they have not irreversibly reduced the adaptability of local communities [92,93]. This can also be explained from the perspective of transforming production methods. First, agricultural production allows farmers to develop diversified businesses, such as by incorporating construction, manufacturing, and trade, opening up sources of income while enabling them to hone various livelihood skills [53]. Second, reform has not altered the traditional family-based production mode in rural areas but instead satisfied the rights of small farming families to freely dispose of labor and use land [94]. Last, a large amount of the surplus labor force has entered urban areas to engage in secondary and tertiary industries, using their wage income to subsidize the livelihoods of rural families and promote the prosperity of the local economy [95].

The results for the agricultural and pastoral areas validate Hypothesis 2, as well as the central point of this study, i.e., that differences in modes of production can significantly impact the ability of ecological restoration projects to improve the livelihoods of farmers and herders. More specifically, residents in agricultural areas can adapt to exogenous changes more quickly and achieve the benefits of an improved income, whereas those in pastoral areas take a longer time to complete this transition. In this study, we did not find that the transition process can be completed in 8 years after the ecological restoration project begins.

4.3. Performance of Ecological Restoration Projects in Desertification Areas

It is important to examine the performance of ecological restoration projects in desertification areas. On the one hand, this serves to further test Hypothesis 2. If the mode of production is indeed an important factor for ecological restoration, then, as discussed in Section 2, it will have a mechanism of influence that is compatible with specific natural conditions. On the other hand, combating desertification has long been one of the focuses of construction in the TNSFP. The related works are likely to inspire real work. Based on the subsample of desertification areas, this study examines income changes among agricultural and pastoral residents after an ecological restoration project begins. In Figures 5 and 6, the shaded areas from the outside to the inside demonstrate the 90% and 68% CIs, respectively.

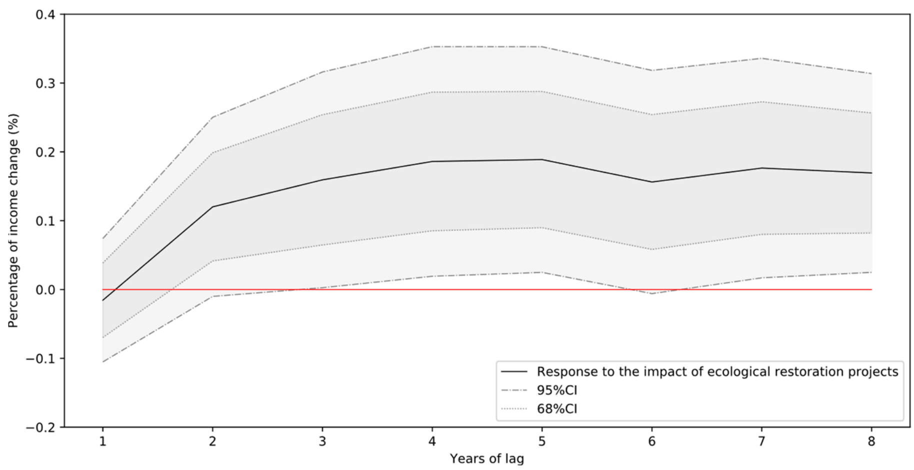

Figure 5. Response of rural residents' per capita disposable income to the TNSFP in agricultural areas with desertification in 8 years.

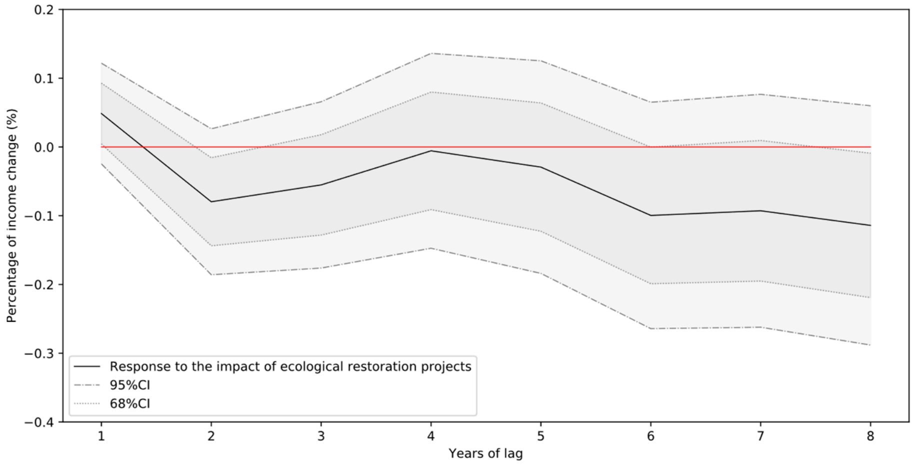

Figure 6. Response of rural residents' per capita disposable income of rural residents to the TNSFP in pastoral areas with desertification in 8 years.

Compared with Figures 3 and 4, Figures 5 and 6 show that ecological restoration projects have a more positive impact on local livelihoods in desertification areas. Specifically, the negative impacts in agricultural areas are no longer significant in the early stages of policy implementation, and the subsequent livelihood improvement effects stabilize at a higher level after the upturn. In pastoral areas, while the negative impacts of transforming production practices remain persistent, they are relatively less intense (from approximately 20% negative impacts in Figure 4 to approximately 10% negative impacts in Figure 6) and less significant. Most of the time, as seen in Figure 6, the negative impacts are insignificant at the 68% level of significance. These results suggest that, in ecological restoration projects, desertification areas are more likely to achieve the benefits of improved livelihoods or, conversely, to suffer less from the negative impacts of transforming the modes of production. This provides direct evidence to support Hypothesis 3.

Figure 6 deserves additional discussion. Although the negative impacts of the transition are weaker than average, there is still no clear improvement trend over an 8-year lag, contrary to expectations. This study offers a possible explanation, suggesting that the specificity of the pastoral modes of production has been underestimated to some extent, and its significance for ecological restoration projects deserves to be re-examined. As mentioned earlier, traditional pastoral communities heavily rely on the organic linkages between people, pastures, and livestock; thus, they must develop diverse and resilient modes of production [38,43]. However, modern ecological restoration projects have evolved from so-called "scientific forestry", the basic principle of which is to treat nature as a commodity and to achieve efficient commodity production in terms of scale, homogenization, and clarity [96] (pp. 11–22). From a technical standpoint, scientific forestry involves planting a limited number of species across vast expanses of land to reduce production costs, simplifying the landscape. However, this simplification also reduces biodiversity, hindering the maintenance of ecosystem stability and increasing the vulnerability to pests, diseases, and extreme weather events [97–99]. In terms of organizational methods, scientific forestry heavily relies on top-down state management, sidelining the involvement of local communities. From a bureaucratic perspective, small private landowners can disrupt established management strategies and deplete ecological resources [100,101]. This could be an even more significant mistake than landscape simplification. Because of this exclusion, the material cycle between plants, animals, and land is disrupted, stripping residents of their livelihoods and culture, significantly diminishing the resilience of the socio-ecological system. Thus, the more diversity is needed, the more tension exists between the traditional modes of production and ecological restoration projects, making it difficult to achieve the latter's goal of improving local livelihoods.

5. Conclusions and Recommendations

The primary contribution of this research lies in utilizing the LP method and machine-learning techniques to analyze panel data from 596 county-level administrative regions within the TNSFP, spanning 2001 to 2020. This analysis confirms the "impact adaptation" mechanism between ecological restoration projects and the livelihoods of rural residents. The regression results indicate that the per capita disposable income initially decreased, then increased, and ultimately surpassed the initial level within 8 years following the ecological restoration project. Additionally, we observed that regions with different modes of production, such as agricultural and pastoral areas, exhibit varying levels of adaptability to ecological restoration projects. People in agricultural areas can gradually adapt to changes after experiencing temporary shocks and utilize new ecosystems to achieve sustained livelihood improvements. In places where pastoral production is the mainstay, the negative effects of these shocks extend for a relatively long period, suggesting that it is more difficult for pastoralists to achieve improvements from ecological restoration projects.

The results of the "impact adaptation" component in China's TNSFP suggest that, to further enhance ecological restoration initiatives, policymakers should primarily address the following concerns: mitigating the intensity of impacts, minimizing the decline in residents' livelihood levels, and reducing the duration of these impacts to facilitate swift livelihood improvement. Particularly in regions with distinct production methods, such as pastoral areas, the impact intensity is pronounced, and the duration of these impacts is prolonged. This poses substantial challenges to the sustainability of ecological restoration projects. This study proposes the following three policy recommendations. Firstly, local differences should be fully considered when designing ecological restoration projects, not only in terms of differences in the natural conditions, such as the climate, moisture, soil, etc., but also in terms of the modes of production. Instead of relying on a single evaluation method, multiple social, economic, and ecological indicators should be comprehensively evaluated. For instance, solely using forest coverage as an assessment metric would incentivize local officials to extensively plant fast-growing species, disregarding actual conditions [5]. Therefore, it is imperative to incorporate indicators such as biodiversity, water consumption, and soil organic matter content. In pastoral regions, policymakers also need to evaluate whether the restored plant communities can accommodate herders' livestock grazing needs.

Secondly, compared with the central government, local governments and grassroots communities may have a better understanding of their localities. Therefore, in the context of developing a reliable supervisory mechanism, it is necessary to provide local governments and grassroots communities with more autonomy and build a coordinated governance pattern involving multiple stakeholders. This is conducive to the timely detection and treatment of heterogeneity problems. For instance, some regions in China have implemented the "first restoration, then subsidy (xian jian hou bu)" approach. This allows landowners to formulate their own ecological restoration plans, apply to the administrative authorities for subsidies, and receive the corresponding subsidies after passing an acceptance inspection within a contracted time. This method provides landowners with fair compensation for their role and lets local communities have more control, helping restore the ecosystem according to how people live there.

Thirdly, when formulating ecological restoration projects, differentiated and flexible governance ideas should be adopted. Especially for communities struggling to adapt, the government should offer more financial, technical, and personnel support or help for a longer period to ensure a smooth transition. In Qingshui District, Inner Mongolia, the local government is promoting the reconstruction of pastoral areas through innovative organizational and livelihood strategies, such as animal husbandry cooperatives and grassland ecotourism. This approach enables herders to move freely between pastoral and urban areas, enjoy modern lifestyles, and engage in pastoral livelihoods while protecting the grassland ecosystem [102].

Of course, as emphasized at the outset of Section 5, this study is limited in terms of time span, sample size, and case selection. More empirical research may be necessary to ascertain whether the "impact–adaptation" mechanism is a universal phenomenon. Diverse modes of production, such as agriculture, pastoralism, and forestry, reflect the unique connection between humans and nature, providing rich materials for further research.

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Notes

[1] For detailed model comparison information, see Supplementary Table S1: Comparison of Out-of-Sample Predictive Performance of Different Machine Learning Models.

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