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Article

Evaluating the Impact of Forest Carbon Sink Project on the Economic Well-Being of Rural Residents: Absolute and Relative Perspectives

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Abstract

Using Chinese county-level panel data from 2007 to 2022, this study employs the propensity score matching–difference-in-differences (PSM-DID) method to empirically assess the impact of Forest Carbon Sequestration Projects (FCSP) on the economic welfare of rural residents in pilot counties, from both absolute and relative perspectives. The study found that from an absolute perspective, FCSP significantly improved the economic welfare of rural residents; but after incorporating relative comparison factors, the positive effect of the project was weakened, especially in the horizontal comparison between rural areas, showing a significant relative welfare loss. The impact of FCSP on rural economic welfare has obvious lag, and long-term implementation is more conducive to improving the absolute and relative welfare levels of rural residents. Heterogeneity analysis shows that the longer the project inclusion period, the stronger the economic welfare effect; the implementation of FCSP in poverty-stricken counties can significantly improve the economic welfare of rural residents compared with non-poverty-stricken counties, and FCSP are more suitable for implementation in non-ethnic areas.

Keywords: forest carbon sink projects(FCSP); economic welfare effects; relative perspective; rural residents

1. Introduction

Addressing climate change and promoting sustainable development are critical missions for the global community today. These efforts concern not only human survival and development, but also global stability, harmony, and prosperity. As a typical market-oriented forest ecological compensation project, forest carbon sinks have the dual goals of addressing climate change [1,2] and promoting sustainable development [3], which is not only to expand forest cover, improve forest quality, and increase carbon sinks, but also to improve the economic welfare of rural residents and promote rural development. However, to avoid carbon leakage, activities such as grazing, planting, and logging in the forest understory of forest carbon sink project sites and surrounding areas are restricted [4–6]. Additionally, the current market transaction mechanism for forest carbon sink projects favors buyers [7], who typically hold pricing power. This leaves rural residents with little bargaining capacity, forcing them to accept terms passively. Rural residents' income from forest carbon sink projects primarily comes from labor services and carbon credit sales. However, these revenues often fail to compensate for opportunity costs. Whether the implementation of forest carbon sink projects has genuinely improved the economic welfare of rural residents remains to be verified.

Rural residents are the primary implementers and land providers for forest carbon sink projects (FCSP) [8]. Ensuring the healthy and sustainable operation of FCSP requires improving the economic welfare of rural residents in project areas and stabilizing their willingness to participate [9]. Studies have shown that, after the implementation of FCSP, rural residents in project areas have increased

their household income through various channels, such as obtaining carbon revenues [10], altering land use patterns [11,12], and adjusting the employment structure of household labor [6,13]. However, this increase in economic income has not significantly enhanced their willingness to participate in FCSP. Field investigations further reveal that, at present, forest rural residents' willingness to continue implementing FCSP remains low [14,15], and the level of implementation is relatively limited [16]. Since rural residents' participation enthusiasm directly affects the operational status of FCSP [9,17], low willingness may hinder the healthy and sustainable operation of these projects. Against this backdrop, uncovering the underlying causes behind the paradox of rising income yet weak implementation willingness among rural residents in FCSP areas holds significant theoretical and practical value.

In welfare economics, the inconsistency between objective welfare and subjective expression is often explained from a relative perspective. Economic income serves as an objective indicator of welfare, while willingness to participate reflects rural residents' subjective expression. In forest carbon sink project (FCSP) areas, objective welfare refers to the absolute income level of rural residents, whereas subjective expression is shaped not only by objective welfare but also by psychological comparisons—namely, subjective welfare. When objective welfare rises but subjective welfare declines due to such comparisons, inconsistencies in participation willingness may emerge. This study argues that such psychological comparisons primarily occur at three levels: (1) longitudinal comparisons between current and previous income levels within the same rural community; (2) horizontal urban–rural comparisons between rural residents in project areas and urban residents; and (3) horizontal inter-rural comparisons between rural residents in project areas and those in non-project areas. Building on this perspective, we construct an analytical framework that integrates both absolute and relative measures of economic welfare, employ propensity score matching (PSM) to identify comparable control groups, and apply the difference-in-differences (DID) approach to empirically assess FCSP's impact on rural residents' economic welfare—with and without accounting for relative factors. The aim is to provide a novel analytical lens for understanding the paradox between rural residents' objective welfare and subjective expression, and to offer policy insights for consolidating FCSP achievements, enhancing rural residents' welfare, and ensuring the projects' sustainable operation.

2. Theoretical Analysis and Research Hypothesis

2.1. *The Positive Impact of FCSP on the Economic Welfare of Rural Residents from an Absolute Perspective*

The implementation of FCSP can increase the income levels of rural residents through the following channels.

First, FCSP can raise rural residents' property income. By contributing forestland as equity, leasing, or transferring land-use rights, rural residents can obtain a certain amount of property income, providing them with an additional source of revenue [18,19].

Second, FCSP can increase wage income. During project implementation, employment opportunities are created, enabling rural residents to earn wages through participation in FCSP activities, thereby raising their labor income [20,21].

Third, FCSP can enhance transfer income. Rural residents may receive grazing loss compensation for participation in FCSP, and the projects can also help break the "resource trap," providing access to external resources and thereby increasing transfer income [22,23].

Fourth, FCSP can generate indirect income. By introducing certain afforestation technologies, the projects can improve rural residents' forestry skills [24] and enhance local human capital [25,26].

Moreover, rural residents can apply the management experience gained from FCSP to other employment or entrepreneurial activities [27]. For example, leveraging these skills in developing forest carbon sink eco-tourism [28,29]. Additionally, FCSP can bring new information channels to project areas, thereby expanding rural residents' social networks, increasing opportunities for external interaction, and improving their social capital [30,31].

Accordingly, we propose Hypothesis 1: From an absolute perspective, the implementation of FCSP can increase the economic welfare of rural residents.

2.2. The Negative Impact of FCSP on the Economic Welfare of Rural Residents from an Absolute Perspective

On the other hand, the implementation of FCSP may reduce the economic welfare of rural residents.

First, FCSP can decrease operating income by altering rural residents' traditional dependence on forestry-based livelihoods. Prior to project implementation, carbon sink forestland was often used for grazing and cultivation. After implementation, the reduction in pasture and arable land results in fewer livestock for grazing and lower crop yields, which may cause a short-term decline in agricultural income [32], thereby generating a negative impact.

Second, FCSP can reduce property income. To prevent carbon leakage, activities such as understory grazing, planting, and timber harvesting in and around project areas are restricted [4–6]. These restrictions also limit rural residents' collection of understory products such as medicinal herbs and mushrooms [6,33], thus reducing their income.

Third, FCSP may lead to the loss of traditional livelihoods. Changes in land-use patterns following project implementation make it difficult for some rural residents to adapt to new production models, rendering their existing production skills obsolete. In the short term, they may struggle to find alternative sources of income, ultimately undermining their economic welfare [34].

Accordingly, we propose Hypothesis 2: From an absolute perspective, the implementation of FCSP will reduce the economic welfare of rural residents.

2.3. The Impact of FCSP on the Economic Welfare of Rural Residents from a Relative Perspective

In pilot counties of forest carbon sink projects, rural residents experience not only changes in absolute income but also engage in other forms of comparative evaluation. While absolute income forms the fundamental basis for individuals' satisfaction, relative income serves as a psychological benchmark influencing their perceived well-being [35]. Comparison is a universal human tendency, and numerous economists have provided empirical evidence for the existence of the "comparison effect" [36–38]. It follows that the overall economic welfare of rural residents can be improved only when both absolute and relative incomes show concurrent enhancement.

2.3.1. Longitudinal Comparison Between Individuals

First is longitudinal comparison, which refers to comparing rural residents' current income with their own past income. According to expectation theory [39], individuals' expectations for the future are often shaped by past living conditions. People generally expect their current standard of living to be no lower than before; when actual income meets or exceeds expected income, rural residents' economic welfare and life satisfaction increase significantly. Existing studies indicate that forest carbon sink projects (FCSP) are typically long-term and sustainable in nature [40]. Stable participation in these projects, combined with the improvement of personal skills, enhances rural residents' prospects for future income growth.

Accordingly, we propose Hypothesis 3a: The implementation of FCSP can improve longitudinal comparison outcomes.

2.3.2. Rural-Rural Comparison Between Groups

Second is horizontal rural-rural comparison, which refers to comparing rural residents' income with that of residents in surrounding rural areas. According to social comparison theory [41], an increase in personal income does not necessarily mean that rural residents will feel happier than before. In practice, rural residents may benefit from FCSP through employment opportunities and wage income; however, they feel relatively satisfied and happy only when their income grows faster than that of nearby residents. If surrounding communities experience higher income growth, rural

residents may feel a deprivation of well-being, even if their absolute income increases. Studies have shown that FCSP provide employment opportunities, land rental income, and diversified income sources, resulting in a significantly higher income growth rate for rural residents in pilot counties compared to those in adjacent non-project counties [42]. Rural residents participating in FCSP thus experience faster income growth than their non-participating counterparts. Moreover, FCSP are often accompanied by policy support and subsidies [43], which further accelerates income growth for rural residents in pilot counties relative to their neighbors, giving them an advantage in horizontal inter-rural comparisons.

Accordingly, we propose Hypothesis 3b: The implementation of FCSP can improve horizontal rural-rural comparison outcomes.

2.3.3. Urban-Rural Comparison Between Groups

Third is horizontal urban-rural comparison, which refers to the income gap between rural residents in pilot counties and urban residents within the same counties. Despite China's sustained economic growth, the income gap between urban and rural residents has continued to widen [44]. An expanding gap can lead to labor outmigration, idle farmland, and diminished incentives for agricultural production. Following the implementation of FCSP, long-term and stable employment opportunities significantly increase rural labor force participation. Compared to urban residents, rural residents employed in carbon projects not only gain stable income sources but also face reduced labor migration to cities [40,45]. This increase in the rural labor force boosts household income and narrows the income gap with urban residents. Furthermore, FCSP implementation is often accompanied by improvements in rural infrastructure and public services [46], including transportation, communication, and water facilities. These improvements enhance rural living standards, promote local economic development, and further narrow the income gap between rural and urban residents in pilot counties.

Accordingly, we propose Hypothesis 3c: The implementation of FCSP can reduce the horizontal urban-rural income gap.

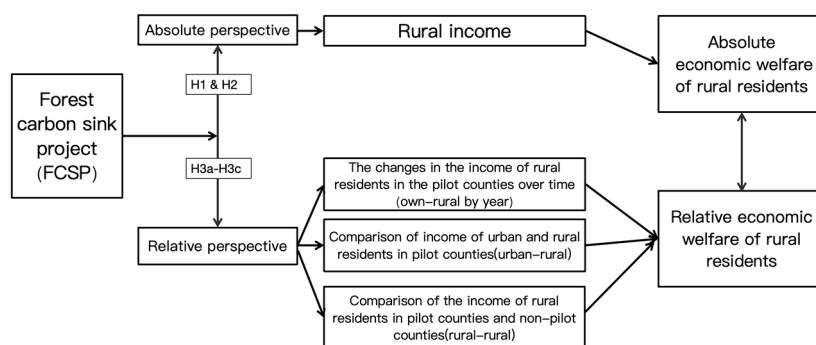


Figure1. Theoretical analysis framework. The impact mechanism of rural residents' economic welfare of forest carbon sink projects from the perspective of absolute and relative.

3. Methods and Data

3.1. Economic Welfare Measurement Method of Rural Residents from a Relative Perspective

3.1.1. Calculation Methods for Vertical Comparison, Rural-Rural Comparison, and Urban-Rural Comparison

Based on the above theoretical analysis, this study divides the economic welfare of FCSP into four components: absolute income, longitudinal comparison, horizontal inter-rural comparison, and horizontal urban-rural comparison. Absolute income refers to the income of local rural residents;

longitudinal comparison measures the difference between the current income of local rural residents and their past income; horizontal inter-rural comparison captures the income gap between local rural residents and those in non-pilot counties; and horizontal urban-rural comparison reflects the income gap between local rural residents and local urban residents.

Drawing on the measurement formulas for individual relative deprivation and intergroup relative deprivation proposed by Ren Guoqiang et al. (2011) [47], Ren Guoqiang et al. (2011) define intergroup relative deprivation as follows: if the overall income distribution is $X = \{x_1, x_2, x_3, \dots, x_n\}$ x is the income of different individuals.

According to the definition of relative deprivation by Runciman and Yitzhaki, the relative deprivation of unit is:

$$D(x_i, x_j) = \begin{cases} x_i - x_j & \text{if } x_i > x_j \\ 0 & \text{if } x_i \leq x_j \end{cases} \quad (1)$$

At the same time, referring to Li Guoping's relative income comparison formula [48], if $I_{i,R,t} > I_{i,R,t-1}$, $U_{j,R} > I_{i,R}$, $I_{i,U} > I_{i,R}$, We list the measurement formulas of vertical comparison, rural-rural comparison, and urban-rural comparison as follows:

$$V_1(I_{i,R,t}, I_{i,R,t-1}) = (I_{i,R,t} - I_{i,R,t-1})/I_{i,R,t} \quad (2)$$

$$V_2(U_{j,R}, I_{i,R}) = (U_{j,R} - I_{i,R})/U_{j,R} \quad (3)$$

$$V_3(I_{i,U}, I_{i,R}) = (I_{i,U} - I_{i,R})/U_{i,U} \quad (4)$$

Further, we define vertical comparison, horizontal rural-rural comparison and horizontal urban-rural comparison for all counties as follows:

$$V_4(I_{i,R,t}, I_{i,R,t-1}) = \frac{1}{N} \sum_{i=1}^n (I_{i,R,t} - I_{i,R,t-1})/I_{i,R,t} \quad (5)$$

$$V_5(U_{j,R}, I_{i,R}) = \frac{1}{N} \sum_{i=1}^n (U_{j,R} - I_{i,R})/U_{j,R} \quad (6)$$

$$V_6(I_{i,U}, I_{i,R}) = \frac{1}{N} \sum_{i=1}^n (I_{i,U} - I_{i,R})/U_{i,U} \quad (7)$$

If $I_{i,R,t} \leq I_{i,R,t-1}$, $U_{j,R} \leq I_{i,R}$, $I_{i,U} \leq I_{i,R}$, Assign $V_1, V_2, V_3, V_4, V_5, V_6$ to 0;

Among them:

Equation (2) is the longitudinal comparison of county i ; $I_{i,R,t}$ indicates the income of rural residents in county i ; $I_{i,R,t-1}$ indicates the income of rural residents in the previous year in county i .

Equation (3) is the horizontal township comparison of county i ; $I_{i,R}$ indicates the income of rural residents in county i ; $U_{j,R}$ indicates the average income of rural residents in counties where forest carbon sink projects have not been implemented.

Equation (4) is the horizontal urban-rural comparison of county i ; $I_{i,R}$ is the same as Equation (3), $I_{i,U}$ indicates the income of townspeople in county; $U_{i,U}$ indicates the average income of urban residents in all counties.

V_1, V_2, V_3, V_4, V_5 , and V_6 are the function expressions of county i vertical comparison, horizontal township comparison, horizontal urban-rural comparison and vertical comparison of all counties, horizontal township comparison, and horizontal urban-rural comparison.

3.1.2. The General Form of the Economic Welfare Function for Residents in Project Areas

Drawing on the utility function form proposed by Boskin[49]:

$u = u(c, \bar{c}; \theta)$; where c represents the level of personal consumption, \bar{c} represents the average consumption level of all people; θ is a parameter that reflects the degree of care of an individual about the relative position.

Assume that there are both pilot counties and non-pilot counties for forest carbon sequestration projects, and that each county consists of two types of areas: urban (U) and rural (R). The rural economic welfare function of county i can then be expressed as:

$$U_{i,R} = u[V_0(I_{i,R}), V_1(I_{i,R,t}, I_{i,R,t-1}), V_2(U_{j,R}, I_{i,R}), V_3(I_{i,R}, I_{i,U}), \theta_1, \theta_2, \theta_3]/z_{i,j} \quad (8)$$

$\theta_1, \theta_2, \theta_3$ represent the parameters of the weights of relative factors in the utility functions of vertical comparison, horizontal rural-rural comparison, and horizontal urban-rural comparison. $z_{i,j}$ represent the basic characteristics of the county.

Furthermore, this study assumes that the rural economic welfare function described above has the following properties:

First, $I_{i,R}$ is positively correlated with the economic welfare of county i , with diminishing marginal returns.

Second, if $I_{i,R,t} > I_{i,R,t-1}$, it indicates that the economic welfare of county i has increased.

Third, the greater the gap between $I_{i,R}$ and $I_{i,U}$, or between $U_{j,R}$ and $I_{i,R}$, the lower the economic welfare of county i .

Fourth, if $\theta_1, \theta_2, \theta_3$ are all equal to zero, it means that the rural economic welfare of FCSP pilot counties is determined solely by rural residents' income; otherwise, it is also influenced by other relative factors.

Therefore, the welfare loss of rural areas in FCSP pilot counties caused by longitudinal comparison, horizontal inter-rural comparison, and horizontal urban-rural comparison can be expressed as:

$$\bar{u}_1 = \frac{(u_{i,\theta_1=\theta_2=\theta_3=0} - u_{i,\theta_1 \neq 0, \theta_2 \neq 0, \theta_3 \neq 0})}{u_{i,\theta_1 \neq 0, \theta_2 \neq 0, \theta_3 \neq 0}} \quad (9)$$

When $\theta_1, \theta_2, \theta_3$ are all non-zero, and $\theta_1 = \theta_2 = \theta_3 = \frac{1}{3}$, this indicates that longitudinal comparison, horizontal inter-rural comparison, and horizontal urban-rural comparison are equally important [50].

As shown in Equation (9), $\bar{u}_1 \in (0,1)$. The larger its value, the greater the rural economic welfare loss in pilot counties caused by relative factors in FCSP.

3.1.3. The Specific Form of the Economic Welfare Function in Project Areas

Drawing on the utility function form of Clark[50]: $u_{it} = \beta_1 \ln y_{it} + \beta_2 \ln (y_{it}/y_t^*)$, The economic welfare of region i can be expressed as:

$$\omega_i = I_{i,R} V(I_{i,R,t}/I_{i,R,t-1})^{\theta_1} V(U_{j,R}, I_{i,R})^{\theta_2} V(I_{i,U}, I_{i,R})^{\theta_3} \quad (10)$$

Logarithmize the above formula:

$$W_i = \ln I_{i,R} + \theta_1 \ln V\left(\frac{I_{i,R,t}}{I_{i,R,t-1}}\right) + \theta_2 \ln V(U_{j,R}, I_{i,R}) + \theta_3 \ln V(I_{i,U}, I_{i,R}) \quad (11)$$

Then all forest carbon sinks and rural economic benefits are:

$$W = \sum_{i=1}^n \ln I_{i,R} + \theta_1 \sum_{i=1}^n \ln V\left(\frac{I_{i,R,t}}{I_{i,R,t-1}}\right) + \theta_2 \sum_{i=1}^n \ln V(U_{j,R}, I_{i,R}) + \theta_3 \sum_{i=1}^n \ln V(I_{i,U}, I_{i,R}) \quad (12)$$

Where $\sum_{i=1}^n \ln I_{i,R}$ is the income of rural residents; $\sum_{i=1}^n \ln V\left(\frac{I_{i,R,t}}{I_{i,R,t-1}}\right)$ is the vertical comparison; $\sum_{i=1}^n \ln V(U_{j,R}, I_{i,R})$ is the rural comparison, and $\sum_{i=1}^n \ln V(I_{i,U}, I_{i,R})$ is the urban-rural comparison.

3.2. An Empirical Model for Analyzing the Impact of FCSP on the Economic Welfare of Rural Residents

To evaluate the impact of FCSP on the economic welfare of rural residents, the single-difference method can be used to compare economic development before and after project implementation. However, since the implementation of FCSP is non-random, using the single-difference method is prone to "selection bias". A more reliable approach is to apply the difference-in-differences(DID) method to assess the policy effects of the project.

Nevertheless, when implementing DID, if the entire sample is used as the treatment and control groups, the vast geographic span of Sichuan may lead to substantial differences between the two groups, potentially introducing bias into the results. Therefore, this study first employs the propensity score matching(PSM) method to match the samples and then applies the DID method to estimate the net impact of FCSP implementation on the economic welfare of rural residents.

1. Propensity Score Matching (PSM)

The propensity score matching (PSM) method is a non-parametric approach that addresses sample self-selection issues by constructing a counterfactual framework, without imposing restrictions on error term distribution, functional form, or other such conditions [51].

The empirical analysis in this study proceeds as follows:

First, Select the characteristic variables X_i , which serve as control variables. Second, Calculate the propensity scores. This study uses a Logit model to estimate the propensity score of county i

implementing a forest carbon sequestration project(FCSP). The model is specified as follows: $\text{logit}(D_i = 1) = \beta_0 + \lambda \text{control} + \xi_i$; Where D_i is the policy dummy variable, and control represents the control variables. Third, Perform propensity score matching. Common PSM algorithms include nearest neighbor matching, radius matching, and kernel matching. The three methods are subjected to balance tests, and by comparing the density function plots before and after matching as well as the model's goodness-of-fit, it is found that the nearest neighbor matching method is more appropriate. Therefore, this study adopts the nearest neighbor matching algorithm to conduct one-to-one matching between the treatment group and the control group.

2. Difference in Difference model (DID)

The difference-in-differences (DID) model is a commonly used policy evaluation method that assesses policy effects by comparing the changes in outcomes between the control group and the treatment group before and after policy implementation. To accurately evaluate the impact of FCSP on the economic welfare of rural residents, this study use DID model, specified as follows:

$$Y_{it} = \beta_0 + \beta_1 \cdot \text{Treat}_i \cdot \text{Post}_i + \sum \beta_x \cdot X_{it} + r_i + \eta_t + \varepsilon_{it} \quad (13)$$

In Equation (13), Y_{it} is the dependent variable, and β_0 is the constant term. Treat_i indicate whether a county participates in the FCSP; Post_i is a dummy variable distinguishing the periods before and after project implementation, $\text{Treat}_i \cdot \text{Post}_i$ is the key explanatory variable measuring whether the carbon sequestration afforestation project is implemented. β_1 represents the net impact of FCSP on the economic welfare of rural residents. X_{it} denotes the control variables, with β_x representing the coefficients of each control variable. r_i captures individual fixed effects that do not vary over time; η_t denotes time fixed effects; ε_{it} is the random disturbance term.

Furthermore, to estimate the dynamic effects of FCSP on the economic welfare of rural residents, the model is specified as follows:

$$Y_{it} = \beta_0 + \sum \beta_k \cdot d_k + \sum \beta_x \cdot X_{it} + r_i + \eta_t + \varepsilon_{it} \quad (14)$$

Where d_k is a dummy variable indicating the k -th year after the implementation of the FCSP pilot county project, and β_k measures the policy effect in the k -th year following project implementation.

3.3. Data Description, Data Source and Variable Selection

1. Data description

This study selects counties in Sichuan Province, China, as the research area. Located in southwestern China, Sichuan possesses abundant afforestation-suitable land resources and holds an important ecological position. With a forest area ranking among the highest in the country, it has unique advantages for developing FCSP.

Moreover, it has been designated by China as one of the key development areas and among the first pilot regions for the forest carbon sequestration industry. In terms of pilot FCSP implementation, Sichuan has long been at the forefront nationally; its carbon sequestration afforestation projects account for 2 of the 5 CDM projects registered with the Executive Board (EB) of the United Nations Clean Development Mechanism, making Sichuan a key region for FCSP development in China [21].

By the end of 2020, a total of 13 counties in Sichuan had successively implemented FCSP. As shown in the Table 1, these projects were launched between 2004 and 2012, covering three types—CCER, CDM, and VCS—with crediting periods of either 20 or 30 years, and substantial variation in project size.

Table 1. Basic Information of Implementation Counties of Carbon Sequestration Afforestation Project in Sichuan Province.

County	Project Type	Project Name	Year of Implementation	Poverty alleviation county	Ethnic county	Project cycle	Area/hm ²
Mianning	CCER	Audi Panda Habitat has multiple benefits	2012	0	1	30	153.4

Jinyang	CCER	Forest restoration and afforestation carbon sink project	2012	1	1	30	181.7
Lixian	CDM	Afforestation and reforestation project	2004	0	1	20	747.8
Maoxian	CDM	of degraded land in	2004	0	1	20	234.9
Beichuan	CDM	northwest Sichuan,	2004	0	0	20	200.2
Qingchuan	CDM	China	2004	0	0	20	190.6
Ganluo	CDM	Novartis Southwest	2010	1	1	30	924.3
Yuexi	CDM	Degraded Land	2010	1	1	30	1245.0
Meigu	CDM	Afforestation and	2010	1	1	30	731.6
Zhaojue	CDM	Reforestation Project	2010	1	1	30	441.8
Leibo	CDM	Reforestation project	2010	1	1	30	854.1
Yingjing	VCS	in Xingjing County, Sichuan Province	2011	0	0	30	159.2

¹ CCER is China's domestic certified emission reduction mechanism for the national voluntary carbon market. CDM, under the Kyoto Protocol and managed by the UN, serves the international compliance market. VCS, run by Verra, is a global voluntary standard for carbon credits used in voluntary carbon markets;² Whether it is a poverty-alleviation county and whether it is an ethnic county, with 1 indicating "yes" and 0 indicating "no."

2. Data source

Due to data completeness and availability constraints, this study selects samples from the period 2007–2022. Given that data for certain counties are unavailable, and that some counties (districts) such as Qianfeng District of Guang'an City implemented projects after 2007 with incomplete data, 44 counties/districts were excluded from the 183 counties in Sichuan Province. Ultimately, data from 139 counties were retained. The data sources include the China County Statistical Yearbook (various years), the Sichuan Statistical Yearbook, statistical bulletins on the national economic and social development of each county in Sichuan, and government work reports.

3. Variable selection

Dependent variables. This study employs five indicators as dependent variables: (1)rural residents' economic welfare without considering relative factors(W1);(2)rural residents' economic welfare considering relative factors(W2);(3)longitudinal comparison(H-H);(4)horizontal rural-rural comparison(R-R);(5)horizontal urban–rural comparison(U-R). These jointly capture the economic welfare effects of FCSP implementation from both absolute and relative perspectives.

Core explanatory variable. The core explanatory variable is whether the county is an FCSP pilot county in a certain year(DID), which is a binary variable. A value of 1 is assigned if the county has implemented an FCSP, and 0 otherwise.

Control variables. The selection of control variables must satisfy the condition of influencing both rural residents' income and the implementation of FCSP. On one hand, FCSP are generally implemented in areas with high ecological vulnerability, which are often highly coupled with economically underdeveloped regions [52]. This suggests that the characteristics of local economic development may affect the likelihood of implementing FCSP [21]. Therefore, this study includes whether the county is a poverty-alleviation county (Poverty), whether it is an ethnic county (Ethnic), road mileage per unit of administrative area (Rma), and per capita GDP (Pgdp) as part of the characteristic variables. On the other hand, FCSP sites are generally located in afforestation-suitable barren hills, sandy wasteland, and other afforestation-suitable land [53]. Agricultural production characteristics can indirectly reflect land attributes. Accordingly, this study includes the share of primary industry employment in total employment (Pie), total power of agricultural machinery (Tpam), the ratio of cultivated land area at year-end to total administrative land area (Rcl), fertilizer consumption (Fercon), and grain yield per unit of cultivated land (Gcl) as additional characteristic variables. All variables are listed in Table 2.

Table 2. Variable selection and explanation

Variable	Name	Definition	Variable Description	Mean	SE
Depeent variables	W1	Economic welfare without considering relative factors	Equation (11) $\theta_1=\theta_2=\theta_3=0$	9.010	0.640
	W2	Economic welfare considering relative factors	Equation (11) $\theta_1=\theta_2=\theta_3=1/3$	8.550	0.840
	H-H	Vertical comparison	V1, Equation (2)	0.560	0.220
	R-R	Horizontal inter-rural comparison	V2, Equation (3)	0.030	0.330
	U-R	Horizontal urban-rural comparison	V3, Equation (4)	1.260	0.740
Core explanatory variable.	DID	Whether a county is an FCSP pilot county	Yes=1, No=0	0.090	0.290
	Poverty	Whether a county is a poverty-alleviation county	Yes=1, No=0	0.240	0.430
Controls	Ethnic	Whether a county is an ethnic county	Yes=1, No=0	0.360	0.480
	Pgdp	Per capita GDP	Per capita GDP of each county (unit: CNY)	29105.00	19965.00
	Pie	Share of primary industry employment in total employment	Ratio of primary industry employment to total employment	0.520	0.180
	Tpam	Total power of agricultural machinery	Total power of machinery used in agriculture, forestry, animal husbandry, and fishery (unit: 10,000 kW)	22.450	17.970
	Rcl	Ratio of cultivated land area to total administrative land area	Cultivated land area at year-end (hectares) divided by total administrative land area (hectares)	0.210	0.390
	Fercon	Fertilizer consumption	Annual fertilizer consumption (unit: tonnes)	13398.00	12318.00
	Gcl	Grain yield per unit of cultivated land	Total grain output (tonnes) divided by cultivated land area at year-end (hectares), unit: tonnes/hectare	1.660	0.620
	Rma	Road mileage per unit of administrative area	Road mileage (km) divided by total administrative area (hectares), unit: km/hectare	1.030	0.710

¹ In the regression analysis, per capita GDP and Fercon was logarithmicized.

4. Empirical Results

4.1. Model Testing

Before proceeding with the main analysis, it is essential to assess the results of the propensity score matching (PSM) through two key evaluations—the balance test and the common support assumption test—to ensure the reliability of the model.

4.1.1. Balance Test

Referring to Chen Qiang, the `pstest` command is used to conduct the balance test. As shown in Table 3, before propensity score matching, these explanatory variables had a significant impact on whether farmers participated in the FCSP (p-values close to zero). However, after matching, these variables were no longer significant, indicating that the effectiveness of using these characteristic variables to predict farmers' participation in the project had diminished, and the sample satisfied the conditional independence assumption.

Table 3. Balancing test

Variable	Matched & Unmatched	Mean		Bias(%)	Reduct(%)	T-test	
		Treated	Control			bias	t
Poverty	U	0.425	0.221	44.500		6.190	0.000
	M	0.425	0.346	17.100	61.600	1.520	0.129
Ethnic	U	0.665	0.333	70.200		9.030	0.000
	M	0.665	0.696	-6.500	90.700	-0.620	0.534
Pgdp	U	23995.000	29552.000	-30.200		-3.580	0.000
	M	23995.000	25914.000	-10.400	65.500	-0.950	0.344
Pie	U	0.623	0.511	69.400		8.300	0.000
	M	0.623	0.614	5.400	92.300	0.520	0.605
Tpam	U	9.884	23.546	-101.400		-9.960	0.000
	M	9.884	9.016	6.400	93.600	1.400	0.162
Rcl	U	0.069	0.111	-28.500		-2.750	0.006
	M	0.069	0.058	8.100	71.400	0.490	0.622
Fercon	U	7274.200	13934.000	-70.800		-7.010	0.000
	M	7274.200	6955.300	3.400	95.200	0.500	0.616
Gcl	U	1.451	1.682	-46.300		-4.830	0.000
	M	1.451	1.325	25.200	45.500	2.390	0.018
Rma	U	0.684	1.062	-64.300		-6.900	0.000

M	0.684	0.624	10.200	84.200	1.260	0.209
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¹Matching algorithm: Propensity scores were estimated using a Logit model, and counties in the treatment group were matched to counties in the control group using 1:1 nearest neighbor matching; ²Balance test method: The ptest command in Stata was used to assess covariate balance before and after matching, reporting mean bias, bias reduction (%), and t-test p-values.³Variable definitions: See Table 2 for definitions of all covariates.

4.1.2. Balance Test

Figure 2 illustrates the distribution of propensity scores (kernel density curves) for the treatment and control groups before and after matching. The vertical axis represents probability density, and the horizontal axis represents propensity score values. Figure (2a) depicts the distribution prior to matching, where the treatment and control groups share minimal overlapping areas. This indicates substantial observable differences between the two groups and suggests that the selection into FCSP implementation is not entirely random across the full sample. Therefore, applying propensity score matching is necessary. Figure (2b) shows the distribution after matching. The kernel density curves of the two groups exhibit a high degree of overlap, indicating that the scores are similar and that few observations were lost during matching. This demonstrates that the matching procedure performed well, yielded representative samples, and eliminated significant differences in covariates between the treatment and control groups.

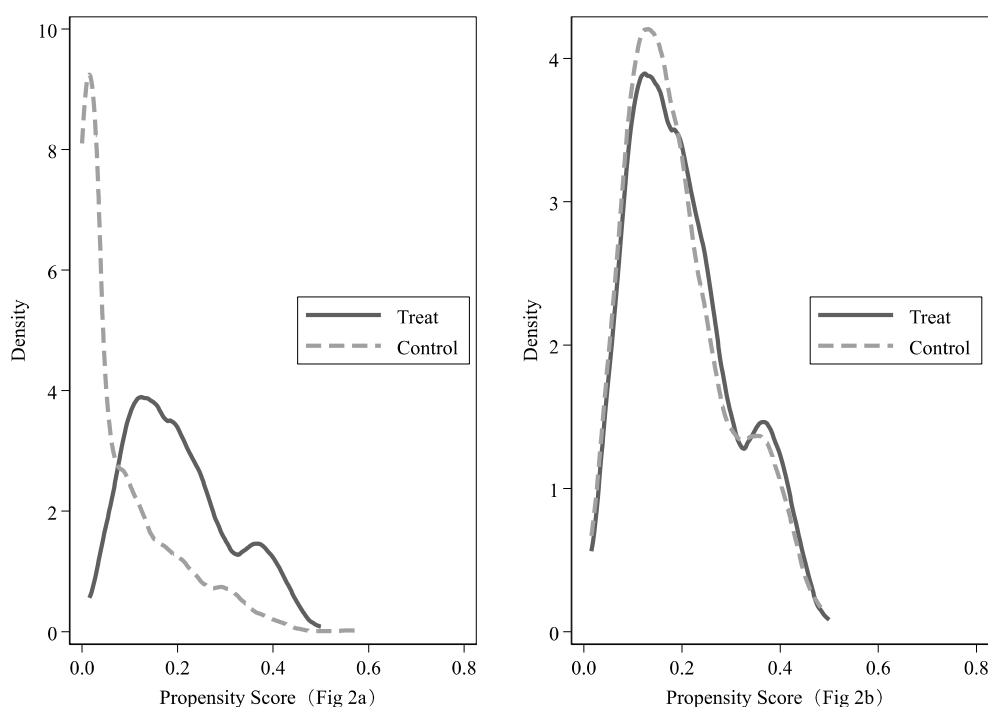


Figure 2. the distribution of propensity scores (kernel density curves) for the treatment and control groups before and after matching; Figure 2a is pre-matching kernel density figure; Figure 2b is After-matching kernel density figure.

4.2. The Utility of Rural Residents' Economic Welfare and Welfare Loss Considering Relative Factors

Table 4 reports the annual average values of rural residents' net income, horizontal urban–rural comparison, horizontal inter-rural comparison, and vertical comparison in FCSP pilot counties. Column2 shows that the annual average net income of rural residents in FCSP pilot counties has exhibited a year-by-year upward trend. Column3 shows that the overall trend of the horizontal urban–rural comparison is a gradual decline, indicating that the urban–rural income gap in FCSP

pilot counties is narrowing year by year, with continuous improvement in coordinated urban–rural economic development. Column4 presents the horizontal inter-rural comparison, which shows an overall increasing trend over the years. Column5 presents the vertical comparison, which shows that, compared to the previous year, the overall rural residents' income in FCSP pilot counties has been decreasing, suggesting a year-by-year decline in rural residents' economic welfare in these counties.

Table 4. Economic welfare utility of rural residents in forest carbon sink pilot counties

year	Mean_Income	U_R	R_R	H_H
2007	2633.692	0.669	0.251	1.000
2008	2970.923	0.687	0.281	1.098
2009	3214.923	0.712	0.263	0.937
2010	3789.692	0.700	0.265	1.119
2011	4567.600	0.672	0.273	0.840
2012	5319.892	0.668	0.270	0.967
2013	6109.610	0.650	0.263	0.968
2014	6938.622	0.629	0.272	0.914
2015	8358.538	0.569	0.256	0.862
2016	9218.692	0.560	0.252	0.878
2017	10168.230	0.551	0.248	0.936
2018	11227.300	0.543	0.242	0.889
2019	9968.923	0.363	0.273	0.799
2020	10889.462	0.349	0.286	0.800
2021	11866.154	0.351	0.301	0.840
2022	12904.538	0.367	0.318	0.804

Based on the above discussion, when relative factors are taken into account, the economic welfare of rural residents declines. This raises the question: how much welfare loss is caused by changes in each relative factor? To address this, a further analysis was conducted.

As previously stated, without considering relative factors, the economic welfare of rural residents in FCSP pilot counties is denoted as W_1 ; when relative factors are considered, it is denoted as W_2 . Table 5 reports the welfare levels of rural residents in FCSP pilot counties under both scenarios. Column 2 shows that without considering relative factors, rural residents' economic welfare in FCSP pilot counties exhibits an overall upward trend. Column 3 reveals that when relative factors are considered, economic welfare declines compared to Column 2, although the overall trend remains upward. This indicates that accounting for relative factors results in a reduction in economic welfare. Column 4 further demonstrates that vertical comparison, horizontal inter-rural comparison, and horizontal urban–rural comparison together lead to an average welfare loss of 9.05%.

Table 5. Absolute Welfare, Relative Welfare and Welfare Loss

year	W1	W2	u
2007	7.854	7.355	0.068
2008	7.958	7.493	0.062
2009	8.054	7.543	0.068
2010	8.220	7.769	0.058
2011	8.403	7.859	0.069
2012	8.555	8.055	0.062
2013	8.694	8.153	0.066
2014	8.823	8.147	0.083

2015	9.009	8.176	0.102
2016	9.108	8.265	0.102
2017	9.207	8.381	0.099
2018	9.308	8.464	0.100
2019	9.149	8.090	0.131
2020	9.227	8.155	0.131
2021	9.302	8.342	0.115
2022	9.374	8.280	0.132
Average	8.7653	8.0329	0.0905

4.3. Economic Welfare Effects of FCSP on Rural Residents

This study uses the rural residents' economic welfare without considering relative factors (W1) and with considering relative factors (W2), calculated according to Equation (11), as dependent variables to estimate the net impact of FCSP implementation on rural residents' economic welfare.

Table 6 presents the results of the average effect test. The empirical findings show that FCSP implementation significantly improves rural residents' economic welfare from an absolute perspective, with a DID coefficient of 0.111, significant at the 1% level, indicating that welfare increases by approximately 0.111 units after project implementation when relative factors are not considered. However, when relative factors are taken into account, the effect turns significantly negative, with a DID coefficient of -0.119, significant at the 5% level, implying an average welfare loss of 0.119 units due to relative comparisons.

Table 6. Average effect test results of the impact of FCSP on rural residents' economic welfare

	W1	W2
DID	0.111*** (0.039)	-0.119** (0.050)
Poverty	-0.043 (0.036)	-0.322*** (0.046)
Ethnic	0.117** (0.047)	0.249*** (0.059)
Pgdp	0.013*** (0.001)	0.012*** (0.001)
Pie	0.228* (0.123)	0.433*** (0.157)
Tpam	0.016*** (0.003)	0.021*** (0.003)
Rcl	0.506** (0.237)	1.687*** (0.302)
Fercon	-0.138 (0.152)	-0.462 (0.173)
Gcl	-0.155*** (0.033)	-0.072* (0.042)
Rma	0.151*** (0.024)	0.172*** (0.031)
_cons	8.031***	7.141***

	(0.105)	(0.134)
Fix_id	Y	Y
Fix_year	Y	Y
N	1179	1179
R2	0.474	0.418

¹ Standard deviation in parentheses; ² And *, **, *** represent 10%, 5%, and 1% saliency levels; ³ The model controls for fixed effects of time and individuals.

Based on the above empirical results, the implementation of FCSP can effectively improve rural residents' economic welfare from an absolute perspective. However, when relative factors are taken into account, rural residents' economic welfare significantly declines. What, then, is the mechanism behind this decline?

To further explain the reasons, this study decomposes rural residents' economic welfare from a relative perspective into three components: horizontal urban–rural comparison (U–R), horizontal inter-rural comparison (R–R), and vertical comparison (H–H). Using the models specified in Equations (13) and (14), we estimate the welfare effects of FCSP from a relative perspective. The regression results, reported in Table 7, show that FCSP implementation significantly narrows the urban–rural gap, with the U–R index decreasing by 0.094 at the 1% significance level. However, it simultaneously increases inter-rural deprivation, with the R–R index rising by 0.129 at the 1% significance level, and reduces vertical comparison scores, with the H–H index falling by 0.211 at the 1% significance level. The magnitude of the positive effect from narrowing the urban–rural gap is smaller than the combined negative impacts of increased inter-rural deprivation and reduced vertical comparison, ultimately leading to a significant decline in rural residents' economic welfare when relative factors are considered.

Table 7. The average effect test results of the economic welfare effect of rural residents of FCSP from a relative perspective

	U-R	R-R	H-H
DID	-0.094*** (0.018)	0.129*** (0.020)	-0.211*** (0.048)
_cons	0.800*** (0.047)	0.379*** (0.052)	0.772*** (0.128)
Control	Y	Y	Y
Fix_id	Y	Y	Y
Fix_year	Y	Y	Y
N	1179	1179	1179
R-sq	0.165	0.391	0.175

¹ Standard deviation in parentheses; ² And *, **, *** represent 10%, 5%, and 1% saliency levels; ³ The model has added fixed effects of control variables, individuals and time.

4.4. Dynamic Effects of FCSP on Rural Residents' Economic Welfare

The above results reflect the average effect of FCSP implementation on rural residents' economic welfare but do not examine whether this impact exhibits lagged effects or dynamic persistence. In the sample, the 13 treatment counties began implementation in different years—specifically in 2004 and 2010–2012—meaning that policy start dates are not uniform. To eliminate potential confounding influences from other policies enacted in different periods, this study selects as the analysis sample the five counties that began implementation in 2010 and investigates their dynamic effects from 2010 to 2022. Using Equation (14), we test the dynamic effects of FCSP on rural residents' economic welfare.

The empirical results are reported in Table 8, where d1–d13 represent the dynamic effects from 2010 (the year of implementation) to 2022. The results indicate that the implementation of FCSP does not significantly improve rural residents' economic welfare in the short term, exhibiting a clear lagged effect, with benefits strengthening over time.

The dynamic effect estimates show that under the absolute perspective (W1), coefficients for the first seven periods (d1–d7) after implementation are insignificant, with the first five (d1–d5) being negative (–0.219 in d1, –0.129 in d2). The positive effect emerges in period 8 (d8 = 0.256, significant at the 10% level) and reaches its peak in period 12 (0.375, significant at the 1% level).

Under the relative perspective (W2). The coefficient in period 7 is –0.456 (significant at the 1% level), and those from periods 8 to 12 remain significantly negative (d10 = –0.654, significant at the 1% level; d12 = –0.642, significant at the 1% level), indicating that FCSP substantially reduces rural residents' welfare during the mid-term when relative factors are considered. By period 13, the coefficient turns positive (0.065) but insignificant, suggesting that the negative influence of relative factors diminishes in the long run.

Overall, the short-term negative effect may stem from the absence of immediate economic returns and potential constraints on agricultural production, leading some part-time farmers to reduce cultivated land without promptly securing non-agricultural employment, thereby lowering welfare in the early years. In the long run, however, FCSP not only improves absolute welfare but also delivers ecological and social benefits that enhance overall utility for participants. Policymakers should therefore prioritize long-term impacts and consider relative welfare effects to achieve a win-win outcome for both the economy and the environment.

Table 8. Test results of the dynamic effect of FCSP on the economic welfare of rural residents

	W1	W2
d1	-0.219 (0.169)	-0.090 (0.213)
d2	-0.129 (0.169)	0.006 (0.213)
d3	-0.036 (0.169)	-0.109 (0.213)
d4	-0.116 (0.133)	-0.259 (0.167)
d5	-0.058 (0.132)	-0.255 (0.167)
d6	0.032 (0.132)	-0.196 (0.166)
d7	0.188 (0.132)	-0.456*** (0.165)
d8	0.256* (0.132)	-0.397** (0.166)
d9	0.241* (0.132)	-0.389** (0.165)
d10	0.249* (0.132)	-0.654*** (0.165)
d11	0.288** (0.132)	-0.582*** (0.165)

d12	0.375*** (0.143)	-0.642*** (0.179)
d13	0.353** (0.150)	-0.065 (0.189)
_cons	7.957*** (0.106)	6.922*** (0.135)
Control	Y	Y
Fix_id	Y	Y
Fix_year	Y	Y
N	1179	1179
R2	0.484	0.446

4.5. Heterogeneity Analysis

4.5.1. Different Project Cycles

From an investment perspective, the longer the project cycle, the greater the risks and the higher the uncertainty of returns. Therefore, differences in the crediting periods of projects may lead to variations in the economic welfare effects of rural residents participating in forest carbon sequestration projects (FCSP). To investigate this, the existing FCSP are divided into two groups based on their crediting periods: 20 years and 30 years.

Table 9 divides FCSP into two groups based on crediting period length—20 years and 30 years—and examines their average effects on rural residents' economic welfare. For 20-year projects, the DID coefficient for W1 (without relative factors) is 0.064 and statistically insignificant, indicating no substantial improvement in absolute welfare. When relative factors are considered (W2), the coefficient becomes -0.140, significant at the 10% level, suggesting that shorter-term projects may generate negative welfare effects due to limited economic gains and stronger relative deprivation. In contrast, for 30-year projects, the DID coefficient for W1 is 0.127, significant at the 5% level, showing that longer-term projects significantly enhance absolute welfare. For W2, the coefficient is -0.117, significant at the 10% level; although still negative, the magnitude is smaller than in the 20-year group, implying a weaker adverse effect from relative factors. Overall, longer crediting periods tend to produce stronger positive impacts on rural residents' economic welfare while mitigating the negative effects of relative deprivation.

Table 9. The average effect test results of the impact of FCSP on the economic welfare of rural residents in different periods

	20-years		30-years	
	W1	W2	W1	W2
DID	0.064 (0.061)	-0.140* (0.077)	0.127** (0.054)	-0.117* (0.070)
_cons	7.933*** (0.117)	7.015*** (0.149)	7.890*** (0.111)	6.966*** (0.143)
Control	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y
Fix_year	Y	Y	Y	Y
N	1056	1056	1099	1099
R2	0.467	0.426	0.495	0.436

¹ The distinction between 20-year and 30-year crediting periods is based on the crediting duration specified in the Project Design Document (PDD). Twenty-year crediting period projects are often implemented earlier, with shorter crediting durations and renewal uncertainties, whereas 30-year crediting period projects have longer crediting periods that can provide more stable long-term returns.

To examine the impact of relative factors on the economic welfare of rural residents, the PSM-DID model was applied to estimate the welfare effects of FCSP with different crediting periods from a relative perspective. The results are presented in Table 10. For projects with a 20-year crediting period (Columns 2–4), the DID estimates show that implementation significantly increased horizontal inter-rural comparison (0.127, significant at the 1% level), indicating greater relative deprivation between rural areas, which in turn reduced economic welfare. In contrast, the effects on horizontal urban–rural comparison (-0.001, not significant) and vertical comparison (-0.123, not significant) were not statistically significant.

For projects with a 30-year crediting period (Columns 5–7), FCSP implementation significantly reduced horizontal urban–rural comparison (-0.174, significant at the 1% level), effectively narrowing the urban–rural gap and thus improving economic welfare. However, it also significantly increased horizontal inter-rural comparison (0.138, significant at the 1% level) and significantly reduced vertical comparison (-0.290, significant at the 1% level), both of which exert negative impacts on welfare.

Overall, for 20-year projects, the significant negative welfare effect after accounting for relative factors is mainly due to the increase in inter-rural disparities. For 30-year projects, although the effect remains significantly negative, the coefficient is smaller, suggesting that the positive impact of narrowing the urban–rural gap partially offsets the negative effects arising from increased inter-rural deprivation and reduced vertical comparison.

Table 10. The average effect test results of the impact of FCSP on the economic welfare of rural residents in different accounting periods from the relative perspective

	20-years			30-years		
	U-R	R-R	H-H	U-R	R-R	H-H
DID	-0.001 (0.027)	0.127*** (0.030)	-0.123 (0.075)	-0.174*** (0.024)	0.138*** (0.028)	-0.290*** (0.068)
_cons	0.740*** (0.052)	0.412*** (0.059)	0.687*** (0.145)	0.736*** (0.049)	0.435*** (0.057)	0.653*** (0.140)
Control	Y	Y	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y	Y	Y
fix_year	Y	Y	Y	Y	Y	Y
N	1056	1056	1056	1099	1099	1099
R2	0.157	0.358	0.154	0.190	0.402	0.186

4.5.2. Different Poverty Attributes

Given that FCSP in Sichuan Province have been piloted in both poverty-alleviated counties and non-poverty counties, this study investigates the differences in their economic welfare effects across rural areas with varying poverty attributes. Table 11 presents the average effect test results of the Forest Carbon Sequestration Project (FCSP) on rural residents' economic welfare, distinguishing between general counties and poverty-alleviated counties.

For general counties, the DID coefficient for W1 (absolute perspective) is 0.067 and not statistically significant, indicating that FCSP implementation does not significantly affect rural residents' economic welfare when relative factors are not considered. However, for W2 (relative perspective), the DID coefficient is -0.197 and significant at the 1% level, suggesting that when relative

factors are taken into account, FCSP implementation significantly reduces rural residents' economic welfare in these areas.

For poverty-alleviated counties, the DID coefficients for both W1 (0.026) and W2 (-0.047) are statistically insignificant, implying that FCSP implementation has no measurable effect on rural residents' economic welfare regardless of whether relative factors are considered. Notably, the negative coefficient for W2 is smaller in magnitude compared to general counties, suggesting a milder reduction in relative welfare for poverty-alleviated counties.

Overall, the results indicate that the adverse relative welfare effect of FCSP implementation is more pronounced in general counties than in poverty-alleviated counties.

Table 11. The average effect test results of the impact of FCSP of different poverty attributes on economic welfare of rural residents

	General County		Poverty alleviation counties	
	W1	W2	W1	W2
DID	0.067 (0.054)	-0.197*** (0.070)	0.026 (0.055)	-0.047 (0.069)
_cons	7.961*** (0.133)	6.912*** (0.173)	8.104*** (0.165)	7.674*** (0.207)
Control	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y
Fix_year	Y	Y	Y	Y
N	831	831	348	348
R-sq	0.471	0.418	0.627	0.437

¹ The distinction between general counties and poverty-alleviated counties is based on the official classification by the Sichuan Provincial Government. Poverty-alleviated counties refer to counties that were officially removed from the national poverty list under China's targeted poverty alleviation program before the implementation of the FCSP. General counties are those without such poverty-alleviation designation during the study period.

Table 12 reports FCSP on rural residents' economic welfare across general counties and poverty-alleviated counties. In general counties, FCSP implementation has no significant effect on the horizontal urban-rural comparison (U-R). However, it significantly increases horizontal inter-rural disparity (R-R) with a coefficient of 0.132 at the 1% significance level, FCSP may intensify inequality between rural areas. Furthermore, the project significantly reduces vertical comparison scores (H-R) with a coefficient of -0.142 at the 5% significance level, indicating a negative impact on welfare from the perspective of intertemporal comparisons.

In contrast, in poverty-alleviated counties, FCSP significantly narrows the urban-rural gap, as shown by the coefficient of -0.121 for U-R, significant at the 1% level. This improvement in urban-rural equity, however, is accompanied by a significant increase in inter-rural disparity, with the R-R coefficient reaching 0.117 at the 1% significance level. Moreover, the reduction in vertical comparison scores is even more pronounced than in general counties, with an H-R coefficient of -0.277 significant at the 1% level, indicating stronger negative intertemporal welfare effects.

Overall, while poverty-alleviated counties benefit more from the narrowing of the urban-rural gap, the gains are offset by the combined negative effects of widening inter-rural disparities and declining vertical comparison scores.

Table 12. The average effect test results of the impact of FCSP of different poverty attributes on economic welfare of rural residents from a relative perspective

	General County			Poverty alleviation counties		
	U-R	R-R	H-R	U-R	R-R	H-R

DID	-0.030 (0.023)	0.132*** (0.028)	-0.142** (0.067)	-0.121*** (0.030)	0.117*** (0.023)	-0.277*** (0.075)
_cons	0.687*** (0.058)	0.422*** (0.069)	0.654*** (0.166)	0.970*** (0.091)	0.319*** (0.068)	0.759*** (0.223)
Control	Y	Y	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y	Y	Y
Fix_year	Y	Y	Y	Y	Y	Y
N	831	831	831	348	348	348
R-sq	0.164	0.355	0.162	0.335	0.316	0.155

4.5.3. Different Ethnic Attributes

Given that China is a multi-ethnic country, substantial differences exist in the economic and social development environments between non-ethnic and ethnic regions. Implementing the FCSP in counties with different ethnic attributes may therefore have varying impacts on local economic welfare. Accordingly, this study examines the heterogeneous effects of FCSP on rural economic welfare based on whether a pilot county is classified as an ethnic county.

The results for non-ethnic counties (Columns 2–3) indicate that FCSP implementation significantly improves rural residents' economic welfare from an absolute perspective. However, when relative factors are considered, the impact becomes statistically insignificant. In contrast, the results for ethnic counties (Columns 4–5) show that FCSP implementation has no significant effect on rural residents' economic welfare from an absolute perspective, but when relative factors are taken into account, it significantly reduces rural residents' economic welfare.

Table 13. The average effect test results of the impact of FCSP of different ethnic on economic welfare of rural residents from a relative perspective

	Non-ethnic country		Ethnic country	
	W1	W2	W1	W2
DID	0.236*** (0.047)	0.019 (0.084)	-0.062 (0.060)	-0.284*** (0.069)
_cons	8.539*** (0.117)	7.667*** (0.209)	8.244*** (0.155)	7.364*** (0.178)
Control	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y
Fix_year	Y	Y	Y	Y
N	525	525	654	654
R ²	0.717	0.539	0.461	0.415

¹ The classification of ethnic and non-ethnic counties is based on the administrative division attributes of the pilot counties. According to the administrative division lists published by the National Bureau of Statistics and local governments, counties designated as "autonomous counties" are classified as ethnic counties, while all others are classified as non-ethnic counties.

Table 14 presents the average effect test results of the impact of FCSP on rural residents' economic welfare from a relative perspective, differentiated by ethnic attributes. The results for non-ethnic counties (Columns 2–4) indicate that FCSP implementation significantly increases inter-rural comparisons, thereby reducing rural residents' economic welfare. For ethnic counties (Columns 5–7), the results show that while FCSP implementation can reduce the urban–rural gap, it simultaneously widens inter-rural disparities and lowers vertical comparison scores to a greater extent. Therefore, the primary reason for the significant decline in rural residents' economic welfare in ethnic counties,

when relative factors are considered, is the increase in inter-rural deprivation and the reduction in vertical comparison.

Table 14. The average effect test results of the impact of FCSP of different ethnic on economic welfare of rural residents from a relative perspective

	Non-ethnic country			Ethnic country		
	U-R	R-R	H-H	U-R	R-R	H-H
DID	0.025 (0.025)	0.130*** (0.031)	-0.107 (0.107)	-0.120*** (0.026)	0.176*** (0.027)	-0.234*** (0.055)
_cons	0.591*** (0.063)	0.045 (0.076)	0.817*** (0.265)	0.722*** (0.067)	0.485*** (0.071)	0.733*** (0.143)
Control	Y	Y	Y	Y	Y	Y
Fix_id	Y	Y	Y	Y	Y	Y
Fix_year	Y	Y	Y	Y	Y	Y
N	525	525	525	654	654	654
R ²	0.091	0.409	0.131	0.208	0.379	0.149

5. Conclusions and Discussion

5.1. Contributions and INNOVATIONS

5.1.1. Contributions

Based on county-level panel data from Sichuan Province spanning 2007–2022, this study employs a propensity score matching–difference-in-differences (PSM-DID) approach to comprehensively evaluate the impact of Forest Carbon Sequestration Projects (FCSP) on the economic welfare of rural residents from both absolute and relative perspectives.

The results indicate that, from an absolute perspective, FCSP significantly improve rural residents' income levels. However, from a relative perspective, the combined effects of vertical comparison, urban–rural comparison, and rural–rural comparison offset the positive impact, even leading to significant relative welfare losses. Among these, relative deprivation arising from rural–rural comparison and the decline in vertical comparison are the primary negative drivers, with their adverse effects outweighing the gains from narrowing the urban–rural income gap. In addition, the project effects exhibit a marked time lag: in the short term, increased opportunity costs and production constraints may reduce welfare, while in the medium and long term, absolute welfare continues to improve and the negative effects of relative welfare gradually weaken.

Heterogeneity analysis further reveals that, in terms of project duration, 30-year FCSP deliver greater improvements in absolute welfare than 20-year projects, with relatively lighter negative impacts on relative welfare. In contrast, the 20-year projects exhibit stronger negative effects, mainly due to widening rural–rural disparities. Regarding poverty attributes, FCSP in general counties show no significant absolute effect but a significantly negative relative effect; in poverty-alleviated counties, although FCSP yield notable benefits in narrowing the urban–rural gap, these are accompanied by greater rural–rural disparities and a decline in vertical comparison. In terms of ethnic attributes, non-ethnic counties exhibit a significant absolute positive effect and an insignificant relative effect, with the main issue being the intensification of rural–rural comparisons. Ethnic autonomous counties, on the other hand, show no significant absolute effect but a significantly negative relative effect, with the negative impact likewise driven by the expansion of rural–rural disparities and the decline in vertical comparison.

5.1.2. Innovations

This study provides new empirical evidence on the economic welfare effects of forest carbon sequestration projects (FCSP) in rural China by explicitly distinguishing between absolute and relative perspectives. Unlike most previous research, which tends to focus solely on absolute welfare changes, this paper integrates relative welfare considerations—capturing inter-regional and inter-household comparisons—to more comprehensively evaluate policy outcomes. In addition, by employing the PSM-DID approach, the study addresses selection bias and ensures more robust causal inference. Furthermore, the analysis incorporates heterogeneity dimensions such as crediting period length, poverty attributes, and ethnic attributes, offering a nuanced understanding of how FCSP impacts vary across socio-economic and cultural contexts.

5.2. Limitations

Despite these contributions, the study has several limitations. First, the measurement of rural residents' economic welfare relies on statistical yearbook data, which may not fully capture informal economic activities or household-level heterogeneity. Second, while the PSM-DID method helps mitigate selection bias, unobserved time-varying factors may still influence the results. Third, the study primarily focuses on Sichuan Province, which, although representative in some respects, may limit the generalizability of the findings to other regions with different economic, environmental, or policy contexts. Finally, the analysis does not explicitly incorporate the potential environmental co-benefits or opportunity costs associated with FCSP, which could further enrich the welfare assessment.

5.3. Future Research Directions

Future research could expand the scope of analysis to include multiple provinces or conduct a nationwide assessment, thereby improving external validity. Micro-level household survey data could be incorporated to better capture individual welfare changes and behavioral responses. Moreover, integrating environmental and social co-benefits into the evaluation framework would provide a more holistic understanding of FCSP impacts. Finally, longitudinal studies with extended post-implementation periods could better capture long-term dynamics and potential lag effects, allowing policymakers to fine-tune project design for sustained economic and ecological benefits.

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