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Does Ecological Planting–Breeding Mix Pattern Improve Farmers' Subjective Well-Being? Evidence from the Middle and Lower Reaches of the Yangtze River

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Abstract: The Chinese government is making vigorous efforts to control agricultural pollution. The promotion of an ecological planting–breeding mix pattern is one of them. Farmers' mode of production will affect their subjective well-being. Thus, this paper aims to analyze the impact of adopting the ecological planting–breeding mix pattern on farmers' subjective well-being based on 895 pieces of survey data from the provinces of Hubei, Hunan, and Jiangxi in the middle and lower reaches of the Yangtze River. Using the endogenous switching regression model, we find that the adoption of the ecological planting–breeding mix pattern has a significant positive effect on farmers' subjective well-being. Based on this counterfactual hypothesis, if the farmers who actually adopted the ecological planting–breeding mix pattern did not adopt it, their subjective well-being would decrease from 4.006 to 3.669. Further examination indicates that self-worth identification, income increase, and neighborhood communication could be potential mechanisms. Additionally, the effect of the ecological planting–breeding mix pattern on subjective well-being is stronger in the group with low financial support. The technical support provided by the government does not have a significant regulatory effect on the adoption of the ecological planting–breeding mix pattern on subjective well-being. Our results suggest that farmers' ecological production behavior can affect their subjective well-being. This may be relevant to many developing countries today that are attempting to adopt ecological agriculture patterns.

Keywords: ecological planting–breeding mix pattern; subjective well-being; sustainable development

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1. Introduction

China's agricultural sector is currently facing complex challenges, such as soil acidification, water contamination, and biodiversity loss. Faced with limited agricultural resources and environmental constraints, scientists are combining traditional farming with modern technology and continually researching environmentally friendly agricultural production methods. The result of this process is the ecological planting–breeding mix pattern. The ecological planting–breeding mix pattern is a type of hybrid farming that combines the techniques of planting and breeding in an ecological way. This pattern mainly includes rice–fish, rice–livestock, forestry–grass–livestock, orchard–livestock, free-range livestock farming, planting–breeding–processing, rice–fish–livestock, animals–biogas–fruits, multiple crops–livestock [1]. This pattern can increase biodiversity in the agricultural system, build material and energy cycles within the agricultural system, and reduce the demand for external material energy in the agricultural system [2,3]. The ecological planting–breeding mix pattern plays an important role. First, this pattern realizes the shift from "resource—product—pollution" to "resource—product—renewable resources" [4,5]. Second, this pattern makes intensive use of the land and improves the yield of the land [6].

Third, this pattern increases the economic benefits to farmers by increasing their income sources [6]. In this way, green development, food production, and farmers' incomes can be developed in synergy. China has been actively implementing the ecological planting–breeding mix pattern in the middle and lower reaches of the Yangtze River.

Currently, a number of studies on the ecological planting–breeding mix pattern have focused on two main areas. First, studies on farmers' adoption behavior of the ecological planting–breeding mix pattern have received much attention. Previous studies have empirically confirmed that several factors, such as capital endowment [7], individual perceptions [6], production characteristics [8], and policy incentives [9], affect farmers' adoption behavior of the ecological planting–breeding mix pattern.

Second, with the maturation and application of the ecological planting–breeding mix pattern, more and more studies have explored the ex post impacts of this pattern. Recent studies provide evidence that the ecological planting–breeding mix pattern has a positive impact on farmers' income [6,10–13] and environmental protection [13–15]. Although there is no doubt about the economic and environmental impact of the ecological planting–breeding mix pattern, its psychological impact remains to be verified. One aspect of this is the impact of mixed farming on farmers' subjective well-being.

While the study of the benefits of farmers' adoption behavior of the ecological planting–breeding mix pattern did not address farmers' subjective well-being, how farmers produce affects their subjective well-being [16–18]. Some researchers have demonstrated a positive relationship between farmers' ecological production and subjective well-being [18–21]. The adoption of the ecological planting–breeding mix pattern has positive externalities, partially due to favorable environmental impact. Particularly in China, agriculture is a "comfort zone" for farmers, where they can secure a basic livelihood while remaining within a familiar social network. Therefore, farmers' sense of well-being may change before and after the adoption of the ecological planting–breeding mix pattern.

Subjective well-being refers to the overall evaluation and emotional experience of an individual's life status according to the psychological self-determined standard [22,23]. Previous studies used self-reported levels of happiness to measure farmers' subjective well-being and found that individual characteristics [24] and the external environment [25] can influence this subjective feeling. Researchers began to pay attention to the subjective initiative of farmers to pursue a happy life. In addition to focusing on the incentive effect of aspirations and self-efficacy on farmers' subjective well-being, it is also important to explore how external production modes affect farmers' subjective well-being.

To fill these research gaps, this paper takes the rice–crayfish co-culture system as an example. It evaluates the impact of adopting the ecological planting–breeding mix pattern on farmers' subjective well-being by constructing an endogenous switching regression model (ESRM) based on 895 pieces of survey data from the provinces of Hubei, Hunan, and Jiangxi in the middle and lower reaches of the Yangtze River. In addition, it further analyzes the potential mechanisms through which the adoption of the ecological planting–breeding mix pattern affects farmers' subjective well-being.

The main contributions of this paper are threefold. First, this is the first study in China to use unique and representative survey data to measure the impact of the ecological planting–breeding mix pattern on farmers' subjective well-being. To avoid estimation errors caused by self-selection bias in the adoption of the ecological planting–breeding mix pattern, an ESRM was employed to estimate the subjective well-being impacts of the ecological planting–breeding mix pattern. Second, it analyzes the internal production characteristics and the external additional characteristics of the ecological planting–breeding mix pattern to explore the potential mechanisms through which the adoption of the ecological planting–breeding mix pattern affects farmers' subjective well-being. Third, the findings of this paper can help policymakers and development practitioners in developing countries with similar agricultural backgrounds to China design and implement their strategies for promoting an ecological planting–breeding mix pattern.

In the next section, we provide a background where we discuss the characteristics of the ecological planting–breeding mix pattern and the empirical evidence validated in the literature to explain the relationship between the adoption of the ecological planting–breeding mix pattern and farmers' subjective well-being. Section 3 describes the data, variables, and empirical model we use. Sections 4 and 5 present the main effects, estimation results, and possible mechanisms. Section 6 presents a concluding discussion.

2. Theoretical Analysis

2.1. The Ecological Planting–Breeding Mix Pattern: Rice–Crayfish Co-Culture System as a Case in Point

The ecological planting–breeding mix pattern refers to the combination of crop, livestock, and fisheries in an efficient agricultural cycle. It mainly includes integrated crops–livestock, animals–biogas–fruits, rice–fish, and forestry–grass–livestock [1]. Among these, the rice–fish co-culture system has attracted wide attention due to its critical implications for both food security and farmers' livelihoods. According to FAO (2022) [26], China's total rice production in 2020 accounted for 27% of the world's total, ranking first in the world. However, rice farming in China faces not only the conflict between ecology and production but also the conflict between small farmers and large markets. In order to achieve a synergistic and sustainable development of ecology, agriculture, and farmers, the government and various agricultural operators have been actively practicing and exploring the rice–fish co-culture system. Using the principle of ecological coupling symbiosis, the rice–fish co-culture synergistically achieves mutual coordination between agriculture and aquaculture and integrates the organic production of rice and fish [27]. In China, the rice–crayfish co-culture system has the largest application area—the highest total production of rice–fish co-culture. China's rice–crayfish co-culture area covers 156.67 million hectares, accounting for 54.71% of the national rice–fish co-culture area in 2022 [28]. In terms of operation, the rice–crayfish co-culture system requires the digging of trenches in the rice field, which means that the farmer's rice field cannot be too small. In addition, the rice–crayfish co-culture system requires farmers to master complex production technology and the fine control of each production link, which places certain demands on farmers' ability and energy. Given this background information, the rice–crayfish co-culture system in China is a case worth exploring.

2.2. Characteristics of Rice–Crayfish Co-Culture System

2.2.1. Internal Operational Characteristics

From an ecological point of view, the rice–crayfish co-culture system has green characteristics. Ecological research shows that rice and crayfish can coexist harmoniously in the same water body. First, rice fields can provide a good habitat for crayfish. The shallow water environment of the rice field has the appropriate light, temperature, and water source for crayfish growth. Second, the activity of crayfish can improve the ecosystem of the rice field. Crayfish in the rice field have uninterrupted feeding, affecting the surface of the soil, and can effectively contain pests and weeds in the rice field to achieve the effect of biological control, reducing the input of pesticides in the rice field [29–31]. Crayfish excrement can be used as a natural fertilizer, reducing the input of chemical fertilizer into the rice field [15]. From there, the rice–crayfish co-culture system can improve the material and energy recycling within the rice field system [32], reduce the input of external pollutants, and promote the green cycle of the rice field ecosystem.

From an economic point of view, the rice–crayfish co-culture system has dual income sources and operational complexity characteristics. First, the rice–crayfish co-culture system can realize "two uses of one water and two harvests from one field". The rice–crayfish co-culture system can maintain rice yield [33] and provide a basic income for farmers. At the same time, there is a positive effect between the rice–crayfish co-culture system and farmers' income [6]. Compared to rice monoculture systems, farmers who adopt the rice–crayfish co-culture system can increase their income by selling crayfish. Crayfish are in demand in China as a popular economic aquatic product for consumption. They are rich in protein and vitamins [34]. They taste delicious after being utilized as food in a number of specific cooking methods [35]. Therefore, crayfish are preferred by Chinese consumers. Second, the rice–crayfish co-culture system is an integrated agricultural technology that requires farmers to use a combination of rice field engineering techniques, safe fertilization techniques, and crayfish disease control techniques in the production process. For farmers who rely on experience, the rice–crayfish co-culture system has a certain technical threshold.

2.2.2. External Add-On Characteristics

In addition to the production and management characteristics of the pattern itself, there are obvious external characteristics associated with the rice–crayfish co-culture system. The process of dissemination, promotion, and adoption of the rice–crayfish co-culture system is characterized by significant government intervention [9]. Governments use a range of policies to encourage farmers to adopt the rice–crayfish co-culture system. There are two main ways of doing this: financial subsidy and technical support.

2.3. The Rice–Crayfish Co-Culture System and Farmers' Subjective Well-Being

Based on the characteristics of the rice–crayfish co-culture system, we can infer the potential outcomes that may result from adopting this mode, which may affect farmers' subjective well-being. We classify these potential mechanisms into internal and external mechanisms, and we summarize the logical path by which the rice–crayfish co-culture system enhances farmers' subjective well-being as follows. With farmers' modernization as its core, this system stimulates the intrinsic motivation of traditional rice farmers to participate in agricultural modernization through technological transformation. Simultaneously, farmers are supported by external financial and technical assistance. Through the joint efforts of the government and farmers to create a modernization dividend, farmers' subjective well-being is continuously enhanced. The theoretical framework is illustrated in Figure 1.

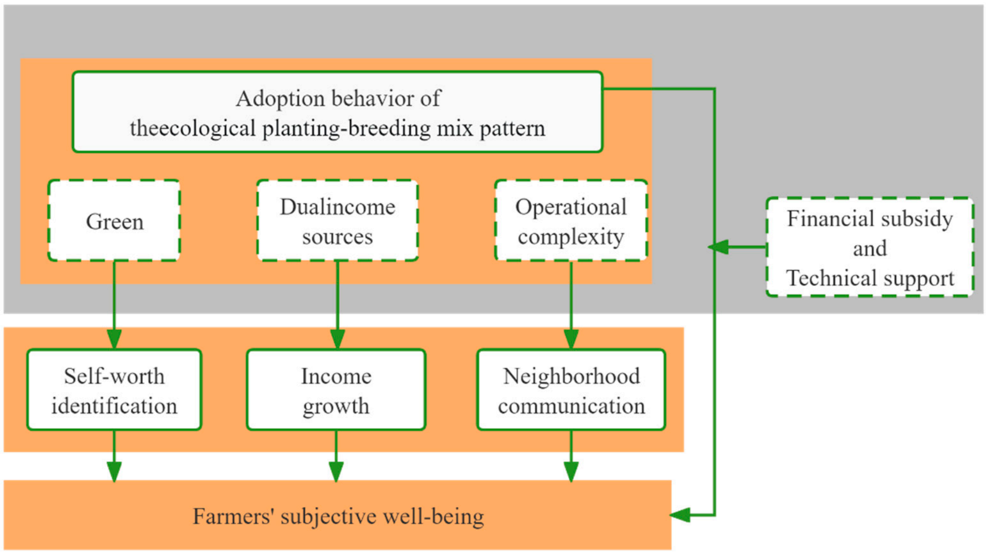

Figure 1. Theoretical framework.

2.3.1. Internal Potential Mechanisms

- Self-worth identification mechanism.

Based on the green characteristics of the rice–crayfish co-culture system, the adoption of this system can enhance farmers' self-value identification, thereby increasing their subjective well-being. Compared with monoculture rice cultivation, the rice–crayfish co-culture system exhibits significant reductions in the use of fertilizers and pesticides [15].

This green farming approach can improve the agricultural environment and enhance the quality of rice and crayfish. Field visits have revealed that farmers can perceive the ecological benefits of the rice–fish co-culture system in the actual adoption process and recognize their contribution to protecting the farmland environment and producing green agricultural products by adjusting their production patterns. This can enhance farmers' value identification with their engagement in agriculture. Existing research has indicated that perceiving self-worth in one's work can enhance subjective well-being [36]. In view of this, the rice–crayfish co-culture system may have a positive impact on farmers' subjective well-being.

- Income growth mechanism.

Based on the income duality of the rice–crayfish co-culture system, the adoption of the rice–crayfish co-culture system can increase farmers' income. This brings subjective well-being to the farmers. As rice is a staple food crop, its market price is relatively low, leading to lower income for farmers who only plant rice. The rice–crayfish co-culture system increases the farmers' source of income while guaranteeing the rice yield. Crayfish is a cash crop characterized by high-value addition. The integrated production of staple crops and cash crops can improve farmers' ability to participate in the market. Chen et al. (2020) confirmed that under counterfactual assumptions if farmers who have not adopted the rice–crayfish co-culture system were to adopt it, their net income per hectare would increase by around 668% [6]. In their analysis using data from 2013 to 2020, Zheng, Hong, and Luo (2021) found a "reverse U-shaped" relationship between per capita disposable income and subjective well-being in China, estimating a turning point at around RMB 26,000 per capita disposable income [37]. According to data from the GSO, the average per capita disposable income of rural residents in China was less than RMB 20,200 in 2022, which is below the tipping point value of RMB 26,000 [38]. There is evidence that income growth is positively correlated with subjective well-being in rural China. Given this, we suggest that the rice–crayfish co-culture system may have a positive impact on farmers' subjective well-being.

- Neighborhood communication mechanism.

Given the complexity involved in implementing the rice–crayfish co-culture system, adopting this pattern may increase the frequency of communication and interaction among adopting farmers, which, in turn, can impact farmers' subjective well-being. Adopting the rice–crayfish co-culture system requires farmers to make certain adjustments to their production and management practices, such as learning how to raise crayfish and adjusting the amount of fertilizer and pesticides they use. First, farmers need to adapt to the production changes brought about by the rice–crayfish co-culture system. In this regard, neighborhood communication as an information acquisition pathway can help farmers overcome information constraints and reduce information search costs [39]. Second, farmers need to understand complex new technologies quickly. Neighborhood communication as an interactive learning path can help farmers grasp the operating principles and essentials of the rice–crayfish co-culture system, thereby improving production efficiency. Mutually beneficial neighborly relationships can provide farmers with instrumental support, which is typically positively correlated with subjective well-being [40–42]. Given this, the rice–crayfish co-culture system may have a positive impact on farmers' subjective well-being.

2.3.2. External Potential Mechanisms

Based on the characteristics of government intervention in the rice–crayfish co-culture system, farmers adopting this pattern receive financial subsidies and technical support from external sources. This external support can positively moderate the impact of the rice–crayfish co-culture system on farmers' subjective well-being. First, the government provides financial subsidies to farmers who adopt the rice–crayfish co-culture system. This can reduce the financial burden on rice–crayfish co-culture farmers to reduce infrastructure construction, such as digging canals, strengthening field ridges, supporting field roads, and power supply [43]. This will also reduce the cost burden on rice–crayfish co-culture farmers for purchasing production inputs such as crayfish feed, biopesticides, and organic fertilizer. Second, the government provides technical support to farmers involved in rice–crayfish co-culture. Farmers are in a weak position when it comes to obtaining information and learning technology. To better serve farmers, the Chinese government has set up agricultural technology extension stations at all levels. As a bridge between the government and farmers, the agricultural technology extension station is mainly responsible for providing effective agricultural information and conducting technical training. In the process of rice–shrimp co-culture, farmers need to constantly gather information and learn new techniques. In the middle and lower reaches of the Yangtze River, agricultural technology extension stations at all levels mainly provide farmers with information technology education, training, and seminars on the rice–shrimp co-culture system. The objective technical guidance provided by the government can help farmers to better implement the rice–crayfish co-culture system. For farmers, financial subsidies and technical support can increase their confidence and adaptability in the rice–crayfish co-culture production process. Therefore, we conclude that under government intervention, rice–crayfish co-culture has a more significant positive impact on farmers' subjective well-being.

The relationship between the adoption of the rice–crayfish co-culture system and farmers' subjective well-being is complex and requires an examination of the potential mechanisms at play. First, due to the variety of production and management characteristics within the rice–crayfish co-culture system, the adoption of this pattern naturally leads to different outcomes for farmers. For example, meaningful production practices can provide farmers with a sense of material achievement while also providing them with a sense of value attainment. Second, when farmers adopt the rice–crayfish co-culture system and rely on their own hands in the pursuit of subjective well-being, this usually occurs simultaneously with the government providing external support to improve farmers' subjective well-being. This is an objective reality in rural China. Therefore, these mechanisms, which can work together in any context, are not mutually exclusive. We cannot isolate any one of them.

3. Materials and Methods

3.1. Data and Sources

The data used in our study were collected through field surveys conducted by our research team in the provinces of Hubei, Hunan, and Jiangxi in China from April to May 2023, focusing on the "Production and benefits of the rice–crayfish co-culture system". These provinces were selected as research sites for several reasons. First, these three provinces have similar geographical characteristics. Hubei Province is located in the Jianghan Plain, Hunan Province is located in the Dongting Lake Plain, and Jiangxi Province is located in the Poyang Lake Plain. All three provinces are located in the middle and lower reaches of the Yangtze River, with favorable natural and geographical conditions and abundant production of fish and rice. Second, these three provinces have a representative scale in terms of rice–crayfish co-culture. In 2022, the total area of rice–crayfish co-cultivation in these three provinces reached 104.1621 million hectares, accounting for about 36.37% of the national total. The rice–crayfish co-culture system has been widely adopted in these provinces. Third, these three provinces have heterogeneity in industrial development. Hubei and Hunan provinces have started earlier and are more mature in terms of breeding techniques and have a more complete industrial chain, while Jiangxi province depends on the "enterprise + cooperative + farmer" form, and the scale of operation has more advantages.

The survey used a combination of stratified and random sampling. To ensure the representativeness of the sample, we selected the Hubei, Hunan, and Jiangxi provinces as the main survey areas in the middle and lower reaches of the Yangtze River. Based on the selected study areas, we conducted a stratified and random sampling of farmers. We randomly selected three sample cities from each of the three provinces, namely Qianjiang, Jingmen, and Huangshi from Hubei Province; Yiyang, Yueyang, and Changde from Hunan Province; and Shangrao, Xinyu, and Jiujiang from Jiangxi Province. The study area is shown in Figure 2. The survey was a face-to-face interview. A total of 1080 questionnaires were distributed and 895 valid questionnaires were returned, giving an effective response rate of 82.87%. Of these, 308 were from Hubei Province, 322 from Hunan Province, and 266 from Jiangxi Province. The survey provided general data on farmers' production and business profiles, risk preferences and perceptions, technology and service availability, agricultural inputs and outputs, marketing and branding, farm households, Internet use, social participation and policy evaluation, and village conditions.

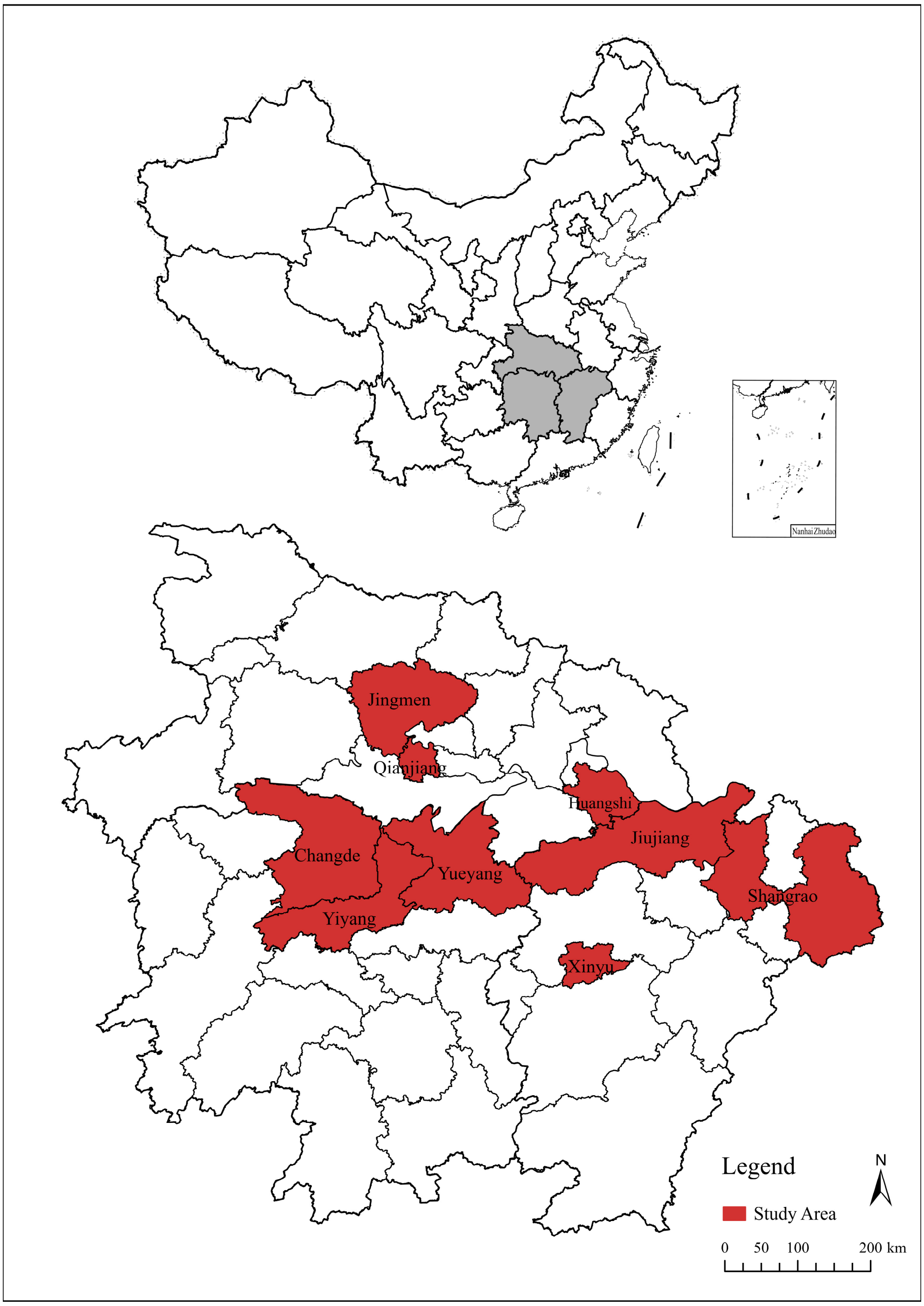

Figure 2. Map of the study area.

3.2. Variable Selection

Dependent variable. The dependent variable in this paper is the farmers' subjective well-being. We wanted to obtain the farmers' overall cognitive assessment of their own living conditions. This assessment needed to be based on farmers' own criteria rather than on predetermined criteria. With this in mind, we learned from previous studies [16,44,45] and used self-reported subjective well-being as an indicator. We asked farmers during the survey, "Overall, do you think you are happy now?" Farmers rated their subjective well-being on a scale of 1–5. From 1 to 5, in order, they are very unhappy, unhappy, generally happy, happy, and very happy.

Core independent variable. The core independent variable in this paper is whether the rice–crayfish co-culture system is adopted or not. Following Tian et al. (2021), this variable is set as a dummy variable [9]. If the farmer adopts the rice–crayfish co-culture system, the value is 1. If the farmer does not adopt the rice–crayfish co-culture system, it means that the farmer only grows rice in the paddy field, and the value is 0.

Control variables. In order to avoid model estimation bias caused by omitted variables, this study includes a set of control variables. Based on the logic of economic theory, reality, and the analysis of influencing factors in the relevant literature, this study selected ten control variables from three aspects, namely the basic characteristics of individuals, the characteristics of the family business, and the characteristics of the external environment. The basic individual characteristics of the household head include age, education, health condition, and village cadre status. The characteristics of the household business include whether or not they are in debt, whether or not they have bought an urban house, and their non-agricultural income. The variables selected from individual characteristics and household business characteristics control the influence of the material and social relationship network on farmers' subjective well-being. The characteristics of the external environment include the distance of the residence from the county government and two provincial dummy variables. These two variables can describe the regional economy and culture at different scales. This allows us to control the influence of regional economic and cultural differences on farmers' subjective well-being. The specific variables are defined and assigned and their descriptive statistics are shown in Table 1.

Table 1. Variable definition and descriptive statistics.

Variable	Definition and Assignment	Mean	S.D
Adoption behavior	Is it advisable to adopt the rice–crayfish co-cultivation? Yes = 1; No = 0	0.73	0.446
Subjective well-being	Do you think you are happy now? very unhappy = 1; unhappy = 2; general = 3; happy = 4; very happy = 5	3.98	0.693
Age	Actual age	54.52	8.952
Education	Years of schooling	8.408	3.2511
Health condition	Very bad = 1; Bad = 2; General = 3; Good = 4; Very good = 5	4.42	0.736
Village cadre status *	Are you serving as a cadre in the village? Yes = 1; No = 0	0.08	0.274
Debt situation	Are you in debt? Yes = 1; No = 0	0.21	0.409
Urban home purchase	Have you bought an urban home? Yes = 1; No = 0	0.25	0.435
Non-agricultural incomes	Total non-agricultural family incomes in 2022 (in RMB ten thousand)	8.58754	14.665167
Distance to county government	The distance of the residence from the county government (km)	26.501	14.3361
Provincial dummy variables	Is it Jiangxi Province? Yes = 1; No = 0	0.3	0.457
	Is it Hunan Province? Yes = 1; No = 0	0.36	0.48

* Village cadres, as agents of the state and representatives of peasants [46], are the main body of village governance elected by the villagers. They hold political and administrative power in local communities (generally one big village or several small villages), but they are not official government employees and enjoy limited government welfare [47]. Village cadre status is an expression of personal ability and is manifested as social capital in economic activities.

From the binary indicator in Table 1, 73% of our sample farmers in this study decided to adopt the rice–crayfish co-culture system. In Table 2, we also report the level of farmers' subjective well-being according to whether they adopted the rice–crayfish co-culture system or not. According to the *t*-test results, the subjective well-being of farmers who adopted the rice–crayfish co-culture system is higher than that of farmers who did not adopt it, and the following section will empirically analyze the effect of adopting the rice–crayfish co-culture system on farmers' subjective well-being.

Table 2. Differences between sample groups.

Variable	Grouping Criterion	Mean	Intergroup Differences
Farmers' subjective well-being	Adopted Unadopted	4.01 3.89	−0.112 **

Note: ** Significant at the 5% level.

3.3. Methods

It is worth noting that this paper argues that the decision variable for farmers' adoption of the rice–crayfish co-culture system cannot be considered fully exogenous. To a large extent, farmers' production decisions are self-selections based on their own characteristics and comparative advantages. Simultaneously, there are unobservable variables that affect farmers' production decisions and subjective well-being. Using the relevant literature as a reference [21,48], this paper used the ESRM in Stata17.0 to assess the impact of rice–crayfish co-culture on farmers' subjective well-being. The use of ESRM has the following advantages. First, it solves the self-selection problem of farmers' decision-making in adopting the rice–crayfish co-culture system. Second, it is able to separately identify and differentiate the factors that affect the subjective well-being of farmers in the adoption group from those in the non-adoption group. Third, it allows the use of counterfactual analysis to assess the subjective well-being effects of the rice–crayfish co-culture system.

The ESRM is used for our empirical analysis to test the impact of the rice–crayfish co-culture system on farmers' subjective well-being, expressed as:

$$Y_i = \tau A_i + \delta X_i + \varepsilon_i \tag{1}$$

where Y_i is the farmers' subjective well-being. A_i is a dummy variable for whether the farmer has adopted the rice–crayfish co-culture system or not: $A_i = 1$, indicating that the farmer has adopted this pattern; $A_i = 0$, indicating that the farmer has not adopted this pattern. X_i is the control variable for basic individual characteristics, household business characteristics, and external environment characteristics of the respondent. τ, δ is the estimated parameter; ε_i is the error term.

The ESRM uses the idea of two-stage estimation. In the first stage, the decision equation is estimated, i.e., the factors affecting the adoption of the rice–crayfish co-culture system by farmers are estimated; see Equation (2). In the second stage, the outcome equations are estimated. We divided the sample farmers into two groups, adopted and non-adopted farmers, and constructed two equations for farmers' subjective well-being; see Equations (3) and (4).

$$A_i = Z_i \gamma + k_i I_i + u_i \tag{2}$$

$$Y_{i1} = \beta_{i1} X'_{i1} + \varepsilon_{i1}, \text{ if } A_i = 1 \tag{3}$$

$$Y_{i0} = \beta_{i0} X'_{i0} + \varepsilon_{i0}, \text{ if } A_i = 0 \tag{4}$$

In Equation (2), Z_i is a set of factors that affect whether farmers adopt the rice–crayfish co-culture system or not. I_i is a vector of instrumental variables. In Equations (3) and (4), Y_{i1}, Y_{i0} denote the subjective well-being of farmers in the adoption and non-adoption groups, respectively. X'_i is a set of explanatory variables. If unobservable factors simultaneously affect farmers' decisions to adopt the rice–crayfish co-culture system and their subjective well-being, there will be a correlation between the residual terms of the decision and outcome equations. To solve this problem, after estimating the decision equation, we calculate the inverse Mills ratio (λ'_i) and introduce it into Equations (3) and (4) to obtain:

$$Y_{i1} = \beta_{i1}X'_{i1} + \sigma_{u1}\lambda'_{i1} + \varepsilon_{i1},\ \text{if } A_i = 1 \tag{5}$$

$$Y_{i0} = \beta_{i0}X'_{i0} + \sigma_{u0}\lambda'_{i0} + \varepsilon_{i0},\ \text{if } A_i = 0 \tag{6}$$

In Equations (5) and (6), λ'_{i1} and λ'_{i0} allow us to control for selection bias due to unobserved variables. The correlation coefficients for the covariates in the decision and outcome equations are ρ_{u1} and ρ_{u0}, where $\rho_{u1} = \sigma_{u1}/\sigma_u\sigma_{i1}$ and $\rho_{u0} = \sigma_{u0}/\sigma_u\sigma_{i0}$. If ρ_{u1} or ρ_{u0} are significant, it means that the selection bias is unobserved. To ensure unbiased estimation of treatment effects, we need to eliminate the selection bias due to observed and unobserved variables.

This study develops a counterfactual analysis framework based on the estimated coefficients of the ESRM. It is used to compare the difference in subjective well-being between farmers who adopt the rice–crayfish co-culture system and those who do not adopt it under realistic and counterfactual conditions, and to evaluate the subjective well-being effect of the rice–crayfish co-culture system in practice.

The expected value of the subjective well-being of farmers who adopt the rice–crayfish co-culture system (treated group) is given as:

$$E[Y_{i1}|A_i = 1] = \beta_{i1}X'_{i1} + \sigma_{u1}\lambda_{i1} \tag{7}$$

The expected value of the subjective well-being of farmers who did not adopt the rice–crayfish co-culture system (untreated group) is given as:

$$E[Y_{i0}|A_i = 0] = \beta_{i0}X'_{i0} + \sigma_{u0}\lambda_{i0} \tag{8}$$

If the treated group did not adopt the rice–crayfish co-culture system, the expected value of their subjective well-being is given as:

$$E[Y_{i0}|A_i = 1] = \beta_{i0}X'_{i1} + \sigma_{u0}\lambda_{i1} \tag{9}$$

If the untreated group adopted the rice–crayfish co-culture system, the expected value of their subjective well-being is given as:

$$E[Y_{i1}|A_i = 0] = \beta_{i1}X'_{i0} + \sigma_{u1}\lambda_{i0} \tag{10}$$

Then, the average treatment effect for the treated group (ATT) is the difference between Equations (7) and (9), as shown below:

$$\begin{aligned} ATT_i &= E[Y_{i1}|A_i = 1] - E[Y_{i0}|A_i = 1] \\ &= (\beta'_{i1} - \beta'_{i0})X_{i1} + (\sigma_{u1} - \sigma_{u0})\lambda_{i1} \end{aligned} \tag{11}$$

The average treatment effect for the untreated group (ATU) is the difference between Equations (8) and (10), as shown below:

$$\begin{aligned} ATU_i &= E[Y_{i0}|A_i = 0] - E[Y_{i1}|A_i = 0] \\ &= (\beta'_{i0} - \beta'_{i1})X_{i0} + (\sigma_{u0} - \sigma_{u1})\lambda_{i0} \end{aligned} \tag{12}$$

In the internal mechanism tests, this paper draws on the empirical thinking of Dell (2010) to test the relationship between the core independent variables and the mechanism variables [49]. We continue to use the ESRM to estimate this relationship.

4. Results

4.1. Instrumental Variable Validity

In order to effectively identify the model, this paper relies on Chen et al. (2020) and introduces "there are a lot of farmers around who are engaged in the rice–crayfish co-culture system" as an instrumental variable [6]. On the one hand, individual behavioral decisions are susceptible to the influence of herd mentality [50], and the adoption of the rice–crayfish co-culture system by a larger number of farmers around them influences farmers' production decisions, leading to their following behavior. On the other hand, the production patterns of surrounding farmers do indirectly affect the farmers' subjective well-being. Therefore, the instrumental variables chosen in this paper meet the requirement of directly affecting the selection equation while indirectly affecting the outcome equation.

In this paper, instrumental variable tests have been conducted to validate their effectiveness. Table 3 presents the test results, with a *p*-value of 0.000 for the Durbin–Wu–Hausman test, rejecting the null hypothesis of "exogeneity". This indicates the presence of endogeneity problems in the adoption of the rice–crayfish co-culture system. The *p*-value of the Kleibergen–Paap rk LM test is also 0, indicating that the instrumental variables are identifiable. Furthermore, the Kleibergen–Paap rk Wald F-value is 608.486, which exceeds the critical value of 10, indicating that there are no problems with weak instrumental variables. Therefore, the selected instrumental variables in this study are considered to be effective.

Table 3. Instrumental variable validity test.

Test Items	Test Statistics	Statistical Value	*p*-Value
Exogeneity test	Durbin–Wu–Hausman	15.976	0.000
Identification test	Kleibergen–Paap rk LM	207.037	0.000
Weak instrumental test	Kleibergen–Paap rk Wald F	608.486	-

4.2. Simultaneous Estimation Results and Analysis

After mitigating the effect of endogeneity problem on the model estimation results, this paper reports the results of the joint estimation of the decision model of farmers' adoption of rice–crayfish co-culture system and the model of subjective well-being effect, as shown in Table 4.

Table 4. Estimation results of the impact of the adoption of the rice–crayfish co-culture system on farmers' subjective well-being.

Variables	Adoption Behavior (n = 895)	Farmers' Subjective Well-Being	
		Adopted (n = 650)	Unadopted (n = 245)
Age	−0.016 ** (0.007)	0.005 (0.003)	−0.006 (0.006)
Health condition	0.184 ** (0.081)	0.040 (0.043)	−0.052 (0.058)
Education	0.012 (0.018)	0.003 (0.009)	−0.021 (0.015)
Cadre status	−0.475 ** (0.205)	0.371 *** (0.101)	0.266 (0.161)
Debt situation	0.343 ** (0.144)	−0.209 ** (0.067)	−0.199 (0.125)
Non-agricultural incomes	−0.002 (0.004)	0.003 (0.002)	0.007 * (0.003)
Urban home purchase	0.151 (0.137)	0.120 * (0.062)	0.109 (0.109)

Table 4. *Cont.*

Variables	Adoption Behavior (*n* = 895)	Farmers' Subjective Well-Being	
		Adopted (*n* = 650)	Unadopted (*n* = 245)
Distance to county government	−0.005 (0.004)	0.000 (0.002)	−0.002 (0.003)
Is it Jiangxi Province	−0.170 (0.151)	−0.112 (0.077)	0.077 (0.112)
Is it Hunan Province	0.235 (0.151)	−0.168 ** (0.063)	0.031 (0.138)
Instrumental variable	0.745 *** (0.053)	-	-
Constant	−1.950 ** (0.673)	3.676 *** (0.319)	4.428 *** (0.525)
lnσ1	-	−0.393 *** (0.034)	-
ρ1	-	−0.530 *** (0.156)	-
lnσ2	-	-	−0.354 *** (0.046)
ρ2	-	-	−0.265 *** (0.118)
Log pseudolikelihood value	−1187.2782	-	-
Observations	895	650	245

Note: Standard errors are reported in parentheses. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

4.2.1. Analysis of Factors Influencing Farmers' Adoption of the Rice–Crayfish Co-Culture System

The results of the decision model estimation show that age has a negative effect on farmers' adoption of the rice–crayfish co-culture system. This may be due to the fact that older farmers are less willing and able to accept and learn new things and are less likely to adopt the rice–crayfish co-culture system. Health has a positive impact on farmers' adoption of the rice–crayfish co-culture system. Physical health is the basis for farmers to learn technology and participate in work. Compared to rice monoculture, the rice–crayfish co-culture system requires farmers to have greater capacity and invest more energy and physical strength. Therefore, poor health status may be an obstacle for farmers to adopt the rice–crayfish co-culture system. Village cadre status negatively affects farmers' adoption of the rice–crayfish co-culture system. In general, farmers who are village cadres are busy with their affairs and invest less time and energy in agricultural work than full-time farmers. This means that farmers who have served as village cadres are even less likely to adopt the rice–crayfish co-culture system. Debt has a positive effect on farmers' adoption of the rice–crayfish co-culture system. This is partly a response to the fact that farmers have high-income expectations from the rice–crayfish co-culture system. The more indebted farmers are, the more they want to improve their profitability and alleviate their financial constraints through the rice–crayfish co-culture system.

4.2.2. Analysis of Factors Influencing Farmers' Subjective Well-Being

The estimation results of the subjective well-being effect model for farmers in the adopter group and farmers in the non-adopter group are shown in Table 4. The status of village cadre has a positive effect on the subjective well-being of farmers in the adopter group. Farmers can gain a sense of honor by holding the status of village cadre. Adopting the rice–crayfish co-culture system actively responds to the national call for green production and can highlight the leading role of village cadres. This further enhances the farmers' sense of honor, which is positively associated with subjective well-being. Indebtedness has a negative impact on the subjective well-being of farmers in the adopter group. Farmers in debt are under economic stress. The adoption of the rice–crayfish co-culture system requires both the reclamation of crayfish ponds and the purchase of production materials such as boats, frames, crayfish feed, etc., which requires adequate production funds. The adoption of the rice–crayfish co-culture system increases the economic pressure on farmers, which, in turn, decreases their subjective well-being. The non-agricultural income of the household has a positive effect on the subjective well-being of farmers in the non-adopters group. A high proportion of non-agricultural household income means that non-agricultural employment is the main source of income for households to support their daily lives. Compared to farmers in the adopter group, farmers who did not adopt the rice–crayfish co-culture system have a single source of agricultural income and low production efficiency. A high proportion of non-agricultural household income can reduce the psychological dependence of farmers in the non-adopter group on agricultural production and reduce the psychological gap caused by the lower production efficiency of farmers in the non-adopter group compared to farmers in the adopter group, which, in turn, improves farmers' subjective well-being. Buying an urban house has a positive effect on the subjective well-being of farmers in the adopter group. Buying a house in an urban area means that farmers have better access to information about agricultural technology and market prices for agricultural products. Compared with the non-adopter group, farmers who adopt the rice–crayfish co-culture system need to learn crayfish farming techniques dynamically and keep track of crayfish market prices in real-time. Convenient information brought by urban home ownership can improve farmers' agricultural production capacity and thus increase their subjective well-being. The estimation of provincial dummy variables shows that farmers adopting the rice–crayfish co-culture system in the Hubei and Jiangxi provinces are happier than those in Hunan Province.

4.3. Analysis of the Average Treatment Effect of Adopting the Rice–Crayfish Co-Culture System on Farmers' Subjective Well-Being

In this paper, Equations (11) and (12) are used to estimate the average treatment effect of the impact of adopting the rice–crayfish co-culture system on farmers' subjective well-being. As shown in Table 5, the estimated results indicate that the adoption of the rice–crayfish co-culture system significantly increases farmers' subjective well-being. In the counterfactual scenario, the subjective well-being of farmers who actually adopt the rice–crayfish co-culture system decreases from 4.006 to 3.669 if they do not adopt it, a decrease of 8.412 percent. Farmers who did not actually adopt the rice–crayfish co-culture system would have increased their subjective well-being from 3.894 to 4.344, an increase of 11.556%, if they had adopted it. In conclusion, the adoption of the rice–crayfish co-culture system can improve farmers' subjective well-being by 8.412–11.556%.

Table 5. The average treatment effect of adopting the rice–crayfish co-culture system on farmers' subjective well-being.

	Adopted	**Unadopted**	**ATT**	**ATU**	**The Rate of Variation (%)**
Adopted	4.006	3.669	0.337 ***	-	8.412
Unadopted	4.344	3.894	-	0.450 ***	11.556

Note: *** Significant at the 1% level.

4.4. Robustness Checks

In order to ensure the stability and reliability of the regression results, this paper adopts the replacement of the regression model to conduct a robustness test of the above empirical results, and the estimation results are shown in Table 6. After replacing the model with an average treatment effect model, the average treatment effect of adopting the rice–crayfish co-culture system on farmers' subjective well-being is 0.438. The result is significant at the 1% statistical level. This suggests that the adoption of the rice–crayfish co-culture system can improve farmers' subjective well-being, proving that the previous estimation results are robust.

Table 6. Robustness test: substitution model.

Effect Category	Observations	ATE	S.D
The average treatment effect of farmers' adoption of the rice–crayfish co-culture system on subjective well-being	895	0.438 ***	0.098

Note: Standard errors are reported in parentheses. *** Significant at the 1% level.

5. Discussion

Based on the characterization of the rice–crayfish co-culture system, in this section, we examine potential mechanisms that may explain the positive association between the adoption of the rice–crayfish co-culture system and farmers' subjective well-being.

5.1. Internal Mechanisms

According to the previous section, the internal production characteristics of the rice–crayfish co-culture system may affect farmers' self-worth identity, income growth, and neighborhood interaction, which, in turn, may affect farmers' subjective well-being. Therefore, the three variables of self-worth identity, income growth, and neighborhood interaction are selected as mediating mechanism variables in this paper. Among them, self-worth identity is mainly reflected in farmers' beliefs that "adopting the rice–crayfish co-culture system can improve the farmland environment" and "adopting the rice–crayfish co-culture system will produce rice and crayfish that are healthy for people". Income growth is mainly reflected in farmers' objective "net agricultural incomes per hectare" and subjective "rice–crayfish co-culture system of perceived economic benefits". Neighborhood interactions are mainly manifested in "exchanging and discussing price information of agricultural products with other farmers in the village", "exchanging and discussing the use of pesticides, fertilizers, crayfish medicines with other farmers in the village", and "exchanging and discussing the operation methods of agricultural technology with other farmers in the village". This paper draws on the empirical thinking of Dell (2010) to test the relationship between the core independent variable and the mechanism variables [46]. We construct an ESRM to test the effects of adopting the rice–crayfish co-culture system on farmers' self-worth identity, income growth, and neighborhood interaction.

The estimated results are shown in Table 7. The average treatment effects for the treated group (ATT) for the impact of adopting the rice–crayfish co-culture system on farmers' self-worth identity, income growth, and neighborhood interaction are all significant at the 1% statistical level. The average treatment effects for the untreated group (ATU) for the impact are also all significant at the 1% statistical level in the counterfactual context. This suggests that the adoption of the rice–crayfish co-culture system can significantly contribute to farmers' self-worth identity, income growth, and neighborhood interaction. The rice–crayfish co-culture system gives farmers a sense of how their organic production practices contribute to the environment and human health, which is consistent with the findings of Chadwick et al. [51]. The rice–crayfish co-culture system increases the diversity of rice farmers' livelihoods and provides more income opportunities for rice farmers, which is consistent with the study by Chen et al. [6]. The rice–crayfish co-culture system enhances opportunities for farmers to exchange information and technology, and invisibly improves farmers' social capital, which is consistent with the conclusion of Tian et al. [52].

Table 7. Internal mechanisms test results.

Mechanism Type	Outcome Variables	Treatment Group			Control Group		
		Adopted	Unadopted	ATT	Adopted	Unadopted	ATU
Self-worth identity	Improving the farmland environment	3.885	3.227	0.658 ***	4.283	3.339	0.944 ***
	Good for human health	3.935	3.345	0.590 ***	4.381	3.339	1.042 ***
Income increase	Net agricultural incomes (RMB 10,000 per ha)	1.935	0.782	1.153 ***	1.723	0.436	1.287 ***
	Economic benefit perception	3.766	3.059	0.707 ***	3.859	3.298	0.561 ***
Neighborhood interaction	Communicate pricing	4.269	3.864	0.405 ***	4.785	3.886	0.899 ***
	Communicate usage and dosing	4.259	3.692	0.567 ***	4.629	3.817	0.817 ***
	Communicate methods	4.182	3.789	0.393 ***	4.496	3.776	0.720 ***

Note: *** Significant at the 1% level.

5.2. External Mechanisms

Considering that external additional characteristics may affect the relationship between the adoption of the rice–crayfish co-culture system and farmers' subjective well-being, this paper selected financial subsidy and technical support as moderating mechanism variables. We measured external mechanism variables as objectively as possible. We asked farmers, "Did you receive a government subsidy in 2022?" If the farmer received a government subsidy, the value of the government subsidy is 1. If the farmer did not receive a government subsidy, the value of the government subsidy is 0. We asked farmers, "Is there an agricultural technology extension station in the village?" If the farmer answered yes, the value of technical support is 1. If the farmer answered no, the value of technical support is 0. The agricultural technology extension station works directly with farmers, providing technical training and advice on rice–crayfish co-culture. Farmers were asked whether there was an agricultural technology extension station in the village, which could reflect the government's technical support to farmers. Following Gedikli, Popli, and Yilmaz (2023), we introduced two variables, financial subsidy and technical support, each of which is multiplied by the core explanatory variable adoption of the rice–crayfish co-culture system to construct an interaction term, and then ran the 2SLS model to address endogeneity [53].

The estimated results are presented in Table 8. Column 1 shows the effect of financial subsidy on the relationship between the adoption of the rice–crayfish co-culture system and farmers' subjective well-being. Column 2 shows the effect of technical support on the relationship between the adoption of the rice–crayfish co-culture system and farmers' subject well-being. The interaction term between financial subsidy and the adoption of the rice–crayfish co-culture system has a negative coefficient and is significant, which suggests that financial subsidy negatively affects the adoption of the rice–crayfish co-culture system to promote farmers' subjective well-being. This is not as expected. The field research found that at this stage, government financial support is skewed toward new agricultural enterprises, while the adoption of the rice–crayfish co-culture system has a greater impact on the subjective well-being of smallholder farmers who receive minimal subsidies. The estimation of the interaction term between technical support and adoption of rice–crayfish co-culture system is insignificant as unexpected, which indicates that technical support does not play a significant role in the positive relationship between the adoption of rice–crayfish co-culture system and farmers' subjective well-being. This may be because there is a time lag in the provision of technical support by agricultural extension services. When farmers encounter operational problems in the process of planting and production, it is difficult to get help the first time. By the time agro-technology extension services provide training, farmers have often found solutions on their own, leading them to believe that technical training does not provide much help and is time-consuming.

Table 8. External mechanisms test results.

	(1)	(2)
	Farmers' Subjective Well-Being	**Farmers' Subjective Well-Being**
Adoption behavior	0.499 *** (0.135)	0.373 *** (0.097)
Financial subsidy	0.289 ** (0.113)	-
Financial subsidy * Adoption behavior	−0.345 ** (0.149)	-
Technical support	-	0.156 (0.151)
Technical support * Adoption behavior	-	−0.132 (0.173)
Characteristics of individuals	Yes	Yes
Characteristics of the family business	Yes	Yes
Characteristics of the external environment	Yes	Yes
R2	0.020	0.031
Observations	895	895

Note: Standard errors are reported in parentheses. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

6. Conclusions

This paper examines the impact of the rice–crayfish co-culture system on subjective well-being and its potential mechanisms using representative provincial data collected from 895 rice households in rural Hubei, Hunan, and Jiangxi, located along the middle and lower reaches of the Yangtze River, China.

Through a series of empirical tests, this paper draws three main conclusions. First, adopting the rice–crayfish co-culture system can significantly improve farmers' subjective well-being. Second, there are potential internal mechanisms that explain the subjective well-being effects of adopting the rice–crayfish co-culture system. These include the self-worth identity mechanism, the income growth mechanism, and the neighborhood interaction mechanism. Third, there are potential external mechanisms that influence the subjective well-being effects of adopting the rice–crayfish co-culture system. Financial subsidy negatively affects the promotion of the rice–crayfish co-culture system adoption on farmers' subjective well-being. Technical support has no significant effect on the positive relationship between the rice–crayfish co-culture system adoption and farmers' subjective well-being.

Based on the research findings, this paper draws several policy implications. First, policymakers should prioritize the subjective well-being effect of adopting an ecological planting–breeding mix pattern. It is important to recognize that farmers' subjective well-being does not depend on government policy support alone. Instead, a comprehensive approach that integrates policy with production and lifestyle can better contribute to farmers' subjective well-being. Under the strategic goal of rural revitalization, there is a need to actively innovate agricultural technology and optimize agricultural management practices to empower farmers. This will help them pursue a better life and improve their subjective well-being. Second, it is imperative to refine the market system for green agricultural products, motivate farmers to actively participate in building brands for green agricultural products, and thus enhance the perceived value of farmers who adopt an ecological planting–breeding mix pattern. For example, policymakers should create an enabling environment that promotes the marketing of green agricultural products. Additionally, agricultural extension workers should effectively communicate the potential environmental significance and economic value of ecological planting–breeding mix pattern to farmers when promoting them. Third, efforts should be made to increase the productivity and income-generating capacity of ecological planting–breeding mix pattern. This will unlock the economic benefits of such practices and ultimately increase the sense of accomplishment for farmers who adopt them. Fourth, due consideration should be given to the important role of informal channels in technology dissemination. Online communication platforms should be established, such as WeChat, and form offline mutual support groups for an ecological planting–breeding mix pattern. This will cultivate a sense of mutual support among farmers in the process of adopting ecological planting–breeding mix pattern.

The results of this study have profound implications for the future practice of sustainable agriculture. The external validity of our study may be limited to rice farmers in China. However, not only the rice sector, but also other crop sectors, such as tea, coffee, and corn, have experienced an overuse of chemical fertilizers. Many Asian countries that once overused chemical fertilizers and pesticides have vigorously developed green agriculture in recent years. It is worth noting that government agencies not only need to promote green production but also need to consider the welfare of smallholder families. Therefore, our findings can provide a reference for promoting the sustainable development of farmers in Asian countries, especially in improving farmers' subjective well-being.

A shortcoming of this paper Is that the research mainly considers the potential mechanism of the subjective well-being effect of ecological planting–breeding mix pattern based on the internal production characteristics and external additional characteristics of the rice–crayfish co-culture system, and does not exclude the possibility of other mechanisms. Therefore, a follow-up study can further explore how the adoption of an ecological planting–breeding mix pattern affects farmers' subjective well-being from different perspectives.

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