frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 17 October 2022
DOI 10.3389/fenvs.2022.1036464

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Environmental Economics and Management,
a section of the journal
Frontiers in Environmental Science

RECEIVED 04 September 2022
ACCEPTED 05 October 2022
PUBLISHED 17 October 2022

CITATION
Zhao X, Cui Z and Zhao F (2022), Does e-commerce participation affect green agrotechnology adoption among reservoir resettlers? The case of China's Three Gorges Reservoir area.
Front. Environ. Sci. 10:1036464.
doi: 10.3389/fenvs.2022.1036464

Does e-commerce participation affect green agrotechnology adoption among reservoir resettlers? The case of China's Three Gorges Reservoir area

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This study explores how promoting e-commerce participation impacts the adoption of green agrotechnology by resettlers in China's Three Gorges Reservoir area and helps rural revitalization and the realization of value from ecological produce. First, we combine induced innovation model theory with the risk perception factor of expected utility theory. A model of resettlers' green agrotechnology adoption under different levels of e-commerce participation is constructed, and research hypotheses are proposed accordingly. Survey data gathered from resettled farmers in Zigui, the first county of the studied area, are tested empirically with an ordered probit model. The results show first, that e-commerce participation significantly and positively affects the level of green agrotechnology adoption at the 1% level; and second, that expectations of the ecological value of agricultural products and the agrotechnology support provided by e-commerce are important driving factors. The promotion effect of different modes of e-commerce participation on agrotechnology adoption differ. The risk-averse behavior of resettlers can weaken the promotion effect of e-commerce participation on agrotechnology adoption.

KEYWORDS

e-commerce participation, green agrotechnology adoption, risk perception, reservoir resettlers, ordered-probit model

1 Introduction

The increasing number of hydropower plants being built around the world to achieve clean energy has led to a large number of compulsory population movements, resulting in the emergence of resettled farmers as a group. In accordance with the World Bank's resettled guidelines, rural resettlers in China are mostly resettled in the back-to-back mode of "returning land to land and agriculture to agriculture" for the sake of continuing their original livelihoods (Yan et al., 2018). However, due to the limited resource-carrying capacity of the Three Gorges Reservoir area, the arable land available there has become increasingly scarce. Most of the compensation land received by resettlers is fragmented and low in quality, causing not only limited output but also significant increases in the cost of crop cultivation (Zhang 2021). Chinese rural re-settlers' per capita income was only about 76% of that of ordinary farmers in 2014. Therefore, fewer than 30% of resettlers actually cultivate the land that the government transferred to them at a high cost, and many tend to abandon the land and go out to work instead (Ni and Shao 2013). Currently, in the context of natural capital stock constraint, the only way to guarantee that resettlers can increase their income from local farming is by applying and promoting green agrotechnology.

Green agricultural technology aims to solve environmental problems and promote sustainable agricultural development. It will improve the soil by reducing pollution, leverage the ecological value of agricultural products, and raise crop yields (Zuo and Fu 2021). The waste of resources and environmental pollution caused by the unscientific nature of traditional agricultural technology hinders the green development of agriculture in resettlement areas. Achieving a green transformation of agricultural development is an important way to solve the current agricultural development challenges in resettlement areas. As resettlers' livelihoods are highly vulnerable and they struggle to withstand the ex-post effects of risks, they mainly choose to avoid risk. Their conservative behavior in agricultural production hinders the adoption of green agrotechnology to a certain extent. Therefore, a long-term mechanism of green agrotechnology adoption is needed to solve the current problem of low level of green agrotechnology in resettlement areas and to achieve sustainable development of resettlement areas and individual income of resettlers.

For involuntary resettlers with impaired livelihood capital and broken social networks of origin, rural e-commerce, a new rural industry with convenient participation channels and an almost zero threshold for resource consumption, has become the first choice to improve the production and marketing of agricultural products (Yin and Choi 2022). For example, in the Three Gorges Reservoir area of China, the town of Xingshan is located in a mountainous area with a low land stock, but resettlers have achieved an average daily sale of 100,000 kg of citrus by using live streaming. The strong development of Internet technology has enriched agricultural e-commerce models, with traditional e-commerce, social e-commerce, and live e-commerce all expanding in scale (Chen et al., 2022). Heterogeneous participation in rural e-commerce brings innovation to the traditional agricultural products business model and concept while effectively enhancing the income of resettled households. At the same time, the online sales model requires quality standardization and ecological branding, which will certainly promote the application of green agrotechnology and bring high-quality change to resettled areas (Xiao et al., 2021).

Current research on empowering rural agents to promote the adoption of green agrotechnology focuses on three aspects. The first is the promotion of environmental regulations and government subsidies, which can be used to guide technology application behavior in agricultural production. Reducing the costs involved in such production will support and guarantee the sustainable application of green agrotechnology (Dong et al., 2022). Second, research has explored the contribution of regional resource endowments, where the level of development, farming history, and soil quality are direct factors determining individual adoption intentions and behaviors (Zeng et al., 2019; Wu and Zhou 2021), while population aging and the stock of agricultural technicians have obvious indirect effects (Natkhov and Vasilenok 2021). A third stream, focusing on the role of rural households and individual characteristics, has found that the degree of green agrotechnology adoption is constrained by farmers' relational capital (Wang et al., 2020), socioeconomic status (Bidogeza et al., 2009), and learning and training opportunities (Chatzimichael et al., 2014).

In contrast, risk preferences play a dominant role in individual production decision behavior (Gao and Niu 2019), and risk perceptions, in turn, positively moderate the degree of association between risk preferences and agrotechnology adoption (Qiu et al., 2020). For example, perceived risk from agricultural production affects the use of irrigation technology (Koundouri et al., 2006), fertilizers (Adnan et al., 2019), *etc.* Since it is difficult for individuals to fully understand the benefits associated with the use of green agrotechnology, they tend to have doubts about the risks they need to take in technology adoption (Chavas and Nauges 2020). However, further studies have shown that farmers may use subjective risk judgements to weigh the pros and cons; that is, there is a negative relationship between the perceived risk of using green agrotechnology and the probability of adoption (Duong et al., 2019). The research outlined above is limited by the fact that the paths between variables have only been tested empirically, while specific influence mechanisms have not yet been theoretically deduced. Hence, such mechanisms are based only on the summary of phenomena and experiences and lack a scientific basis. Further exploration is required of such mechanisms and the paths whereby the interactive feedback model of e-commerce operation–agrotechnology application–income enhancement can be realized.

The Chinese government has implemented appropriate support policies for Reservoir resettlers, and the livelihood level and social integration of this group have been significantly improved. Ensuring the sustainable self-development of involuntary project resettlers has attracted research attention globally (Karimi and Taifur 2013). The current research was conducted as follows. First, we constructed a model of the benefits of green agrotechnology adoption by resettled households under different e-commerce participation scenarios, based on utility optimization theory and induced agricultural technological innovation theory. Second, we introduced risk perception as a moderating variable and combined it with expected utility theory to improve the multi-factor influence mechanism model of resettled technology adoption. Third, we proposed research hypotheses according to the theoretical derivation and empirically tested the theoretical model using the ordered probit model with survey data gathered from resettled farmers in Zigui, Hubei province, China, the first county in the Three Gorges Reservoir area. Next, we explored how the promotion of rural e-commerce participation affects the adoption of green agrotechnology by resettlers and the core elements within this process and investigated the perturbing influence of the particular risk preferences of involuntarily relocated populations in regard to promoting modern agricultural technology and achieving sustainable livelihood development. Last, we provide support for decision making in regard to compensating and supporting resettlers in water conservancy and hydropower projects.

2 Theories and hypothesis

In the theory of agricultural supply chain integration, in response to the impact of the agricultural business segment on the production segment, induced agricultural technological innovation theory was proposed at the start of the 20th century. This theory argues that the business model is closely related to agricultural technological innovation (Cowan et al., 2015) and that a proposed increase, decrease, or change of production and business factors will necessarily bring about technological innovation (Schultz 1987). Accordingly, it is clear that the promotion of Internet technologies and the development of rural e-commerce will inevitably promote changes in production by farmers, namely the use of green technologies in agriculture. On the one hand, the combination of e-commerce and the digital economy completes the construction of a digital system for the agricultural industry which is more conducive to the value-added and market demand transfer of green agricultural products and allows for more convenient mining and teaching of green agricultural technologies (Fu and Zhang 2022). On the other hand, the expansion of agricultural product sales by e-commerce and logistics platforms has led to a surge in the number of end customers with green consumption needs. The trend of standardization and branding of agricultural products has led to increasingly stringent requirements for the production process, which has also forced the improvement and standardization of the use of resettled agricultural technologies (Dong et al., 2021) as shown in Figure 1.

In the process of compulsory relocation, Reservoir resettlers lose their livelihood capital, livelihood capacity, and social network. Thus, the focus of subsequent development has been on how to achieve maximum benefits under resource constraints (Zhang 2021). It is a requirement of the principle of developmental resettled for hydropower projects in China that the post-resettled production and living standards of resettlers should not be lower than those before relocation. Therefore, whether resettled farmers can promote the application of green agrotechnology in agricultural production after participating in rural e-commerce is mainly determined by the related profit, so it can be judged according to the profit function corresponding to different participation situations of e-commerce, as shown in Eq. 1.

$$\pi_i = TR(Q) - TC(Q) \tag{1}$$

where π_i is the profit of resettlers selling household agricultural products; $i = 0$ means through an online e-commerce channel, and $i = 1$ means along the traditional offline channel. Q is the agricultural production level of resettled households in the resettled area, $TR(Q)$ is the total income derived from agricultural cultivation, and $TC(Q)$ is the corresponding total expenditure. Here, it is assumed that the production level Q of resettled households can be expressed by Eq. 2.

$$Q = f[I(g), g] \tag{2}$$

In the above equation, g is the degree of green agrotechnology adoption by resettled households, and I is other agricultural production factor inputs. The degree of households' inputs is closely related to the level of agrotechnology they use, so the latter can be expressed in the functional form $I(g)$. Assuming that the price of agricultural production factor I is P^0 and the unit price of green agrotechnology input is P^1, the profit of resettled agricultural output can be shown as in Eq. 3.

$$\pi_i = TR(Q) - TC(Q) = P_i Q - P^0 I(g) - P^1 g \tag{3}$$

At this point, it is necessary to find the optimal level of adoption of green agrotechnology for resettlers under the profit maximization condition, which is the derivative of profit π_i to the degree of adoption of agrotechnology g as shown in Eq. 4.

$$\frac{d\pi_i}{dg} = P_i \cdot \left[\frac{\partial Q}{\partial I} \cdot \frac{dI}{dg} + \frac{dQ}{dg}\right] - P^0 \cdot \frac{dI}{dg} - P^1 = 0 \tag{4}$$

In the above equation, $P_i \cdot dQ/dg$ can be regarded as the marginal benefit of green agrotechnology adoption by resettlers, denoted as MR_i, while $P^0 \cdot dl/dg + P^1$ is the marginal cost of agrotechnology adoption, denoted as MC_i. While the network direct sales model allows customers to sell their products directly, it also allows customers to obtain ecological and high-quality agricultural products more conveniently (Tian et al., 2022). Then it feeds this demand to resettled households quickly, which becomes a source of motivation for this group to apply green agricultural technology. For example, in the resettled area of Guojiaba Township, Zigui County in the Three Gorges Reservoir area, a water and fertilizer integrated navel orange planting base was built with the help of an e-commerce platform, and the track from the orchard to the road was electrified and a full production cycle traceability system with an integrated QR code was designed.

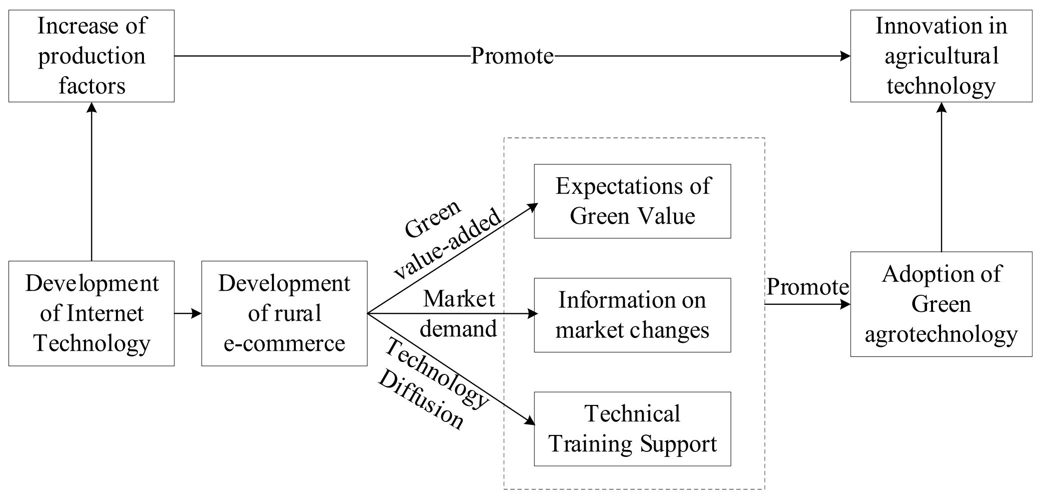

FIGURE 1
Analytical framework based on induced agricultural technological innovation theory.

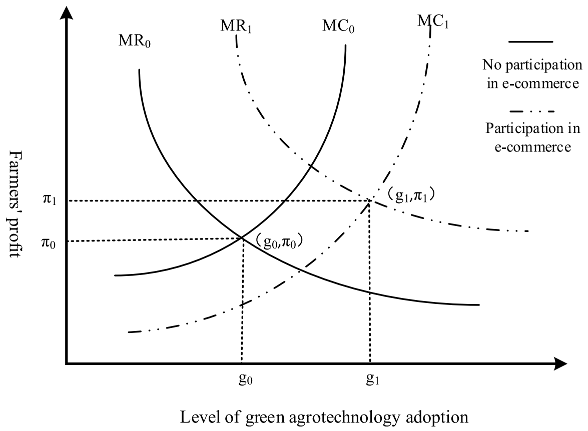

FIGURE 2
Linkages between e-commerce participation and resettlers' green agrotechnology adoption.

The results calculated from Eq. 4 is shown in Figure 2. In the case of resettled households participating in e-commerce, when $MC_1 = MR_1$, the optimal green agrotechnology adoption level is g_1, and when resettled households do not participate in e-commerce, the optimal value of green agrotechnology adoption at this point can be obtained from $MC_0 = MR_0$ as g_0. The current participation of resettlers in e-commerce will significantly increase the sales price of agricultural products. For example, the traditional channel sale price of pomegranate in Yunnan reservoir area of the lower Jinsha River hydropower station in 2021 was 0.5 USD/kilogram (kg). While through e-commerce do boutique retailing, it can be sold at 0.62 USD/kilogram (kg), an increase of more than 20%. So, when $P_1 > P_0$, there is $g_1 > g_0$, and the following research hypothesis can be proposed.

Hypothesis 1. Participation in e-commerce has a catalytic effect on resettled growers' green agrotechnology adoption behavior.

Different e-commerce participation models will have different benefits for resettled households as the participating subjects and circulation links vary. This paper classifies resettled households' e-commerce participation model as either platform e-commerce or social e-commerce, according to the survey data. The platform e-commerce model refers to resettled households selling through online trading platforms, such as Taobao and Jindong. The social e-commerce model refers to such households selling through a network of acquaintances to form a fixed source of online customers, such as through WeChat or QQ. The platform e-commerce model may obtain higher product revenue as a large number of merchants are participating: While the platform products are highly competitive barriers to entry, the requirements for technical investment are also higher. The social e-commerce model has price advantages, but resettled households have a limited network group of acquaintances, and the fact that e-commerce has a limited effect on increasing income leads to less willingness to adopt technical innovation and lower rates of green agrotechnology adoption. Accordingly, the following research hypothesis can be proposed.

Hypothesis 2. There are differences in the promotion of green agrotechnology adoption among resettled households according to various e-commerce participation models, with the platform e-commerce model outperforming the social e-commerce model.

However, a single profit-seeking factor is not sufficient in explaining the motivation of resettled households when they adopt green agrotechnology (Adnan et al., 2021). The increased vulnerability of livelihood and the relatively scarce livelihood capital led to a weakening in the ability of involuntary resettled groups to tackle risks to their livelihoods (Gong et al., 2020). However, the application of green agrotechnology may also give rise to additional risks, including technological, natural, and market risks. For example, compared with chemical pesticides, organic pesticides are difficult to operate and highly targeted. Resettlers faced with planting new crops in resettled areas may be vulnerable to yield reduction after application of a new technology. Especially if they are not familiar with pesticide selection, application dosage, and application time (Fang et al., 2021). In addition, resettlers whose original social networks are a great distance away from the resettled area and who have poor information channels may face failure to achieve high quality and high prices for their agricultural products, and with high technology costs (Lu et al., 2018). Therefore, resettlers have a lot of uncertainty when adopting green agrotechnology, and thus perceive the existence of risks, and in view of their relatively weak risk tolerance, they are mostly risk-averse subjects. In other words, the greater levels of risk perception in the resettlers' technology adoption behavior will directly affect the role played by e-commerce in the promotion of such behavior. From the expectation-utility theory, the utility function of resettlers' participation in rural e-commerce is shown in Eq. 5.

$$U(W-e) = E[U(W+\varepsilon)] \tag{5}$$

Where U and E are the utility and expected utility functions of resettled households, respectively, W is the production and marketing input, ε is the stochastic return, and e is the risk premium, which indicates the degree of resistance to green agrotechnology among resettled e-commerce participants. In order to analyze whether risk perception affects the propulsive effect of e-commerce on agrotechnology adoption behavior, the relationship between resettled risk perception and risk preference e must first be clarified. It is assumed that the benefit utility $U(W)$ of resettled e-merchants is second-order derivable. Then a Taylor series expansion is carried out for both sides of Eq. 5 based on the point W. The results are shown in Eq. 6.

$$E\left[U(W) + U'(W)\varepsilon + \frac{1}{2}U''(W)\varepsilon^2 + R\right] = U(W) + U'(W)e + R \tag{6}$$

R in the above equation is the higher order remainder term of Eq. 6, and the process of transforming the resettled participation in the electric utility U in Eq. 5 by the equation is shown in Eq. 7.

$$U(W-e) = U(W) + U'(W)e + R \approx U(W) + U'(W)e \tag{7}$$

Similarly, an equation transformation of the resettled expected utility function E in Eq. 5 is shown in Eq. 8.

$$\begin{aligned} E[U(W+\varepsilon)] &= E\left[U(W) + U'(W)\varepsilon + \frac{1}{2}U''(W)\varepsilon^2 + R\right] \\ &\approx U(W) + U'(W)E(\varepsilon) + \frac{1}{2}U''(W)E(\varepsilon^2) \end{aligned} \tag{8}$$

Since resettlers are mostly risk-averse after experiencing loss of livelihood, R is basically negligible and has $E(\varepsilon) = 0$, therefore at this point, $E(\varepsilon^2) = Var(\varepsilon)$. According to Eqs 5, 7, 8 are equivalent by association, which leads to Eq. 9.

$$U(W) + \frac{1}{2}U''(W)Var(\varepsilon) = U(W) - U'(W)e \tag{9}$$

An equation transformation of Eq. 9 can locate the willingness to resist green agrotechnology e of e-commerce resettled households, as shown in Eq. 10.

$$e = -\frac{1}{2}\frac{U''(W)}{U'(W)}Var(\varepsilon) = \frac{1}{2}k(e)Var(\varepsilon) \tag{10}$$

It can be calculated that $U''(W)/U'(W) = k(e)$ in the above equation, while $Var(\varepsilon)$ represents the external factors affecting resettlers' returns. This is the variance of random returns, which can be considered as being the perceived income risk held by resettled households. In the case that resettled households tend towards risk-aversion, $k(e)$ is relatively stable. If the degree of resettled risk perception $Var(\varepsilon)$ is higher, the value of e increases, indicating that resettlers are more resistant to green farming techniques. According to the above analysis, the following research hypothesis can be proposed:

Hypothesis 3. Individual risk perceptions will constrain the degree to which e-commerce participation promotes the adoption of green agrotechnology by resettled households.

3 Data, models and variables

3.1 Location selection and data sources

The Three Gorges Reservoir has flooded 260 km^2 of arable land, and there are 354,000 rural resettlers settled in the area. This has resulted in an extremely limited environmental capacity to produce food. Zigui County in Hubei, at the head of the Three Gorges Project Reservoir, is both a resettled area and classed as a "national poverty-stricken county," with 25% of its total population being Reservoir resettlers. As the climate and soil environment are very suitable for the growth of Navel oranges, Zigui County has become famous as China's "Navel Orange Township." Therefore, in recent years, through the Three Gorges resettled support funds and other promotional projects, Zigui County has been encouraged to adopt green agriculture. At present, the Zigui navel orange production area covers 23,200 ha and has an annual output of 605,000 metric tons. Across the area's 12 towns and 116 villages, about 198,000 people

TABLE 1 Number of resettled households' adoption of various green agricultural technologies.

Sample townships	Resettlers	E-commerce participation	Physical control	Pollution-free pesticides	Soil testing fertilizer	Laminated water control	Grafting	Fertilizer integration
Maoping	159	126	54	48	36	27	51	9
Guojiaba	240	153	126	129	126	24	192	21
Guizhou	186	81	105	114	93	24	156	18
Shuitianba	75	39	51	30	36	3	57	18
Tatal	660	399	336	321	291	66	456	66

are engaged in related industries, and this is the only national citrus production area that produces fresh fruit throughout the year.

In order to solve the difficulties caused by the lack of land to compensate resettlers in the county, as well as a lack of social resources and the low premium capacity of agricultural products, Zigui County took the lead in innovating an e-commerce development model in 2014 and was selected as one of the second batch of national "e-commerce-demonstrating rural counties" in 2019. In recent years, the proportion of online sales of Navel oranges has accounted for about 55% of total sales, and the per capita net income of orange farmers increased from 1,967 USD in 2014 to 3,372 USD in 2018, becoming an important way to enhance the income of resettlers. In addition, e-commerce promotes the adoption of solar pest control lights, water and fertilizer integration, Internet of Things (IoT, through which things are connected through the Internet) management, and other green agrotechnology, using networks to strengthen the ecological brand marketed as "a river of clear water, green mountains on both sides of the river, four seasons of fresh oranges."

The data used in this study come from the Navel orange electric business and green agrotechnical survey conducted in the resettlement area of Zigui County, Hubei Province during December 2020. The sampling points were selected from a total of 34 resettlement villages and groups in three towns and one township, namely Maoping Town, Guojiaba Town, Guizhou Town, and Shuitianba Township. At present, each of the four has an electric e-commerce logistics center, an e-commerce service center, and other infrastructure and service facilities and has several green agrotechnology demonstration orchards or planting bases, such as the Bajiaolou Green Technology Tour Park, the Flying Green Plant Protection base in Guogutai Village, Guojiaba Township, and the Alibaba Group's Future Farm in Choumushu Village, Shuitianba Township. All these were sampled.

The specific sampling method was to randomly select eight to 10 sample villages in each township, then randomly conduct household surveys. A total of 688 resettlers were interviewed. After samples with no response or doubtful key information were excluded, 660 valid questionnaires were obtained. The number of resettled households' adoption of various green agricultural technologies is shown in Table 1.

According to the list of technical systems in the "Technical Guidelines for Green Agricultural Development (2018–2030)," resettled households mainly apply six types of green agrotechnologies: physical control technology, pollution-free pesticide technology, soil formula fertilizer technology, film and water control technology, water and fertilizer integration technology, and grafting technology. Of these, 120 households (18.2%) have adopted two kinds of technologies, and 249 households (37.7%) have adopted four or more kinds of technologies, which shows that green agrotechnologies are in the emerging stage in the resettlement area.

3.2 Model construction

Using Li et al. (2020) classification of degree of agrotechnology adoption, we divided resettlers' agrotechnology adoption into five categories, from low to high, and assigned them the following values: lower adoption = 1, low adoption = 2, moderate adoption = 3, high adoption = 4, and higher adoption = 5. Since, as an explanatory variable, the degree of resettlers' agrotechnology adoption g is a multi-valued ordered variable, we used the ordered probit model to explore the influencing factors involved, and the underlying regression model constructed is shown in Eq. 11.

$$g_i^* = \alpha_1 + \beta_1 EP_i + \beta_2 GPE_i + \beta_3 TTS_i + \lambda_1 CV_i + \sigma_i \qquad (11)$$

In Eq. 11, EP_i, GPE_i, and TTS_i represent e-commerce participation, agricultural price expectation, and agrotechnology training of the ith resettled household, respectively, while CV_i represents a series of control variables and σ_i is a random disturbance term. g_i^* is a latent variable of the degree of green agrotechnology adoption of resettled household i. Let C1<C2<C3<C4<C5 be the threshold, then g_i values can be discretized by g_i^* as shown in Eq. 12.

$$g_i = \begin{cases} 1 & g_i^* \leq C_1 \\ 2 & C_1 \leq g_i^* \leq C_2 \\ 3 & C_2 \leq g_i^* \leq C_3 \\ 4 & C_3 \leq g_i^* \leq C_4 \\ 5 & C_4 \leq g_i^* \leq C_5 \end{cases} \tag{12}$$

If the random disturbance term σ_i obeys the standard normal distribution, X is a vector of actual observations of sample households for all independent variables, and ϕ denotes the cumulative distribution function. The impact mechanism of each adoption degree is shown in Eq. 13.

$$\begin{cases} P(g_i = 1|X) = P(g_i^* \leq C_1) = \Phi_1 \\ P(g_i = 2|X) = P(C_1 \leq g_i^* \leq C_2) = \Phi_2 \\ P(g_i = 3|X) = P(C_2 \leq g_i^* \leq C_3) = \Phi_3 \\ P(g_i = 4|X) = P(C_3 \leq g_i^* \leq C_4) = \Phi_4 \\ P(g_i = 5|X) = P(C_4 \leq g_i^* \leq C_5) = \Phi_5 \end{cases} \tag{13}$$

After an ordered-probit model is constructed in Eq. 13, the regression coefficients can be estimated using the maximum likelihood estimation (MLE) method. In addition, we conducted additional analyses independent of the probit model. To analyze the extent to which e-commerce participation drives the adoption of agricultural technologies, we analyze the marginal effects of each independent variable, as shown in Eq. 14.

$$\partial P(g_i = n|X)/\partial x_j = -\Phi_n \beta_j \tag{14}$$

Where $n = 1,2,......5$ represents the five degrees of resettled green agrotechnology adoption, x_{ij} is the jth independent variable of sample i, and β_{ij} is the coefficient to be estimated for x_{ij}. The marginal effects were analyzed according to the sign and coefficients of the results.

3.3 Variable selection

3.3.1 The dependent variables of this paper is resettled households' adoption of green technologies in navel orange cultivation

The specific measurement has six categories of green agricultural technologies adopted by resettled households, and the value is assigned as 1 if adopted, and 0 if not. Due to variations in natural capital among resettled households, it is not suitable to use equal weighting among the categories because of limitations placed on the use of different green agricultural technologies. Therefore, the four dimensions of economic benefits, resource saving degree, ecological benefits, and operational feasibility are considered comprehensively, and the entropy value method is applied to determine their weighting coefficients. The steps are as follows: 1)Calculate the indicator weight $p_{ij} = X_{ij}/\sum_{i=1}^{m} X_{ij}$ for item i under the jth indicator of resettled household X_{ij}, where m is the number of evaluation dimensions. 2) Measure the entropy value of indicator j $e_j = -\sum_{i=1}^{m} p_{ij} \ln p_{ij} / \ln m$. 3) Derive the entropy weight $w_j = (1 - e_j)/\sum_{j=1}^{n} (1 - e_j)$ of the jth indicator. 4) Obtain the weight coefficients by calculating the weight of each secondary indicator of the evaluation dimensions, as shown in Table 2.

3.3.2 Independent variables

According to the model deduction of the previous theoretical analysis, it can be seen that the participation behavior of e-commerce. The expected sales price of agricultural products are the keys to promoting the adoption of green agrotechnology among resettlers. The improvement of agrotechnology application capacity through training is also an important factor (Liu et al., 2022).

3.3.3 Moderating and controlling variables

According to the aforementioned theoretical model, it is clear that the perceived risk factors of resettled households have an impact on e-commerce's promotion of the use of agrotechnology. These involve various aspects and varying degrees of perception, such as natural conditions, market environment, and technical capacity. According to previous studies, there are two main types of control variables. One is demographic characteristics, including gender, age, and the level of education of respondents. The other is household endowment, including the maximum years of education of members, the proportion of household labor force, annual household income, navel orange planting area, and support from local cooperative organizations.

The definition and descriptive statistics of each variable are shown in Table 3, in which the mean value of adoption of green agrotechnology is 1.763. The overall application degree still needs to be improved; however, participation in e-commerce is more than half, indicating that resettlers generally have enthusiasm to engage in e-commerce. At the same time, the current support for training in the use of agricultural technology is still insufficient with the mean value is 0.414. The risk perception of the application of agricultural technology is around the mean value, which needs to be controlled and further development of e-commerce is required to promote the popularity of green agricultural technology in resettled areas.

4 Empirical results

4.1 Impact of e-commerce participation behavior on the degree of green agrotechnology adoption

Before testing the role of e-commerce participation behavior in the promotion of the application of resettled farming techniques, a multiple cointegration test between the relevant independent variables was required. The resulting variance inflation factor (VIF) was far below 10, without cointegration

TABLE 2 Evaluation indicators and weights of the degree of adoption of various types of green agrotechnology by resettled households.

Target layer	Level 1 indicators	Secondary indicators	Secondary indicator weights	Weighting of primary indicators
Degree of adoption of green agrotechnology	Physical control technology	Economic benefits	0.019	0.075
		Resource conservation degree	0.019	
		Eco-friendly effect	0.018	
		Operability	0.019	
	Pollution-free pesticide technology	Economic benefits	0.018	0.070
		Resource conservation degree	0.018	
		Eco-friendly effect	0.017	
		Operability	0.017	
	Soil testing and fertilizer technology	Economic benefits	0.014	0.056
		Resource conservation degree	0.014	
		Eco-friendly effect	0.014	
		Operability	0.014	
	Lamination and water control technology	Economic benefits	0.096	0.383
		Resource conservation degree	0.095	
		Eco-friendly effect	0.096	
		Operability	0.096	
	Water and fertilizer integration technology	Economic benefits	0.095	0.386
		Resource conservation degree	0.098	
		Eco-friendly effect	0.096	
		Operability	0.097	
	Grafting and splicing technology	Economic benefits	0.007	0.030
		Resource conservation degree	0.007	
		Eco-friendly effect	0.007	
		Operability	0.009	

problems. We then examined whether the original data satisfied the parallel regression hypothesis and found that the chi-square value was not significant. This meant the hypothesis was valid for analysis using the ordered-probit model. Finally, regression models were constructed when no-control variables (Model I), household head characteristics (Model II), and household head characteristics and household endowment (Model III) were added. The regression models are shown in Table 4.

As shown in Table 4, e-commerce participation significantly and positively influenced resettled navel orange growers' green agrotechnology adoption behavior at the 1% level, i.e., Hypothesis 1 holds. To analyze the influence mechanism, the relationship between e-commerce participation behavior, agricultural price expectation, and technical training support was further investigated here, as shown in Table 5. The regression results show that there is a significant positive correlation between participation in e-commerce and factors that support technology adoption support regarding such as price expectation of agricultural products and technical training support.

According to the model regression results above, participation in e-commerce has a significant positive effect on resettled households' adoption of green agrotechnology. Specifically, various government subsidies and agricultural policies increased their green agricultural product price expectations after participating in e-commerce. For example, Zigui County has successively issued documents such as "Implementation Opinions on Accelerating E-commerce Development" and "Implementation Plan of E-commerce in Rural Areas Project," which have greatly enhanced the information used by resettlers in their agrotechnology inputs. At the same time, resettlers have been given more technical training opportunities. For example, platforms such as Suning University and Jingdong Business School dispatched lecturers to

TABLE 3 Definition of variables and descriptive statistics.

Variable types	Variable name	Variable definition and assignment	Average	Standard deviation
Dependent variable	Level of adoption of green agrotechnology	Comprehensive calculation of the application of each type of agrotechnology (entropy method)	1.763	1.113
Independent variables	E-commerce participation	Participation = 1; No participation = 0	0.605	0.490
	Green product price expectations	Very low = 1; relatively low = 2; average = 3. relatively high = 4; very high = 5	3.436	0.648
	Technical training support	Accepted = 1; Not accepted = 0	0.414	0.494
Moderating variables	Risk perception	Perceived risk in green agrotechnology application: very small = 1; relatively small = 2; average = 3; relatively large = 4; very large = 5	2.782	1.076
	Gender	Male = 1, Female = 0	0.664	0.474
	Age	Actual age (years)	48.514	11.316
	Education level	Years of education (years)	9.777	2.925
Control variables	Maximum number of years of education for members	Maximum number of years of education for family members (years)	12.891	3.059
	Household labor force ratio	Ratio of labor force population to total population	0.725	0.235
	Annual household income	Total household income in 2020 (USD)	1.892	2.272
	Orange planting area	Household-owned orange cultivation area in 2020 (hectare)	0.7367	4.5678
	Local partner organizations support	Yes = 1; No = 0	0.164	0.371

TABLE 4 Regression results of the impact of green farming technology adoption among resettled orange growers.

Variable types	Variable name	Model I	Model II	Model III
		Coefficient (robust standard error)	Coefficient (robust standard error)	Coefficient (robust standard error)
Independent variables	E-commerce participation	0.821*** (0.191)	0.793*** (0.210)	0.859*** (0.211)
	Green product price expectations	0.647*** (0.135)	0.648*** (0.135)	0.664*** (0.136)
	Technical training support	0.516*** (0.168)	0.533*** (0.169)	0.481*** (0.175)
Control variables	Risk perception		−0.217 (0.176)	−0.151 (0.182)
	Gender		0.003 (0.009)	0.002 (0.010)
	Age		0.026 (0.035)	0.029 (0.037)
	Education level			0.002 (0.037)
	Maximum number of years of education for members			−0.164 (0.369)
	Household labor force ratio			−0.021** (0.009)
	Annual household income			0.001 (0.001)
	Orange planting area			−0.081 (0.228)
Pseudo-R^2		0.1467	0.1505	0.1635
Observed values		660	660	660

Note: *, **, and *** are statistically significant at the 10%, 5%, and 1% levels, respectively.

12 townships in Zigui County to teach e-commerce production and operation.

Based on the Hypothesis 1 test, the degree of resettlers' agro technology adoption under the role of each factor was further analyzed to explore whether the marginal effects of different degree types affected were sensitive, as shown in Table 6.

The results in Table 6 show that the percentage of resettled households with low technology adoption will decrease by 25% after they participate in e-commerce, while resettled households with moderate, higher, and high adoption will increase by 6.3%, 3.7%, and 7.4%, respectively. It is confirmed that the awareness and adoption of green farming techniques among resettlers are

TABLE 5 Correlation between e-commerce participation and green agrotechnology adoption support elements for resettled households.

Dependent variable		Green product price expectations	Technical training support
Independent variables	E-commerce participation	0.733*** (0.180)	0.542***(0.209)
Control variables		Controlled	Controlled
Pseudo-R^2		0.575	0.0988

TABLE 6 Marginal effects of each influencing factor on the degree of resettlers' adoption of agricultural technology.

	Very low adoption type	Low adoption type	Moderate adoption type	High adopted type	Very high adoption type
E-commerce participation	−0.252*** (0.052)	0.076*** (0.017)	0.063*** (0.018)	0.037** (0.015)	0.074*** (0.024)
Green product price expectations	−0.198*** (0.037)	0.060*** (0.015)	0.050*** (0.013)	0.029*** (0.011)	0.059*** (0.017)
Technical training support	−0.158*** (0.049)	0.048*** (0.017)	0.040*** (0.015)	0.023** (0.010)	0.047*** (0.018)

TABLE 7 Differences in the impact of different e-commerce participation models on resettlers' green agrotechnology adoption.

Group	Processing effects	Processing group	Control group	Difference	Standard error	*t*-test value
Overall sample	ATT	2.092	1.565	0.527	0.210	2.50
Platform e-commerce model	ATT	2.551	1.265	1.286	0.319	4.03
Social e-commerce model	ATT	1.815	1.284	0.531	0.258	2.06

enhanced under the e-commerce model. Resettled households with a low level of green agrotechnology application also decreased by 19.8% and 15.8%, respectively, as the price of agricultural products improved and agrotechnology training grew in popularity, but it was not as significant as the effect of e-commerce participation.

4.2 The impact of e-commerce participation model on the degree of adoption of green agricultural technology

To analyze the heterogeneity in the impact of different e-commerce participation models, this paper further empirically tested the impact of e-commerce participation models on resettled households' green farming skills. Statistics found that, among the sampled households participating in e-commerce, 153 (38.3%) used the platform e-commerce model sample and 246 (62.7%) used the social e-commerce model sample. The empirical results are shown in Table 7. According to the level of technology adoption classified by the previous section (1–5), from the overall sample, the degree of increase in agrotechnology adoption by farmers participating in e-commerce was 0.527, while the degrees of increase for the platform e-commerce and social e-commerce models were 1.286 and 0.531, respectively. The results indicate that the degree of increase for the platform e-commerce model was greater, suggesting that it could bring about a greater increase in agrotechnology adoption than the social e-commerce model.

4.3 Results of the moderating effect of risk perception

To verify the moderating role of risk perception in resettled agrotechnology adoption, Model IV was constructed by introducing the interaction term between e-commerce participation and risk perception. The results are shown in Table 8, which indicate that while e-commerce participation significantly increases the adoption of green agrotechnology, risk perception has a significant negative correlation to it. Indeed, the negative coefficient of the interaction term confirms that risk perception weakens the positive relationship between e-commerce participation and agrotechnology adoption, so Hypothesis 3 is valid.

TABLE 8 Analysis of moderating effects of risk perception.

Variable types	Variable name	Model IV	Model V	Model VI
		Coefficient (robust standard error)	Coefficient (robust standard error)	Coefficient (robust standard error)
Independent variables	E-commerce participation	1.971*** (0.562)	3.748*** (0.642)	2.220*** (0.425)
	Risk perception	−0.174** (0.151)		
	Green product price expectations		1.016*** (0.246)	0.558*** (0.154)
	Technical training support		0.744** (0.308)	0.352* (0.199)
Interaction items	E-commerce participation * Risk perception	−0.361** (0.184)	−0.799*** (0.195)	−0.518*** (0.129)
Control variables	Controlled	Controlled	Controlled	
Pseudo-R^2	0.1538	0.1991	0.1987	
Observed values	660	660	528	

For example, when the rainfall in Zigui and other places reached historical extremes in the summer of 2021, to ensure the taste of fresh navel oranges was maintained, the local migration management recommended the adoption of land mulching technology in the selenium-rich planting bases of Seven Princesses, Shi Wai Tian Yuan and other major e-commerce companies. However, if the residual film cannot be effectively recovered or is uncovered too late, the film will be left in the soil by weathering and decaying, and its long-term accumulation will result in serious damage and pollution to the soil. This means that the households with high soil quality requirements are cautious about employing this technology. Hypothesis 3 also illustrates that both the objective risk caused by external shocks and the subjective risk caused by incomplete information after relocation may have a significant impact on agricultural production decisions. Resettled households with weak resilience to potential risks to their livelihood, especially, are often forced to make careful trade-offs between low risk and high profit.

4.4 Robustness test

To test the robustness of our empirical results, one method was to construct another ordered-logit model (Model V) for the ordered variable of degree of resettlers' green farming technology adoption to conduct a regression analysis. The other was to extract 80% of resettlers' sample households and test them again through the ordered-probit model (Model VI). The results of both are shown in Table 8. As displayed in Table 8, there is essentially no difference in the sign (positive and negative values) of the regression coefficients for Models V and VI, or the significance level of the coefficients. This indicates the strong robustness of the hypotheses derived from the theoretical model, as well as the mechanisms of influence of the selected independent and control variables on the dependent variable.

5 Discussion

Based on relevant theories, this study reveals the impact of resettled households' e-commerce participation on their green technological innovations, determines the impact mechanisms, and conducts an empirical test. Our results summarize the results and experiences of modernizing involuntary among Three Gorges Reservoir area in China, which may provide a modellable case study for future rural revitalization in China. This may solve the sustainable livelihood problems of involuntary resettlers in other countries.

Due to the limited environmental capacity in the resettlement area, participation in social e-commerce among Reservoir resettlers is high, and it has gradually replaced the traditional agricultural cooperatives as the first choice to expand the distribution channels of agricultural products and generate family income. At the same time, although the adoption of green agrotechnology among resettlers is gradually expanding, adoption levels remain low to medium. Previous studies have mostly focused on the income-generating effects of e-commerce and the adoption factors and environmental effects of green agrotechnology (Takahashi and Muraoka 2019; Peng et al., 2021; Li et al., 2022), with less research on the interrelationship between the two, but the huge impact of e-commerce on agricultural production cannot be ignored. Our results show that e-commerce participation significantly increases the level of resettlers' green agrotechnology adoption, shrinks the proportion of households with low adoption, and increases the proportion of resettled households with high adoption. This is similar to the findings of Li et al. (2021). Specifically, agricultural price expectations and related agrotechnology training support from e-commerce were the most important agrotechnology adoption drivers, and the former was more sensitive, indicating that resettlers urgently need to rely on green agricultural development to cope with an industrial hollowing-out in the

Three Gorges Reservoir area due to natural capital loss and compensation resource constraints. However, green value-added agricultural products and e-commerce-assisted agrotechnical training mainly act on resettled households with low agrotechnical skills and, without the participation of e-commerce, will have limited impact effects.

Heterogeneous e-commerce participation models impact agrotechnology adoption differently. Many studies have shown that as e-commerce continues to develop, different e-commerce models, such as social e-commerce and platform e-commerce, are available (Luo 2022). Because the platform e-commerce model requires high household endowment, which is difficult for resettled households to afford, most such households choose the social e-commerce model. Chinese people value social relationships and are very good at using them (Zhang and Yang 2022). Resettled households share product information through social networks and word of mouth and can expand their product sales network more simply. Resettlers' awareness and adoption of green farming techniques have increased under various e-commerce models. Of these, platform e-commerce participation brings the greatest degree of enhancement; the traditional e-commerce participation model has more intense market competition and consumers' product requirements are higher (Heuer et al., 2015), which pushes resettled households to continuously improve the level of green agrotechnology adoption. In contrast, due to the limited network of resettled households' acquaintances, the demand for green agrotechnology adoption driven by social e-commerce is lower, as is the degree of improvement it brings.

Related studies have shown that uncertainty in the application and use of technologies when new technologies are introduced will also cause uncertainty in income (Chavas and Shi 2015; Hörner and Wolln 2022). Involuntary resettlers have a tendency to avoid livelihood risks and fear their own lack of resilience, thus, if they perceive risks in technology application, they are likely to weaken the green agrotechnology promotion effect brought about by e-commerce participation. Theoretical improvements and innovations are often not convincing to farmers (Bozzola and Finger 2020), especially when the technical barriers to green agrotechnology application are high or the effectiveness of use is uncertain, which will lead to higher risk perceptions in technology adoption and thus make e-commerce resettlers cautious about green agrotechnology.

Some shortcomings must be acknowledged. First, the agrotechnology selected in this paper is citrus cultivation technology, and the significance of other agricultural products still needs to be verified. Second, we tested limited factors influencing green agrotechnology. Government regulation and incentives, the role of markets, and individual capabilities still need to be further verified. Third, the rho-squared value is not at a high degree, so the model in this paper can continue to be improved. Subsequent studies can improve on the above aspects.

6 Conclusion and policy recommendations

Based on previous technology adoption theories, this paper constructs a theoretical model of green agrotechnology adoption by resettled households in the development of e-commerce in hydropower project reservoirs, taking into account the characteristics of Chinese involuntary project resettlers, the objective of maximizing expected returns, and the perceived risk to technology application posed by resettlers' livelihood risk resistance. Drawing on survey data from resettled households in Zigui, the first county in the Three Gorges Reservoir area, the hypotheses derived from the theoretical model were tested empirically by using the ordered probit model. The conclusions are as follows: Green agrotechnology has become more popular among resettlers, but the overall adoption level is still low; participation in e-commerce has a significant positive impact on the adoption of green agrotechnology at the 1% level. The ecological value expectation of agricultural products and the agrotechnology support provided by e-commerce are the most important driving factors, but their current effects are mostly limited to resettled households with a low level of agrotechnology. Compared with the social e-commerce participation model, platform e-commerce brings more significant improvements in technology adoption. The risk perception in resettled households' agrotechnology application weakens the promotion effect of e-commerce participation on agrotechnology adoption, while the risk perception of e-commerce participation weakens the promotion effect of the latter on the adoption of green agrotechnology.

Based on these findings, the following policy recommendations are proposed: 1) supporting fund should be used to improve network and logistics infrastructure. Through the combination of e-commerce policy and late-stage supporting system for resettlers, we can increase the participation rate of e-commerce and promote the application of green agricultural technology. 2) On the basis of the regional brand of the products in the resettled area, we embed the spirit of resettlers and create a special brand. On the one hand, it can realize the traceability of the whole growth cycle of agricultural products, and on the other hand, it can do the whole cycle of product development and expand a variety of products. This can enhance the agronomic value expectation of resettlers by adding value to agricultural products. 3) The government-led e-commerce associations in resettled areas should promote each other with the informal business organizations of resettlers formed by e-commerce platforms. It is necessary to provide green agrotechnology training more precisely. However, it is necessary to promote close interaction between resettlers and local residents through joint participation in e-commerce. Through small-scale technology demonstration and field guidance, the dissemination and exchange of tacit knowledge in the application of agricultural technology in resettler communities should be promoted. 4) To address the risk-averse tendency of reservoir resettlers in the application of green agricultural technology, the government of resettled areas should strengthen the publicity and popularize the knowledge of technical risks to avoid excessive precautionary behavior by resettlers. Meanwhile, the government should cooperate with insurance agencies to encourage farmers to purchase agricultural insurance policies. Such insurance policies are specifically used to share the technical costs incurred by resettler groups during the medium- and long-term growth periods of agricultural products and are incorporated into late-stage systems of risk sharing. This can reduce resettlers' hesitancy to adopt green agrotechnologies.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors contributed to the study conception and design. The first draft of the manuscript was written by ZC, XZ, and FZ. All authors commented on previous version of the manuscript. All authors read and approved the final manuscript.

Funding

This research was financially supported by National Natural Science Foundation of China: Livelihood Elasticity Measurement and Simulation Research on Later Supporting Strategies of Involuntary Resettlers from the Perspective of Habitat Mutation (Project Number: 72271142). The Major Program of National Social Foundation of China: Study on the governance and late-stage support of inter-county relocation communities (Project Number: 21&ZD183).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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