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Does Buddhist belief matter to pesticide application? Evidence from rice farmers in southern China

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Excessive pesticide use in agriculture poses significant environmental and health risks, making it crucial to understand the factors influencing farmers' pesticide use. While previous research has examined individual, economic, social and political factors, the impact of religious beliefs, particularly Buddhism, remains underexplored. This study uses the control function approach to analyze survey data from 3410 rice farmers in China (2018–2019), assessing how Buddhist belief affects pesticide use. The results indicate that Buddhist farmers use fewer pesticides per hectare and incur lower pesticide costs compared to non-Buddhist farmers. Robustness checks confirm the reliability of the findings. The negative effect of Buddhist belief on pesticide use is more pronounced among farmers who have received rice cultivation training, have a high level of risk perception, and hold cooperative membership, while this effect is weaker for farmers with more farming experience. Furthermore, the influence of Buddhist belief varies with farmers' propensity to believe in Buddhism. These findings highlight the potential of integrating cultural and religious dimensions into agricultural policies to promote rational and sustainable pesticide application.

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Introduction

In recent years, countries have increasingly prioritized addressing severe ecological and environmental challenges, implementing measures such as “emphasizing environmental protection” and “comprehensive pollution prevention and control”. Agriculture, while serving as a fundamental pillar industry essential to human life, production, survival, and development, also contributes significantly to environmental pollution. Pesticides, as a critical input in agricultural production, play a vital role in enhancing crop yields, boosting farmers’ incomes, ensuring food security, and maintaining social stability. However, the growing use of pesticides has led to significant negative externalities, including heightened agricultural surface pollution and escalating food safety concerns, which are becoming increasingly urgent issues to address.

In China, the issue of irrational pesticide use remains prevalent. From 2004 to 2014, as the area of crop cultivation gradually expanded, the difficulty of pest and disease control increased, leading to an overall upward trend in pesticide usage. According to data from the National Bureau of Statistics, pesticide use reached 1.8033 million tons in 2014, an increase of approximately 30.11% compared to 1.386 million tons in 2004, with the average pesticide use efficiency only at 35%. Farmers generally lack knowledge about proper pesticide use and primarily rely on recommendations from retailers and subjective judgment to make spraying decisions (Zhao et al. 2018; Li et al. 2022; Yang et al. 2024), resulting in increased production costs and pesticide residues exceeding safe limits. In response to the excessive use of pesticides, the Ministry of Agriculture of China issued the “Zero Growth Action Plan for Pesticide Use by 2020” in 2015, aiming to effectively control pesticide use, ensure food security, and promote sustainable agricultural development. Based on this plan, government agencies have developed and strictly enforced regulatory measures in the production, operation, sale, and use of pesticides. Since 2017, pesticide use has decreased annually, maintaining a reduction of more than 5% each year. In 2021, the total pesticide use nationwide was reduced to 1.2392 million tons, achieving significant success in China’s pesticide reduction efforts. However, due to the large and dispersed rural population, enforcing pesticide regulations at the local level remains challenging, and farmers’ private pesticide application practices are difficult to monitor strictly. Therefore, the only way to effectively control pesticide input at its source and promote sustainable agricultural development is to encourage farmers to make rational pesticide application decisions based on sound judgment.

The phenomenon of excessive pesticide use has sparked widespread attention in the academic community. On one hand, scholars recognize that pesticides hold an essential and irreplaceable role in agricultural production under current technological conditions (Soares and de Souza Porto, 2009). On the other hand, concerns persist about the adverse effects of excessive pesticide use, including surface pollution, environmental degradation, and food safety risks (Cabrera et al. 2008; Hunke et al. 2015). These concerns have spurred research into the factors influencing pesticide application behavior. How can the phenomenon of pesticide overuse be explained? The factors influencing pesticide application behavior can be broadly categorized into internal and external factors. Internal factors primarily relate to individual characteristics, with extensive literature (Fan et al. 2015; Zhao et al. 2018; Li et al. 2014; Jin et al. 2017) examining the impact of variables such as experience, knowledge, education, and risk perception. External factors, on the other hand, include government regulatory enforcement, policy dissemination, technical training, advanced equipment availability, and weather conditions (Abhilash and Singh, 2009; Li et al. 2014; Nie et al. 2018).

According to Carvalho (2006), emerging regions invest significant labor, inexpensive yet highly polluting chemical fertilizers, and pesticides to boost agricultural yields. However, our survey data reveal the opposite trend. Despite the underdeveloped rural economies in central and western China¹, pesticide application in these regions is relatively low. Why is this the case? We observe that compared to the more economically advanced eastern regions, rural religious belief—particularly Buddhism—is more prevalent in central and western China. This raises the question: is there a causal relationship between religious belief and farmers’ pesticide application? Prior literature provides valuable insights. Hand and Van Liere (1984) examined the relationship between religion and environmental attitudes, finding that non-Jewish Christians were most opposed to the idea of “human dominance over nature.” They also observed that church attendance could be a measure of environmental awareness, with high attendance among conservative denominations correlating with less environmental awareness, while liberal denominations showed less agreement with this view. Greeley (1993) proposed a religion-politics-ethics-environment model and concluded that the link between religion and environmental attitudes in the United States is spurious, as political and moral factors weaken the connection between biblical doctrine and environmental attitudes. Hayes and Marangudakis (2000) highlighted notable disparities within Christianity regarding denominational and intra-denominational environmental attitudes, emphasizing the need to link theological concepts to strengthen arguments. In China, rural religious beliefs have distinct implications for environmental behavior and pollution. Li (2010), using regression analysis, concluded that beliefs about gods and the afterlife have a stronger influence on environmental pollution status than the type of belief or participation in religious activities. Wan and Si (2015) found that religious belief positively influences residents’ engagement in environmental protection behaviors. Similarly, Huang (2021) discovered that indigenous religions, particularly Buddhism, have a stronger and more positive impact on environmental protection behaviors compared to foreign religions.

How does religious belief influence farmers’ pesticide use? The Value-Belief-Norm (VBN) theory, proposed by Stern et al., (1999) to explain the origins of environmental behavior, suggests that individual value systems significantly impact environmental attitudes. Schwartz (1977) identifies three core values relevant to environmental behavior: ecological, altruistic, and self-interested values. As a social construct with both cultural and institutional attributes (Stark and Finke, 2000), religion exerts implicit constraints and regulatory mechanisms that guide farmers in rational pesticide application and addressing ecological challenges. In essence, the impact of religious belief on pesticide use stems primarily from its role in shaping doctrines and values. Specifically, religious beliefs and practices prevalent in rural societies influence farmers’ perceptions of the natural environment, serving as a code of conduct that guides their behavior (Lam and Shi, 2008; Yachkaschi and Yachkaschi, 2012). Despite this, few studies have thoroughly examined the causal relationship between religious belief and pesticide use or explored the underlying mechanisms in depth. The China Religious Report shows that among the five officially recognized religions (Buddhism, Taoism, Islam, Catholicism, and Christianity), Buddhists constitute the largest group, accounting for 9%, with the majority being rural residents (Jin and Qiu, 2012). Therefore, analyzing the impact of Buddhist belief on pesticide use and its potential mechanisms is highly representative. Based on the survey data of farmers in 12 rice-producing provinces in southern China, this study analyzes the influence of Buddhist belief on pesticide use in the current cultural pluralism with a focus on Buddhist beliefs. The study

demonstrates that Buddhist belief has a negative role in pesticide application. Particularly, Buddhist belief significantly lowers both the average pesticide dosage per ha and the average pesticide cost per ha by 48.53% and 53.0%, respectively. In addition, rice planting training, risk perception of pests and diseases, and cooperative membership can strengthen the relationship between Buddhist belief and pesticide dosage. In contrast, the rice planting experience can weaken the pesticide reduction effect of Buddhist belief. Furthermore, the treatment effect of Buddhist belief performs heterogeneity for marginal farmers due to some unobservable characteristics.

Compared to previous studies, this study makes several key contributions. First, it advances the literature on religious belief and pro-environmental behavior. While existing studies have largely explored this relationship from a theoretical perspective (Hand and Van Liere, 1984; Greeley, 1993; Kinsley, 1995; Gottlieb, 2006; Li, 2010; Wan and Si, 2015; Huang, 2021), they have not quantified the treatment effect of religious belief on pesticide use or examined its internal mechanisms. This study addresses these gaps by providing robust empirical evidence of the relationship between Buddhist belief and pesticide use behavior, thereby extending the research frontier.

Second, the study offers an in-depth analysis of the heterogeneous effects of Buddhist belief on pesticide use and uncovers the underlying mechanisms. On one hand, it incorporates observable factors such as rice farming training, planting experience, risk perception regarding pests and diseases, and cooperative membership into the regression framework, highlighting their moderating effects on the relationship between Buddhist belief and pesticide use. On the other hand, it investigates the heterogeneous effects of unobservable factors, estimating the marginal treatment effects for farmers with varying levels of religiosity. These analyses clarify the pathways through which Buddhist belief influences pesticide use, representing a significant advancement in the existing literature.

Third, the findings provide actionable insights for policy-makers. The results can guide government agencies in designing targeted policies to promote pesticide reduction, particularly in rural areas with socio-cultural conditions similar to those in China. By integrating these insights into policy frameworks, governments can better address environmental challenges and support sustainable agricultural practices.

The structure of this study is as follows. Section “Background” provides an overview of Buddhist beliefs in China. Section “Theory analysis” outlines the theoretical framework linking Buddhism to pesticide application. Section “Data and method” details the data sources and empirical methods. Section “Empirical results” presents the estimation results, followed by a discussion in section “Discussion”. Finally, section “Conclusion” concludes with key findings and policy implications.

Background

In contrast to the West, mainland China has a distinctly unique religious landscape. Since the country’s founding, policies have emphasized religious control, limiting the extent to which religion can permeate society and influence individuals. However, following the relaxation of the political environment after the mid-1990s, the content and structure of many rural religious beliefs became closely tied to the lives and knowledge levels of rural residents. As a result, religious belief has experienced rapid growth in dissemination and the number of followers. In recent years, religion has gained increasing popularity in rural China. According to the World Value Survey (WVS), the proportion of religious believers in China rose from 7% in 1999 to 14% in 2020, with the proportion of Buddhist adherents increasing from 3% to

9% between 2015 and 2020. Additionally, the China Religion Report indicates that most religious practitioners in China reside in rural areas (Jin, 2019). The underdeveloped state of rural areas in China provides fertile ground for various religious beliefs to spread and take root. Faced with unmet aspirations due to the urban-rural development gap, farmers often turn to religion for support. Consequently, the development of rural life and the unique characteristics of religious belief in China have fostered the flourishing of religion in these areas.

China’s contemporary religious landscape is complex. First, various religions coexist, including the five institutional and universal religions: Buddhism, Taoism, Christianity, Catholicism, and Islam. These religions embody deep ecological consciousness within their cultural and theological teachings, emphasizing harmony between humans and nature. Specifically, Buddhism regards nature as sacred and warns that human attempts to alter or destroy it will ultimately lead to self-destruction (Lam and Shi, 2008; Yachkaschi and Yachkaschi, 2012); Taoism advocates the concepts of “the unity of heaven and man” and “man follows nature”, highlighting the intrinsic connection between humanity and nature. Christianity emphasizes the equality of all beings and advocates for coexistence with all things. It calls for an environmental ethic based on love rather than utilitarianism, warning that God will punish those who harm the environment, even though nature was created for human use (Yachkaschi and Yachkaschi, 2012). Similarly, Islam and traditional folk beliefs encourage harmonious coexistence between humans and nature, asserting that maintaining ecological balance is essential for sustainable development. Second, it is common for individuals to hold multiple religious beliefs simultaneously. For instance, a person may identify with both Buddhism and Christianity. Third, traditional folk beliefs hold a significant place in the belief systems of rural communities. These beliefs are often rooted in natural religions and integrate elements of traditional Chinese culture, such as worship of clan deities and earth gods, routine festivals, worship gatherings, nature worship with associated taboos, divination, and spells. Such practices are deeply embedded in the psychological structure of rural populations and reflect the enduring influence of folk religion.

Chinese folk beliefs are characterized by a strong utilitarian focus, emphasizing present-day well-being. Unlike complex and abstract religious doctrines, ordinary people tend to prioritize the tangible benefits that various deities can bring to their daily lives and seek ways to sustain those benefits through religious practices. For instance, farmers often visit temples to worship the “Four Heavenly Kings”, praying for favorable weather to ensure a good harvest. Another defining feature of Chinese folk beliefs is their mystical nature. In ancient societies, where scientific understanding was limited, people often felt perplexed by unpredictable natural and social phenomena. Unable to provide rational explanations, they adopted a mystical worldview, treating natural objects and forces as possessing life, willpower, and divine authority. This mystical perspective fostered a form of nature worship, offering insights into addressing environmental challenges by promoting self-restraint and conduct regulation through personal norms. Folk beliefs in China are also distinctly localized. Given the country’s vast geography and diverse population, regional cultures have developed unique local deities, rituals, and practices. Under the policy of religious freedom, especially in ethnic minority areas, communities draw ecological inspiration from their spiritual reverence for forests, mountains, totems, temples, and myths (Yuan, 2005; Jing, 2009). For example, the Sani people of the Yi ethnicity conduct secret branch sacrifices, the Dai people follow the “Longlin” belief, and the Blang people perform branch sacrifices at Longjing to pray for rain. These primitive religious rituals embody a deep ethic of

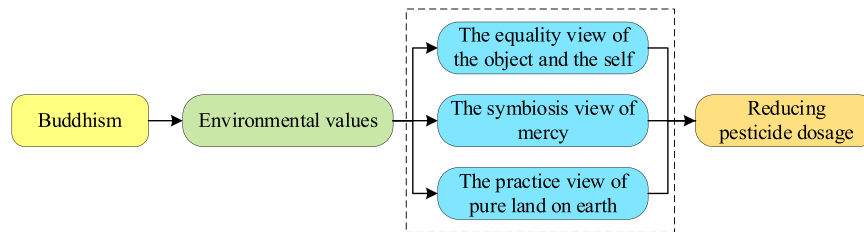


Fig. 1 Framework of Buddhism influencing pesticide application.

ecological and environmental protection, compelling adherents to respect water and forest resources, conserve water, and refrain from cutting down trees.

Theory analysis

Religious belief and farmers' pesticide application behavior. Stern et al., (1999) posits that religious or spiritual beliefs may play a fundamental role in addressing environmental issues, a proposition later supported by empirical studies (Beck and Miller, 2000; Owen and Videras, 2007). As social entities with both cultural and institutional dimensions (Stark and Finke, 2000), religions provide implicit constraints and regulatory mechanisms that form a crucial basis for understanding farmers' rational pesticide application behavior. The institutional attributes of religion are reflected in its organized structures and formal institutions, which impose behavioral norms that regulate individual actions. Meanwhile, its cultural attributes emerge from its status as a unique cultural phenomenon, shaping the ideologies, consciousness, and practices of adherents (Gordon, 1964). Religious beliefs significantly influence the value systems of believers, embedding environmental concepts within their teachings. These teachings encourage respect for the environment and foster environmental values from both a collective and personal perspective. Consequently, they guide farmers toward rational pesticide application, reducing ecological pollution (Hand and Van Liere, 1984; Hayes and Marangudakis, 2000; Kula, 2001; Truelove and Joireman, 2009; Mangunjaya, 2011; Jusoff et al., 2011).

Buddhism and farmers' pesticide application behavior. Environmental conservation practices align with the Buddhist doctrine of karma, which asserts that all things on Earth are interdependent and connected within an organic ecosystem. In other words, both Buddhist teachings and environmental conservation share the belief that humans and nature are unified and that harming the environment ultimately harms oneself. Preserving one's spiritual perfection requires protecting the ecosystem (Lu and Liang, 2009). The ecological principles embedded in Buddhist teachings significantly shape the values of believers, encouraging respect for the environment. These teachings guide farmers toward adopting environmentally friendly farming practices, using pesticides judiciously, and minimizing or avoiding ecological pollution, based on the principles of "unity of being", "compassionate coexistence", and "pure land on Earth" (Xu and Wei, 2015), as depicted in Fig. 1.

(1) Promote the equality concept of "sameness of object and subject"

As the Shurangama Sutra says, "Pure bhikkhus and bodhisattvas do not tread on the grass when they walk on the wrong path, let alone pluck it with their hands". This reflects a fundamental recognition of the right to life and the intrinsic value of both human beings and nature. It rejects the concept of human supremacy and advocates for the harmonious coexistence of humans and nature. For Buddhist farmers, the Buddhist principle of "sameness of object and subject" gradually permeates their

consciousness through religious practices. This principle encourages them to develop environmental values and to reflect critically on how human actions impact the delicate ecosystem. It fosters a sense of responsibility for environmental protection and highlights the need to avoid disrupting the perfection of nature. In agricultural production, this awareness promotes environmentally favorable practices, such as reducing pesticide use.

(2) Uphold the symbiotic concept of "compassion for all"

As stated in the 13th volume of the Dhammapada: "Of all the remaining sins, killing is the most serious; of all the virtues, no killing is the most important, and among all the worlds, saving one's life is the most important", Buddhism advocates the ideology of "compassion" and "karmic reincarnation". For Buddhist farmers, the Buddhist principle of "compassion for all" gradually permeates their consciousness through participation in religious activities. This encourages them to develop environmental values, viewing weeds and pests as living beings. As a result, they believe that using traditional pesticides, such as insecticides and herbicides, violates the prohibition against killing and generates negative karma. This understanding leads them to reduce the use of conventional pesticides in their agricultural practices, recognizing the harmful effects of such actions.

(3) The practical view of creating a "pure land on earth"

In the Amitabha Sutra, Buddha states, "The lotus in the pond is as big as a wheel, greenish green, yellowish yellow, reddish red, white and white, and delicately fragrant and clean". Through their participation in religious activities, Buddhist farmers aspire to self-improvement and the transformation of society, ultimately leading to the "land of bliss". They believe that the use of pesticides and herbicides in farming disrupts the transformation of the "pure land on earth". As a result, they reduce their use of pesticides in agricultural practices, recognizing the harmful impact on both the environment and their spiritual goals.

Data and method

Data source. We obtain pooled cross-sections data from a field survey of farmers in 12 rice-producing provinces in southern China between 2018 and 2019. The survey adopts a completed questionnaire structure, and well-trained researchers are assigned to conduct one-on-one interviews and record information. The questionnaire covers aspects of the household head, household characteristics, rice production inputs and outputs, and marketing. Research locations and subjects are identified through a stratified sampling method. From January to March 2018, we contact the agricultural management departments of 12 rice-producing provinces in southern China, including Sichuan, Chongqing, Guizhou, Hunan, and so on (as shown in Fig. 2). With the help of the relevant departments, we select five prefecture-level cities in each province which produce rice. Next, we select three townships in each prefecture-level town with the assistance of the prefecture-level government departments. Then, based on the information provided by the township's agricultural management department, we select 2 villages in each township, with these villages chosen as fixed observation sites. Finally, the village committee supplied us with a detailed list of rice farmers.

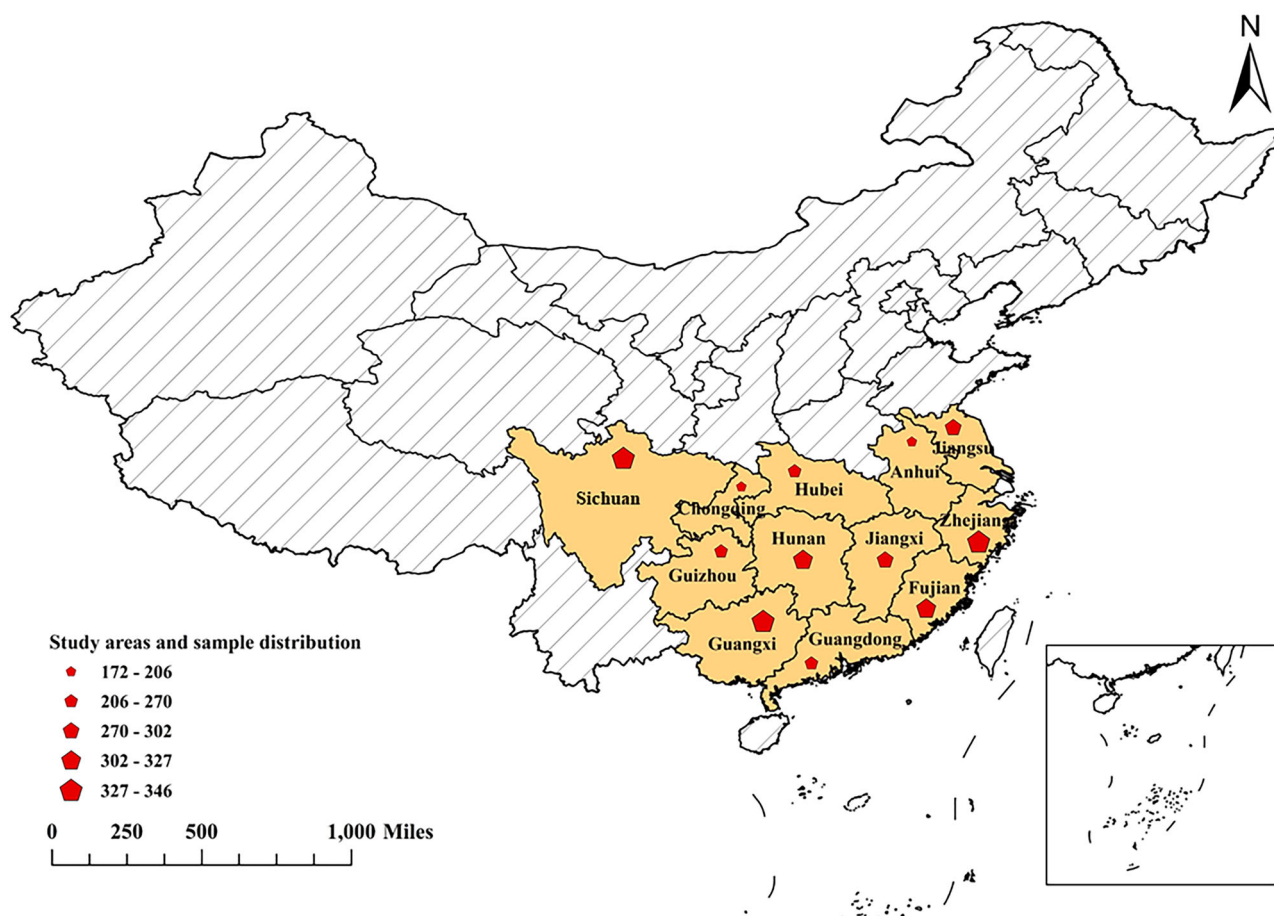


Fig. 2 Study areas and sample distribution.

We identify about 5 farmers as subjects in each village by random sampling. From January to March 2019, we repeated the random sampling procedure in all villages surveyed last year, and 5 farmers in each village were selected to participate in the survey. During the 2 years, we received 3518 questionnaires, of which 3410 were valid.

Variable selection. (1) Buddhist belief

Buddhist belief is represented by a dummy variable, which is set to 1 if the household head practices Buddhism and 0 otherwise. Among the 12 provinces where micro-surveys were conducted, Hunan, Guizhou, and Chongqing rank as the top three in terms of the proportion of farmers who practice Buddhism. The highest rate of Buddhist belief among farmers is found in Hunan Province, where it reaches 11%, while Jiangxi Province has the lowest rate at 3.4%. The distribution of Buddhist belief in the survey area is shown in Fig. 3.

(2) Pesticide dosage

Based on the studies of Schreinemachers et al. (2020) and Möhring et al. (2020), the average pesticide dosage per hectare is used to measure farmers' pesticide application behavior in this study. Among the 12 selected sample provinces, Fujian, Jiangsu, and Anhui rank as the top three in terms of pesticide usage, with Fujian having the highest pesticide usage at an average of 39.41 kg per hectare, and Chongqing having the lowest at 13.86 kg per hectare. The pesticide dosage data is presented in Fig. 4.

(3) Control variables

Based on previous studies about pesticide use (Fan et al. 2015; Zhao et al. 2018; Jin et al. 2017), we control two variable groups, including individual and household characteristics. Individual

characteristics include age, gender, health status, education status, training status in rice cultivation techniques, and risk perception toward rice pests and diseases. Household characteristics consist of household size, household assets per capita, number of laborers engaged in agricultural production, rice planting area, and membership in farmer professional cooperatives. These control variables all affect farmers' pesticide use and must be controlled in the regression analysis to mitigate the problem of bias due to omitted variables. The variable definitions are presented in Table 1.

Empirical methods. To estimate the effect of Buddhist belief on farmers' pesticide application, we develop the following regression model:

$$C_i = \alpha_1 Z_i + \alpha_2 X_i + \rho, C_i = \begin{cases} 1, & \text{if } C_i \geq 0 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$y_i = \beta_0 + \beta_1 C_i + \beta_2 X_i + \varepsilon \quad (2)$$

where y_i represents pesticide use by the household i , which includes the mean pesticide dosage and pesticide fee per ha. C_i denotes whether the household head believes in Buddhism. If the household head believes in Buddhism, C_i is marked as 1, and 0 otherwise. X_i is a set of control variables that influence both y_i and C_i . ρ and ε are random errors that affect farmers' pesticide application. $\alpha_i (i = 1, 2)$ and $\beta_i (i = 0, 1, 2)$ are the set of parameters to be estimated. And Z_i is an instrumental variable that directly affects household heads' Buddhist beliefs but has no effect on pesticide application. The parent's Buddhist belief is selected as an appropriate instrumental variable because the Buddhism

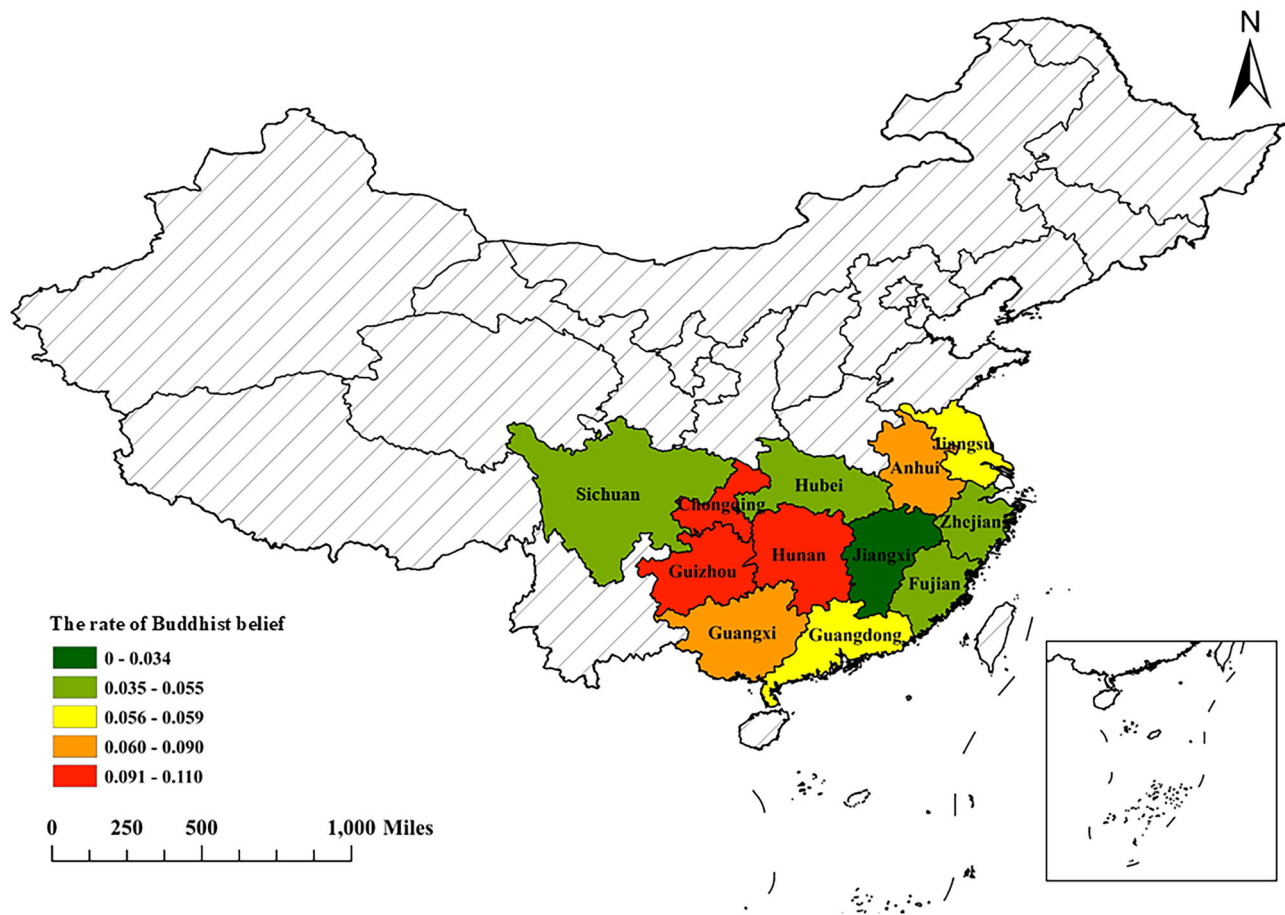


Fig. 3 The rate of Buddhist belief.

belief of the householder's parents will not directly affect the householder's pesticide use but will affect the householder's pesticide use by influencing his religious belief (Durkin and Greeley, 1991; Iannaccone, 1990; Bisin and Verdier, 2000). However, using the ordinary least square (OLS) to estimate y_i will cause endogeneity problems because omitted variables, reverse causality, and measurement errors in Buddhist belief will result in correlations between ρ and ε and bias the coefficient estimates. Hence, we introduce the control function (CF) approach, the endogenous treatment-effects model, and the heteroscedasticity-based identification strategy to address the estimation bias derived from endogeneity problems.

Control function approach. The CF approach can effectively control the bias brought on by endogeneity problems (Rivers and Vuong, 1988; Wooldridge, 2015). This method employs instrumental variables (IV) to identify causal effects correctly and offers more flexibility than standard IV estimates (two-stage least squares, 2SLS) in terms of functional form. In the first phase, generalized residuals are predicted by Eqs. (1) and (2) and can be written as follows:

$$R = C_i \lambda (\alpha_1 Z_i + \alpha_2 X_i) - (1 - C_i) \lambda (-\alpha_1 Z_i - \alpha_2 X_i) \quad (3)$$

where λ is the inverse Mills ratio, the generalized residuals are bought into Eq. (2) as additional explanatory variables in the second phase. Then Eq. (2) can be derived as

$$y_i = \beta_0 + \beta_1 C_i + \beta_2 X_i + \beta_3 R + \varepsilon \quad (4)$$

If the coefficient of the residual term β_3 in Eq. (4) is insignificant, the estimates of the endogenous explanatory variables are consistent (Wooldridge, 2015); conversely, the

explanatory variable is endogenous and can be corrected for endogeneity bias in the coefficient β_1 .

Endogenous treatment-effects estimation. This study also introduces the endogenous treatment-effects model to estimate the role of Buddhist belief on pesticide dosage. The primary models are given as follows:

$$y_{i0} = E(y_{i0} | x_i) + \varepsilon_{i0} \quad (5)$$

$$y_{i1} = E(y_{i1} | x_i) + \varepsilon_{i1} \quad (6)$$

$$t_i = E(t_i | R_i) + v_i \quad (7)$$

$$y_i = t_i y_{i1} + (1 - t_i) y_{i0} \quad (8)$$

$$E(\varepsilon_{ij} | x_i, R_i) = E(\varepsilon_{ij} | R_i) = E(\varepsilon_{ij} | x_i) = 0 \text{ for } j \in \{0, 1\} \quad (9)$$

$$E(\varepsilon_{ij}, t) \neq 0 \text{ for } j \in \{0, 1\} \quad (10)$$

y_{i0} here is the pesticide dosage of the household head i without Buddhist belief, and y_{i1} is the pesticide dosage of the household head i with Buddhist belief; t_i is an observed binary variable. If the household head is Buddhist, t_i could be denoted as 1, and 0 otherwise; ε_{ij} and v_i are unobserved components. Determine each potential outcome by an expected value ε_{ij} conditioned on a set of vectors x_i and an unobserved random component ε_{ij} for $j \in \{0, 1\}$. Equation (9) indicates that the unobserved components in the potential results are not related to R_i . Equation (10) states that the components not observed in the potential outcome equation are related to the treatment status. Therefore, the

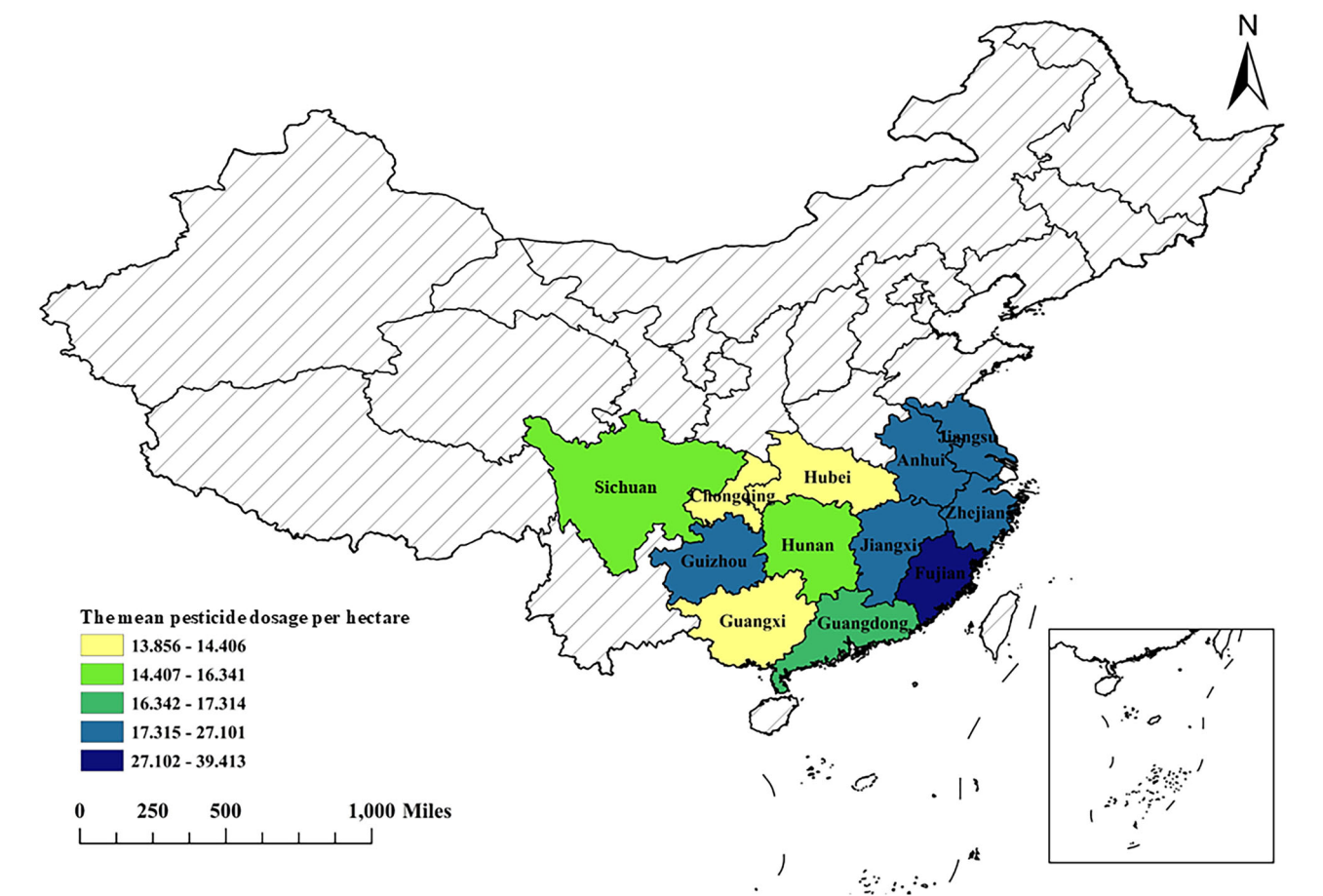


Fig. 4 The mean of pesticide dosage per hectare.

Table 1 Variable definitions.	
Variables	Definitions
Pesticide dosage	The mean pesticide dosage per ha (kg)
Ln(Pesticide dosage)	The natural logarithm of the mean pesticide dosage per ha
Pesticide fee	The mean pesticide fee per ha (yuan)
Ln(pesticide fee)	The natural logarithm of the mean pesticide fee per ha
Buddhist	1 if the household head believes in Buddhism, 0 otherwise
Parents-Buddhist	1 if parents of the household head believe in Buddhism, 0 otherwise
Gender	1 if the household is a male, 0 otherwise
Age	Age of the household head (years)
Schooling	Period of schooling of the household head (years)
Health	Health status of the household head. 1=bad, 2=general, and 3=good
Experience	The number of rice planting years of the household head (years)
Planting training	1 if the household head has accepted rice planting technology training, 0 otherwise
Risk perception	The household head's level of risk perception towards rice diseases and pests. 1 if the risk perception is high, and 0 if the risk perception is low
Assets	Household assets per capita (yuan)
Ln(assets)	The natural logarithm of household assets per capita
Household size	The number of household members
Agricultural workforce	The number of the workforce engaged in agricultural production
Membership	1 if the household is the member of a farmer professional cooperative, 0 otherwise
Rice area	Rice planting area of the household (ha)
Ln(Rice area)	The natural logarithm of rice planting area of the household

correlation between t_i and the unobserved components would have to be the same as the correlation between ε_{ij} and v_i . Then, $E(\varepsilon_{ij}, |, t_i)$ can be derived as

$\hat{v}_i$ is the difference between t_i and $E(t_i, |, R_i)$, which is gotten by using the probit estimator, and $E(y_{ij}, |, x_i, v_i, t_i)$ could be figured up. Thereby an equation could be given if the outcome is linear:

$$E(\varepsilon_{ij}, |, t_i) = E(\varepsilon_{ij}, |, E(t_i, |, R_i) + v_i) = E(\varepsilon_{ij}, |, v_i) = v_i \delta_{2j} \quad (11)$$

$$E(y_{ij}, |, x_i, v_i, t_i = j) = x_i' \delta_{1j} + v_i \delta_{2j}, j \in \{0, 1\} \quad (12)$$

Table 2 Results of descriptive statistical analysis.

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Pesticide dosage	3410	20.88	26.04	0	450
Ln(Pesticide dosage)	3410	2.676	0.934	0	6.111
Pesticide fee	3410	953.3	608.1	1.608	3750
Ln(Pesticide fee)	3410	6.582	0.894	0.475	8.230
Buddhist	3410	0.0695	0.254	0	1
Parents-Buddhist	3410	0.0672	0.250	0	1
Gender	3410	0.918	0.275	0	1
Age	3410	51.95	7.536	21	65
Schooling	3410	8.169	2.616	0	17
Health	3410	2.402	0.533	1	3
Experience	3410	26.80	10.24	1	49
Planting training	3410	0.802	0.399	0	1
Risk perception	3410	0.448	0.497	0	1
Assets	3410	35,435	51,429	900	609,750
Ln(Assets)	3410	10.07	0.818	6.802	13.32
Household size	3410	4.589	1.612	1	15
Agricultural workforce	3410	2.049	0.790	0	7
Membership	3410	0.230	0.421	0	1
Rice area	3410	3.537	15.97	0.0133	311.7
Ln(Rice area)	3410	-0.573	1.487	-4.317	5.742

$$E(y_{ij}, |, x_i, v_i, t_i = j) = \Phi(x'_i \delta_{1j} + v_i \delta_{2j}) \quad (13)$$

The average treatment effect (ATE) and the potential-outcome means (POMs) can be estimated by introducing the generalized method of moments (GMM), and the moment conditions in the GMM estimation for the linear model are given as follows:

$$\frac{1}{n} \sum_{i=1}^n x'_i (y_i - x'_i \hat{\delta}_{1j} + \hat{v}_i \hat{\delta}_{2j}) t_i = 0 \quad (14)$$

$$\frac{1}{n} \sum_{i=1}^n x'_i (y_i - x'_i \hat{\delta}_{1j} + \hat{v}_i \hat{\delta}_{2j}) (1 - t_i) = 0 \quad (15)$$

$$\frac{1}{n} \sum_{i=1}^n R'_i \left\{ t_i \frac{\varphi(R'_i \hat{\tau})}{\Phi(R'_i \hat{\tau})} - (1 - t_i) \frac{\varphi(R'_i \hat{\tau})}{1 - \Phi(R'_i \hat{\tau})} \right\} = 0 \quad (16)$$

$$\frac{1}{n} \sum_{i=1}^n \left\{ (x'_i \hat{\delta}_{10} + \hat{v}_i \hat{\delta}_{20}) - \widehat{POM0} \right\} = 0 \quad (17)$$

$$\frac{1}{n} \sum_{i=1}^n \left\{ (x'_i \hat{\delta}_{11} + \hat{v}_i \hat{\delta}_{21}) - \widehat{POM0} - \widehat{ATE} \right\} = 0 \quad (18)$$

where $\hat{v}_i = t_i - \Phi(R'_i \hat{\tau})$, n presents the amount of observations, and $\hat{\delta}_{11}, \hat{\delta}_{20}, \hat{\delta}_{21}, \hat{\tau}, \widehat{ATE}$ and $\widehat{POM0}$ are all parameters. The POMs could be estimated by

$$\frac{1}{n} \sum_{i=1}^n \left\{ (x'_i \hat{\delta}_{11} + \hat{v}_i \hat{\delta}_{21}) - \widehat{POM1} \right\} = 0 \quad (19)$$

where $\widehat{POM1}$ is a parameter.

Heteroscedasticity-based identification strategy. Furthermore, the heteroscedasticity-based identification strategy proposed by Lewbel (2012) is employed in this study to identify the robustness of estimated results. The heteroscedasticity-based identification method breaks the restriction that traditional instrumental variable estimation must meet the exclusionary constraint, which only has to meet the condition that the error is heteroskedasticity. Suppose Z_i is an internal instrumental vector, which can be a subset of X_i or identical to X_i . Then, C_i in Eq. (2) can be

estimated by

$$C_i = \eta Z_i + \omega \quad (20)$$

Higher-moment instruments $(Z_i - \bar{Z}_i) \hat{\omega}_i$ can be generated by using residuals of Eq. (20). Where $\bar{Z}_i$ is the mean of Z_i , and $\hat{\omega}_i$ is the estimated residual of Eq. (20). Based on Lewbel (2012), β_1 in Eq. (2) is consistently estimated without excluding restrictions when three conditions are fulfilled. First, $E(X'_i \varepsilon_i) = 0, E(Z'_i \omega_i) = 0$ means that all of the variables in X_i are exogenous to y_i , and all of the variables in Z_i are exogenous to C_i . Second, $\text{Cov}(Z_i, \varepsilon_i \omega_i) = 0$ indicates that Z_i is uncorrelated with the product of two error terms in Eqs. (2) and (20). Third, $\text{Cov}(Z_i, \omega_i^2) \neq 0$ requires that there exists heteroscedasticity in Eq. (20).

Marginal treatment effect. This study estimates the marginal treatment effects (MTEs) to examine the heterogeneous effects of Buddhist belief on pesticide dosage from unobservable characteristics. The generalized Roy model serves as the foundation for MTE estimation (Schroeder, 2010; Andresen, 2018).

$$Y_j = \mu_j(X_i) + U_j \text{ for } j = 0, 1 \quad (21)$$

$$Y = DY_1 + (1 - D)Y_0 \quad (22)$$

$$D = \mathbb{1}\{\mu_D(Z) > V\}, \text{ where } Z = (X_i, Z_-) \quad (23)$$

Y_1 and Y_0 , respectively, represent the potential outcomes (pesticide dosage) in treated and control groups, and they are the functions that contain a set of control and observable variables X_i . Since the $\mathbb{1}$ in Eq. (23) is an indicator function, the selection Eq. (23) can be treated as a latent index. This is a simplified form that models selection as a treatment and as a function of the observables X_i and the instruments Z_- . These observables influence the probability of treatment but not the potential outcomes. Where V denotes unobservables and is a resistance to the determining treatment of Buddhist belief. In general, the unobservable V obeys a continuous distribution. Therefore, the selection equation can be written as $P(Z) > U_D$. Where U_D are the quantiles of V , $P(Z)$ is the propensity score. Meanwhile, the estimation of MTEs should abide by two main assumptions. One of the assumptions is conditional independence ($U_0, U_1, V \perp Z_- | X_i$), and the other is separability $E(U_j, |, V, X_i) = E(U_j, |, V)$.

Following this model, the MTEs can be defined as (Heckman and Vytlacil, 1999, 2005, 2007):

$$\begin{aligned} MTE(x, u) &\equiv E(Y_1 - Y_0, |, X_i = x, U_D = u) \\ &= x(\beta_1 - \beta_0) + E(U_1 - U_0, |, U_D = u) \end{aligned} \quad (24)$$

where $x(\beta_1 - \beta_0)$ represents the heterogeneity in observables, while $E(U_1 - U_0, |, U_D = u)$ represents the heterogeneity in unobservables. They measure the average outcome gains for individuals with observable X_i and unobservable resistance U_D . In other words, MTE can be interpreted as the mean treatment outcomes for individuals at the margin of indifference.

Empirical results

Descriptive statistical analysis. Table 2 displays the descriptive statistical analysis. Household heads who believe in Buddhism account for 6.95%; the mean pesticide dosage per ha is 20.88 kg, and the mean pesticide fee per ha is 953.3 yuan. In terms of individual characteristics, most heads of households are male with about eight schooling years and are of middle age. On average, household heads have planted rice for 26.8 years. About 80% have received technology training in rice planting, and 44.8% perceive a high risk of pests and diseases. Regarding

Table 3 The differences between the control and treatment groups.

Variables	Control group (Not Buddhist)		Treat group (Buddhist)		Difference	
	Mean	S.D.	Mean	S.D.	Mean	P-value
Ln(Pesticide dosage)	2.714	0.921	2.164	0.949	−0.550	0.000
Ln(Pesticide fee)	6.614	0.865	6.158	1.137	−0.455	0.000
Gender	0.916	0.278	0.949	0.220	0.034	0.067
Age	52.001	7.502	51.262	7.965	−0.740	0.145
Schooling	8.134	2.614	8.637	2.604	0.503	0.004
Health	2.397	0.533	2.464	0.525	0.067	0.063
Experience	26.832	10.190	26.388	10.850	−0.444	0.520
Planting training	0.802	0.399	0.802	0.400	0.000	0.998
Risk perception	0.458	0.498	0.316	0.466	−0.141	0.000
Ln(Assets)	10.068	0.816	10.133	0.847	0.066	0.234
Household size	4.597	1.619	4.481	1.523	−0.116	0.284
Agricultural workforce	2.044	0.781	2.110	0.900	0.066	0.218
Membership	0.224	0.417	0.308	0.463	0.084	0.003
Ln(Rice area)	−0.590	1.484	−0.352	1.521	0.238	0.018

S.D. denotes the standard deviation.

Table 4 Benchmark results.

Variables	(1) Ln(Pesticide dosage)	(2) Ln(Pesticide dosage)	(3) Ln(Pesticide fee)	(4) Ln(Pesticide fee)
Buddhist	−0.454*** (0.063)	−0.723*** (0.128)	−0.398*** (0.073)	−0.634*** (0.136)
Residual		0.178** (0.073)		0.156** (0.078)
Gender	(0.069) (0.048)	(0.062) (0.050)	0.071 (0.052)	0.077 (0.051)
Age	−0.014*** (0.004)	−0.014*** (0.004)	−0.011*** (0.004)	−0.011*** (0.004)
Schooling	−0.012* (0.006)	(0.010) (0.007)	0.001 (0.007)	0.002 (0.006)
Health	(0.046) (0.043)	(0.043) (0.042)	0.023 (0.045)	0.026 (0.046)
Experience	0.007*** (0.002)	0.007*** (0.002)	0.007*** (0.003)	0.007*** (0.003)
Planting training	−0.072* (0.044)	−0.080* (0.043)	−0.105*** (0.038)	−0.111*** (0.040)
Risk perception	0.304*** (0.031)	0.295*** (0.031)	0.098*** (0.030)	0.090*** (0.030)
Ln(Assets)	−0.141*** (0.024)	−0.139*** (0.023)	0.065*** (0.025)	0.067*** (0.025)
Household size	−0.028*** (0.010)	−0.029*** (0.010)	0.018* (0.010)	0.017* (0.010)
Agricultural workforce	−0.105*** (0.024)	−0.104*** (0.025)	−0.035* (0.021)	−0.034* (0.020)
Membership	0.048 (0.041)	0.057 (0.042)	(0.017) (0.041)	(0.009) (0.041)
Ln(Rice area)	0.045*** (0.014)	0.046*** (0.015)	−0.069*** (0.015)	−0.068*** (0.015)
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Constant	4.961*** (0.379)	4.930*** (0.381)	6.062*** (0.393)	6.035*** (0.396)
R-squared	0.145	0.146	0.091	0.092
Observations	3410	3410	3410	3410

Notes: Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

household characteristics, the mean household asset per capita is 35435 yuan, with about four people in a household, of which two laborers are engaged in agricultural production. Each household grows about 3.54 ha of rice and has 23% of cooperative members.

Table 3 reveals the differences between the control and treatment groups, providing evidence that Buddhist farmers use fewer pesticides and spend less on pesticides than non-Buddhist farmers. Additionally, Buddhist farmers are more educated, less experienced in farming, have larger rice planting areas, and are more likely to be members of cooperatives.

Benchmark results. The benchmark results are presented in Table 4. The results from OLS estimation reveal a significant reduction of 45.4% in pesticide use per ha and a significant reduction of 39.8% in pesticide fees per ha for Buddhist farmers. It is noted that the residuals obtained using the CF approach in both columns (2) and (4) are significant at $p < 0.05$, indicating that the variable of whether the household head is Buddhist or not is endogenous. Therefore, the results estimated by the CF approach are chosen as the optimal benchmark estimation results. Also, time and region fixed effects are incorporated into the regression to control the effects on the estimation results due to time and region changes.

Table 5 Results of endogenous treatment-effects.

Variables	(1) ATE	(2) POmean	(3) TME1	(4) OME0	(5) OME1
Treated vs Control	−0.826*** (0.165)				
Control		2.739*** (0.019)			
Treated		1.913*** (0.164)			
Buddhist			1.903*** (0.097)		
Gender			0.168 (0.161)	−0.062 (0.048)	−0.158 (0.243)
Age			0.012 (0.010)	−0.013*** (0.004)	−0.007 (0.015)
Schooling			0.041*** (0.015)	−0.010 (0.007)	0.011 (0.024)
Health			0.110 (0.110)	−0.029 (0.044)	−0.191 (0.162)
Experience			0.001 (0.006)	0.007*** (0.002)	0.009 (0.009)
Planting training			−0.215** (0.102)	−0.058 (0.046)	−0.471*** (0.136)
Risk perception			−0.176** (0.078)	0.308*** (0.032)	0.029 (0.127)
Ln(Assets)			0.055 (0.061)	−0.133*** (0.025)	−0.181** (0.080)
Household size			−0.021 (0.027)	−0.028*** (0.010)	−0.009 (0.042)
Agricultural workforce			0.032 (0.054)	−0.093*** (0.024)	−0.208*** (0.080)
Membership			0.258** (0.102)	0.085* (0.044)	−0.258** (0.125)
Ln(rice area)			0.048 (0.035)	0.038** (0.015)	0.128** (0.053)
Year fixed effect			Yes	Yes	Yes
Region fixed effect			Yes	Yes	Yes
Constant			−3.505*** (1.030)	4.794*** (0.391)	4.985*** (1.407)
Observations	3410	3410	3410	3410	3410

Notes: POM represents the potential-outcome means; OME0 represents the untreated potential-outcome equations; OME1 represents the treated potential-outcome equations; ***, **, * denote significance at 1% level, 5% level, and 10% level. Robust standard errors are presented in parentheses. Test of endogeneity: Ho: treatment and outcome unobservables are uncorrelated, $\chi^2(2) = 11.78$, Prob > $\chi^2 = 0.0028$.

The results of the CF approach study reveal that Buddhist farmers use 48.53% fewer pesticides on average per ha and spend 53.04%² less on pesticides on average per ha. The results of this study can be explained by the actual situation in China. Increasing pesticide inputs is an easy way to ensure yields, as agricultural production is susceptible to various risks. Farmers often prefer to reduce uncertainty by adopting farming practices that stabilize farm income (Di Falco and Perrings, 2005). Profit-driven farmers, especially those in poverty, are more focused on ensuring substantial harvests because their subsistence needs are not met, and they are less willing to risk lower yields by reducing pesticide use (Liu and Huang, 2013). However, religion serves as a unique cultural phenomenon that offers comfort amid the uncertainty faced by believers, influencing their thoughts, values, and habits (Gordon, 1964). The values of believers are significantly shaped by their religious beliefs. The environmental principles embedded in these beliefs encourage believers to care for the environment and develop environmental values based on both individual and collective human interests. These principles, in turn, guide them to adopt environmentally friendly farming practices, rationalize pesticide use, and reduce ecological pollution (Beck and Miller, 2000; Owen and Videras, 2007).

The regression results for the control variables in Table 4 indicate that age, training in planting techniques, household assets per capita, household size, and the number of agricultural laborers in the household are negatively associated with pesticide dosage. In contrast, factors such as rice planting experience, risk perception, and rice planting area are positively related to pesticide dosage. Additionally, the estimation results show a positive correlation between household assets per capita, household size, rice planting area, and pesticide expenditure per hectare. These findings align with existing studies (Fan et al. 2015; Zhao et al. 2018; Li et al. 2014; Jin et al. 2017).

Robustness tests

Endogenous treatment-effects estimation. The endogenous treatment-effects model is introduced in our study to verify the influence of Buddhist belief on pesticide dosage. In Table 5, the values of POmean indicate that the expected pesticide dosage is 6.77 kg/ha if all of the farmers practice Buddhism and 15.47 kg/ha if none of the farmers do. When all farmers practice Buddhism, the average pesticide dosage lowers by 30.16% and is significant at a 1% level compared to the situation when no farmers practice.

Table 6 Results of the heteroskedasticity-based identification strategy.

Variables	(1) Standard IV	(2) Lewbel	(3) Lewbel+IV
Buddhist	−0.823*** (0.142)	−1.228*** (0.419)	−0.867*** (0.136)
Control variables	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Constant	2.733*** (0.017)	2.761*** (0.033)	2.735*** (0.017)
Adjusted R-squared	0.135	0.095	0.126
F statistic	23.66	22.07	24.25
Breusch–Pagan (p-value)	—	0	0
Hansen J statistic (p-value)	—	0.992	0.768
Endogeneity test (p-value)	0.003	0.029	0.001
Cragg–Donald Wald F statistic	>30	>30	>30
Observations	3410	3410	3410

Robust standard errors in parentheses.
*** $p < 0.01$.

Table 7 Moderating effects.

Variables	(1) Ln(Pesticide dosage)	(2) Ln(Pesticide dosage)	(3) Ln(Pesticide dosage)	(4) Ln(Pesticide dosage)
Buddhist	−0.478*** (0.169)	−1.036*** (0.223)	−0.641*** (0.134)	−0.642*** (0.131)
Buddhist×Planting training	−0.294** (0.137)			
Buddhist×Experience		0.012* (0.006)		
Buddhist×Risk perception			−0.317** (0.135)	
Buddhist×Membership				−0.235* (0.130)
Residual	0.172** (0.074)	0.174** (0.072)	0.193*** (0.072)	0.172** (0.073)
Control variables	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Constant	4.901*** (0.380)	4.945*** (0.381)	4.909*** (0.379)	4.929*** (0.381)
Observations	3410	3410	3410	3410
R-squared	0.147	0.148	0.148	0.147

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

These results obtained by the endogenous treatment-effects model are consistent with those obtained by the CF approach, which further confirms a negative association between Buddhist belief and pesticide dosage.

Heteroscedasticity-based identification strategy. We also employ heteroscedasticity-based identification strategy (Lewbel, 2012) to examine the effect of Buddhist belief on pesticide dosage. First, to deal with the endogeneity of Buddhist belief, we use the standard IV method to estimate the effect of Buddhist belief on pesticide dosage by rice farmers, with the Buddhist belief of household heads' parents serving as an external instrumental variable. The results from column (1) in Table 6 demonstrate that Buddhist belief can reduce pesticide dosage by 82.3% and are significant at $p < 0.01$. Second, column (2) shows the results of the heteroskedasticity-based identification strategy. The value of the Breusch–Pagan test is significant at $p < 0.01$, which means that the error term in the regression equation is heteroskedasticity, satisfying the condition of using this identification strategy. The F-statistic is 22.07, which is much larger than 10. Thus, the

internal instrumental variable we construct is sufficiently reliable. The internal instrumental variables are also valid, as shown by the Hansen J statistic's non-significant p -value. The results in column (2) show that Buddhist belief can reduce pesticide dosage. Finally, the results of using both internal and external instrumental variables are shown in column (3), further demonstrating the validity of all instrumental variables and the fact that Buddhist belief reduces the pesticide dosage. As a result, our estimation results are robust.

Moderating effects analysis. To determine the heterogeneous effect of Buddhist belief on pesticide dosage, this study inquiries into the moderating effects of key variables such as planting training, experience, risk perception, and cooperative membership by forming four mutual terms with Buddhist belief individually and using the CF approach. The moderating effects are shown in Table 7, where the three variables of planting training, risk perception, and cooperative membership strengthen the negative correlation between Buddhist belief and pesticide dosage.



Fig. 5 Moderating effects of rice planting training.

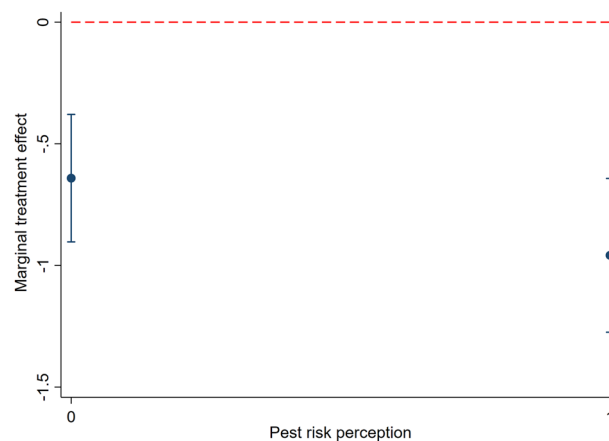


Fig. 7 Moderating effects of risk perception toward pests and diseases.

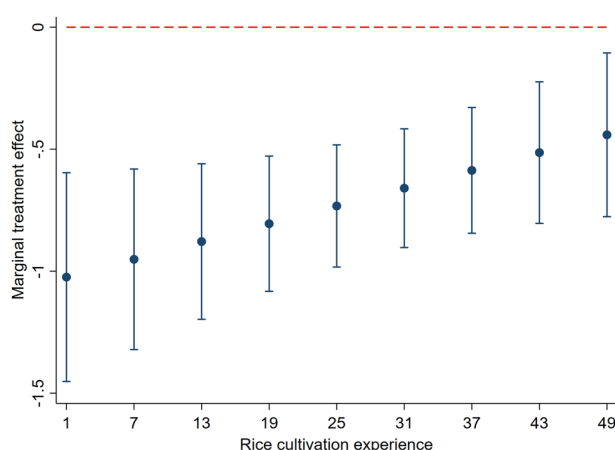


Fig. 6 Moderating effects of rice planting experience.



Fig. 8 Moderating effects of cooperative membership.

In contrast, the opposite moderating effect is observed for the rice planting experience.

As depicted in Fig. 5, rice planting training shows a positive moderating effect on the negative correlation between Buddhist belief and pesticide dosage. The impact of Buddhist belief on reducing pesticide dosage is more pronounced for farmers who have received planting training. On the one hand, compared to untrained farmers, those who have received training possess greater knowledge of pesticide use, better awareness of pesticide exposure avoidance, and safer application practices (Timprasert et al. 2014; Damalas and Koutroubas, 2017). On the other hand, trained farmers are more likely to recognize the health and environmental issues associated with excessive pesticide use (Cabrera et al. 2008; Hunke et al. 2015). Therefore, rice planting training amplifies the pesticide-reducing effect of Buddhist belief.

Figure 6 illustrates the moderating effect of the rice planting experience. The results reveal that the negative effect of Buddhist belief on pesticide dosage diminishes with increasing experience in rice planting. This finding is in line with some research (Böcker and Finger, 2017; Zhao et al. 2018), indicating that planting experience is an essential factor contributing to farmers' overuse of pesticides. Farmers typically judge pesticide use based on their subjective experience because previous application experience has formed path dependence. However, such experience can sometimes result in unscientific "bad habits" (Zhao et al. 2018). When spraying pesticides, farmers may overlook pesticide types, dilution ratios, and safety intervals, instead increasing application

intensity over a short period to control crop pests and diseases more effectively (Wu and Hou, 2012; Böcker and Finger, 2017). Thus, the planting experience can weaken the pesticide reduction effect of Buddhist belief.

Figure 7 plots the moderating effect of risk perception toward pests and diseases, revealing that the negative role of Buddhist belief on pesticide dosage is intensified for farmers with higher risk perception compared to those with lower risk perception. Most farmers are risk-averse and use various methods to manage production risks, as agricultural output is highly vulnerable to pests and diseases. When farmers perceive a high risk of being affected by pests and diseases, the most common strategy to secure yields is to increase pesticide use (Di Falco and Perrings, 2005; Liu and Huang, 2013). Therefore, the impact of Buddhist belief in reducing pesticide use is likely to be more pronounced among farmers with higher risk perceptions, due to the presence of substitution effects.

Figure 8 demonstrates the moderating effect of cooperative membership. It can be seen from Fig. 8 that farmers who join a farmer professional cooperative have a stronger negative impact on pesticide dosage due to their Buddhist beliefs than farmers who do not. The results are interpretable. Previous studies suggest that cooperatives help reduce irrational pesticide use by monitoring and regulating the agricultural practices of their member. Additionally, membership in cooperatives promotes safe agricultural production and serves as a key channel for the diffusion of agricultural technologies, including the adoption of integrated pest management techniques, drone spraying, and the

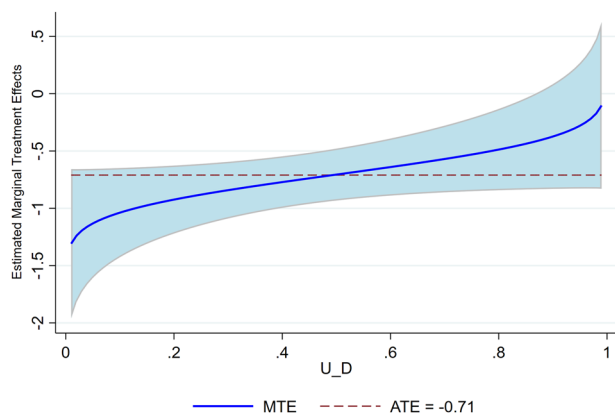


Fig. 9 The results of marginal treatment effects from unobservable characteristics.

use of organic fertilizers (Ma and Abdulai, 2018; Chen et al. 2020; Li et al. 2021). Therefore, cooperative membership can enhance the pesticide-reducing effects of Buddhist belief.

The marginal treatment effects analysis. It is interesting that the effect of Buddhist belief on pesticide dosage may exhibit heterogeneity due to some unobservable characteristics. Since these characteristics are person-related, they are frequently challenging to observe yet may influence farmers' pesticide use behavior, which furthers the heterogeneity of the effect of Buddhist belief on pesticide use. Therefore, it is important to explore the heterogeneity in treatment effects brought on by invisible factors to further understand the underlying mechanisms.

We estimate the MTEs corresponding to different U , depicted in Fig. 9. The red dashed line represents the average treatment effect (ATE) of Buddhist belief on pesticide dosage is -0.71 . The horizontal axis U denotes the resistance faced by farmers in receiving treatment for Buddhist beliefs. Farmers with higher U values are less likely to be Buddhist. Conversely, farmers with lower U values are more likely to be religious. The 99 different values of U correspond to MTEs that form a blue curve, with the blue-shaded portion representing the 95% confidence interval. As shown in Fig. 9, most Buddhist farmers have negative MTE reaching -1.35 , which is more significant than the ATE. As the propensity for Buddhist belief diminishes, the treatment effect will be weakened and even smaller than the ATE. Remarkably, for those farmers who are least inclined to believe in Buddhism, the impact of Buddhist belief on their pesticide dosage is insignificant, as the confidence interval encompasses zero. The outcome can be theoretically explained. A farmer who leans toward Buddhism agrees with and endorses Buddhist principles such as the equality of object and subject, compassion for all, and the purity of the planet. Thus, the effect of Buddhist belief on pesticide dosage exhibits significant heterogeneity due to this unobservable value.

Discussion

Pesticide overuse is a significant issue in many developing countries, endangering both the ecological environment and food security. Unlike previous studies, this study investigates the influence of Buddhist belief on pesticide use among rice farmers and the mechanisms using the CF approach, the endogenous treatment-effect model, and the heteroskedasticity-based identification strategy from a cultural perspective using the Chinese Buddhist belief as a case study. First, we find that farmers who

follow Buddhism tend to apply fewer pesticides, which may be closely related to Buddhist teachings and values. Buddhist belief shapes the values of believers, guiding them to protect the environment and adopt sustainable production practices. Second, this study examines the heterogeneity of treatment effects from observable and unobservable characteristics. We discover that rice cultivation training, pest risk perception, and cooperative membership can strengthen the pesticide-reduction effect of religiosity. Conversely, rice cultivation experience weakens this treatment effect. Unobservable factors, such as farmers' perceptions and values of environmental protection, may also influence the effect of religiosity on pesticide dosage among indifferent farmers who are on the margin between believing and non-believing Buddhism.

This study contributes to the existing research on farmers' pesticide use behavior by connecting Buddhist culture to farmers' pesticide use behavior, providing new evidence for the environmental externalities associated with Buddhist beliefs. Our study is innovative in that it is the first to empirically examine the effect of Buddhist beliefs on pesticide dosage and to confirm the underlying mechanisms. While previous studies have explored the influence of Christianity (Hand and Van Liere, 1984; Hayes and Marangudakis, 2000; Truelove and Joireman, 2009) and Islam (Kula, 2001; Mangunjaya, 2011; Jusoff et al. 2011) on environmental attitudes and perceptions, this study is unique in focusing on Buddhism. Additionally, our estimations are robust, addressing potential endogeneity issues related to Buddhist belief using multiple empirical methods. Furthermore, the study shows that Buddhist beliefs help shape believers' perceptions of environmental protection. The heterogeneity analysis offers valuable insights into the relationship between Buddhist beliefs and pesticide use, providing empirical evidence to inform government policy on pesticide reduction.

Finally, this study has some limitations that may serve as a direction for subsequent research. First, the limitation arises from the distinction of religious beliefs among the sample farmers. Our primary focus is on Buddhist belief, and we do not discuss the impact of Taoism, Islam, Catholicism, or Christianity on pesticide use. This is because folk beliefs are widespread in rural China, where people combine and reconfigure deities from various religious traditions, creating a complex and heterogeneous belief system. It is not uncommon for an individual to simultaneously follow more than one religion. In this unique context of Chinese folk religion, it is difficult to distinctly differentiate an individual's religious affiliation. Therefore, we focus on Buddhism, which has the highest proportion of adherents in rural China, while a small number of individuals may also practice other religions. Second, the limitations of this study are related to its external validity. Since this research focuses specifically on the Chinese context, which has unique characteristics regarding Buddhist beliefs, the findings may not be directly applicable to other regions, such as India, where cultural and religious contexts may differ. Therefore, the results of this study may not be easily generalized beyond China. Expanding the scope of the study to include other regions and cultural contexts could provide valuable insights into the relationship between culture and pesticide use behavior. Third, there are limitations related to the identification of marginal treatment effects from unobservables. Although we identified that the pesticide reduction effect of Buddhist beliefs may vary due to unobservable factors, our current analysis of these factors remains theoretical because of the limitations of the estimation strategy. Future research could focus on innovative methods or breakthroughs in addressing the identification of marginal treatment effects from unobservable variables to provide a more comprehensive understanding of the mechanisms at play.

Conclusion

The content and form of rural religious culture are closely linked to farmers' lives and greatly influence believers' values. The environmental concepts embedded in Buddhist teachings can enable believers to establish environmental values, thus guiding farmers to apply pesticides rationally and mitigate environmental pollution problems. In this study, we examine the effect of belief in Buddhism on farmers' pesticide use by employing the CF approach based on farm household survey data from 12 rice-producing provinces in the south of China. Our findings support the idea that there is a link between Buddhist belief and pesticide use. Buddhist belief leads to a significant reduction in farmers' pesticide dosage per ha and pesticide fee per ha by 48.53% and 53.04%, respectively. Further evidence for the causal relationship between Buddhist belief and pesticide application is provided by the endogenous treatment-effects model and the heteroskedasticity-based identification strategy. Additionally, this study also explores the moderating effects of rice planting training, planting experience, risk perception, and cooperative membership on the negative association between Buddhist belief and pesticide dosage. We find that the effect of Buddhist belief in reducing pesticide dosage is enhanced for farmers who participate in rice planting training, have a higher risk perception, and join a cooperative. In contrast, for farmers with extensive planting expertise, the pesticide use reduction effect of Buddhist belief is weakened. Finally, the role of Buddhist belief in pesticide reduction exhibits heterogeneity, which might be a result of the unobservable characteristic of farmers' perceptions and values of environmental protection.

Based on these findings, this study proposes five policy implications. First, the government should recognize the potential of Buddhism in promoting environmental protection, especially in rural areas. Buddhist beliefs can serve as a significant force in guiding farmers to develop environmental values. By integrating Buddhist teachings with environmental awareness, farmers can better understand that rational pesticide use aligns with both the demands of sustainable agricultural development and their religious doctrines.

Second, strengthen rice farming training programs and integrate Buddhist beliefs to enhance farmers' environmental awareness. Research indicates that rice farming training effectively raises farmers' awareness of pesticide reduction. Policies should therefore promote the widespread implementation of rice farming training programs, particularly by tailoring the training content to align with farmers' Buddhist beliefs. Training should include scientific knowledge of pesticide application, green pest control techniques, and environmentally friendly pesticide alternatives.

Third, provide differentiated support policies for different groups of farmers. Research shows that farmers' planting experience influences the relationship between Buddhist beliefs and pesticide use. For farmers with limited planting experience, the government can enhance training and technical support to help them adopt scientific farming methods. For farmers with extensive planting experience, policies can encourage participation in cooperatives or environmental projects to strengthen their recognition and practice of pesticide reduction. Tailored measures should be developed to meet the diverse needs of farmers, maximizing the impact of Buddhist beliefs on pesticide reduction.

Fourth, improve farmers' risk perception to enhance the intrinsic motivation for environmentally friendly behavior. Policies should focus on increasing farmers' awareness of environmental risks, helping them understand the health and environmental hazards of excessive pesticide use. The government can conduct environmental education, promote green agricultural products, and carry out risk assessments to improve

farmers' environmental consciousness and risk awareness. Strengthening their intrinsic motivation can encourage farmers to adopt more environmentally friendly farming practices and reduce pesticide use.

Fifth, encourage farmers to join cooperatives to strengthen collective supervision and promote sustainable production. Membership in cooperatives not only enhances farmers' economic benefits but also enables collective organizations to regulate pesticide usage. Policies should actively encourage farmers to join farmer professional cooperatives, leveraging these platforms for collective supervision and technical guidance. Cooperative members can supervise each other's practices and collaborate to strengthen environmental awareness and responsibility, further advancing pesticide reduction and environmental protection efforts.

Data availability

Due to restrictions imposed by research collaborators, the data used in this study are not publicly available. The authors do not have the rights to share the dataset. Readers with legitimate requests may contact the corresponding author for further inquiries.

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Notes

1. Based on *the rural revitalization strategy* released by the Chinese government in September 2018, Han et al. (2019) established the China Rural Development Index, and the measurement results showed that the level of rural economic development in the eastern region is significantly higher than that in the central and western regions. Eastern region including Beijing, Tianjin, Shanghai, Jiangsu, Shandong, Hebei, Zhejiang, Guangdong, Fujian, and Hainan; Central region including Hubei, Hunan, Anhui, Shanxi, Jiangxi, and Henan; Western region including Chongqing, Sichuan, Yunnan, Guizhou, Guangxi, Shaanxi, Qinghai, Gansu, Ningxia, Xinjiang, and Inner Mongolia.
2. The regression coefficients estimated by the CF approach in Table 4 for Buddhist -0.723 and -0.634 are the absolute values after logarithmic treatment. The treatment does not change the nature of the data and the correlation. The effect of Buddhist belief on pesticide use as well as the cost of use should be discounted to: $e^{-0.723} - 1 = -0.4853$; $e^{-0.634} - 1 = -0.5304$.

References

- Abhilash PC, Singh N (2009) Pesticide use and application: an Indian scenario. *J Hazard Mater* 165(1):1–12
- Andresen ME (2018) Exploring marginal treatment effects: flexible estimation using Stata. *Stata J* 18(1):118–158
- Beck R, Miller CD (2000) Religiosity and agency and communion: their relationship to religious judgmentalism. *J Psychol* 134(3):315–324
- Bisin A, Verdier T (2000) Beyond the melting pot?: cultural transmission, marriage, and the evolution of ethnic and religious traits. *Q J Econ* 115(3):955–988
- Böcker TG, Finger R (2017) A meta-analysis on the elasticity of demand for pesticides. *J Agric Econ* 68(2):518–533
- Cabrera L, Costa FP, Primel EG (2008) Risk estimate of water contamination by pesticide in South of Brazil. *Quim Nova* 31:1982–1986
- Carvalho FP (2006) Agriculture, pesticides, food security and food safety. *Environ Sci Policy* 9(7–8):685–692
- Chen Q, Wachenheim C, Zheng S (2020) Land scale, cooperative membership and benefits information: unmanned aerial vehicle adoption in China. *Sustain Futur* 2:100025
- Damalas CA, Koutroubas SD (2017) Farmers' training on pesticide use is associated with elevated safety behavior. *Toxics* 5(3):19
- Di Falco S, Perrings C (2005) Crop biodiversity, risk management and the implications of agricultural assistance. *Ecol Econ* 55(4):459–466
- Durkin Jr JT, Greeley AM (1991) A model of religious choice under uncertainty: on responding rationally to the nonrational. *Ration Soc* 3(2):178–196
- Fan L, Niu H, Yang X, Qin W, Bento CPM, Ritsema CJ et al. (2015) Factors affecting farmers' behaviour in pesticide use: Insights from a field study in northern China. *Sci Total Environ* 537:360–368

- Gordon MM (1964) Assimilation in American life: the role of race, religion, and national origins. Oxford University Press on Demand
- Gottlieb RS (ed) (2006) The Oxford handbook of religion and ecology. OUP USA
- Greeley A (1993) Religion and attitudes toward the environment. *J Sci Study Relig* 32(1):19–28
- Hand CM, Van Liere KD (1984) Religion, mastery-over-nature, and environmental concern. *Soc Forces* 63(2):555–570
- Hayes BC, Marangudakis M (2000) Religion and environmental issues within Anglo-American democracies. *Rev Relig Res* 159–174
- Heckman JJ, Vytlacil E (2005) Structural equations, treatment effects, and econometric policy evaluation. *Econometrica* 73(3):669–738
- Heckman JJ, Vytlacil EJ (1999) Local instrumental variables and latent variable models for identifying and bounding treatment effects. *Proc Natl Acad Sci USA* 96(8):4730–4734
- Heckman JJ, Vytlacil EJ (2007) Econometric evaluation of social programs, part II: Using the marginal treatment effect to organize alternative econometric estimators to evaluate social programs, and to forecast their effects in new environments. *Handb Econ* 6:4875–5143
- Huang J (2021) Religious belief and environmental protection behavior choice of Chinese residents. *J Shaanxi Acad Gov* 35(2), 66–79 (in Chinese)
- Hunke P, Mueller EN, Schröder B, Zeilhofer P (2015) The Brazilian Cerrado: assessment of water and soil degradation in catchments under intensive agricultural use. *Ecohydrology* 8(6):1154–1180
- Iannaccone LR (1990) Religious practice: a human capital approach. *J Sci Study Relig* 297–314
- Jin J, Wang W, He R, Gong H (2017) Pesticide use and risk perceptions among small-scale farmers in Anqiu County, China. *Int J Environ Res Public Health* 14(1):29
- Jin Z (2019) How to understand the status and role of religious governance in the modernization of China's governance system. *Stud World Relig* 4:1–7 (in Chinese)
- Jin Z, Qiu Y (2012) Blue book of religions: annual report on religions in China. Social Science Academic Press, China (in Chinese)
- Jing J (2009) Cognition and awareness: environmental protest in a Chinese village. *China Agric Univ J Soc Sci Ed* 26(4):6–14 (In Chinese)
- Jusoff K, Samah SAA, Akmar S (2011) Environmental sustainability: what islam propagates. *World Appl Sci J* 12(special issue):46–53
- Kinsley DR (1995) Ecology and religion: ecological spirituality in cross-cultural perspective. Prentice Hall
- Kula E (2001) Islam and environmental conservation. *Environ Conserv* 28(1):1–9
- Lam KC, Shi G (2008) Factors affecting ethical attitudes in mainland China and Hong Kong. *J Bus Ethics* 77(4):463–479
- Lewbel A (2012) Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. *J Bus Econ Stat* 30(1):67–80
- Li H, Liu Y, Zhao X, Zhang L, Yuan K (2021) Estimating effects of cooperative membership on farmers' safe production behaviors: evidence from the rice sector in China. *Environ Sci Pollut Res* 28(20):25400–25418
- Li H, Zeng EY, You J (2014) Mitigating pesticide pollution in China requires enforcement, farmer training, and technological innovation. *Environ Toxicol Chem* 33(5):963–971
- Li R (2010) Beliefs and environmental protection: an empirical study. *Acad Bimest* 3(6):70–74 (in Chinese)
- Li Z, Hu R, Zhang C, Xiong Y, Chen K (2022) Governmental regulation induced pesticide retailers to provide more accurate advice on pesticide use to farmers in China. *Pest Manag Sci* 78(1):184–192
- Liu EM, Huang J (2013) Risk preferences and pesticide use by cotton farmers in China. *J Dev Econ* 103:202–215
- Lu Y, Liang J (2009) First exploration of religion and environmental protection in Chinese society. *Acad Bimest* 3:40–46 (In Chinese)
- Ma W, Abdulai A (2018) IPM adoption, cooperative membership and farm economic performance: insight from apple farmers in China. *China Agric Econ Rev* 11(2):218–236
- Mangunjaya FM (2011) Developing environmental awareness and conservation through Islamic teaching. *J Islam Stud* 22(1):36–49
- Möhrling N, Ingold K, Kudsk P, Martin-Laurent F, Niggli U, Siegrist M, Finger R (2020) Pathways for advancing pesticide policies. *Nat Food* 1: 535–540
- Nie Z, Heerink N, Tu Q, Jin S (2018) Does certified food production reduce agrochemical use in China? *China Agric Econ Rev* 10(3):386–405
- Owen AL, Videras JR (2007) Culture and public goods: the case of religion and the voluntary provision of environmental quality. *J Environ Econ Manag* 54(2):162–180
- Rivers D, Vuong QH (1988) Limited information estimators and exogeneity tests for simultaneous probit models. *J Econ* 39(3):347–366
- Schreinemachers P, Grovermann C, Praneetvatakul S, Heng P, Nguyen TTL, Buntong B, Pinn T (2020) How much is too much? Quantifying pesticide overuse in vegetable production in Southeast Asia. *J Clean Prod* 244:118738
- Schroeder DA (2010) Marginal treatment effects. In: Accounting and causal effects. Springer, New York, NY, pp 275–300
- Schwartz SH (1977) Normative influences on altruism. In: Advances in experimental social psychology, vol. 10. Academic Press, pp. 221–279
- Soares WL, de Souza Porto MF (2009) Estimating the social cost of pesticide use: an assessment from acute poisoning in Brazil. *Ecol Econ* 68(10):2721–2728
- Stark R, Finke R (2000) Acts of faith. University of California Press
- Stern PC, Dietz T, Abel T, Guagnano GA, Kalof L (1999) A value-belief-norm theory of support for social movements: the case of environmentalism. *Hum Ecol Rev* 6(2):81–97
- Timprasert S, Datta A, Ranamukhaarachchi SL (2014) Factors determining adoption of integrated pest management by vegetable growers in Nakhon Ratchasima Province, Thailand. *Crop Prot* 62:32–39
- Truelove HB, Joireman J (2009) Understanding the relationship between Christian orthodoxy and environmentalism: the mediating role of perceived environmental consequences. *Environ Behav* 41(6):806–820
- Wan C, Si H (2015) A study on the regression model of impact of religious belief on resident's environmental behavior. *J Xinzhou Teach Univ* 31(6):104–109 (in Chinese)
- Wooldridge JM (2015) Control function methods in applied econometrics. *J Hum Resour* 50(2):420–445
- Wu L, Hou B (2012) China's farmer perception of pesticide residues and the impact factors: The case of Jiangsu Province. *China Agric Econ Rev* 4(1):84–104
- Xu W, Wei B (2015) The ecological thoughts of Buddhism and their effects on environment protection of Dunhuang. *J Arid Land Resour Environ* 29(7):24–28 (In Chinese)
- Yachkaschi A, Yachkaschi S (2012) Nature conservation and religion: an excursion into the Zoroastrian religion and its historical benefits for the protection of forests, animals and natural resources. *For Policy Econ* 20:107–111
- Yang C, Liang X, Xue Y, Yuan Zhang Y, Xue Y (2024) Can government regulation weak the gap between green production intention and behavior? Based on the perspective of farmers' perceptions. *J Clean Prod* 434:139743
- Yuan G (2005) The eco -protection implications in the religious belief and culture of the minority nationality: cases and analysis. *Acad Explor* 4(2):105–111 (in Chinese)
- Zhao L, Wang C, Gu H, Yue C (2018) Market incentive, government regulation and the behavior of pesticide application of vegetable farmers in China. *Food Control* 85:308–317
- Han L, Wang S, Liu C (2019) China's Rural Development Progress and Regional Comparison: A Study based on Assessment of China's Rural Development Index from 2011 to 2017. *Chin Rural Econ* 7:2–20

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Author contributions

Houjian Li: conceptualization, methodology, software, visualization, data curation, and funding acquisition. Andi Cao: methodology, formal analysis, writing—original draft, writing—review and editing, visualization. Han Zhang: formal analysis, validation and writing—original draft. Lili Guo*: investigation, supervision, writing—review and editing, funding acquisition.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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