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The role of social interaction in farmers' water-saving irrigation technology adoption: testing farmers' interaction mechanisms

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In rural areas, neighborly relationships are complex, and farmers' behaviors are largely influenced by neighborly interactions. The promotion of agricultural technologies should not overlook the social interactions between farmers. Based on survey data from farmers in Minqin, China, this paper explores the role of overall social interaction and its various dimensions in farmers' adoption of water-saving irrigation technology, focusing on the testing of three interactive mechanisms during the technology adoption process. The goal is to provide scientific policy suggestions for government when promoting agricultural technologies. The results show the following: social interaction promotes the adoption of water-saving irrigation technology among farmers; among the four dimensions of social interaction, the depth and frequency of social interaction facilitate the adoption of these technologies; social interaction promotes technology adoption through endogenous interaction mechanism, situational interaction mechanism, and social norm mechanism, with situational interaction mechanism and social norm mechanism playing a more significant role; social interaction has a stronger impact on farmers with longer farming experience and higher irrigation costs. Therefore, the government should emphasize the important role of social interaction in the adoption of agricultural technologies and accelerate the diffusion of these technologies through fostering technical exchanges among farmers, cultivating demonstration households, and implementing differentiated promotion strategies.

Keywords Social interaction, Technology adoption, Interaction mechanism testing, Water-saving irrigation technology

Improving farmland water conservancy equipment is the way to solve the contradiction between agricultural water supply and demand and improve water irrigation efficiency. Promoting the application of water-saving irrigation technology (WSIT) in arid areas can effectively guarantee food security worldwide, realize the virtuous cycle of agricultural water conservancy, and promote the sustainable development of water resources[1,2]. Water-saving irrigation technology (WSIT) has been developed in response to the current shortage of water resources and the prominent conflict between water supply and demand. It is a new scientific irrigation method that can achieve localized precision irrigation, saving both water and labor. It mainly includes canal seepage prevention, water transportation through pipelines, sprinkler irrigation, and micro-irrigation techniques. Research has shown that WSIT plays a role in reducing drought risk, conserving water and soil resources, and promoting agricultural transformation[3]. However, in reality, WSIT has not been widely used. Especially in some less-developed countries or regions, WSIT remains at the level of technology demonstration and is not promoted in agricultural production[4]. This is not only a waste of resources for new agricultural technologies but also hinders the transformation of agricultural development and the improvement of agricultural production efficiency.

Farmers are both rational individuals and social beings[5]. As the main adopters of agricultural technology, farmers' behaviors are widely influenced by their relationships with neighbors[6]. The promotion of agricultural technology should not overlook the social interactions among neighbors[7]. Social interaction is a sociological concept that refers to the mutual influence between individuals and between individuals and groups[8]. Durlauf believes that individuals can influence other individuals through their own preferences, budget constraints, and beliefs, thereby forming complex social interaction networks[9]. In the process of interaction, more information feedback is generated, which helps reduce risks[10]. Ellison and Fudenberg argue that when the costs and benefits of choices are unknown, individuals usually make decisions based on verbal communication (social interaction)[11].

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Social interaction can facilitate information sharing, reduce transaction costs, and lower participation barriers[12]. Social interaction forms a channel through which information influences farmers' decision-making[13].

Social interaction has rich connotations and structures. Some scholars use a single dimension to construct social interaction variables, such as the number of neighbors, the frequency of visiting neighbors, or the number of times one participates in religious activities[10], or the number of people visited during the Chinese New Year[14]. In addition, indicators such as community interview rates, expenses for weddings and funerals, and communication costs[15], the frequency of exchanging information with nearby relatives and friends[16], and expenses for social gifts[17] are also considered measures of social interaction.

Some scholars believe that a single indicator is insufficient to fully reflect the situation of social interaction and may lead to biased results, so they recommend constructing a comprehensive indicator to measure social interaction. Based on Mead's symbolic interactionism, social interaction can be divided into five dimensions: direction, depth, breadth, frequency, and intensity[18,19], where direction reflects the orientation of social interaction, indicating the nature of the relationship between the parties; depth reflects the extent of social interaction, indicating the degree of mutual dependence between the parties; breadth reflects the scope of social interaction, indicating the size of the interaction fields; frequency reflects the number of social interactions within a certain time period; and intensity reflects the strength of social interaction, indicating the intensity of emotions in the interactions. Later, since both depth and intensity reflect the degree of social interaction, representing the mutual dependency of the participants, the two were combined into one dimension, called interaction depth.

How does social interaction play a role in farmers' adoption of technology? Manski suggests that there are two types of interaction mechanisms in the process of farmers adopting technology[20]. One is endogenous interaction mechanism. This refers to the influence of other people's decisions on a farmer's behavior, which in turn may also affect other members. That is, a farmer decides whether to adopt a technology based on the behavior of the majority around them—if most people adopt it, they will too, similar to the herd effect[21]. The other one is situational interaction mechanism. This refers to a farmer's behavior being influenced by the characteristics of other members, but their decision does not affect others. A farmer decides whether to adopt a technology based on the outcome others experience from using it—if the outcome is good, they adopt; if the outcome is poor, they do not, which can be understood as a demonstration effect[22,23].

Some scholars divide the mechanism of social interaction into three categories: information acquisition mechanism (farmers obtain technical information through social interaction), experience sharing mechanism (farmers gain technical experience through discussing common topics and sharing experiences), and social norms mechanism (decisions may be influenced by the social norms reflected by the people around them)[24,25].

Previous studies have performed extensive research on the influence of social interaction on farmers' technology adoption and have achieved fruitful results. At the same time, there are some shortcomings. First, social interaction is rich in content[20], while there is no consensus on the dimension division of social interaction[26]. Second, the role of social interactions in farmers' technology adoption is unclear[20], particularly regarding the classification of interaction mechanisms in technology adoption, and there has been little empirical testing.

Therefore, this paper analyzes the role of social interaction in farmers' WSIT adoption by dividing social interaction into four dimensions, using data from a survey of farmers in Minqin, China, as an example. The purpose of the study is, on one hand, to improve the research on the impact of social interaction on farmers' behaviors through a comparative analysis of the overall and various dimensions of the effects of social interaction in the adoption of technology by farmers. On the other hand, it aims to reveal the mechanisms of social interaction by examining the interaction process in farmers' technology adoption, providing a reference for the government in making informed decisions regarding agricultural technology promotion.

The potential innovations of this study include two aspects. In terms of research perspective: Unlike existing studies that are based on the assumption of rational economic behavior by farmers, this paper, from the perspective of social interaction, breaks away from the traditional economic assumption of rational actors by focusing on the social nature of farmers. It introduces social interaction into the analytical framework of farmers' technology adoption, thoroughly demonstrating the impact of social interaction on the adoption of WSIT by farmers. This is expected to bring theoretical innovation in the study of technology adoption by farmers. In terms of research approach: The study divides social interaction into four dimensions, examining both the overall impact of social interaction and the role of each dimension in farmers' technology adoption. Additionally, it defines the mechanisms through which social interaction influences farmers' adoption of technology based on three major social interaction mechanisms, aiming to enrich the theory of social interaction.

The remainder of the study is organized as follows. The second part is the theoretical foundation. It theoretically analyzes the mechanism by which social interaction affects farmers' technology adoption and formulates a series of theoretical hypotheses to be tested. The third part presents the data, variables and empirical model of this paper. The fourth part presents the empirical results of this paper. Through an analysis of the role of social interaction in farmers' adoption of WSIT, it examines three interaction mechanisms, verifies the proposed theoretical hypotheses, and conducts an analysis of the issues of endogeneity, robustness, and heterogeneity in the research. The fifth section presents the conclusions of this paper and illustrates the policy implications. The final part is the discussion.

Theoretical frameworks and hypotheses

Impact of social interaction on farmers' adoption of WSIT

Social interaction can reduce the risks associated with farmers' adoption of technology, promote information sharing, and reduce transaction costs and participation barriers[8]. The higher the degree of individual social interaction, the greater the likelihood of participation[7]. Social interaction has a significant impact on farmers' decisions to adopt WSIT.

Social interaction theory suggests that farmers' decision-making behavior is directly influenced by their own characteristics and the environment in which they live. Farmers' access to technical information is based on "self-exploration" and "relatives and friends"[27]. Communication among farmers is one of the main channels for them to obtain technical information; the more frequent and deep farmers' contacts are, the higher their technology adoption rate[28]. Therefore, farmers can directly reduce their technical information search costs by visiting demonstration fields and consulting on irrigation technology issues to solve the problem of a low technology adoption rate due to the lack of social interaction[17]. If farmers expand the diffusion and dissemination of new technologies by increasing the level of social interaction, they can gain a deeper understanding of the benefits of new technologies. Social interaction positively influences farmers' overall purchasing behavior, and the positive influence of social interaction is stronger in labor-intensive purchasing behavior[29]. Effectively combining the neighborhood effect and social interaction can improve the operational efficiency and influence of each extension service department, which in turn positively promotes technology adoption[30]. Based on the above analysis, Hypothesis 1 is proposed:

H1: Social interaction promotes the adoption of WSIT among farmers.

Interaction mechanism in farmers' technology adoption

The key to clarifying the mechanisms underlying the social interaction that influence farmers' technology adoption is to examine the interaction mechanisms of farmers' technology adoption. By reviewing the existing literature and classifying social interaction based on the direction in which it influences farmers' adoption of technology, this paper suggests that social interaction primarily exerts its effect through three mechanisms: endogenous interaction, situational interaction, and social norms mechanisms.

Endogenous interaction mechanism refers to behavior where an individual is influenced by the group and, in turn, affects the group; the interaction is bidirectional.

Situational interaction mechanism reflects the behavior of demonstration farmers that influences the decisions of group members; the interaction is unidirectional, directed towards the demonstration farmers.

Social norms mechanism indicates that an individual's decision may be influenced by the social norms reflected by those around them; the interaction is unidirectional, directed towards the group's norms.

A. Endogenous interaction mechanism.

The influence of endogenous interaction on individual decision-making is mainly manifested as follows: an individual's technology adoption decision is influenced by the contemporaneous behavior of his or her reference group members, and the individual's own decision is in turn influenced by the decision of the reference group members[6,31] (e.g., if other farmers plant more/less, I also plant more/less). Thus, endogenous interaction implies that there is a mutual correspondence between individual farmers and reference group members, which is also known as the partner group effect[7]. Additionally, based on the rational economic person hypothesis, Fang and Chen argue that farmers' decisions are not independent of each other but are influenced by each other, and individual farmers refer to the choices of others around them to improve the quality of their own decisions[32]. Endogenous interaction usually includes two mechanisms, verbal information exchange and communication to obtain pleasure[12]. The former enables individuals to obtain knowledge related to decision-making from surrounding people to solve the problem of insufficient information, while the latter enables residents to obtain pleasure and satisfaction from communication with surrounding people and improve the level of psychological utility[33]. According to social learning theory[34], social learning is still the most important learning channel for farmers. In the case of farmers' WSIT adoption, for example, potential technology adopters make decisions by visiting demonstration fields, asking technology adopters for advice, and exchanging technical questions, and this beneficial endogenous interaction contributes to technology adoption rates. We argue that the intuitive meaning of the endogenous interaction mechanism is that an individual adopts when others adopt, so the effect of social interaction to promote farmers' technology adoption is more significant in areas with a high number of technology adopters. Based on the above analysis, Hypothesis 2 is proposed:

H2: Social interaction promotes farmers' WSIT adoption behavior through an endogenous interaction mechanism.

B. Situational interaction mechanism.

Situational interactions are those in which the choices of other actors adjust individual expectations and thus influence individual behavior[6]. This is mainly reflected in the one-way effect in which individuals' decisions are influenced by the characteristics of reference group members, but their own decisions do not counteract the reference group members[5]. This is also known as the model group effect or role model effect. It focuses on the effect of others' adoption of the same kind of decision for positive or negative consequences[7]. For example, an individual may plant whatever others plant that can make money. In empirical studies, situational interaction effects are used to explain individual behavior in terms of common characteristics of group members[13]. When individuals perceive that technology adoption by others "works well", a positive demonstration effect is produced, decision-makers are influenced by the positive demonstration effect, and the likelihood of technology adoption behavior increases[35]. Conversely, a negative effect causes decision-makers to reject the adoption of a new technology.

Based on the above, it is argued that the situational interaction mechanism intuitively means that individual adoption depends on others doing well after adoption. Therefore, agricultural technologies are more effective in areas where technology adoption can produce better results. The demonstration effect of situational interaction is that when the adoption of WSIT brings benefits to farmers, these successful experiences send positive signals to potential adopters to join the queue of WSIT users. Conversely, when the adoption of WSIT does not bring benefits to farmers, these failure cases negatively guide the promotion of WSIT and reduce farmers' desire to adopt. The above analysis leads to Hypothesis 3:

H3: Social interaction promotes farmers' WSIT adoption behavior through a situational interaction mechanism.

C. Social norm mechanism.

Social norms are essentially a type of psychological motivation. Farmers' decisions may be influenced by the social norms reflected within their social network. If an individual deviate from group norms, it can harm their social status, and their behavior will naturally be affected[22,36–38].

On the one hand, social norms are the reflection of the universal laws of people's social behavior and social relations and are a generalization of the basic requirements of a certain social class for people's behavior and interrelationships. On the other hand, social norms may be fixed by some customs and traditions or recognized by the state or groups and constitute the code of behavior generally followed by members of society[39]. Unlike the coercive legal system, social norms are based on informal social sanctions or rewards that guarantee the implementation of behavior. Social norms are divided into descriptive and prohibitive norms, which help individuals make quick decisions or guide people's behavior to think systematically about the content of norms, respectively[40]. Therefore, individuals often refer to others' behavioral decisions or are influenced by others' perceptions before making decisions. Farmers learn about the applicability of other farmers' behavioral decisions to their own decisions before making technology adoption decisions and then follow these constraints to achieve consistency with the behavioral decisions of surrounding farmers. An individual's decision may be influenced by the social norms reflected in the choices of his or her reference group members[7]. Xiao et al. argue that by observing the technology adoption decisions of other members, an individual can learn about the appropriate behavior of the social group to which he or she belongs and can expect to make decisions that are similar to the average of the reference group members[41]. The individual expects to choose strategies that are consistent with the social norms followed by members of his or her reference group, which can increase the individual's income and reduce the income gap, help the individual earn the respect of others, and thus increase his or her level of utility and satisfaction and avoid punishment[42].

In summary, this paper argues that the social norms mechanism is expressed in the degree of concern for the wealth of others within the context of social interactions. The impact of social interactions driving technology adoption among farmers is more significant in the presence of a larger income gap. Therefore, Hypothesis 4 is proposed:

H4: Social interaction promotes farmers' WSIT adoption through the social norm mechanism.

Data, variables and empirical model
Data
Basic information of the survey

The data we used in this paper were obtained from a household survey conducted by the research team in Minqin, China. The basic information about the research area is as follows:

Minqin is located in northwest China, with low hills, plains and deserts in the region. It has a temperate continental arid climate with a very fragile ecological environment. Precipitation is low and unevenly distributed, evaporation is high, the climate is dry, and drought disasters occur frequently. The special natural environment causes farmers in the region to suffer from drought; therefore, the government attaches great importance to water conservancy construction work in Minqin. Currently, three groundwater drip irrigation demonstration areas, two agricultural precision irrigation demonstration areas, two solar greenhouse drip irrigation demonstration areas and one comprehensive water-saving irrigation demonstration garden have been built in the region, with a demonstration area of 15,700 mu. The region is mainly dominated by drought-tolerant crops such as corn and cotton, with corn sowing area accounting for 34% of the cultivated land area. The cultivation ratio of fruits and vegetables is low, accounting for 14% of the main arable land area, among which honeydew melon accounts for more than 84%. Minqin honeydew melon is famous nationwide.

The survey used a stratified sampling method, selecting samples in three layers: county, township/town, and village. Approximately 10% of households were randomly selected in each village for the questionnaire survey, with a total of 500 households from 20 villages being sampled. The survey returned 500 completed samples, achieving a 100% response rate. After excluding incomplete or inconsistent questionnaires, 443 valid responses were obtained, resulting in a validity rate of 88.60%. The data used in this article is derived from these 443 valid samples.

The sample size formula is typically used to determine the reasonableness of the sample size. This formula provides a sample estimate that does not take population size into account, making it particularly suitable for large populations, as sample size is less affected by population size when the population is very large.

The sample size formula is as follows: $N\left(Sample\ Size\right) = \frac{Z^2 \times P \times (1-P)}{e^2}$

In this formula, $N\left(Sample\ Size\right)$ represents the required sample size for the survey, Z is the Z-score corresponding to the confidence level, P is the expected effect size, and e is the confidence interval.

Based on the formula, when the confidence level is 95%, the expected effect size is 0.5, and the acceptable margin of error is 5, the required sample size is approximately 384.16. In this study, the sample size is 443, which is greater than 384.16, indicating that the sample size is reasonable.

Variables		Number of observations	Percentage (%)	Variables		Number of observations	Percentage (%)
Gender	male	329	74.30	Education level	illiterate	71	16.00
	female	114	25.70		primary school	92	20.80
Age	<=45	116	26.20		middle school	177	40.00
	> 45 &<=55	186	42.00		high school	101	22.80
	> 55 &<=65	110	24.80		college	2	0.45
	> 65	31	7.00	Risk appetite	risk-loving	74	16.70
Years of farming experience	<=20	80	18.10		risk-neutral	244	55.10
	> 20 &<=30	172	38.80		risk-averse	125	28.20
	> 30 &<=40	121	27.30	Personal influence	village cadres	34	7.70
	> 40	70	15.80		villager	409	92.30

Table 1. Basic information of the samples.

Variables	Definition	Nonadopters [a]	Adopters [a]	T test
Age of household head	years	51.640	51.790	-0.150
Personal impact	1 = smaller; 2 = medium; 3 = larger	1.107	1.141	-0.034
Years of farming experience	years	30.630	31.920	-1.291
Education level	1 = illiterate; 2 = primary school; 3 = middle school; 4 = high school; 5 = college	2.687	2.731	-0.044
Family size	number of people in household	4.427	4.532	-0.105
Number of males in household	number of males in household	1.366	1.391	-0.025
Number of females in household	number of females in household	1.198	1.356	-0.157** [b]
Number of farmers in household	number of farmers in household	2.038	2.141	-0.103*
Years of living in the village	years	50.860	48.360	2.500*
Member of Water Users Association	yes = 1; no = 0	0.588	0.724	-0.137***
Cognition of WSIT	very little = 1<-->5 = very much	1.107	1.147	-0.041
Cognition of WSIT adoption importance	extremely unimportant = 1<-->5 = extremely important	2.374	2.712	-0.337***
Cognition of WSIT adoption effect	extremely bad = 1<-->5 = extremely good	3.160	3.272	-0.112
Household water expenditure	ten thousand yuan	0.336	0.453	-0.117***
Irrigation water price	cheaper than before = 1<-->5 = more expensive than before	4.092	4.250	-0.158***
Irrigation water comes entirely from groundwater	disagree = 1<-->5 = agree	1.939	1.846	0.093***
Number of plots cultivated in household	number of plots cultivated in household	8.656	8.503	0.153
Maximum area of arable land plots	mu	6.112	6.565	-0.453
Minimum area of arable land plots	mu	1.835	2.476	-0.641
Number of observations		131	312	

Table 2. Characteristics of WSIT adopters and nonadopters in Minqin. [a] The data in this column are average of the variables;. [b] Significance Lever: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$. Same below.

The selection of the sample should follow the principles of representativeness, randomness, and validity. Representativeness means that the sample can represent the overall characteristics of the research object. The research object is farmers in Minqin, and the sample includes farmers of different ages, genders, education levels, and years of farming experience (see Table 1), ensuring the representativeness of the sample. Randomness means that the sample selection must be random. The survey was conducted using a random sampling method, ensuring the fairness and objectivity of the sample. Validity means that the quality of the sample should be guaranteed. In this survey, in-depth one-on-one interviews with farmers were conducted, and all questionnaires were personally filled out by the research team members, ensuring the authenticity and accuracy of the data collection.

The basic information of the sample is shown in Table 1:

Descriptive statistics

Table 2 reports the descriptive statistics of some important characteristics between adopters and nonadopters. According to the survey data, 131 farmers did not adopt WSIT, accounting for 29.57% of the survey sample. The main reasons why farmers are not willing to adopt WSIT include the following: 46.12% of farmers think that the land area is small and the plots are scattered, so it is difficult to bring scale benefits to farmers with high-cost WSIT equipment inputs; 21.97% of farmers believe that there are problems after the installation and use of WSIT equipment, and no one follows up and repairs the equipment; and 77.65% of farmers think that there are no demonstration households around for technical guidance.

A total of 312 households adopted WSIT, accounting for 70.43% of the total interviewed farmers. Among them, 92.52% of the farmers adopted WSIT mainly due to promotion by agricultural extension staff or the demonstration role of government model villages. When making the adoption decision, 79.05% of farmers thought that the investment in WSIT facilities should be borne by the government, and they were more willing to invest in labor. A total of 80.67% of the farmers noted that they valued the economic benefits of the use of the technology. Government subsidies were also an important factor in farmers' adoption decisions. A total of 52.9% of farmers said they received government subsidies for equipment after adoption, and 47.68% said they also received technical subsidies. For the postadoption maintenance of WSIT, 37.01% of farmers stated that the Irrigation District Administration was responsible for maintenance, 49.13% of farmers stated that individuals were responsible for follow-up equipment maintenance, and a small number of farmers stated that no one was responsible for maintenance of the equipment.

Variables

Social interaction

Social interaction has a rich connotation, and using a single indicator to measure farmers' social interaction may lead to biased results[27]. Therefore, this paper draws on the definition of social interaction from socioeconomics and classifies it into four dimensions based on the types and social functions of interaction[19,20]: depth of social interaction (depth of SI), frequency of social interaction (frequency of SI), direction of social interaction (direction of SI) and breadth of social interaction (breadth of SI), forming an indicator system for social interaction.

Depth of SI reflects the degree of social interaction and determines the degree of interdependence between the interacting parties. Specifically, farmers' technology adoption behavior can be expressed by whether they join agricultural cooperatives, and information acquisition and screening can be characterized by judging the number of WSIT adopters, such as whether many of their neighbors and friends and relatives adopt WSIT.

Frequency of SI refers to the number of social interactions that occur between individuals within a certain period of time. The frequency of SI is often related to good interpersonal relationships. For example, how can we tell which people in a class are good friends? It is those students who interact frequently, have many interactions, and are together often. The adoption of WSIT for farmers can be expressed in terms of the frequency of contact with friends and relatives, which can usually be expressed in terms of the frequency of spending time with friends and relatives, the frequency of visiting neighbors, and whether there are many people who try to help them solve problems when they encounter difficulties.

The direction of SI is the direction of social interaction, reflecting the good or bad relationship between the two sides of the interaction, including emotional relationships (Is it affectionate or repulsive? Is it harmonious or antagonistic?), interest relationship (Is it aligned or conflicting, and to what extent?), and status relations (Are they equal or unequal? What is the pattern of power distribution?)[43]. Specifically, in terms of farmers' WSIT adoption behavior, the emotional relationship can be characterized by whether the relationship between villagers is cordial, the interest relationship can be characterized by the number of water use disputes, and the operation of rules and regulations can measure whether status is equal and whether power is properly distributed.

Breadth of SI refers to the scope and field of social interaction. In terms of the scope of interaction, the more comprehensive the scope involved, the more extensive the interaction. For the field of interaction, the clearer the behavioral norms in the field, the more extensive the interaction. Specifically, the scope of interaction for farmers' WSIT adoption behavior can be characterized by the breadth of external contacts and the number of sources of information, and the field of interaction can be measured by the amount of expenditure on human gifts.

The specific index definitions and descriptions are shown in Table 3:

Scholars adopt the idea of dimensionality reduction to measure multidimensional indicators. In this paper, the entropy value method is used to measure the four dimensions of social interaction and the comprehensive indicators of social interaction. The measurement results are as follows:

SI	Weight	Indicator	Definition	Weight	Min	Max	Mean	S.D.
Depth of SI f_1	0.6615	Whether joined agricultural cooperatives or not v_1	1 = yes; 0 = no	0.9356	0.000	1.000	0.074	0.263
		Many people around adopted WSIT v_2	extremely disagree = 1<-->5 = extremely agree	0.0644	1.000	5.000	3.341	1.180
Frequency of SI f_2	0.1746	Frequency of going out with friends? v_3	never = 1<-->5 = frequently	0.7208	1.000	5.000	2.005	0.958
		Frequency of visiting neighbors v_4	never = 1<-->5 = frequently	0.2147	1.000	5.000	3.106	1.072
		Many people will help when difficulties are encountered v_5	very little = 1<-->5 = a lot	0.0645	1.000	5.000	3.831	0.773
Direction of SI f_3	0.0479	Relationship with other villagers v_6	extremely uncomfortable = 1<-->5 = extremely comfortable	0.2401	2.000	5.000	3.926	0.539
		Number of water disputes in the village v_7	many = 1<-->5 = never	0.4509	1.000	5.000	3.790	1.037
		Village rules and regulations function well v_8	extremely disagree = 1<-->5 = extremely agree	0.3090	1.000	5.000	3.404	0.777
Breadth of SI f_4	0.1160	My family has various sources of information v_9	strongly disagree = 1<-->5 = strongly agree	0.1495	1.000	5.000	3.483	0.908
		Favor gift expenditure v_{10}	ten thousand yuan	0.8505	0.000	10.000	0.307	0.509

Table 3. Evaluation index of social interaction.

$$\begin{cases} f_1 = 0.9356 * v_1 + 0.0644 * v_2 \\ f_2 = 0.7208 * v_3 + 0.2147 * v_4 + 0.0645 * v_5 \\ f_3 = 0.2401 * v_6 + 0.4509 * v_7 + 0.3090 * v_8 \\ f_4 = 0.1495 * v_9 + 0.8505 * v_{10} \\ SI = 0.6615 * f_1 + 0.1746 * f_2 + 0.0479 * f_3 + 0.1160 * f_4 \end{cases} \quad (1)$$

In Eq. (1), $v_1 \ldots v_{10}$ are the variables of social interaction, $f_1 \ldots f_4$ represent the depth of SI, the frequency of SI, the direction of SI and the breadth of SI, respectively, and *SI* is the value of the comprehensive index of the social interaction of farmers.

Control variables
The influence of farmers' individual factors[44,45], household factors[46,47], and policies[48,49] on farmers' WSIT adoption decisions has been generally recognized by many scholars. Therefore, in this paper, the factors of gender[50], age[51], farming experience[52], risk preference[53], dry crop acreage[54], water expenditure[55], and water price[56] were selected as control variables for inclusion in the model.

In addition, other control variables are selected in this paper, including personal influence. Leaders can guide and drive their subordinates to accomplish their target tasks through their own influence[57]. When promoting technology, as village cadres with strong personal influence in the village, they can establish a demonstration effect by being the first to adopt a new technology, thereby motivating other farmers to adopt it. Based on this, this paper characterizes personal influence by the position held in the village and includes it as a control variable in the model.

Cognitive attitude is another key factor that influences farmers' WSIT adoption decisions. Farmers' WSIT cognition is an important prerequisite for the emergence of farmers' propensity to adopt WSIT and has a significant impact on WSIT adoption[58]. Weak cognition can hinder the adoption of WSIT[1]. WSIT can promote technological progress in food production, increase total factor productivity, improve food production conditions, and increase farmers' farming returns[59], so the clearer the perception of the importance of WSIT is, the more farmers tend to adopt it. The more knowledge farmers have about the income increase and adoption effect produced by the new technology, the more actively they will adopt the new technology[10]. Therefore, the cognitive attitudes of farmers (Cognition of WSIT, Cognition of WSIT adoption importance, Cognition of WSIT adoption effect) are included in the control variable system. The specific descriptive statistics of the variables in this paper are shown in Table 4.

3.3 Empirical model
To test Hypothesis 1, the following technology adoption decision-making model for farmers was constructed:

$$TA_i = I(\alpha + \sum\nolimits_{j=1}^{k} \beta_{ij} X_{ij} + \gamma_{m1} \mathrm{SI} + \varepsilon_i)\varepsilon_i \sim N(0,1) i = 1,2,3 \cdots \ N \quad (2)$$

In the above equation, TA_i denotes the adoption decision of the *ith* farmer, which is 1 if adopted and 0 otherwise. X_i denotes the control factors affecting the adoption of farmer *i*, and *SI* is the social interaction index of farmers determined by the entropy method. α is the constant term, $\beta_{\,i}$ and $\gamma_{\,m1}$ are the regression coefficients, and ε_i denotes the random error term. I is the indicative function, which means that TA_i takes the value of 1 when the latter condition is satisfied; otherwise, it is 0.

On the basis of the above equation, the indicators of the four dimensions of social interaction were incorporated into the model. The farmers' technology decision-making model is shown below:

$$TA_i = I(\alpha + \sum\nolimits_{j=1}^{k} \beta_{ij} X_{ij} + \gamma_{t1} f_1 + \gamma_{t2} f_2 + \gamma_{t3} f_3 + \gamma_{t4} f_4 + \varepsilon_i)\varepsilon_i \sim N(0,1)\, i = 1,2,3 \cdots \ N \quad (3)$$

In the above equation, f_1, f_2, f_3, and f_4 represent the depth of SI, frequency of SI, direction of SI and breadth of SI, respectively, and $\gamma_{\,t1}$, $\gamma_{\,t2}$, $\gamma_{\,t3}$, and $\gamma_{\,t4}$ are the regression coefficients of the corresponding dimensions.

For the testing of the three interaction mechanisms proposed in Hypotheses 2 to 4, indicator variables representing the three interaction mechanisms were designed and incorporated into the model. The three interaction mechanisms in farmers' WSIT adoption behavior were verified by observing the changes in their coefficients.

Since the differences in farmers' subjective evaluations are the key factors that influence the effect of social interaction, the subjective evaluations of farmers on different aspects are taken as the core characterizing variables of the interaction mechanism. The test model of the interaction mechanism is constructed by adding interaction terms.

A. Endogenous interaction mechanism test:

$$TA_i = I(\alpha \sum\nolimits_{j=1}^{k} \beta_{ij} X_{ij} + \gamma_{m1} SI + \gamma_{n1} Participation + \gamma_{k1} SI * Participation + \varepsilon_i)\varepsilon_i \sim N(0,1)\, i = 1,2,3 \cdots \ N \quad (4)$$

B. Situational interaction mechanism test:

$$TA_i = I(\alpha \sum\nolimits_{j=1}^{k} \beta_{ij} X_{ij} + \gamma_{m2} SI + \gamma_{n2} Earning + \gamma_{k2} SI * Earning + \varepsilon_i)\, \varepsilon_i \sim N0,1)\, i = 1,2,3 \cdots \ N \quad (5)$$

Variables	Definition	Min	Max	Mean	S.D.	Expected direction
Technology adoption (TA_i)	0 = not adopted; 1 = adopted	0.000	1.000	0.704	0.457	
Social interaction (SI)	see Table 3	1.179	2.905	1.707	0.246	Positive
Depth of SI (f_1)	see Table 3	1.000	2.266	1.276	0.250	Positive
Frequency of SI (f_2)	see Table 3	1.000	5.000	2.516	0.736	Positive
Direction of SI (f_3)	see Table 3	1.291	5.000	3.705	0.562	Positive
Breadth of SI (f_4)	see Table 3	0.238	8.572	1.063	0.459	Positive
Gender (x_1)	1 = male; 0 = female	0.000	1.000	0.743	0.438	Positive
Age (x_2)	years	25.000	78.000	51.747	8.863	Negative
Personal impact (x_3)	1 = smaller; 2 = medium; 3 = larger	1.000	3.000	1.131	0.472	Positive
Risk appetite (x_4)	1 = risk-loving; 2 = risk-neutral; 3 = risk-averse	1.000	3.000	2.115	0.661	Negative
Years of farming experience (x_5)	years	2.000	60.000	31.535	10.107	Positive
Area of drought-tolerant crops (x_6)	mu	0.000	100.000	19.197	15.207	Negative
Water expenditure (x_7)	ten thousand yuan	0.000	1.500	0.419	0.275	Positive
Irrigation water price (x_8)	cheaper than before = 1<-->5 = more expensive than before	1.000	5.000	4.203	0.435	Positive
Cognition of WSIT (x_9)	very little = 1<-->5 = very much	1.000	4.000	1.135	0.414	Positive
Cognition of WSIT adoption importance (x_{10})	extremely unimportant = 1<-->5 = extremely important	1.000	5.000	2.612	0.871	Positive
Cognition of WSIT adoption effect (x_{11})	extremely bad = 1<-->5 = extremely good	1.000	5.000	3.239	0.901	Positive
Participation [a]	Many farmers around me adopt WSIT. 1 = yes; 0 = no	0.000	1.000	0.535	0.499	Positive
Earning	Agricultural income of surrounding adopters has generally increased after adopting WSIT. 1 = yes; 0 = no	0.000	1.000	0.433	0.496	Positive
Incomegap	Agricultural incomes vary widely in our village. 1 = yes; 0 = no	0.000	1.000	0.479	0.500	Positive
Average SI of other farmers in the same village [b]	Average SI of other farmers in the same village	1.369	1.580	1.479	0.072	Positive

Table 4. Definition of variables and descriptive statistics. [a] Participation, earnings and income gap are indicator variables for the endogenous interaction mechanism, situational interaction mechanism and social norm mechanism. [b] The variable was selected as the instrumental variable for social interaction for endogenous test.

C. Social norm mechanism test:

$$TA_i = I(\alpha + \sum_{j=1}^{k} \beta_{ij}X_{ij} + \gamma_{m3}SI + \gamma_{n3}Incomegap + \gamma_{k3}SI * Incomegap + \varepsilon_i)\varepsilon_i \sim N(0,1)\, i = 1, 2, 3 \cdots N \quad (6)$$

In the above three equations, participation is the core variable for the endogenous interaction mechanism ("I will adopt if others adopt"), which indicates farmers' evaluation of the adoption of WSIT by others in their area/village, with 1 if the number is large and 0 otherwise. Earnings is the core variable of the situational interaction mechanism ("I will adopt if others have high adoption benefits"), which indicates farmers' evaluation of the benefits of adopting WSIT for others in their area/village, with 1 if the benefits are high and 0 otherwise. Income gap is the core variable for the social norm mechanism (the greater the intragroup variation, the more likely it is that group identity can be achieved by referring to group adoption decisions) and represents farmers' evaluation of income differences in their area/village, with 1 for large income differences and 0 otherwise.

$$\frac{\partial TA}{\partial SI} = \gamma_m + \gamma_k * Participation/Earning/Incomegap \quad (7)$$

The above equation implies that $Participation/Earning/Incomegap$ influences the bias effect of SI. The interaction mechanisms of social interaction on farmers' WSIT adoption are verified.

Results

Impact of social interaction on farmers' WSIT adoption

To ensure the accuracy of model parameter estimation, a multicollinearity test was conducted on the variables before performing the regression analysis. In Model 1, the maximum Variance Inflation Factor (VIF) is 4.81, and in Model 2, the maximum VIF is 4.84, both of which are much less than 10. Therefore, there is no multicollinearity issue between the variables (see Table 5).

Model 1 and Model 2 were constructed based on Eqs. (2) and (3). Model 1 verified the impact of social interaction on farmers' WSIT adoption. Model 2 introduced four dimensions of social interaction indicators to verify the impact of social interaction structure on farmers' technology adoption decisions. The results are shown in Table 5.

The results of Model 1 show that the estimated coefficient of the composite indicator of social interaction is 1.671 and is significant at the 1% statistical level. This means that social interaction can positively influence farmers' adoption of WSIT. This indicates that social interaction plays a positive role in farmers' decision to adopt WSIT; the deeper farmers' social interaction is, the more likely they are to adopt WSIT. Farmers can obtain technology information, exchange use experiences, reduce technology adoption risks and transaction costs, and promote technical cooperation through social interaction[60]. This finding is consistent with our previous expectation of Hypothesis 1, so Hypothesis 1 is verified.

In terms of the social interaction structure (see Model 2), the coefficients of the depth of SI and the frequency of SI are positive and pass the tests at the 1% and 10% significance levels, respectively, indicating that both the depth of SI and the frequency of SI have positive effects on farmers' WSIT adoption. The deeper the interaction, the more farmers are able to identify effective information, reduce the risk and uncertainty of adopting WSIT, and reduce their concerns. The more frequent their interactions, the deeper the technical exchange and mutual learning among farmers, the more the adoption process can be advanced, and the more likely farmers will be to adopt WSIT.

The direction of SI and the breadth of SI fail to pass the significance test, which may be due to their low weighting in the social interaction dimension and dilution of their observed variables in the regression. Alternatively, although the magnitude of the two dimensions differs significantly, the people they interact with tended to be homogeneous[24], and the difference in the breadth of SI and direction of SI that truly plays a role in WSIT adoption is further reduced by the closeness of the village in which the farmer lives.

The negative coefficient of the breadth of SI indicates that the more comprehensive the scope and field of interaction of farmers, the less willing they are to adopt WSIT. This result is very interesting. Although it fails the significance test, it is still worth considering. The possible reason is that the more comprehensive the scope of social interaction, the more mixed the information sources are and the more uneven the quality of information is, which increases the cost of information screening for farmers and discourages their adoption.

Among the control variables, years of farming experience and water expenditure were significantly positive at the 5% and 1% levels, respectively, indicating that the longer the farming period and the higher the water consumption expenditure, the more farmers tend to adopt WSIT, which is consistent with traditional technology diffusion theory. Price is the regulator of resource consumption. The higher the price of irrigation water is, the more it stimulates farmers' potential demand for WSIT and motivates them to make adoption decisions. Cognition of the importance of WSIT adoption is significantly positive at the 1% level, indicating that the more farmers understand the importance of agricultural technology for grain production, the more inclined they are to adopt WSIT. Therefore, in the process of technology promotion in the future, we should pay attention to making farmers fully aware of the importance of WSIT to ensure food production and improve production efficiency to promote their adoption of technology.

	Model 1			Model 2		
Explanatory variables	**Coefficient**	**Standard error**	**VIF**	**Coefficient**	**Standard error**	**VIF**
Social interaction (SI)	1.671***	(0.574) [a]	1.14			
Depth of SI (f_1)				1.730***	(0.652)	1.05
Frequency of SI (f_2)				0.277*	(0.162)	1.18
Direction of SI (f_3)				0.184	(0.188)	1.06
Breadth of SI (f_4)				-0.283	(0.237)	1.09
Gender (x_1)	0.065	(0.274)	1.13	0.023	(0.276)	1.14
Age (x_2)	-0.033	(0.028)	4.81	-0.033	(0.028)	4.84
Personal impact (x_3)	0.249	(0.251)	1.02	0.279	(0.254)	1.03
Risk appetite (x_4)	-0.067	(0.177)	1.12	-0.091	(0.179)	1.13
Years of farming experience (x_5)	0.051**	(0.025)	4.67	0.048*	(0.025)	4.73
Area of drought-tolerant crops (x_6)	-0.017	(0.011)	1.70	-0.017	(0.011)	1.74
Water expenditure (x_7)	1.800***	(0.537)	1.44	1.847***	(0.542)	1.44
Irrigation water price (x_8)	1.058***	(0.347)	1.24	1.057***	(0.348)	1.24
Cognition of WSIT (x_9)	0.190	(0.289)	1.04	0.190	(0.296)	1.06
Cognition of WSIT adoption importance (x_{10})	0.491***	(0.144)	1.17	0.502***	(0.145)	1.17
Cognition of WSIT adoption effect (x_{11})	0.090	(0.129)	1.10	0.077	(0.130)	1.10
Log likelihood	-238.13544			-235.41527		

Table 5. The influence of social interactions on farmers' WSIT adoption. [a] Standard error in parentheses. Same below.

Testing the interaction mechanisms of social interaction in farmers' WSIT adoption

Results of the three interaction mechanisms testing separately

Models 3, 4, and 5 were constructed based on Eqs. (4), (5) and (6), respectively, to verify the endogenous interaction mechanism, situational interaction mechanism, and social norm mechanism in the adoption process of WSIT by farmers. Model 6 is based on the indicator variables representing the three interaction mechanisms that are incorporated into the model simultaneously to verify the strength of the effect of the three interaction mechanisms. The results are shown in Table 6.

In Model 3, the coefficient of the cross term between social interaction and participation is 2.792 and passes the 5% significance test; thus, Hypothesis 2 is verified. This indicates that social interaction plays a facilitating role in farmers' adoption of WSIT through the endogenous interaction mechanism. The more adopters of WSIT there are around farmers, the more farmers tend to adopt the technology. Farmers transfer technology information through social interactions with people around them, learn about other people's decisions, and follow the behavior of most people in making technology adoption decisions. This also suggests that farmers' technology adoption decisions are blind and that herd mentality exists, which is also called the "herd effect". In response to this phenomenon, we should pay attention to the cultivation of the "leader" when promoting agricultural technology and guide farmers to follow the behavior of demonstration households to make adoption decisions through the role of demonstration households.

In Model 4, the coefficient of the cross term between social interaction and earnings is 5.433 and passes the 1% significance test; therefore, Hypothesis 3 is verified. This indicates that social interaction plays a facilitating

	Model 3	Model 4	Model 5	Model 6
Social interaction (SI)	2.264***	2.942***	2.471***	3.540***
	(0.650)	(0.743)	(0.674)	(0.818)
Participation	0.543**			0.346
	(0.244)			(0.260)
SI×Participation	2.792**			1.557
	(1.215)			(1.324)
Earning		1.185***		1.084***
		(0.300)		(0.297)
SI×Earning		5.433***		4.339***
		(1.564)		(1.552)
Income gap			0.493*	0.432
			(0.258)	(0.264)
SI×Income gap			4.835***	4.146***
			(1.322)	(1.351)
Gender (x_1)	0.121	0.0880	0.0925	0.114
	(0.275)	(0.279)	(0.279)	(0.284)
Age (x_2)	-0.0360	-0.0303	-0.0312	-0.0319
	(0.0288)	(0.0283)	(0.0284)	(0.0290)
Personal impact (x_3)	0.221	0.127	0.310	0.164
	(0.250)	(0.263)	(0.252)	(0.266)
Risk appetite (x_4)	-0.0682	-0.0739	-0.0546	-0.0827
	(0.178)	(0.182)	(0.180)	(0.185)
Years of farming experience (x_5)	0.0507**	0.0516**	0.0534**	0.0532**
	(0.0257)	(0.0252)	(0.0252)	(0.0257)
Area of drought-tolerant crops (x_6)	-0.0194*	-0.0220*	-0.0175	-0.0235*
	(0.0111)	(0.0113)	(0.0110)	(0.0120)
Water expenditure (x_7)	1.896***	1.962***	1.804***	2.017***
	(0.553)	(0.554)	(0.547)	(0.579)
Irrigation water price (x_8)	1.095***	1.192***	1.076***	1.198***
	(0.353)	(0.360)	(0.352)	(0.366)
Cognition of WSIT (x_9)	0.238	0.215	0.177	0.223
	(0.293)	(0.298)	(0.283)	(0.293)
Cognition of WSIT adoption importance (x_{10})	0.507***	0.485***	0.532***	0.540***
	(0.146)	(0.148)	(0.148)	(0.151)
Cognition of WSIT adoption effect (x_{11})	0.0878	0.110	0.113	0.133
	(0.131)	(0.135)	(0.131)	(0.137)
Log likelihood	-233.70366	-224.98159	-229.75818	-216.72434

Table 6. Results of interaction mechanisms testing.

role in farmers' adoption of WSIT through a situational interaction mechanism. The higher the benefits of technology adoption are for surrounding people; the more farmers are inclined to adopt the technology. The situational interaction mechanism influences people's behavioral decisions through demonstration results. Wu et al. suggest that individuals form different value perceptions of technology based on the effectiveness of the technology[16]. If the overall benefit of adopting WSIT increases for the surrounding population, farmers perceive the benefit to be greater than the cost and have higher perceived value, thus making a technology adoption decision. Conversely, if the surrounding population generally experiences a loss after adopting WSIT, farmers perceive the benefit to be less than the cost and have lower perceived value, which discourages them from adopting WSIT. This one-way shaping of the situational interaction mechanism achieves group influence on individual farmers' decisions[61]. Potential adopters change the perceived value of the technology by evaluating the effect on other adopters and eventually make adoption decisions.

In Model 5, the coefficient of the cross term between social interaction and the income gap is 4.835 and passes the 1% significance test. This result indicates that social interaction plays a significant role through social norm mechanisms in farmers' WSIT adoption decisions, reflecting the influence of social group norms on individual farmers' behavior. By choosing the same adoption decision as the average of the reference group members to reduce the income gap between the individual and the group through the same behavior, farmers implicitly show their adherence to the common social norms behind this adoption decision and thus are able to gain more respect and cooperation from the reference group members[7].

When the income gap between the farmer and the surrounding reference group members becomes larger and most people abandon the traditional irrigation model in favor of WSIT and when social interaction occurs, WSIT becomes a topic that farmers talk about in their daily lives. The adoption of WSIT becomes the new "descriptive norm" behavior, which leads more potential technology adopters to consider WSIT desirable and worth adopting. Thus, the excessive income gap in the "public consciousness" of the farmer tells the farmer that the adoption of WSIT is valid, acceptable, and safe through social normative mechanisms, helping the individual farmer make a quick decision. Thus, social interaction drives farmers' adoption decisions through social norm mechanisms. Hypothesis H4 is supported.

In Model 6, the situational interaction mechanism and the social norm mechanism pass the 1% significance test, but the endogenous interaction mechanism does not pass the significance test. This may be because most farmers have many years of farming experience, and their rich farming experience makes it difficult for them to change the farming methods and strategies they have learned over the years without seeing obvious benefits from technology adoption[3]. Farmers, as "rational economic people", also continue to modify their behavior in "learning by doing", become more rational and cautious[9], and reduce their blind following behavior. Therefore, before making the decision to adopt WSIT, feedback on the benefits farmers have received for the same decision is more informative than the number of adopters, and the endogenous interaction mechanism similar to the "herd effect" is dwarfed by the combined effect of the three mechanisms.

Intergroup effect comparison of the interaction mechanism

To further explore the interaction mechanisms in the influence process, this paper draws intergroup effect maps for the three kinds of social interactions following the practice of Zheng and Liu[62].

We divide the indicator variables of the three interaction mechanisms into a high-level group (one standard deviation larger than the mean) and a low-level group (one standard deviation smaller than the mean) and describe the impact of social interaction on farmers' WSIT adoption under different levels of interaction mechanisms. The intergroup effect is described in Fig. 1.

Among the three interaction mechanisms, the positive effect of social interaction on farmers' WSIT adoption was stronger in the high-level group than in the low-level group, and the linear slope was greater in the high-level group than in the low-level group. This result indicates that along with the strengthening of the interaction mechanism, the positive influence of social interaction on WSIT adoption through the endogenous interaction mechanism, situational interaction mechanism and social norm mechanism is deepening and WSIT adoption results are significantly higher, which demonstrates the validity of the findings of this paper. In addition, we find

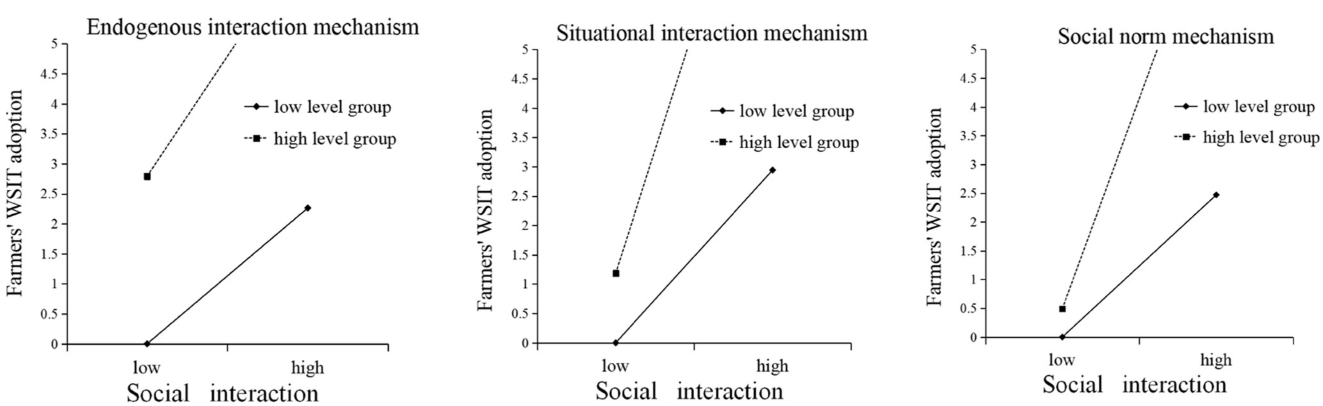

Figure 1. Intergroup effect of the interaction mechanism.

that among the three social interaction mechanisms, the situational interaction mechanism and social norm mechanism are significantly more effective than the endogenous interaction mechanism.

Endogenous test

The process by which social interactions influence farmers' adoption of WSIT may be affected by endogeneity. Endogenous interaction, situational interaction, and social norms reflect the comparison between a farmer's own interactions and those of the surrounding community, mainly highlighting the characteristics of the surrounding community. Thus, the likelihood of endogeneity from these three variables is relatively low. However, it is highly likely that farmers' acquisition of information and social learning through social interactions could lead to endogeneity problems. That is, farmers may not adopt WSIT because they obtained relevant information from social interactions but rather because adopting these technologies requires improving their own abilities and knowledge, thereby motivating continuous learning. Therefore, to address potential endogeneity issues, the instrumental variable method is used.

The selected instrumental variable needs to be highly correlated with the potentially endogenous explanatory variable while remaining uncorrelated with the model's random disturbance term[63]. Drawing from Zhang et al.[64] and Zhang et al.[65], "the average social interaction of other farmers in the same village" is chosen as the instrumental variable for endogeneity testing. On the one hand, rural society, as a "society of acquaintances," entails mutual influence through social interaction among farmers, satisfying the relevance requirement for instrumental variables. On the other hand, the social interaction of other farmers is unrelated to the specific farmer's adoption of WSIT, meeting the exogeneity requirement for instrumental variables.

The results of the instrumental variable estimation (Table 7) show that the Wald test value is significant at the 1% statistical level, indicating the presence of endogeneity in the regression model and confirming the effectiveness of using the instrumental variable method. Subsequently, a weak instrumental variable test was conducted. The results of the first stage show that farmers' level of social interaction is significantly positive at the 1% level, and the F-value in the first stage exceeds 10, indicating no issue of weak instrumental variables. From the second-stage regression results, after using the instrumental variable model, social interaction still has a significant positive effect on farmers' adoption of WSIT, further validating hypothesis H1.

Robustness tests

To ensure the robustness of the study, this section will employ the following methods for further testing to verify the reliability and validity of the regression results.

A. Restricting sample conditions.

This paper adopts the method of restricting sample conditions for robustness testing, drawing on the approach of Yang et al.[66]. Since adopting WSIT requires certain physical conditions for farmers, and considering the health status of elderly farmers, it is possible that some older farmers may be unable to engage in agricultural production[67]. Therefore, this study excludes samples of farmers over the age of 70 and re-conducts the empirical analysis. The results, as shown in Table 8 (Models 7 and 8) are consistent with the full sample results. Overall, social interaction still significantly promotes the adoption of WSIT at the 1% significance level. From the perspective of the four dimensions, depth of SI and frequency of SI passed the 1% and 10% significance tests, respectively, and the signs and significance of the variables remain highly consistent with the previous conclusions. This indicates that the findings are robust.

B. Changing the model.

The robustness of the study is further tested by re-estimating the effect of social interaction using a different model and observing whether the regression results change. Table 8 (Models 9 and 10) present the regression results of the Probit model. The results show that, under this model, social interaction still significantly promotes farmers' adoption of WSIT. Among the four dimensions, depth of SI and frequency of SI significantly promote the adoption of WSIT. The regression coefficients and significance levels of the variables remain consistent, once again indicating that the empirical results are reliable and that the conclusions are robust.

Variables	SI	Technology adoption
Average SI of other farmers in the same village	0.771***(0.159)	/
SI	/	1.813***(0.459)
Control variable [a]	Controlled	Controlled
First-stage F value	23.530	/
Wald chi2(10)	57.61***	
Number of observations	443	

Table 7. Endogenous test of instrumental variables. [a] Control variables are consistent with Table 4. Same below.

	Restricting sample conditions				Changing the model			
	Model 7		Model 8		Model 9		Model 10	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
SI (SI)	1.653***	0.574			0.892***	0.311		
Depth of SI (f_1)			1.704***	0.648			0.878***	0.325
Frequency of SI (f_2)			0.273*	0.162			0.163*	0.094
Direction of SI (f_3)			0.167	0.189			0.086	0.112
Breadth of SI (f_4)			-0.274	0.236			-0.151	0.147
Control variable	Controlled		Controlled		Controlled		Controlled	
Log likelihood	-232.330		-229.801		-233.172		-230.903	

Table 8. Results of robustness tests.

	Poor farming experience		Rich farming experience		Low irrigation water expenditure		High irrigation water expenditure	
	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
SI	1.599** (0.718)		2.011* (1.022)		1.443**(0. 0.736)		1.878*(1.031)	
Depth of SI		3.220*** (1.181)		0.282 (0.844)		1.011** (0.663)		9.468*** (3.564)
Frequency of SI		0.034 (0.210)		0.701** (0.303)		0.190 (0.226)		0.354 (0.271)
Direction of SI		0.089 (0.244)		0.373 (0.332)		0.376 (0.236)		-0.172 (0.385)
Breadth of SI		-0.274 (0.269)		-0.342 (0.827)		0.002 (0.664)		-0.404 (0.305)
Control variable	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
LR chi^2	38.39	48.56	30.7	33.49	25.73	45.05	25.73	37.96
Prob > chi^2	0.000	0.000	0.002	0.004	0.012	0.000	0.012	0.000
Observation	257		186		262		181	

Table 9.. Results of heterogeneity analyses

Heterogeneity analyses

To study the differences in the effects of social interaction among different groups, this section groups the samples according to two criteria: farming experience and irrigation water expenditure, to explore the different roles of social interaction in technology adoption among different farmer groups.

Estimation by farming experience groups

The sample is divided into two subsamples based on the farmers' years of farming experience: the poor farming experience group (below the average years of farming) and the rich farming experience group (above the average years of farming). The analysis is then conducted again, and the results are shown in Table 9.

From the perspective of overall social interaction (Model 11 and Model 13), social interaction is significantly positive at the 5% and 10% levels in both groups, respectively, indicating that social interaction promotes the adoption of WSIT among both poor and rich farming experience farmers. Comparing the coefficients, it is found that the effect of social interaction is stronger for the rich farming experience group than for the poor farming experience group, suggesting that farmers with more farming experience rely more on social interaction to understand and learn about WSIT.

From the perspective of the four dimensions of social interaction (Model 12 and Model 14), the depth of SI in the poor farming experience group passes the 1% significance test, while the frequency of SI in the rich farming experience group passes the 5% significance test. This indicates that for farmers with poor farming experience, the depth of SI has a stronger promoting effect on their technology adoption. In contrast, for farmers with rich farming experience, the frequency of SI plays a more significant role.

Estimation by irrigation water expenditure groups

The sample is divided into low irrigation water expenditure group (below the average irrigation water expenditure) and high irrigation water expenditure group (above the average irrigation water expenditure). The two groups are estimated separately, and the results are shown in Table 9.

According to the results (Model 15–18), social interaction passes the significance test in both groups, with the effect of social interaction being stronger in the high irrigation water expenditure group. The results for the four dimensions of social interaction are consistent with the results from the overall regression. This indicates that, overall, social interaction has a stronger promoting effect on the adoption of technology by farmers in the high irrigation water expenditure group. Structurally, depth of SI plays a more significant role in promoting technology adoption among the high irrigation water expenditure group.

The reason for this result may be that farmers with high irrigation water expenditures are more dependent on water resources in agricultural production, and their production costs are higher. Social interaction helps these farmers share water management experiences, reduce water costs, and encourage them to learn and adopt WSIT[68]. Therefore, social interaction has a stronger promoting effect on farmers with higher irrigation water expenditures.

Conclusions and policy implications

This paper examined the role of social interaction in farmers' WSIT adoption based on 443 household data, constructed a model to verify the endogenous interaction mechanism, situational interaction mechanism and social norm mechanism in the process of social interaction influencing farmers' WSIT adoption, and obtained the following conclusions.

1) Overall, social interaction has a significant positive contribution to farmers' WSIT adoption. The adoption behavior of individual farmers is directly influenced by social interactions with other farmers in the village, and the probability of WSIT adoption increases with the depth of social interactions.
2) The four dimensions of social interaction have different effects on WSIT adoption. The depth and frequency of SI have a significant positive contribution to the adoption of WSIT. The depth of SI has the greatest contribution to farmers' WSIT adoption behavior, followed by the frequency of SI.
3) All three interaction mechanisms, the endogenous interaction mechanism, situational interaction mechanism and social norm mechanism, play an active role in farmers' decisions to adopt WSIT. Specifically, the endogenous interaction mechanism promotes farmers' information exchange and access, the situational interaction mechanism facilitates the demonstration effect of successful WSIT input cases that farmers will follow, and the social norm mechanism makes farmers follow common social norms and refer to the group average for adoption decisions.
4) The role of the situational interaction mechanism and social norm mechanism in promoting farmers' technology adoption is more obvious. "Rational" farmers are no longer limited to "following" the adoption decisions of the surrounding group but pay more attention to the effects after technology adoption and make rational decisions through social learning and "learning by doing". These two interaction mechanisms deepen the positive effect of social interaction on the adoption of WSIT in different ways and significantly increase the likelihood of farmers' adoption of WSIT.
5) The effect of social interaction in promoting the adoption of WSIT varies significantly across different farmer groups. Social interaction has a stronger impact on technology adoption among farmers with longer farming experience and higher irrigation water costs.

The policy implications of the above findings are as follows. (1) The government should continue to promote the construction of village neighborhoods, broaden farmers' information exchange channels, build a technology exchange platform, help farmers escape the time and space constraints of information exchange, and enhance social interactions among farmers. High-frequency and in-depth communication among farmers on agricultural technology issues should be encouraged with a view to improving the reliability and stability of farmers' WSIT adoption behavior and guiding and motivating farmers to make WSIT adoption decisions. (2) Farmers pay more attention to feedback on the benefits of WSIT, so in the process of promoting WSIT, the government should strengthen the follow-up of the adoption effect of WSIT, not just at the level of technology demonstration. The government should increase publicity about the adoption benefits to demonstration households or farmers who have adopted the technology, pay attention to the radiation-driven role of demonstration households, guide the social interaction between demonstration households and potential adopters, and allow the good adoption effect to drive potential adopters to make adoption decisions. (3) The promotion of WSIT should be aimed toward villages with large agricultural income disparities. The large disparity in agricultural income among farmers is conducive to the role of the social norm mechanism in promoting the adoption of WSIT to reduce income disparity and gain group acceptance. At the same time, the role of social interaction can be enhanced to reduce the cost of diffusion and shorten the time of the diffusion of new technologies through interaction mechanisms.

Discussion

Connections and differences with existing research

Regarding the measurement of social interaction, some studies have used a single indicator to measure social interaction[10,12–15], which, although capable of representing one aspect of social interaction, may not provide comprehensive results. Other sociological studies measure social interaction from multiple dimensions, but these are mostly limited to qualitative analysis[20,69,70]. This study draws on the dimensional classification of social interaction from socioeconomics and constructs four dimensions of social interaction to empirically analyze the overall and dimensional roles of social interaction in farmers' technology adoption. This enriches the theories of social interaction and farmers' technology adoption.

From the research findings, (1) overall, social interaction effectively promotes farmers' technology adoption. This is consistent with existing research[27] as social interaction can reduce the information search costs in technology adoption[17] and provide opportunities for skill learning, experience sharing, and mutual assistance[7,27,70,71]. However, the impact of the four dimensions of social interaction on the decision to adopt WSIT is not consistent, which is rarely quantitatively analyzed from a structural perspective in existing research. (2) Social interaction can promote farmers' adoption of WSIT through three interaction mechanisms: endogenous interaction, contextual interaction, and social norms. When these three are included in the model simultaneously, it is found that situational interaction and social norm have a more significant effect on promoting technology adoption, while endogenous interaction is not significant. This conclusion also reflects the shift in farmers' roles between being socially driven and being rational actors. The endogenous interaction mechanism is similar to the herd effect, which is characterized by blind following[71,72], whereas the situational interaction mechanism (demonstration effect) and social norm mechanism are based on rational decisions made after farmers observe the results of technology adoption and the disparities within the group[73,74]. Current analyses of farmers' social interaction mechanisms mainly focus on theoretical discussions, often analyzing farmers from the single identity of a rational actor, and lack consideration of the role shift between social and rational actors[75–77].

Limitations and future improvement
There are still some limitations in this study, which need to be improved in further research. On the one hand, the study of social interaction on farmers' adoption of WSIT should be a long-term process of change, and it is difficult to have a profound study on this issue simply by using cross-section data. If long-term tracking survey data can be obtained, it will be of far-reaching significance for in-depth study on the mechanism of social interaction affecting farmers' WSIT adoption.

On the other hand, in terms of the survey area, sample selection should not be limited to one place. In this study, only Minqin was selected as the survey area, which is somewhat regrettable. Of course, this kind of rigorous and detailed survey data with a large region and time span requires a lot of manpower, financial resources, material resources and time investment. Under the current conditions, the investigation results of existing research are not easy.

In future studies, it is necessary to form a complete investigation system as far as possible, establish a variety of fixed observation points, organize investigation teams to conduct long-term follow-up investigations, and form a database on the influence of social interaction on farmers' technology adoption, so as to further analyze the role of social interaction on farmers' dynamic adoption of WSIT, which will be more meaningful.

Data availability
The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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