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What drives the adoption of sustainable production technology? Evidence from the large scale farming sector in East China

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A B S T R A C T

Sustainable agricultural production technologies such as formula fertilizer and soil testing have caught attentions from government agencies and scholars as a potential solution to environmental problems associated with overuse of fertilizers. A lack of motivation from farmers has slowed the adoption of sustainable technologies in China, resulting in continued deterioration of the rural environment. Recently, China's agriculture is experiencing rapid consolidation due to structural adjustments and labor migration. Large scale farming is becoming a major force for promoting sustainable rural development and agricultural production. This study applies the theory of planned behavior to explain the adoption of formula fertilizer and soil testing technology among 690 large scale producers in Eastern China. The path analysis shows the attitude, subjective norm (perceived social pressure), and perceived behavior control (perceived ability or risk) significantly increase farmers' adoption intention. The only path that determines the actual behavior directly is behavioral intention. These findings suggest that, in addition to social, economic and institutional factors, policies aiming at promoting sustainable agricultural production should address the psychological dimensions of technology adoption. Effective approaches should be developed to cultivate farmers' positive attitudes, social norms consciousness, perceived abilities, as well as reduce perceived risks to increase their interests in adopting the technology.

1. Introduction

Excessive application of chemical fertilizers and continuing nutrient loss have caused various environmental problems, including eutrophication (surface water), nitrate accumulation (groundwater), and greenhouse gas emissions (Zhang et al., 2015; Ng et al., 2018). China is the world's largest consumer of fertilizers with applications that exceeded 225 kg/ha (the standard to prevent water pollution in developed countries) in 1995 and kept increasing ever since. In 2018, fertilizer applications reached a high of 358.22 kg/ha (National Bureau of Statistics of China, 2019), which was 59.21% higher than the standard (225 kg/ha). Compared to developed countries that have a high fertilizer use efficiency at 60%–70%, the efficiency of nitrogen fertilizers in China is only about 30%, while those of phosphate and potash fertilizers are between 10-25% and 35–50%, respectively (Guo et al., 2014).

To address these problems, many countries have been promoting various sustainable technologies (Guan et al., 2005). Sustainable production technologies could enhance the agricultural productivity and resilience of agricultural systems, and minimize adverse environmental effects (Zaman, 2019). Sustainable practices involve reducing the use of inputs that are potentially harmful to the environment and shifting towards a more locally based economy (Wezel et al., 2014). The literature has studied straw return technology in China (Zhao et al., 2014), organic fertilizers in Tanzania (Arslan et al., 2017), and integrated plant nutrition management in Nigeria (Ayeni, 2011). India has expanded the use of a balanced nutrient management plan based on soil testing (Wani et al., 2015), and some countries in Asia have employed site-specific nutrient management strategies for rice production (Dobermann et al., 2003).

Research shows adopting sustainable agricultural technologies plays an important role in food security and rural poverty alleviation (Khan et al., 2013). Conway and Barbier (2013) found that the application of organic fertilizer contributes significantly to

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environmental sustainability. Application of formula fertilizer based on soil testing and controlled release fertilizers reduce overuse of fertilizers and nutrient loss in agriculture (Ni et al., 2011). The effective adoption of integrated pest management may reduce water and soil pollution and input costs (Wezel et al., 2014).

As the largest developing country, China's sustainable agricultural development bears important implications for other countries that are facing similar issues (Li et al., 2018). China has been promoting the formula fertilizer and soil testing (FFST) technology since 2005. The site-specific nutrient management approach helps to efficiently use fertilizers based on soil testing and minimize the environmental damage from fertilizer overuse. FFST stands out from other sustainable technologies because of its effectiveness in preventing soil and water pollution. Field trial results show FFST can increase crop yield by 6–10% and increase profits by more than 450 RMB per hectare (Sun, 2009). Life-cycle environmental benefit analysis suggests FFST could significantly reduce the emissions of various pollutants, with total nitrogen and total phosphorous declining by 1.36% and 4.9%, respectively (Wang et al., 2012). The Chinese government regarded this technology as a critical measure to address agricultural pollution. As of 2016, the Chinese central government has invested approximately 9.20 billion RMB in promoting FFST, covering 2498 counties and 26.67 million hectares (Ministry of Agriculture and Rural Affairs of China, 2017) that accounted for 19.77% of the total cropland in China in 2016 (National Bureau of Statistics of China, 2017).

Studies often assume that farmers make production technology decisions based on utility or profit maximization (Just and Pope, 1979; Guan and Wu, 2020). Many economic models have been proposed to analyze the factors affecting farmers' adoption of eco-friendly technologies, including farm size, uncertainty and risk, credit and financial constraints, access to technical information, and farmers' educational attainment (Magruder, 2018). Man and Li (2010) found the three most important factors affecting Chinese farmers' decisions regarding adoption to be input cost, household asset level, and risk. Based on a review of 23 studies investigating the adoption of conservation agriculture technologies, Knowler and Bradshaw (2007, p.44) concluded "there are few if any universal variables that regularly explain the adoption of conservation agriculture across past analyses". Michler et al. (2018) found that despite improved chickpea variety in Ethiopia having no impact on yields farmers still adopted the technology. Because of the multi-layered, complex nature of farmers' livelihoods objectives and decision-making, profit-maximizing economic models are intrinsically limited in capturing the farmers' decision-making process (Lynne et al., 1988). Due to the limited explanatory power of socioeconomic factors, scholars look into psychological factors such as farmers' perceptions and attitudes to explain farmers' adoption behaviors, for instance, Singh et al. (2020), Kernecker et al. (2019) and Hou et al. (2018) have incorporated farmers' perception into their models.

The above literature suggests demographic, socioeconomic and institutional factors could be the explanation for low technology adoption rate, however, these factors may not fully capture the complexity of farmers' behavior. Farmers may not adopt an innovation even when the economic theory predicts they should. Vice versa, farmers may adopt a sustainable technology even when economic benefits are not clear in the short term. There is a missing link in explaining the adoption decisions of sustainable technologies in addition to socioeconomic factors and we suggest it is the psychological facet of adoption behaviors.

Since the introduction of the Household Responsibility System in China in the late 1970s, land has been divided and allocated to individual households according to family size (Wan and Cheng, 2001). Most family farms are smallholders or subsistence farming given the limited amount of land owned per household. The typical farmland size of a rural household is approximately 7.5 mu (0.5 ha) according to the recent national agricultural census of China (Wu et al., 2018). As China's economy develops, industrialization and urbanization have triggered a large scale migration of agricultural labor into cities and the non-farm sectors. Therefore, land consolidation that forms larger operations with the economies of scale has become a crucial component of China's agricultural modernization. The heightened competition among agricultural producers in China has made large scale farming the major force in China's agriculture and has significantly affected the rural development. Our study focuses on large scale farming and in general, farms larger than 50 mu (3.33 ha) could be considered large scale farming in China (Luo et al., 2019).

The objectives of this study are twofold. First, it investigates socio-psychological factors influencing farmers' adoption behavior regarding sustainable technologies based on the theory of planned behavior (TPB). TPB is a classical theory in social psychology which provides a useful framework for understanding and predicting individuals' adoption behavior regarding environmental protection measures (Menozzi et al., 2015a). Second, it adds to the knowledge of technology adoption behavior by focusing on large scale producers, which have been a major force in driving modernization in China's agriculture. Our results generate insights that will help policymakers to develop appropriate policy interventions to achieve sustainable development in rural areas.

The remainder of the study is organized as follows: Section two introduces the literature review and theoretical framework. Section three presents the data and estimation methods. The results are presented in section four, the section five provides an in-depth discussion and conclusion and policy implications are presented in section six.

2. Literature review and theoretical framework

2.1. Previous empirical studies

The TPB model can be used to analyze farmers' intention and actual behavior regarding sustainable agricultural technologies. Previous studies have used TPB to investigate farmers' intentions in adopting these technologies. Terano et al. (2015) found attitudes, subjective norms and perceived control positively influenced farmers' intentions to adopt sustainable practices in Malaysia. Menozzi et al. (2015b) discovered attitude was a significant factor in the intentions to adopt sustainable practices in Italy, while subjective norms and perceived controls were insignificant motivators. Zeweld et al. (2017) revealed attitude, normative issues and perceived control positively affect farmers' intentions to adopt minimum tillage in Ethiopia. Despotović et al. (2019) found attitude, subjective norms, and perceived behavioral control, together with farm size, explain 49% of farmers' intention to use integrated pest management practices in Serbia.

Some research has applied TPB to analyze farmers' actual adoption behavior regarding sustainable practices. Lynne et al. (1995) considered farmers' attitudes toward water-saving irrigation measures, subjective norm, and perceived behavioral control as significant predictors of farmers' investments in these measures. Beedell and Rehman (2000) used TPB to analyze farmers' conservation-related behavior in the UK. Wauters et al. (2010) employed TPB to elicit the factors explaining the adoption of soil erosion controlling practices in Belgium. Yazdanpanah et al. (2014) examined perceived behavioral control exerts a direct influence on Iranian farmers' adoption of new irrigation systems and rainwater harvesting techniques, whereas attitudes and subjective norms indirectly influence this behavior via behavioral intention.

The TPB model is well supported empirically as a theoretical foundation to investigate pro-environmental behaviors (Greaves et al., 2013). Some studies used TPB to study the adoption of agri-environmental technologies. However, research in the context of China is limited.

2.2. Theoretical framework

The TPB is a classical theory in the field of social psychology that explains and predicts human behaviors. It assumes human behavior is rational and not solely dependent on individuals' will. It is based on the theory of reasoned action (Ajzen and Fishbein, 1973), stating that a person's actual behavior is directly guided by his/her behavioral intention, while the behavioral intention is jointly determined by the subjective norm and attitude. However, because the theory of reasoned action assumes that behavior is controlled by individuals' will, it cannot be applied to behaviors in which individuals have incomplete volitional control. In order to expand the scope of this theory, Ajzen amended it, adding perceived behavioral control, formally proposing TPB in 1991 (Fig. 1).

2.2.1. Attitude toward FFST

Attitude toward a behavior refers to the degree to which a person has a favorable or unfavorable evaluation of the behavior (Ajzen, 1991). It includes an individual's judgment of behavior morality, and a desire to perform the behavior (Leonard et al., 2004). An individual tends to possess a favorable attitude when the outcomes are positive and, is likely to engage in that behavior (Han et al., 2010). Positive attitudes are likely to arise from the perceived or expected good economic, environmental and societal outcomes from the adoption of sustainable technologies. In this study, attitude toward FFST is measured by farmers' attitudes towards the outcomes of adopting FFST. Positive outcomes include increased yield, reduced fertilizer usage, alleviated water pollution, and improved soil quality (Pandey et al., 2012; Yang, 2014). In this study, we hypothesize that:

H1. Producers' attitude toward FFST has a positive and significant effect on behavioral intention.

2.2.2. Subjective norm

Subjective norm refers to perceived social pressure to perform or not perform a behavior (Ajzen, 1991). If an individual believes people important to them approve (disapprove) the behavior, then he will be more (less) likely to perform sound behavior, thus affecting their behavioral intention. Taylor and Todd (1995) have described the variable as "the effect of other people's opinion, superior influence, and peer influence". Primary sources of social pressure are government, extension agents, and neighbors (Hunecke et al., 2017). Family is also another significant source of pressure because household decisions are likely discussed by the whole family. Regarding subjective norm, our hypothesis is:

H2. Producers' subjective norm has a positive and significant effect on behavioral intention.

2.2.3. Perceived behavioral control

Perceived behavioral control is the perceived ease or difficulty of performing a behavior (Ajzen, 1991). It is an individual's perception of a person's available resources and opportunities to perform the behavior. Perceived behavioral control assesses an individual's perception of how well he can control the factors that may facilitate or constrain his ability to handle a specific situation (Han and Yang, 2011). When individuals believe they possess more resources and opportunities, anticipate fewer obstacles, and perceive greater control over the behavior, they are more likely to adopt the technology. Perceived behavioral control affects both behavioral intention and actual behavior directly according to TPB. Farmers in the developing countries are faced with significant production risks (e.g., climate variability) because of their reliance on rain-fed agriculture (Hazell et al., 2010). In our study, perceived behavioral control is measured by a combination of perceived ability and perceived risk of adopting FFST. The hypothesized roles of perceived behavioral control are as follows:

H3. Producers' perceived behavioral control has a positive and significant effect on behavioral intention.

H4. Producers' perceived behavioral control has a positive and significant effect on actual behavior.

2.2.4. Behavioral intention

A central component of TPB is an individual's intention to perform a certain behavior. This intention indicates how much effort an individual is willing to exert to perform a behavior, which has a direct impact on actual behavior. We ask farmers to indicate whether they intend to adopt or promote FFST to measure

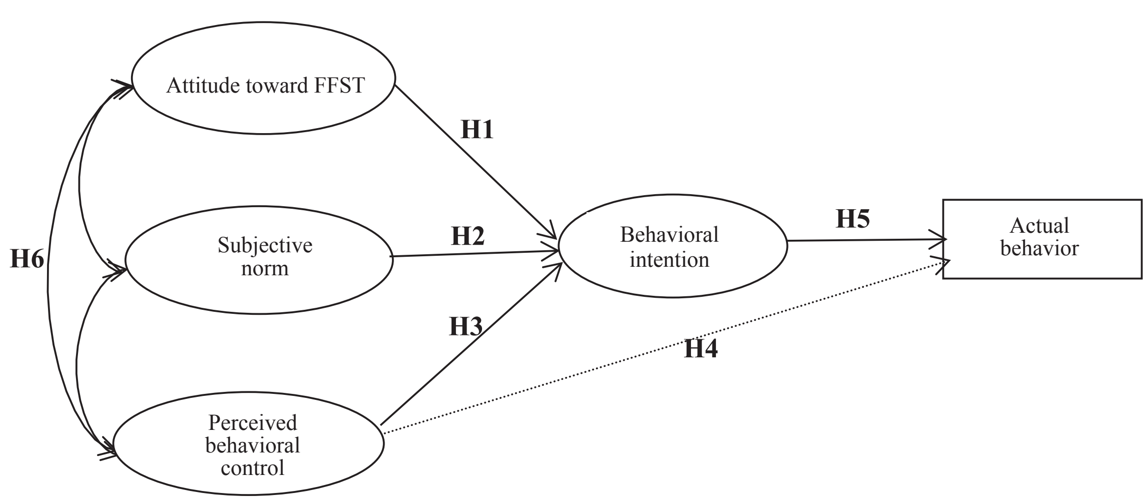

Fig. 1. The conceptual framework for TPB applied to FFST.

behavioral intention in our study. Our hypothesis is:

H5. Producers' behavioral intention has a positive and significant effect on actual behavior.

2.2.5. Actual behavior

There are two types of variables in behavior studies, namely latent variables (that cannot be directly measured) and observed variables (that can be observed and used to infer the information of latent variables). Actual behavior is observable and it is a binary variable. For example, Wauters et al. (2010) directly assessed the adoption of conservation agriculture practices as a binary variable (yes-no) using TPB.

In understanding adoption behavior regarding sustainable technology, a dichotomous variable would suffice (Wauters et al., 2010). The actual behavior reported by farmers is observable and coded as a binary variable, while other TPB constructs, including attitude toward FFST, subjective norm, perceived behavioral control and behavioral intention are latent variables, and thus cannot be observed or directly measured. A set of questions is designed to infer the information for the underlying latent variables (see Table 1). Farmers were asked to respond on a five-point Likert-scale, ranging from "strongly disagree" (1) to "strongly agree" (5). Our final hypothesis is:

H6. There are interactions between producers' attitude toward FFST, subjective norm, and perceived behavioral control.

3. Data and method

3.1. Questionnaire design

A questionnaire was developed using a three-stage process: (1) a literature review conducted to identify candidate constructs and measures used in previous research; (2) a five-point Likert-scale design approved by experts; (3) a preliminary test to determine the reliability of the questionnaire constructs. The questionnaire designed to investigate farmers' adoption behavior regarding FFST consisted of three sections: (1) introduction to the research background; (2) farmers' demographic characteristics, including gender, age, and educational attainment; (3) TPB-constructs as defined in Table 1.

3.2. Data collection

Data were collected in Jiangsu and Jiangxi provinces in China in 2016 (Fig. 2). These provinces are located in the middle and lower reaches of the Yangtze River, and represent the largest concentration of freshwater lakes in China (Cui et al., 2013). They are China's important provinces of agriculture with rice and wheat being the primary crops.

The stratified random sampling was adopted in sample selection. Eight sample counties (districts) were selected according to the economic condidtion and cultivated land area in each province. Two to four towns were randomly selected from each county. We then randomly selected 20 farmers from the roster of large scale producers in each town. We conducted the surveys via in-person interviews. 704 large scale producers were surveyed, and 690 (98.01%) valid responses were collected. Table 2 contains their demographics.

3.3. Data analysis

The structural equation model (SEM) was employed because of its capability to analyze the relationship and interactions between latent variables and observable variables. SEM can produce an accurate measurement with multiple indicators. SEM allows simultaneous assessment of the reliability and validity of theoretical constructs and the estimation of the relationships among these constructs (Lomax and Schumacker, 2004). We used AMOS for the analysis (Arbuckle, 2003).

The SEM includes two inter-related procedural models: a measurement model and a structural model. The measurement model illustrates how the latent variables are measured by the observed variables, and the structural model specifies the relationship between the latent variables (Sarstedt et al., 2014). The model can be written as follows:

$$y_1 = \gamma_{11}ATT_1 + \gamma_{12}ATT_2 + \gamma_{13}ATT_3 + \gamma_{14}ATT_4 + \beta_1 y_2 + \beta_2 y_3 + \varepsilon_1 \quad (1)$$

$$y_2 = \gamma_{21}SN_1 + \gamma_{22}SN_2 + \gamma_{23}SN_3 + \beta_3 y_1 + \beta_4 y_3 + \varepsilon_2 \quad (2)$$

$$y_3 = \gamma_{31}PBC_1 + \gamma_{32}PBC_2 + \beta_5 y_1 + \beta_6 y_2 + \varepsilon_3 \quad (3)$$

$$y_4 = \gamma_{41}BI_1 + \gamma_{42}BI_2 + \beta_7 y_1 + \beta_8 y_2 + \beta_9 y_3 + \varepsilon_4 \quad (4)$$

$$y_5 = \beta_{10} y_3 + \beta_{11} y_4 + \varepsilon_5 \quad (5)$$

wherey_1-$y_5$represent attitude toward FFST, subjective norm, perceived behavioral control, behavioral intention, and actual

Table 1
Measurement of the variables.

Variables	Measurement variables	Variable definition	Literature sources
Attitude toward FFST	ATT_1	This technology can increase yield.	(Pandey et al., 2012; Yang, 2014)
	ATT_2	This technology can reduce the amount of fertilizers applied.	
	ATT_3	This technology can protect soil quality.	
	ATT_4	This technology can mitigate water pollution.	
Subjective norm	SN_1	The government and technical extension staff think you should adopt the technology.	Tonglet et al. (2004)
	SN_2	Your neighbors think you should adopt the technology.	
	SN_3	Your family thinks you should adopt the technology.	
Perceived behavioral control	PBC_1	Do you have the ability to adopt the technology?	Terry (1995)
	PBC_2	Can you bear the risk of adopting the technology?	Manstead and van Eekelen (1998)
Behavioral intention	BI_1	Would you like to adopt the technology?	Ajzen (1991)
	BI_2	Would you like to promote the technology to neighbors?	
Actual behavior	–	Did you adopt the technology this year?	Ajzen (1991)

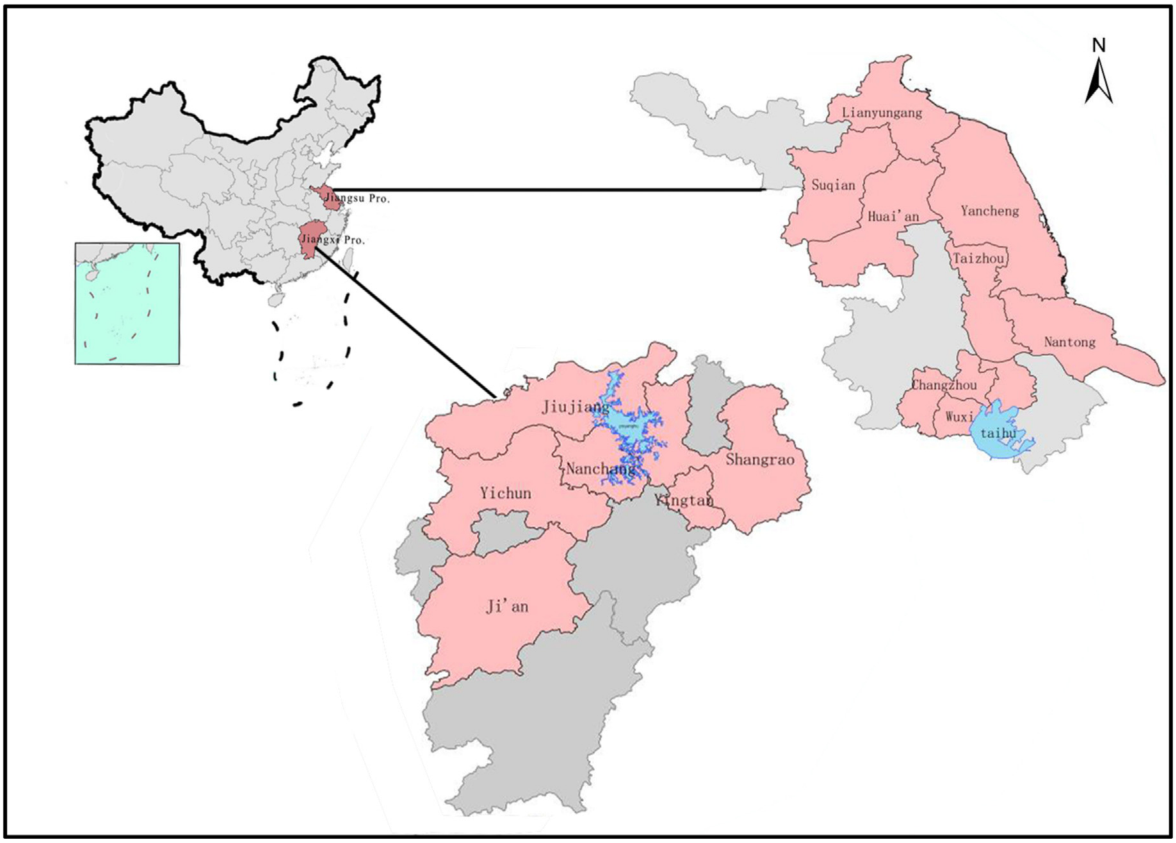

Fig. 2. Location of the study areas.

Table 2
Demographics of respondents.

Characteristic	Classification	Sample size	Percentage (%)
Gender	Male	656	95.07
	Female	34	4.93
Age (years)	18–39	85	12.32
	40–49	280	40.58
	50–59	248	35.94
	60 & above	77	11.16
Educational attainment (years)	0	22	3.19
	1–6	146	21.16
	7–9	333	48.26
	10–12	144	20.87
	13 & above	45	6.52

behavior, respectively; $\beta_i$represents the path coefficients between the latent variables; $\gamma_i$represents the path coefficients between the observed and latent variables, and ε_i represents residuals.

4. Results

4.1. Description statistics

Table 3 presents the means and standard errors of variables. The latent variable of attitude toward FFST is proxied by answers to four questions: whether FFST can increase yield (ATT_1), reduce the amount of fertilizers applied (ATT_2), protect soil quality (ATT_3), and mitigate water pollution (ATT_4). In a 5-point measurement scale, the reported mean ATT_1, ATT_2, ATT_3, and ATT_4 scores are 3.697, 3.526, 3.651 and 3.632, respectively. They are all greater than 3, which means that, overall, farmers show a positive attitude toward FFST. The subjective norm is proxied by answers to three questions: whether the government and technical extension staff (SN_1), neighbors (SN_2) and family members (SN_3) agree with the idea that farmers should adopt FFST. The mean score of SN_1 is the highest (3.413). This indicates farmers have higher perceived social pressure from the government and technical extension staff (SN_1) than from neighbors (SN_2) and family members (SN_3). Two questions are developed to measure the perceived behavioral control: the perceived ability to adopt FFST (PBC_1) and the perceived risk of adopting it (PBC_2). Behavioral intention is measured by answers to two questions: would you like to adopt FFST (BI_1) and would you like to promote the technology to your neighbors (BI_2)? In a 5-point measurement scale, the mean BI_1 and BI_2 scores are 3.916 and 3.925, respectively, which suggest farmers have a positive intention to adopt or promote the technology. However, positive intention doesn't directly translate into actual behavior. On average, 20.6% of farmers reported they adopted FFST this year.

4.2. Measurement model: reliability and validity

Reliability measures the consistency of TPB-constructs and is generally determined using the coefficient of Cronbach's Alpha (CA). The CA values range from 0 to 1, with higher values reflecting higher reliability. The general rule of thumb is a CA coefficient higher than 0.7 indicates high reliability (Tonglet et al., 2004). As shown in Table 4, the CA coefficients for respondents' attitudes toward FFST, subjective norm, and perceived behavioral control are 0.874, 0.950, and 0.777, respectively, all exceeding 0.7. Fornell and Larcker (1981) have also suggested a CA coefficient greater than 0.6 is acceptable in applied research. The CA coefficient for

Table 3
The mean and standard errors of each variable.

Variables	Variable definition	Mean	S.D.
Attitude toward FFST	This technology can increase yield. (ATT_1)	3.697	0.775
	This technology can reduce the amount of fertilizers applied. (ATT_2)	3.526	0.857
	This technology can protect soil quality. (ATT_3)	3.651	0.791
	This technology can mitigate water pollution. (ATT_4)	3.632	0.770
Subjective norm	The government and technical extension staff think you should adopt the technology. (SN_1)	3.413	1.295
	Your neighbors think you should adopt the technology. (SN_2)	3.122	1.262
	Your family thinks you should adopt the technology. (SN_3)	3.236	1.280
Perceived behavioral control	Do you have the ability to adopt the technology? (PBC_1)	3.101	1.081
	Can you bear the risk of adopting the technology? (PBC_2)	3.183	1.038
Behavioral intention	Would you like to adopt the technology? (BI_1)	3.916	0.834
	Would you like to promote the technology to neighbors? (BI_2)	3.925	0.875
Actual behavior	Did you adopt the technology this year?	0.206	0.405

Table 4
The reliability and validity of the latent variables in the measurement model.

Latent variables	Number of measurement variables	CA	KMO	Bartlett (significance)
ATT	4	0.874	0.824	1405.615 (0.000)
SN	3	0.950	0.731	2236.063 (0.000)
PBC	2	0.777	0.500	355.192 (0.000)
BI	2	0.623	0.500	157.539 (0.000)

Note: CA is the abbreviation of Cronbach's Alpha. The Kaiser-Meyer-Olkin (KMO) values and Bartlett sphericity test values are obtained by factor analysis.

behavioral intention is 0.623, which is above 0.6. Therefore, there is consistency within the four measurement constructs.

Before estimating the model, we evaluated the validity of the data structure of the five-point Likert-scale for this study. If the sample data can be used for factor analysis, the Likert-scale generally has good construct validity. The Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests can be used to determine whether the sample data is suitable for factor analysis. The KMO statistic value varies between 0 and 1, and it should be greater or equal to the acceptable threshold of 0.5 for satisfactory factor analysis to proceed (Norusis, 2008). Kaiser (1981) also suggests a KMO equal to 0.50 is adequate for factor analysis. When Bartlett's p-values for all the latent variables are less than 0.01, the sample data are suitable for factor analysis and therefore have appropriate construct validity. Based on the results shown in Table 4, the Likert-scale has sufficient construct validity.

4.3. Structural model: goodness of fit

As shown in Table 5, all the indicators demonstrate the goodness of fit; in other words, the model fits the data well.

4.4. Hypothesis testing

Fig. 3 displays the results of the hypotheses tests. All path coefficients, except for the one between perceived behavioral control and actual behavior, were positive and significant at the 1% significance level. This indicated respondents' attitudes toward FFST, subjective norm, and perceived behavioral control had statistically significant, positive effects on behavioral intention, thus supporting our hypotheses H1, H2, and H3. Additionally, the effect of perceived behavioral control on actual behavior was not significant; however, the behavioral intention had a significant and positive effect on actual behavior. Therefore, hypothesis H4 was rejected, while hypothesis H5 was supported. There were also statistically significant interactions between attitude toward FFST, subjective norm, and perceived behavioral control, which supported hypothesis H6.

5. Discussion

5.1. Path analysis

Fig. 3 presents the standardized path analysis of the structural model. The beta values of the path coefficients indicate the direction and magnitude of the influence of the predictors on the latent constructs (Zhang et al., 2013). First, attitude toward FFST had a strong positive effect ($\beta_7 = 0.301$, $P < 0.01$) on behavior intention. Rezaei-Moghaddam and Salehi (2010) found attitude toward precision agriculture technologies positively affected farmers' adoption intention in Iran. Wauters et al. (2010) and Zeweld et al. (2017) indicated that attitude could effectively explain the adoption intention towards sustainable agricultural practices. Our results indicate that one point increase in farmers' attitude toward FFST

Table 5
Fit indices of the structural model.

Model fit index	Recommended acceptable level	Index value
Chi-square value/degree of freedom	1−3.0	1.923
GFI	≥0.9	0.978
RMSEA	<0.05	0.037
NFI	≥0.9	0.904
TLI	≥0.9	0.931
CFI	≥0.9	0.951

Note: GFI denotes Goodness of Fit Index, RMSEA Root Mean Square Error, NFI Normed Fit Index, TLI Tucker-Lewis Index, and CFI Comparative Fit Index.

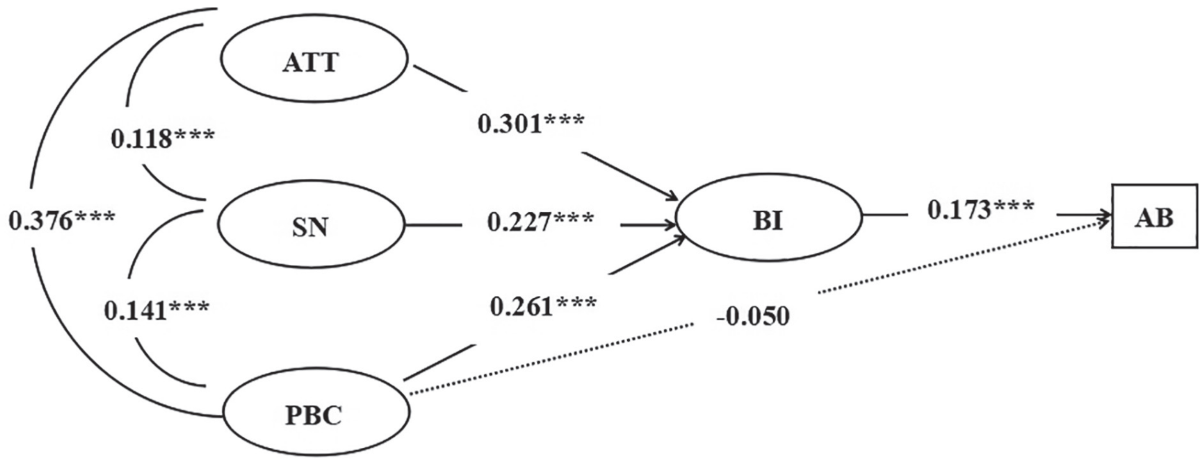

Fig. 3. The standardized path coefficients and significance of the structural model.
Note: *** indicates $p < 0.01$. ATT represents attitude toward FFST, SN subjective norm, PBC perceived behavioral control. BI behavioral intention, AB actual behavior.

raised their behavior intention by 0.301 points. This implied attitude toward FFST contributed more to the formation of farmers' behavioral intention than perceived behavioral control and subjective norm ($\beta_7>\beta_9>\beta_8$). This is consistent with the research of Van Hulst and Posthumus (2016), which showed that attitude and perceived behavioral control played important roles in contributing to intentions to adopt conservation agriculture practices. Generally, when farmers realize FFST could increase yield, reduce the amount of fertilizers applied, protect soil quality, and mitigate water pollution, they are more willing to adopt it.

The subjective norm, which represents the influence of reference groups and external forces (namely government, agricultural extension staff, neighbors, and their family), had a significant and positive effect ($\beta_8 = 0.227$, $P < 0.01$) on farmers' behavioral intention. Geng et al. (2010) and Borgstede and Andersson (2010) found the social pressure was an important factor to influence enterprises' willingness to adopt cleaner production technologies. Beedell and Rehman (2000) also found social norms, such as community influence, had an impact on farmers' willingness to adopt new technologies. In the literature, Far and Moghaddam (2015) examined subjective norm would affect farmers' intention to adopt water saving measures. Zeweld et al. (2017) demonstrated that favorable subjective norms lead to stronger intentions to adopt sustainable practices, such as minimum tillage and row planting. Based on the self-categorization theory, individuals are more likely to identify themselves within a specific group and imitate that group's behavior to avoid being left out and gain social acceptance (Cialdini and Goldstein, 2004). Farmers' willingness to adopt organic farming can be constrained by sociological barriers (negative opinions of family and other farmers regarding organic agriculture) (Gardebroek, 2006).

Perceived behavioral control, which accounts for farmers' perceptions of ability (Terry, 1995) and perceived risk (Manstead and van Eekelen, 1998) to adopt FFST, had a significant and positive effect ($\beta_9 = 0.261$, $P < 0.01$) on farmers' behavioral intention. As suggested by Zeweld et al. (2017), the greater the perceived behavioral control, the stronger the farmers' intention to adopt advanced farm practices. Even if a farmer had a positive attitude toward FFST, his perceived ability and perceived risk would also influence behavior intention. The significant effect of perceived behavioral control on behavioral intention may indicate the presence of some inhibiting factors or the absence of some necessary skills or resources to perform the behavior (Wauters et al., 2010).

Farmers' behavioral intention had a significant and positive effect on actual behavior ($\beta_{11} = 0.173$, $P < 0.01$). Wauters et al. (2010) showed that behavioral intention is the dominant determinant of the behavior. The stronger the behavioral intention, the more likely the farmers would adopt FFST. Behavioral intention can affect actual behavior only if the behavior in question is under volitional control. While some behaviors may meet this requirement, they still depend on external factors such as the availability of opportunities and resources (e.g., time, money and skills). In this study, farmers' perceived behavioral control did not have a significant effect ($\beta_{10} = -0.050$) on actual behavior. Ajzen and Madden (1986) suggested that a direct impact on actual behavior from perceived behavioral control might appear only when perceived behavioral control was close to farmers' actual behavioral control.

Further findings showed the path coefficients between attitude toward FFST (ATT) and subjective norm (SN) ($\beta_1 = \beta_3 = 0.118$, $P < 0.01$), those between SN and perceived behavioral control (PBC) ($\beta_4 = \beta_6 = 0.141$, $P < 0.01$), and those between ATT and PBC ($\beta_2 = \beta_5 = 0.376$, $P < 0.01$) were all significant and positive. This indicated ATT, SN, and PBC were interdependent, which is consistent with previous studies (Huhtala, 2003). This study further confirmed farmers' behavioral intention had a significant impact on actual behavior, suggesting their behavioral intention served as a medium between ATT and actual behavior, SN and actual behavior, and PBC and actual behavior.

5.2. Theoretical and practical implications

The contribution of this study from the theoretical perspective is expanding and validating the applicability of TPB to analyze the psychological factors that may affect agricultural technology adoption decisions in a country that has a different land ownership institution and agricultural system. The theoretical framework of TPB adequately explains producers' adoption behavior regarding FFST. Our study suggests the theory could be applied to a broader application setting to examine the adoption decision of soil and water pollution prevention technologies.

From an empirical application perspective, this study uses the social psychology theory—the TPB model—to explore factors driving the adoption of sustainable production technology in China. This complements the current body of literature that investigate technology adoption either from the perspective of economics alone, or by focusing only on psychological cognition variables (El-Kassar and Singh, 2019; Kernecker et al., 2019; Singh et al., 2019). This research is the first study that applies TPB to analyze large scale producers' adoption behavior regarding environmentally friendly technologies in China. Large scale farming is a force of rural development in China and is critical for the modernization of China's agriculture. Their adoption of sustainable production technology has important implications for the environment and will have spillover effects to the entire agricultural sector.

6. Conclusion and policy implications

6.1. Conclusion

This study applies TPB to analyze the adoption of FFST in the large scale farming sector in China. The results suggest the usefulness and applicability of TPB in determining the adoption behavior regarding FFST. We validated the conceptual framework, identified the determinants of technology adoption, and tested our hypotheses using data collected in a survey.

The results show the farmers' adoption intention regarding FFST is driven by three determinants: attitude toward FFST, subjective norm and perceived behavioral control. The attitude toward FFST has the strongest impact on the willingness to adopt FFST compared to perceived behavioral control and subjective norm. Hence, if farmers realize that FFST has economic and environmental benefits (e.g., increasing yield, reducing fertilizer use, alleviating water pollution, and improving soil quality), they would have a positive attitude toward FFST and may be more willing to adopt it.

Subjective norm, referring to the social pressure perceived by farmers, significantly influences their adoption intention regarding FFST as farmers are subjected to cultural norms and social expectations consciously and subconsciously. In this study, social pressure comes from government, agricultural extension staff, neighbors, and farmers' family. Higher perceived social pressure raises farmers' intentions to adopt FFST. The positive and significant correlation between perceived behavioral control and adoption intention regarding FFST indicates that farmers' positive perceptions about their abilities to successfully adopt the technology could encourage farmers to adopt it.

Farmers' adoption intention has a positive and significant effect on actual adoption behavior. Farmers are more likely to execute the intention and adopt FFST when they see the technology as beneficial (Adnan et al., 2018). Perceived behavioral control does not have a significant impact on their adoption behavior. Knowler and Bradshaw (2007) argued people's behaviors are usually under the control of normative or attitudinal control while the impact of perceived behavioral control on actual behavior is trivial. Finally, the results support the hypothesis that there are statistically significant interactions between attitude toward FFST, subjective norm, and perceived behavioral control.

6.2. Policy implications

This study provides useful insights for policymakers seeking to promote FFST. Policies should aim to improve farmers' attitude toward FFST. One example would be, showing the serious consequences of fertilizer overuse via visual demonstrations or by providing examples of successful FFST projects to build farmers' confidence in FFST. Policymakers should pay attention to the opinions or suggestions of groups that could impact farmers' technology adoption decisions. This suggests they should also channel technology information to these groups, including agricultural extension staff, neighbors, and their immediate family members. Policies could further focus on increasing farmers' perceived abilities and reducing their perceived difficulties in adopting FFST. Our results generate insights that could help policymakers develop appropriate policy interventions to achieve agricultural sustainable development. When making policies to promote sustainable production, it is important to address the psychological dimensions of technology adoption, in addition to social, economic and institutional factors.

6.3. Limitations and future research

From a theoretical perspective, a common criticism of attitude-based research is that self-reported behavior and actual behavior might be inconsistent in some observations. Researchers have found that TPB could account for the issue when the attitudes and behaviors are accurately defined (Armitage and Conner, 2001). Future research could collect observed adoption data to further validate the TPB model. This study used information collected in Jiangsu and Jiangxi provinces in East China. More comprehensive studies covering a larger geographical region at the national level could increase our understanding. Moreover, future research could extend the TPB model to include farmers' environmental concerns/beliefs (Bamberg, 2003), environmental knowledge (Fryxell and Lo, 2003), and moral norms (Fishbein and Ajzen, 2011) in farmers' decision-making process.

Declaration of 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.

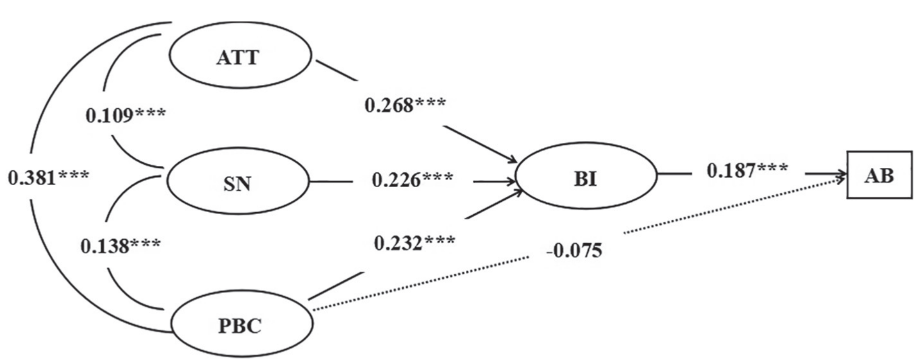

Fig. A1. The results of the structural model using LISREL software.
Note: *** indicates p < 0.01. ATT represents attitude toward FFST, SN subjective norm, PBC perceived behavioral control. BI behavioral intention, AB actual behavior.

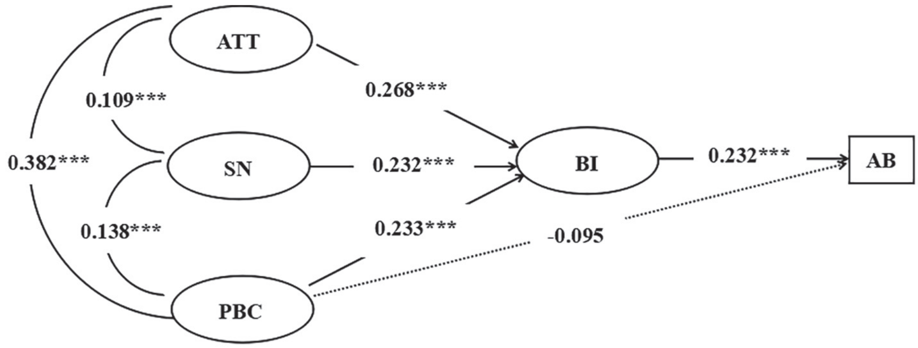

Fig. A2. The results of the structural model using STATA software.
Note: *** indicates p < 0.01. ATT represents attitude toward FFST, SN subjective norm, PBC perceived behavioral control. BI behavioral intention, AB actual behavior.

CRediT authorship contribution statement

Jing Li: Software, Investigation, Writing - original draft. **Shuyi Feng:** Conceptualization, Funding acquisition, Supervision. **Tianyuan Luo:** Writing - review & editing. **Zhengfei Guan:** Writing - review & editing.

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