Factors affecting Farmers' Adoption of and Willingness to Pay for Biodegradable Mulch Films in China

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Declaration of interests

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Abstract

Biodegradable mulch films (BDMs) technology is an environmentally-friendly substitute to traditional plastic mulch films in agricultural production. Given the high price and it is new to the market, it is not easy for farmers to accept and adopt it. This paper aims to explore the key factors affecting farmers' adoption of and willingness to pay for BDMs to understand the complex process of farmers' decision-making. This paper employs a double hurdle model to explore the multi-stage decision-making process in the adoption of BDMs using the sample of 1247 observations from Yunnan province China, where two mechanisms of decision-making (i.e., direct rejection of technology and lack of resources) were used to capture zero willingness to pay (WTP) for BDMs. The results indicate the two-stage decision-making process, where the role of technology-specific characteristics is more important than adopter-specific characteristics in the adoption of BDMs in China – training for understanding and using the technology has a positive effect on both the adoption and willingness to pay. The paper is the first attempt that empirically analyses the determinants of farmers' WTP for BDMs. It contributes to the literature on adoption analysis by 1) considering farmers' adoption choices as a two-step process by using a hurdle model and 2) addressing the importance of technology-specific characteristics on farmers' WTP for BDMs. Understanding the role of factors on different stages of farmers' decision-making could assist policymakers in designing programs, specifically tackling difficulties confronting farmers at different stages of decision-making.

Keywords: double hurdle model; biodegradable mulch film; farmer; China; WTP

1. Introduction

With the population growth and economic development, the global usage of plastic is rising significantly, and one of the main sources is plastic films used in agriculture for mulching (Jambeck *et al*., 2015). Different from the developed countries, where plastic mulch is mainly used with micro-irrigation, Chinese farmers use plastic mulch on a vast scale independent of micro-irrigation, but for water conservation, weed control, and higher production (Liu *et al*., 2014). So far, the use of plastic film mulching technology (mainly polyethylene (PE) mulches) in China has helped increase the yields of cash crops by 20% to 60% (Ingman, Santelmann, and Tilt 2015), and its land area in plastic mulch has exceeded the world's total land area in micro-irrigation (Liu *et al*., 2014). However, the extensive use of plastic mulch films has caused severe environmental problems, because a large number of plastic mulch residues have not been appropriately recycled, directly leading to land and water pollution (Roy and Dutta, 2019). Particularly, in the high mountain areas of southwestern China, such as Sichuan and Yunnan province, the use of recycling machines is limited by the landscape, and thus recycling is associated with high labor demand and cost. Besides the geographical disadvantages, the plastic mulch film used in China is thinner than 0.008 mm that is significantly lower than the international standard (e.g. 0.02 mm in Europe and Japan) (Liu *et al*., 2014), making it more difficult to recycle the residues completely. According to a national survey in 2019, about one-third of plastic mulch films were left in the land, and 80% of plastic mulch films picked up from land were either dumped without proper treatments or burned up (Yan and Liu, 2020). Consequently, although the usage of plastic mulch films has not been the largest compared to that of the northwestern area, the residues of plastic films in the southwestern provinces have been substantially high (Yan and Liu, 2020).

Therefore, besides encouraging farmers to adopt "best recycling practices", the Chinese government starts introducing biodegradable mulch films (BDMs) through demonstration farms, in particular in the regions confronting the difficulty of recycling plastic film residues (e.g., southwestern China). Meanwhile, there has been a change in crop choice from planting traditional food crops (e.g., rice and wheat) to cash crops, such as fruits and vegetables, mainly due to the high return of cash crops and policy supports from the central and local government (Huang *et al*., 2010). It is expected that the use of plastic films in southwestern China will continue to grow significantly (Yan and Liu, 2020). However, except for the demonstration farms operated by the government, few farmers have attempted to adopt BDM, mainly due to its high price that is about 3 times higher than PE films, and uncertainty about its efficiency that BDMs can be broken down easily and not having the expected functions (e.g., water conservation). It is, therefore, important to understand what drives or hinders farmers' adoption the new technology, i.e., BDMs, to maintain crop production and productivity while reducing the environmental pollution of plastic film residues. Note that many smallholder farmers rely on subsidies in technology adoption in China (Ding *et al*., 2011; Yu and Jensen, 2010), and thus the adoption of BDMs may rely on the cost-effectiveness of the subsidy policy. Hence, prior to implementing any subsidy policy for the adoption of BDMs, policymakers need to know what determines farmers' adoption and willingness to pay for BDMs.

The existing studies show that farmers' adoption of sustainable practices and new technologies are contingent on a number of factors that are categorized into five broader categories, namely, farm and farmer specific characteristics, social and cultural norms, availability of support and resources, and perceived benefit. (e.g., Barham *et al*., 2015; Dumbrell *et al*., 2016; Mekonnen *et al*., 2020; Pannell *et al*., 2006; Weber, 2012). Farmers' adoption is also dependent on the types of practices and technologies, but the practice or technology itself has been under-emphasized (Pannell and Zilberman, 2020). A recent study by de Oca Munguia and Llewellyn (2020) states that more emphasis should be placed on analyzing the impact of technology characteristics in adoption analysis. Additionally, when targeting developing countries, the adoption analysis needs to consider the distinctive features when analyzing farmers' adoption decision-makings (Pannell and Zilberman, 2020). For example, the majority of farms in the developing countries are small scale rather than large commercial farms (Llewellyn and Brown, 2020); the role of technologies in agricultural production is to enhance crops to further increase production and feed the poor people in developing countries (Huang *et al*., 2002). In that way, the impact of farm and farmer characteristics on adoption behavior may be dependent on the economic-historical context (Burton 2014). Besides, farmers in developing countries usually lack an adequate understanding of the new technologies due to the difficulty of accessing relevant information or training programs (Chen *et al*., 2013; Yang *et al*., 2021). Therefore, these two gaps addressed in the adoption literature lead us to consider the technology-specific characteristics and the distinctive features of the targeted region in China in analyzing the determinants of farmers' adoption of BDMs.

It was not until recent years that researchers attempted to address the issue of plastic pollution from agricultural production in China. The existing studies are from the field of agriculture and environmental science, mainly focusing on measuring the amount of residual mulch films for different crops and the impact on crop yields and greenhouse gas emissions. (e.g., He *et al*., 2018; Zhang *et al*., 2016). To our best knowledge, no study attempts to address plastic film pollution from understanding farmers' decision-making. Till now, the literature on the determinants of farmers' decision-making of sustainable agricultural practices in China have mainly focused on good management of fertilizer, pesticide, and water quality protection (e.g. Pan *et al*., 2017; Sun *et al*., 2018; Wang *et al.* 2018; Wu and Hou, 2012).

Therefore, this study aims to investigate determinants of farmers' choices of adoption and willingness to pay for BDMs in China by using a double hurdle model, where two mechanisms of decision-making (i.e., a direct rejection of technology and lack of resources) were used to capture zero willingness to pay

(WTP) for BDMs. A sample of 1247 observations used in the study was sourced from a survey of farmers in Yunnan province, China, mainly because: 1) the usage of plastic mulch films is relatively high (Liu, He and Yan, 2014); 2) the central and local government starts promoting the use of BDMs. The contributions of this study are threefold. First, it addresses the importance of technology-specific characteristics and the impact on farmers' adoption and pay for the new technology, BDMs in our case. Second, the study considers farmers' adoption choices as a two-step process by using a double hurdle model, where farmers have to overcome the hurdle of whether or not to adopt and achieve the decision of how much to pay for the technology. Third, the results and findings of the study may contribute to the design of policy instruments in motivating the adoption of BDMs in China, for instance, to provide some insights into determining the value of substitutes for farmers' adoption of BDMs.

The rest of the paper is structured as follows. Section 2 specifies the conceptual analysis framework and econometric models used in the study. Section 3 presents the sample data and descriptive statistics of the variables used in the econometric models. The empirical results and findings are presented and discussed in Section 4, followed by the last section to conclude.

2. Method and Data

2.1. Empirical Analysis Framework

The decision on whether or not to adopt a specific technology and how much to pay for that technology can be made jointly or separately (Gebremedhin and Swinton, 2003). Either way can cause the censored nature of farmers' WTP, with a large proportion of zeros presented in WTP. To deal with the zero-left censored WTP, the Tobit model (Tobin 1958) and the extensions have been largely used to correct the problem of zero observations in a variety of research fields, in particular in analyzing consumer expenditure and demand (Gallet and List, 2003; Jones 1989). This paper follows the analysis framework for zero-left censored WTP from consumer expenditure (Gillingham and Tsvetanov 2019; Jones 1989), and we conceptualize the sources of farmers' zero WTP for BDMs. As shown in Figure 1, there are two main sources of zero WTP, including 1) direct rejection: the farmer directly reject adopting BDMs due to the farmer's preferences over another mulching technology, for example, PE mulch films; 2) lack of resources: the farmer would like to adopt BDMs but cannot afford to pay it.

[insert Figure 1]

Therefore, the sources of zero WTP can be modeled as:

$$\begin{cases} Y_1^* = \beta_1^{\mathrm{T}} X_1 + \varepsilon_1 \\ Y_2^* = \beta_2^{\mathrm{T}} X_2 + \varepsilon_2 \end{cases}, \quad (1)$$

here the two equations represent the two decision mechanisms of zero WTP. Y_1^* and Y_2^* are latent variables representing farmers' adoption decisions and levels of WTP for BDMs; X_1 and X_2 represent the independent variables impacting the two decision mechanisms, associated with unknown vector coefficients β_1 and β_2; and $\varepsilon_1 : N(0,1)$ and $\varepsilon_2 : N(0,\sigma^2)$ are the random disturbances. Specially, for the technology rejection mechanism (first equation in Equation 1), if $Y_1^* < 0$, biodegradable mulching technology is not adopted as it is not considered by farmers as a relevant mulching technology. The second equation defines the levels of WTP for BDMs, and thus, if $Y_2^* < 0$, BDMs are not adopted because a negative WTP implied by resource constraints – labor, financial, and information support cannot be realized.

A double hurdle model is utilized to support the decision-making context conceptualized in Figure 1. Originally formulated by (Cragg 1971), the double hurdle model is a parametric generalization of the Tobit model, in which two separate stochastic processes determine the decision to adopt and WTP for the technology (Jones, 1989; Yen and Jones, 1997). In the double hurdle model, Y_1^* and Y_2^* is used to model each decision process, and both hurdles have equations (shown in Equation 1) associated with the effects of the included factors as the independent variables. It assumes that farmers make two sequential decisions concerning adopting and WTP for a technology. First, the farmer decides whether or not to adopt the technology (the first hurdle). Second, the level of WTP that shall be used in purchasing the technology (the second hurdle). Hence, the first hurdle is a sample selection equation estimated with a Probit model and the second hurdle involves an outcome equation, which uses a truncated model to determine the WTP for BDMs. This second hurdle uses observations only from those respondents who indicated a positive WTP value of the use of a technology (Martínez-Espiñeira 2006; Noltze *et al.*, 2012).

The double hurdle model fits our problem of measuring crowding out because it allows for the fact that fixed costs may affect a farmer's adoption, but once the decision to adopt has been made, fixed costs may not affect the WTP decision. Each hurdle is conditioned by factors, such as farmer and farm characteristics (adopter-specific characteristics), technology-specific characteristics, and farmers' awareness, perceptions, and knowledge of the technology (shown in the middle of Figure 1). Note that these independent variables may appear in both equations or either of one, and most importantly, a variable appearing in both equations may have opposite effects in the two equations (Jones, 1989; Yen and Jones, 1997).

Combining the log-likelihood function for zero and positive WTP observations, the sample likelihood function for this double hurdle model can then be written as (Jones 1989):

$$\ln L = \sum_{i|Y_i=0} \ln L_i^- + \sum_{i|Y_i>0} \ln L_i^+, \quad (2)$$

where the first term estimates the status of Y_i (whether $Y_i = 0$ or $Y_i > 0$) capturing the contribution of a zero observation to the sample log-likelihood function and the second term estimates WTP (the exact value of Y_i, if $Y_i > 0$. Specifically,

$$\ln L_i^- = \ln(1 - \frac{\Phi(\beta_1^{\mathrm{T}} X_{1i}, \frac{\beta_2^{\mathrm{T}} X_{2i}}{\sigma}; \rho)}{\Phi(\frac{\beta_2^{\mathrm{T}} X_{2i}}{\sigma})});$$

$$\ln L_i^+ = -\ln\sigma + \ln\Phi(\frac{e_i}{\sigma}) + \ln\Phi(\frac{\beta_1^{\mathrm{T}} X_{1i} + \frac{\rho}{\sigma} e_i}{\sqrt{(1-\rho^2)}}) - \ln\Phi(\frac{\beta_2^{\mathrm{T}} X_{2i}}{\sigma}), e = Y_i - \beta_2^{\mathrm{T}} X_{2i}, \quad (3)$$

here, $\Phi(\bullet)$ denotes the probability density and cumulative distribution function of an N(0,1) random variable; and e is the "residual" of the fit representing the contribution of a positive observation to the log-likelihood function. Note the general model shown in the above nests several other formulations. We assume $\rho \neq 0$, indicating the adoption equation and WTP equation are correlated, i.e., ε_1 and ε_2 are not independent. Note when $\rho = 0$, the double hurdle model may collapse to the independent Cragg model or the Tobit model nested within the independent Cragg model, with the further assumption that the adoption probability is 1. Hence, further statistical tests will be used to test for the independence of the adoption equation and WTP equation.

2.2. Data and variables

The study area Yunnan province is located in the southwest of China, which has a strong agricultural focus. However, level land for agricultural production is scarce in Yunnan, with only 5% of the land is under cultivation and more than 94% of the land categorized as mountainous areas (Ding *et al*., 2011). Given the geographical disadvantages, plastic mulch films have been extensively applied in Yunnan to help increase production and productivity. In addition, the types of crops planted in Yunnan determine the large use of plastic mulch films – besides having the traditional food crops, such as rice, Yunnan's agriculture industry is well-known for its cash crops. In particular, the tobacco industry is the main "export" product and makes up a large part of the provincial GDP, and the flower industry takes 50% of China's cut flower production. Additionally, in recent years, Yunnan has developed strong competitive potential in its fruit and vegetable industries due to its climatic and ecological advantages, and the high demand from the market further drives the expansion of planting areas of fruit and vegetable. The technology of plastic mulching helps maintain the high yield of tobacco and fruit and vegetable. Besides the difficulty of planting in upland plains and sloped hillsides, farmers find it hard to collect residual plastic mulch films. Hence, though not being ranked at the top regarding the usage of PE films, the residues of plastic films in Yunnan have been substantially high (Yan and Liu, 2020). Being one of the BDMs "pilots", the local government has built demonstration farms to show and educate farmers regarding the utilization of BDMs. However, till now, the adoption rate of BDMs has almost been zero.

Data used in this study were collected through a survey from different crop growers in Yunnan province of China between July and November 2018. The objectives of the survey are to analyze pollution sources of agricultural production and understand the current status of using plastic mulch films and farmers' adoption and pay for BDMs. The design of the questionnaires for the survey has undergone two stages. First, we conducted a pilot survey in three randomly chosen villages of Yunnan. 36 farmers were randomly chosen and interviewed by trained interviewers in person. The results of the pilot study provide a thorough understanding of the utilization of plastic mulch films in the context of Yunnan, and the initial questionnaire was tested and adjusted accordingly. Based on the results of the pilot study, a structured farm and household questionnaire was finalized and used in the second stage survey. Several trained interviewers were sent out to conduct face-to-face interviews with 1358 farmers randomly chosen from 128 villages out of 26 counties in Yunnan. This provides a final sample of 1247 valid questionnaires[1]. Specifically, we collected the information about farmers' adoption and willingness to pay for BDMs, their perception and knowledge of the plastic mulching technology for both PE mulch films and BDMs, and farm and farmer characteristics (e.g. farm size, age, and income). Table 1 presents a descriptive and statistical summary of the variables included in the study.

[Insert Table 1]

There are two outcome variables (dependent variables), adoption and WTP, to be included in the two equations of the double hurdle model. Figure 2 shows a clear pattern of the zero-left censored WTP, with 195 farmers chose not to adopt BDMs. The average per kg WTP for BDMs was found to be 13.7 China yuan across the farmers who are willing to adopt BDMs. Although 83% of farmers stated they are willing to adopt BDMs, when all the zeros (not willing) are included in calculating the average WTP, we got a lower per kg WTP of 11.6 China yuan.

[Insert Figure 2]

[1] Note that 111 questionnaires were excluded as they are either incomplete or errorness.

The potential determinants of farmers' adoption and WTP are categorized into three groups of independent variables, including farm and farmer characteristics, technology-specific characteristics, and farmers' awareness, perception, and knowledge of plastic mulching technology. Farm and farmer characteristics include demographic factors, such as farmers' age, gender, ethnicity, and education, and income level, as well as farm-related variables of farm type, farm size, and types of crops planted. Overall, as shown in Table 1, farmers in the sample are mainly male with a relatively low education level, and the majority of the farms are small-scale, with a large proportion of them planting tobacco and fruit and vegetables. Technology-specific characteristics are closely related to farmers' awareness and knowledge of BDMs. In our case, the efficiency of BDMs is highly valued by farmers followed by the attribute of price, and only a small proportion of farmers (21%) are aware of any forms of promotions for the adoption of BDMs. Note we included the variables that are related to PE mulches, given BDMs are seen as an alternative technology to PE mulches to be adopted in the future. Although the majority of farmers notice the negative impact of PE mulches on the environment, about 61% of farmers have maintained the same level of PE usage and 28% have it increased in the past five years. This is mainly explained by their perceptions of the usefulness of plastic mulching technology in agricultural production, with approximately 96% of farmers see the technology as important. Lastly, getting a subsidy for recycling plastic residues and training opportunities may also affect their decisions on using BDMs.

3. Empirical Results

For comparison purposes, we report the results from the double hurdle model and Tobit model regarding factors affecting farmers' WTP for BDMs in Table 2: the first two columns present results from the double hurdle model for adoption and WTP and the third column presents the results from the Tobit model. For the factors affecting WTP (the second and third columns), the coefficient estimates of the double hurdle model are different from those of the Tobit model at various degrees. Notably, for example, the main crop type – tobacco is found to have no effect on farmers' WTP for BDMs in the double hurdle model but is negatively significant in the Tobit model; for the variables of "main crop", statistically significant effects are detected in the Tobit model but not in the double hurdle model. The differences in the estimation results of the two models indicate the Tobit model cannot capture the technology selection mechanism shown in Figure 1, where farmers first choose to adopt BDMs and then decide their WTP for the technology. Once they go over the first hurdle, some factors affecting the first hurdle may not affect the second hurdle of WTP. Note that the correlation coefficient ρ is positive and statistically significant, indicating the two hurdles are positively correlated, and thus the two selection mechanisms need to be considered jointly. In addition, the values of Loglik, AIC, and BIC support choosing the double hurdle model to estimate farmers' WTP for BDMs. Hence, our interpretation of the results is based on the double hurdle model: in hurdle 1, farmers decide whether or not to adopt BDMs, and if one chooses to adopt, hurdle 2 considers ones' WTP associated with per kg BDMs.

[Insert Table 2]

For the variables of farm and farmer characteristics, the demographic factors, such as age, gender, and ethnicity, and farm characteristics, including farm size, farm type, and the number of labors, have no impact on farmers' adoption of BDMs. However, education is found to be an important determinant of both farmers' adoption and WTP. The positive effect of education indicates that farmers with higher education levels tend to be more likely to adopt BDMs and are willing to pay more for the use of BDMs. This finding is consistent with many existing studies on technology adoption for farmers across the developed and developing world (e.g., Dumbrell *et al*., 2016; Ma *et al*., 2012; Pannell *et al*., 2006). For other farm characteristics, income and the type of crop, are found to only influence farmers' adoption OF BDMs. Farmers with higher household income are more likely to adopt BDMs, but they are less likely to adopt BDMs if the percentage of agricultural income increases. Intuitively, it is easier for farmers with higher household income to try out new technologies, given the high price of BDMs and the fixed cost associated with learning and training for the adoption of BDMs (Barham *et al*., 2015; Marí *et al*., 2019). However, farmers who mainly rely on agricultural income may concern about the high cost of BDMs and find it risky to invest in BDMs, compared to those who have more off-farm income (Gedikoglu *et al*., 2011).

Farmers' adoption of BDMs differs across types of crops planted. Compared to food crop growers, tobacco and other crop growers are less likely to adopt BDMs, and fruit & vegetable growers are more likely to adopt BDMs. Sastre *et al*. (2017) state that farmers often relate themselves to the crops they grow, and some are proud of growing the crops for generations – their decision-making of adopting technology and practice is dependent on the types of crops they grow. In our case, the difference across types of crops indicates a direct technology rejection of tobacco and flower growers. As the pillar industry for Yunnan's economy, the tobacco industry has its own supply chain and operation system to manage suppliers (tobacco growers). For instance, to ensure the quality and quantity of tobacco production, the industry provides a variety of support for tobacco growers, including providing low price PE mulch films, training, and subsidy (Huang *et al*., 2010). Similarly, flower cooperatives provide flower growers with strong support, including technology training and networking. Given the support they obtain from the industry, the two groups of farmers are less likely to change from using PE mulch films to BDMs. Table 3 shows the predicted adoption (the probability) and WTP (per kg BDMs in China Yuan) across the groups of growers at the sample means of independent variables. Based on the results, the estimated probability of adopting BDMs for tobacco growers and other crop growers are relatively low compared to food crop growers and fruit & vegetable growers. Regarding the predicted values of WTP, fruit & vegetable growers have the highest WTP whilst tobacco growers have the lowest. However, regardless of the types of growers, the estimated WTP is similar to the per kg price of PE films (around 10-14 China Yuan), meaning it is far less than the market price of BMDs (22-28 China Yuan).

[Insert Table 3]

Compared to farm and farmer characteristics, more technology-specific variables are found to affect farmers' adoption of and WTP for BDMs. Higher usage of PE mulch films increases the propensity for farmers to adopt BDMs, and farmers' WTP for BDMs is higher if they have had an increase in mulch usage in the past five years. Training is found to be an important determinant of farmers' adoption and WTP; those who obtain training for mulching technology (offered by the government or industry) are more likely to adopt and pay more for BDMs. Training in the form of workshops, field days on demonstration farms, or "farmer school" are generally regarded to an important pathway of knowledge transformation: experts can directly provide farmers with information and knowledge about new technologies; farmers can network and share knowledge with other farmers, increasing their confidence in adopting new technologies or practices (Baird et al., 2016). Receiving a subsidy for recycling residual plastic films does not affect either farmers' adoption or WTP.

The attributes that are directly related to BDMs may influence farmers' choices of whether or not to adopt BDMs and how much to pay for BDMs. Interestingly, farmers who see price as the most important attribute are more likely to adopt and pay more for BDMs than those who value the other attributes of BDMs, such as efficiency and quality. This finding indicates that, when price is the focus of BDMs, farmers may have already overcome the adoption barrier (e.g., technology barrier), whilst farmers who value efficiency and quality the most are still skeptical about the technology. Brand and farmers' awareness of the promotion of BDMs have no influence on their adoption and WTP.

All the perception variables are found to influence farmers' adoption but not WTP. Note that, if farmers are aware of the negative impact of PE mulch films on the environment, they tend to adopt an environmentally friendly technology, i.e., BDMs. Their perceptions of the usefulness of the mulching technology increase the likelihood of BDMs adoption – the more important they feel about plastic film mulching in agricultural production the more likely they adopt BDMs. This reflects the natural embedded connection between perception/ awareness and behavior change (Ajzen, 1991, Wang *et al*., 2018). However, high perception and/ or awareness may not necessarily lead to high WTP.

4. Discussion and Conclusion

This paper uses a double hurdle model to empirically analyze the determinants of farmers' adoption of BDMs in China, using the survey data from Yunnan province. It is the first attempt that explores both farmers' adoption of and WTP for BDMs. Considering using BDMs is relatively new in China and many other countries, understanding the different factors that affect farmers' decision-making is important for promoting the use of BDMs in agriculture. The double hurdle model has the advantage of modeling farmers' decision-making in two stages. We address the impact of three groups of factors, i.e., farm and farmer characteristics, technology-related and perception - and awareness-related variables, on farmers' adoption and WTP. Our results show that farmers have to overcome the first hurdle, i.e., choose to adopt or not adopt, and then decide how much they are willing to pay for BDMs. Notably, we find that education, training, and preference over the attributes of BDMs significantly affect farmers' adoption and WTP. However, once farmers decide to adopt BDMs, many other factors that affect their adoption, such as income and crop type, may not affect their WTP for BDMs.

Results and findings of the study may lead to several policy implications. To begin with, it is important that policymakers understand the key barriers of farmers' adoption prior to investigating their WTP for BDMs. The double hurdle modeling process provides some insights into better targeting farmers' needs at different decision-making processes. Second, the role of technology-specific characteristics is more important than adopter-specific characteristics in the adoption of BDMs in China, and possibly in other developing countries. It is not until recent years BDMs have been introduced to farmers as a substitute for PE mulching technology. Hence, to promote the adoption of BDMs, more emphasis should be placed on providing information and knowledge about technology characteristics (de Oca Munguia and Llewellyn, 2020). Farmers need to have a good understanding of the technology before making decisions. Notably, training is an ideal investment for both policymakers and farmers. Besides offering information, it provides opportunities for farmers, experts, and policymakers to exchange and share knowledge, experience, and most importantly, to build trust that contributes to farmers' adoption of BDMs (Baird *et al*., 2016, Yang *et al*., 2021). Additionally, given the price of BDMs is generally higher than PE mulch films, participating in training may motivate farmers to invest more (i.e., higher WTP) in the new mulch films that are environmentally friendly and not requiring recycling efforts. Lastly, policymakers need to consider the difference in WTP amongst different crop growers, and the overall WTP (11 – 14 RMB) for BDMs is much lower than the market price (22 – 28 RMB). The government may promote the adoption of BDMs for tobacco and flower growers through tobacco firms and flower cooperatives that provide technical training and support to farmers. Similarly, when targeting other areas or countries with high usage of plastic mulch films, the local government has to relate the promotional policy to the specific crops grown by farmers.

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Figures

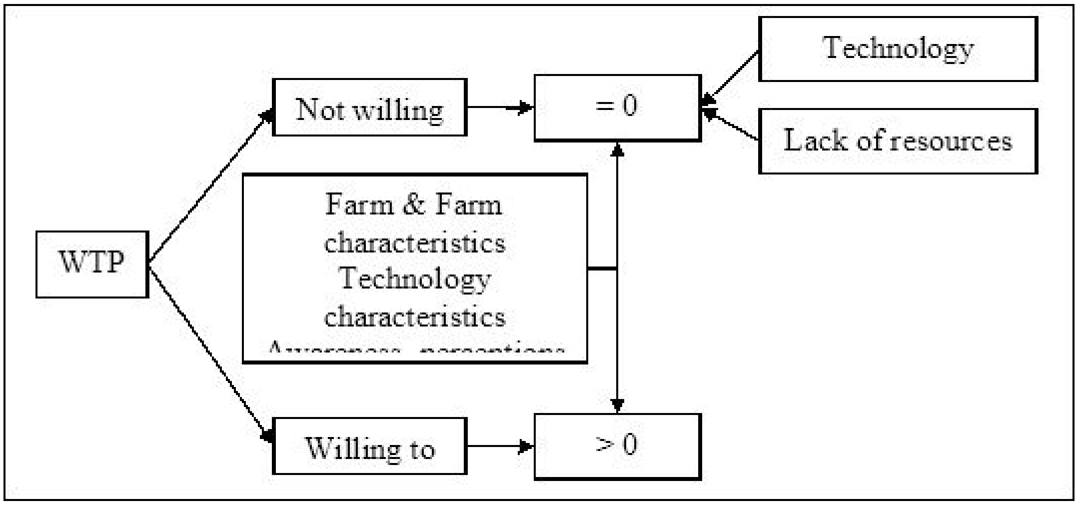

Figure 1

The conceptual analysis framework of farmers' WTP for BDMs.

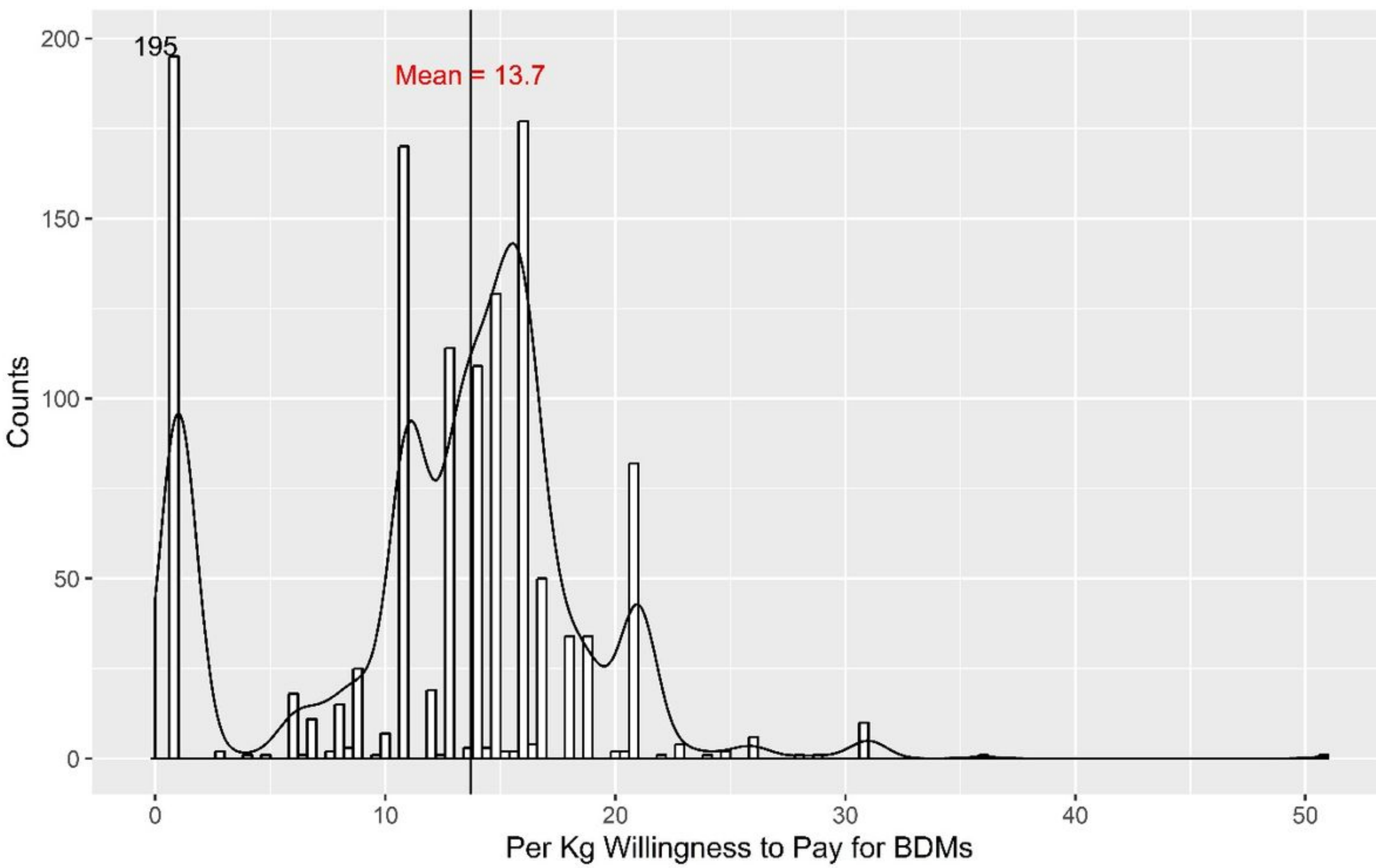

Figure 2

the distribution of farmers’ WTP for BDMs.