## Effects of joint adoption for multiple green production technologies on welfare-a survey of 650 kiwi growers in Shaanxi and Sichuan

Multiple green production technologies

229

Received 9 June 2020 Revised 23 August 2020 Accepted 3 November 2020

Zhe Chen, Apurbo Sarkar, Xiaojing Li and Xianli Xia College of Economics and Management, Northwest A&F University, Yangling, China

#### Abstract

AO:1

AQ:2

**Purpose** – Based on the survey data of 650 kiwi growers from Shaanxi and Sichuan provinces, this paper used multiple endogenous transformation regression models to explore the effect of the joint adoption of green production technology on farmer's welfare. The purpose of the study is to analyze the influence of green production technology on the yield, household income and socioeconomic characteristics of Kiwi fruit growers.

**Design/methodology/approach** – In the context of the study, multiple endogenous transformation model (MESR) are adopted, but self-actualization tactics were adopted to deal with the instrumental variables. The empirical data has been collected via a combined hierarchical sampling and random sampling, whereas a well-structured Likert scale questionnaire was adopted as well. The empirical data has been processed with the help of STATA 15.1 version.

**Findings** – The study found a positive impact of adopting green production technology. Moreover, the joint adoption of green production technology by kiwi growers has significantly increased the yield, economic values of Kiwi and household income of kiwi farmers. The households with higher asset value, better land quality, weaker credit constraints, more technical training and stronger government promotion and support from local governments are the most likely to adopt pest control technology and soil management technology jointly.

**Originality/value** – The prime innovation of the paper is to measure the impact of technology combination adoption on farmer's welfare is evaluated, rather than the impact of single sub technology on farmer's welfare.

Keywords Welfare, Green technology, Joint adoption, Multiple technologies

Paper type Research paper

© Zhe Chen, Apurbo Sarkar, Xiaojing Li and Xianli Xia. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

The author (s) acknowledge the anonymous reviewers for their contribution to improving this paper. The author (s) also acknowledge the lab assistants and supportive family and friends for their encouragement and mental support.

Declaration.

*Conflicts of Interest:* The author (s) declares no conflict of interest.

*Funding acknowledgement statement:* This study is supported by the National Social Science Foundation of China (Grant Number-17BJY137), Northwest A&F University basic scientific research operating expenses humanities and social sciences major cultivation project (Grant Number-2452020055).



International Journal of Climate Change Strategies and Management Vol. 13 No. 3, 2021 pp. 229-249 Emerald Publishing Limited 1756-8692 DOI 10.1108/IJCCSM-06-2020.0054

#### **IICCSM** 1. Introduction

13.3

230

Green production technology is the fundamental driving force to promote the highquality and modern development of agriculture and plays a vital role in promoting the quality and efficiency of agricultural products and improving the agricultural production environment (Adnan et al., 2019). However, practically, most farmers still rely excessively on the input of traditional chemicals such as pesticides and fertilizers to increase output to cut the input of agricultural resources and gain short-term benefits (Wang et al., 2018), indicating that farmers are not enthusiastic about adopting green production technology. Undoubtedly, due to the problems of low technological developments, weaker economic conditions and insufficient risk response capabilities of some small farmers (Feder and Umali, 1993; Joffre et al., 2019). there are significant disparities in the capability of different farmers to adopt the technology. Farmers have an adverse technological selection (Duflo et al., 2011), which has increased the difficulty in promoting green production technology and cause a reduction in the efficiency of adopting green production technology. Therefore, further exploration of the incentives that affect the adoption of green production technology is of considerable significance to improve the farmer's adoption of green production technology, breaking the constraints and obstacles that restrict the adoption of green production technology by small landholders, promoting the advancement of agricultural technology in China and promoting the green transformation of China's agricultural development.

Existing literature shows that the adoption of agricultural technology can improve farmer's agricultural production methods, increase agricultural output, increase farmer's household income, and thus may improve the overall farmer's family welfare (Anang et al., 2020; Wossen et al., 2019; Kumar et al., 2020; Chang and Tsai, 2015). However, the adoption of agricultural technology also faces high utilization costs (Gómez et al., 2014). For small-scale farmers with decentralized operations, lack economic incentives for technology adoption, so they often face cost pressures and have to give up technology adoption (Mariano et al., 2012). However, some scholars believe that adopting agricultural technology is the leading way to increase farmer's income and improve farmer's livelihood (Schiopu, 2015; Wossen et al., 2017). Some scholars believe that the impact of technology adoption on increasing farmer's income and their welfare is not significant. Under the dual pressure of the factor and product market, the adoption of technology must promote the increase of farmer's income through multiple mechanisms. However, in reality, it is not easy to coordinate among the various mechanisms, resulting in the effect of increasing farmer's income is not significant enough (Das *et al.*, 2020). It can be seen that the output and welfare effects of adopting agricultural technology are still controversial in some extents.

Farmer's adoption of green production technology in agriculture is not a one-time and straightforward decision, but a dynamic decision process is involved in which they continuously learn, improve or give up over time (Bunclark et al., 2018). At the same time, some scholars pointed out that agricultural technology consists of a combination of complementary or alternative sub-technology. The applicability of technology and cost constraints determine that they may mainly adopt multiple technology combinations when farmers choose to take green production technology decisions (Moyo and Veeman, 2004). However, the existing research focuses on analyzing the impact of single agricultural production technology on farmers and may ignore the economic information brought by farmers adopting multiple agricultural technologies. Although some studies have begun to focus on the correlation effect of multiple

technologies among farmers (Rahelizatovo and Gillespie, 2004), less attention has been paid to the welfare effect of multiple technologies adopted by farmers.

In general, to assess the welfare effect of farmer's adoption of agricultural technology, it is necessary to consider the "self-selection" and endogenous problems that may exist in the process of agricultural technology adoption by farmers. This paper takes the two major types of green production technologies, i.e. pest control technology and soil management technology as the research objective, and the study takes the field survey data of 650 kiwi growers in the main Kiwi producing areas of Shaanxi and Sichuan provinces and used multiple endogenous conversion models (MESR). Based on correcting observable and unobservable selection biases, we construct a "counterfactual" framework to explore the impact of the adoption of multiple agricultural green production technologies on the welfare of kiwi growers, intending to promote farmer's green production efficiency of technology adoption.

The rest of the paper is as follows. Based on the above analysis, Section 2 of this paper defines the connotation of green production technology of Kiwi and makes a literature review on the influencing factors and welfare effects of farmer's technology adoption. Section 3 introduces data sources, research methods, variable sources and descriptive statistical analysis of variables. Section 4, based on the data of kiwi growers in Shaanxi and Sichuan provinces in 2018, empirically analyzes the impact of the joint adoption of green production technology on the welfare of growers. The discussion and observation are given in Section 5. Finally, depending on the empirical research results, this paper puts forward countermeasures and suggestions in Section 6.

#### 2. Definition of connotation and literature review

#### 2.1 Definition of the connotation of green production technology

According to the "Guidelines for Agricultural Green Development Technology (2018– 2030)" issued by the Ministry of Agriculture and Rural Affairs of China, agricultural green production technologies mainly include: "Cultivated land quality improvement and conservation technology, agricultural water control and rain-fed dry farming technology, reduction in the application of fertilizer and pesticide and efficiency improvement technology, green and efficient production technologies for livestock and grass, etc. There are three main types of pest control technologies: physical control technologies, which includes the use of insecticidal lamps, insecticidal plates and insect nets; biological control technologies, which includes parasitic and predatory natural enemies mainly through the protection or artificial release of natural enemies for the effective control of pests; scientific drug application technology, which includes the use of low-toxicity, low-residue, environment-friendly pesticide technology and their alternative, precise and safe use technology of pesticides. There are two main types of soil management technology during kiwi planting: application of organic fertilizer refers to organic compound fertilizers formed by accumulation and fermentation of organic materials such as animal and plant residues or human and animal excretion as well as includes commercial organic and farm fertilizers; and soil testing formula technology is an agricultural science and technology household project initiated by the country in response to agricultural non-point source pollution and the deterioration of the ecological environment. It is a precision fertilization technology that reduces chemical fertilizer input and improves chemical fertilizer utilization efficiency (Rogers et al., 2014).

Multiple green production technologies

2.2 Research on the factors influencing farmer's technology adoption

**IICCSM** 

13.3

232

As the main body and executor of technology adoption, the influence factors of farmer's technology adoption have always been the concern of scholars. Research on influencing factors of technology adoption focuses on four aspects. First, the perspective of risk preference, Barham et al. (2015) believed that farmers would fully consider the risks they faced and their ability to resist risks when adopting technologies. Smith and Ulu (2017) pointed out that due to the co-existence of net income uncertainty and risk of improper technology application, risk aversion has a negative effect on the adoption of green prevention and control technology by farmers. However, in terms of the actual situation, some scholars also found that farmer's risk preference had not received an active response in technology adoption (Aklin et al., 2018). Second, the perspective of policy support, Omotilewa et al. (2019) indicated that the government significantly promoted the adoption of biocontrol technology by farmers through scientific demonstration, technical training and financial subsidies. The third is the social network perspective, as a large number of studies have shown that trust relationship and information transmission in social networks have increased the adoption of new technologies by farmers (Bandiera and Rasul, 2006). Further studies have found that social networks at different stages have different impacts on agricultural technology adoption (Maertens and Barrett, 2013). Fourth, the perspective of farmer's endowment of resources; farmer technology adoption usually matches household resource endowments (Uddin et al., 2014). Land resources, household's financial status, household's age, household size and education all affect farmers' green production technology adoption (Phibbs, 2002; Ricker-Gilbert and Jones, 2015).

#### 2.3 Research on the impact of technology adoption on farmer's welfare

The influence of technology adoption on the welfare of farmers has gradually attracted the attention of scholars. The relevant research studies have been carried out from three aspects:

First, the relationship between technology adoption and agricultural output; some scholars believe that technology adoption has increased the agricultural production (Anang *et al.*, 2020); while some scholars hold the opposite view that technology adoption requires excessively high physical capital investment and cannot significantly increase the output of agricultural products (Das *et al.*, 2020). Compared with the pest control technology, the scholars have concluded the effect of soil testing formula technology on crop yield and the growth was relatively consistent, and they all believed that the soil testing formula technology had a significant stimulating effect on crop yield (Liu *et al.*, 2019).

Second, the relationship between technology adoption and household income; Chang and Tsai (2015) believed that the adoption of green production technology could significantly increase the farm income. However, some scholars also found that technology adoption could not uphold the increase in farm income. Specifically, most agricultural products are inelastic products. While technology adoption led to the increase of output, it led to the oversupply of agricultural products and ultimately decline in market prices, which ultimately had a weak effect on the improvement of farmer's income (Fernandez-Cornejo, 1998).

Third, the relationship between technology adoption and agricultural production costs; as the main body of agricultural production, farmers have the desire to improve technology and increase income. However, the excessively small investment scale and high-risk failure make it unable to bear the cost of technology adoption (Mariano *et al.*, 2012) and will

increase the additional labour input. The income-increasing effect of technology adoption is less than the unit input cost of supporting factors, which will eventually reduce the interest of farmers for technology adoption.

It can be seen from the literature review that the existing literature still has the following deficiencies. In the research on the factors influencing farmer's technology adoption, though attention has been paid to the impact of various factors on technology adoption, the factors affecting the adoption of multiple technology combinations have not been paid enough attention. Few studies have explored the effects and heterogeneity of multiple technologies on farmer welfare. The research on the relationship between the adoption of specific cash crop grower's technology and the welfare effect of growers is not sufficient. Besides, some existing models do not take bias effects into account in the estimated results caused by the sample selectivity problem.

### 3. Data sources, research methods and variable selection

#### 3.1 Data sources

The data of this study came from the field survey conducted by the research group "Chinese Kiwi Industrial Technology System" from kiwi growers in the main Kiwi producing areas of Shaanxi and Sichuan provinces from September to October 2018. The research team used a combination of hierarchical sampling and random sampling techniques to select samples. The specific sampling process is as follows: 4–5 townships were randomly selected in each county (city), and then three villages were randomly selected in each township, and finally 8–10 kiwi growers were randomly selected in each village. A total of 702 questionnaires were distributed to farmers in this survey. After data screening and elimination of the questionnaires with missing data of crucial variables, 650 valid questionnaires were used for final econometric analysis. The data was collected through face-to-face interview, and the questionnaire mainly includes household demographic structure, income and expenditure, characteristics of agricultural production and adoption of agricultural technologies. The village questionnaire survey is mainly for the village cadres who know the situation of the village, involving the population structure and economic development of the village. In the study areas, the income from kiwi fruit accounted for an average of 85.27% of the total agricultural income of farmers. Although the government carried out agricultural technology training and strengthened the guidance of agricultural technicians to promote the adoption of agricultural technology, increase production and increase household's income; nonetheless, kiwi growers still suffer from the low output and low net income.

#### 3.2 Research methods

The main objective of the current study focuses on the impact of the joint adoption of green production technology on the welfare of farmers. For feeding the research objectives, we have adopted multiple endogenous transformation model (MESR), whereas we adopted self-actualization tactics to deals with the instrumental variables. The model is set as follows:

$$Y_i = \alpha X_i + \eta D_i + \varepsilon_i \tag{1}$$

Whereas,

 $Y_i$  represents the welfare level of farmer *i*,  $D_i$  is the adoption of green production technology of farmer *i* ( $D_i$ = 1, means PCT<sub>0</sub>SMT<sub>0</sub>;  $D_i$ = 2, means PCT<sub>1</sub>SMT<sub>0</sub>;  $D_i$ = 3, means PCT<sub>0</sub>SMT<sub>1</sub>;  $D_i$ = 4, means PCT<sub>1</sub>SMT<sub>1</sub>), Multiple green production technologies

IJCCSM
13.3

234

- $X_i$  = control variable (including the characteristics of the head of household, the characteristics of family management, and the regional conditions that affect the welfare level of the grower), $\alpha$  and
- $\eta$  = parameters to be estimated, and
- $\varepsilon_i$  = random error term subject to independent and identical distribution.

In equation (1), whether a grower adopts green production technology is often a "selfselection" decision made by growers based on their personal characteristics and expected benefits. It will be affected by some unobservable factors (such as management ability, physical strength and risk preference, etc.) and observable factors (such as resource endowment, education and training, etc.). These factors will also affect the adoption of green production technology and the welfare level of farmers. PSM is the most commonly used method to deal with selection bias, but PSM only considers the influence of observable factors. In this paper, we need to consider the selection bias caused by both observable and non-observable factors. Therefore, this paper uses multiple endogenous transformation model (MESR) for estimation (Narayanan, 2014). The MESR model usually contains a multivariate selection equation and multiple result equations. The selection equation and result equations are estimated by using the full information maximum likelihood method. The estimation idea is as: in the first stage, multiple logit regression is used to estimate the selection equation; in the second stage, the inverse Mills ratio calculated in the first stage is brought into the result equations, and a consistent estimate of the model is obtained. According to the estimation results, the "counterfactual" framework is constructed to analyze the expected value of welfare under different green production technologies adopted by kiwi growers and to estimate the average treatment effect (ATT) of the treatment group; that is, the difference between the observable welfare and counterfactual welfare under different green production technologies adopted by growers.

For MESR model, it is assuming that the grower is risk-neutral, whether the grower adopts a certain green production technology often depends on the difference  $D_i^*(D_i^* = D_f^* - D_n^*)$  between the expected net income  $D_f^*$  and the current net income level  $D_n^*$  of adopting the green production technology. When the expected net income of adopting the technology is higher than the net income of not adopting it, the grower will choose to adopt it, at this time  $D_i^* > 0$ . Nevertheless,  $D_i^*$  is an unobservable variable and can be expressed as follows:

$$D_i^* = \gamma Z_i + \mu_i \tag{2}$$

$$D_{i} = \begin{cases} 1, D_{i}^{*} > \max_{m \neq 1} D_{m}^{*} \\ \vdots & (j = 1, 2, \dots, J) \\ J, D_{i}^{*} > \max_{m \neq j} D_{m}^{*} \end{cases}$$
(3)

(3)

Where

 $D_i^*$  is the latent variable of the categorical variable  $D_i$ ,

 $Z_i$  is a group of variables that influence the farmers' decision-making, and the explanatory variables in  $Z_i$  are allowed to overlap within  $X_i$ . However, to ensure that the equation can be identified, there is at least one variable in  $Z_i$  (Identification variable) not

included within  $X_i$ . This variable should directly affect the adoption of green production technology by growers, but not directly affect the welfare level of growers. Whereas,  $\gamma$  is the parameter to be estimated, and  $\mu_i$  is the random error term subject to independent and identical distribution. In equation (3), j(j = 1, 2, ..., J) is the adoption of the *j*-th green production technology:

- j = 1 means PCT<sub>0</sub>SMT<sub>0</sub>,
- j = 2means PCT<sub>1</sub>SMT<sub>0</sub>,
- j = 3 means PCT<sub>0</sub>SMT<sub>1</sub> and
- j = 4means PCT<sub>1</sub>SMT<sub>1</sub>.

If the grower adopts the *j*-th green production technology, then  $D_i^* > \max D_m^*$ . The welfare equation of growers adopting the *j*-th green production technology can be expressed as:

$$\begin{cases} y_{1i} = \beta_1 x_{1i} + \sigma_1 \hat{\lambda}_{1i} + \mu_{1i}, D_i = 1 \\ \vdots & j = 1, 2, 3, 4 \\ y_{ji} = \beta_j x_{ji} + \sigma_j \hat{\lambda}_{ji} + \mu_{ji}, D_i = J \end{cases}$$
(4)

Where,

 $x_{ii}$  is a series of explanatory variables, and

 $\mu_{ji}$  is a random error term subject to independent and identical distribution. Whereas,  $\hat{\lambda}_{ji}$  is the inverse Mills ratio calculated by equation (2), which is introduced into the resulting equation to solve the sample selection bias. Moreover,  $\sigma_j = \operatorname{cov}(\mu_i, \varepsilon_i)$  represent the covariance of the error term between the selection equation and the result equation. If the  $\sigma_j$  is statistically significant, it indicates that the adoption of green production technology by farmers is related to their welfare, and it is necessary to correct the selection deviation. The corrected result can reflect the impact of technology adoption on its welfare.

For the estimated ATT, the estimation results of the MESR model has been utilized, whereas, the conditional expectations of the farmer's welfare under the adoption of different agricultural technologies can be calculated. By constructing a "counterfactual" framework, the ATT of the technology adopters can be calculated. Based on the estimation result of equation (4), the expectation of the welfare conditions adopted by the farmers' green production technology can be expressed as equation (5), and the conditional expectation of the farmers' welfare under the "counterfactual" scenario is expressed as equation (6):

$$E\left(y_{ji}|D=j,x_{ji},\hat{\lambda}_{ji}\right) = \beta_j x_{ji} + \sigma_j \hat{\lambda}_{ji}$$
(5)

$$E\left(y_{1i}|D=j,x_{ji},\hat{\lambda}_{ji}\right) = \beta_1 x_{ji} + \sigma_1 \hat{\lambda}_{ji}$$
(6)

Using the difference between equations (5) and (6) as the ATT) of the 'grower's selection technique j, the expression is as follows:

$$ATT = E(y_{ji}|D = j, x_{ji}, \hat{\lambda}_{ji}) - E(y_{1i}|D = j, x_{ji}, \hat{\lambda}_{ji}) = (\beta_j - \beta_1)x_{ji} + (\sigma_j - \sigma_1)\hat{\lambda}_{ji}$$
(7)

Where  $(\beta_j - \beta_1) x_{ji}$  represents the expected change in the average outcome variable, while  $(\sigma_j - \sigma_1) \lambda_{ji}$  corrects the selective bias for the difference in unobserved variables.

production technologies

Multiple green

### IJCCSM 3.3 Variable selection

The current study focuses on the welfare of kiwi growers. For the measurement of the welfare indicators of farmers, many scholars measured it from different angles, mainly using indicators such as household income, consumption expenditure and productive expenditure of farmers. While combining the available data and field research, this study focuses on whether the adoption of green production technology can increase kiwi production and income of kiwi growers. Specifically, this study selects the kiwi yield, income from kiwi fruit and the household income to measure the welfare status of farmers.

This study mainly evaluates two types of agricultural green production technologies, including pest control technology and soil management technology. For the pest control technology, because it is limited to the study area and the research problem, this study only focuses on the physical control and biological control technology. The grower may adopt any of these two technologies, that is, the grower adopts the pest control technology. For the soil management technology, the farmer adopts any one of the applications of organic fertilizer technology and the soil testing formula and fertilization technology, that is, the farmer adopts the soil management technology.

Based on selecting core explanatory variables and identification variables, to further control the impact of other variables on the welfare of farmers, this paper refers to the research of related scholars (Keesstra *et al.*, 2016; Kumar *et al.*, 2020; Mariano *et al.*, 2012; Moyo and Veeman, 2004) and select the characteristics of the head of household, household demographic structure, characteristics of cultivated land resources and characteristics of family production and management as control variables. The descriptive statistics of variables are shown in Table 1. The results in Table 1 show that 42% of the sample growers have adopted pest control technology, and 38% of the sample growers have adopted soil management technology. From the point of joint technology adoption, 17% of the farmers adopt both the pest control technology and the soil management technology, 25% of the sample farmers only adopt the pest control technology. While 37% of growers neither adopt pest control technology by farmers is still not high.

#### 4. Estimated results and analysis

#### 4.1 Analysis of the influencing factors of green production technology joint adoption

Tables 2 and 3 are the regression analysis estimates of the first and second stages of the MESR model, respectively. In Table 2, the estimates of the marginal effects of the factors influencing the adoption of green production technology by farmers are presented. Specifically, in this paper, the reference group of "none of them are adopted" is used to estimate with the order logit model.

Table 2 shows that the gender of the head of the household has a negative impact on the farmers' adoption of  $PCT_0SMT_1$  and is statistically significant at 10%. That is, households headed by women are more likely to adopt  $PCT_0SMT_1$  and vice versa. The age of the head of household has a significant and negative impact on the farmer's adoption of  $PCT_0SMT_1$ , whereas, the younger the head of household, the more inclined to adopt only soil management techniques. The education level of head of the household has a positive impact on the farmer's adoption of  $PCT_0SMT_1$  and significant at the statistical level of 10%. This indicates that the higher the education levels of the head of the household, the higher the possibility that the farmers only adopt the soil management technology. The asset value has a positive effect on the adoption of  $PCT_1SMT_1$  by growers and is statistically significant at 5%, indicating that growers with high fixed asset values are more likely to achieve joint

13.3

Variable	Variable definition	Mean	SD	Multiple green
<i>1.outcome variables</i> Kiwi yield Kiwi income Household income	The yield of kiwi per mu (tons/mu) The income of kiwi per mu (ten thousand yuan/mu) Per capita household income (ten thousand yuan/person)	1.49 1.00 3.87	1.09 0.57 3.33	technologies
$\begin{array}{l} \textit{2.Treatment variables} \\ \text{PCT}_1 \text{SMT}_0 \end{array}$	Whether to adopt pest control technology (PCT): $1 = yes$ ; $0 =$	0.25	0.43	237
PCT <sub>0</sub> SMT <sub>1</sub>	NO Whether to adopt soil management technology (SMT): 1 =	0.21	0.41	
$PCT_1SMT_1$	Yes; 0 = no Adopt both pest control technology and soil management	0.17	0.38	
PCT <sub>0</sub> SMT <sub>0</sub>	technology (Joint adoption): $1 = \text{yes}$ ; $0 = \text{no}$ Neither adopt pest control technology nor adopt soil management technology (Non adoption): $1 = \text{yes}$ ; $0 = \text{no}$	0.37	0.48	
3.Explanatory variables		0.00	0.01	
Gender	1 = male; 0 = remale	0.90	0.21	
Education	Education level of householder: 1 = below primary school; 2 = primary school; 3 = junior high school; 4 = high school; 5 = tertiary school and above	2.84	0.79	
Asset value	Value of household fixed assets (ten thousand vuan)	30.80	19.06	
Household size	Total family population (person)	3.19	1.41	
Migrant work	Proportion of migrant workers (%)	32.37	33.42	
Cooperative	Whether to join the cooperative: $1 = yes; 0 = no$	0.10	0.30	
Kiwi scale	Actual cultivated kiwi area (mu)	5.99	4.23	
Land fragmentation	Number of kiwi plots (blocks)	4.10	3.07	
Land quality	Soil quality of the largest kiwi planting site: 1 = very poor; 2 = relatively poor; 3 = general; 4 = relatively good; very good= 5	3.39	0.97	
Annual watering	Annual watering frequency of Kiwi (times)	5.33	4.06	
Credit constraints	Difficulty of borrowing: 1 = very easy; 2 = relatively easy; 3 = general; 4 = relatively difficult; 5 = very difficult	2.86	1.16	Table 1.           Variable definitions           and statistical
Notes: mu is the unit of	of land area in China; where, one mu is equal to 0.667 ha			descriptions

technology adoption. The migrant work has a positive impact on farmers' adoption of  $PCT_1SMT_0$  and is statistically significant at 1%, that is, the higher the migrant workers, the more likely the farmers to adopt pest control technologies. Whether or not to join the cooperative has a positive impact on the farmers' adoption of  $PCT_1SMT_0$  and is significant at the significance level of 1%, that is, the farmers who join the cooperative prefer to adopt  $PCT_1SMT_0$ . Land fragmentation has a significant positive effect on farmer's adoption of  $PCT_1SMT_0$ , indicating that growers with a high degree of land fragmentation are more likely to use pest control technology. The land quality has a positive impact on the farmer's' adoption of  $PCT_0SMT_1$  and  $PCT_1SMT_1$ , which are statistically significant at 5% and 1% levels respectively. It shows that the better the land quality, the farmers tend to adopt soil management technology or even joint technology and the probability of joint technology adoption is higher than the probability of adopting soil management technology alone. The annual watering frequency has a significant negative impact on the farmers' adoption of  $PCT_0SMT_0$ , but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it has a positive effect on the farmer's adoption of  $PCT_0SMT_0$  but it

13,3				
	Variables	$PCT_1SMT_0$	$PCT_0SMT_1$	$PCT_1SMT_1$
	Gender	-0.074 (0.074)	-0.132* (0.068)	-0.001 (0.064)
	Age	0.023 (0.100)	-0.177*(0.085)	-0.055(0.071)
238	Education	0.019 (0.070)	0.125* (0.072)	-0.029(0.064)
200	Asset value	-0.027(0.023)	-0.015(0.022)	0.042** (0.019)
	Household size	-0.086 (0.054)	0.042 (0.048)	0.022 (0.040)
	Migrant work	0.031*** (0.009)	-0.012(0.008)	0.006 (0.007)
	Cooperative	0.261*** (0.072)	-0.003(0.051)	0.053 (0.035)
	Kiwi scale	-0.039(0.039)	-0.049(0.032)	0.035 (0.025)
	Land fragmentation	0.010* (0.006)	-0.007 (0.006)	0.005 (0.004)
	Land quality	-0.005 (0.016)	0.038** (0.016)	0.090*** (0.015)
	Annual watering	$-0.064^{***}$ (0.021)	0.090*** (0.023)	-0.011 (0.018)
	Credit constraints	0.028* (0.015)	0.002 (0.013)	$-0.027^{**}(0.012)$
	Information accessibility	-0.009 (0.014)	0.031** (0.013)	0.011 (0.011)
	Township distance	-0.012(0.028)	$-0.053^{**}(0.027)$	0.038 (0.025)
	Technical training	$-0.071^{***}$ (0.026)	-0.019(0.021)	0.099*** (0.018)
	Technical guidance	-0.011 (0.036)	0.214*** (0.026)	0.022 (0.025)
	Government promotion	-0.025* (0.014)	-0.012(0.013)	0.059*** (0.014)
	The joint significance value of ins	strumental variables $\chi^2$	129.22	20***
Table 9	The joint significance value of con	ntrol variables $\chi^2$	157.64	40***
Table 2.	Wald value $\chi^2$		268.93	50***
the first stage of the	Number of samples		65	50
MESR model	<b>Notes:</b> * <i>p</i> < 0.1; ** <i>p</i> < 0.05; *** <i>p</i>	p < 0.01. Robust standard error	s are in parentheses	

**HCCSM** 

technology. Credit constraints have a significant positive impact on farmers' adoption of  $PCT_1SMT_0$ , but a significant negative impact on the adoption of  $PCT_1SMT_1$ .

Besides, for the explanatory variables in the MESR model, the selection equation contains not only explanatory variables but also at least one identification variable which appears in the selection equation but not in the result equation, the selected five identification variables in this study (i.e. Information accessibility, township distances, technical training, technical guidance and government promotion) affect the adoption of green production technology by farmers to varying degrees.

Table 3 portrays the second stage of MESR of adopting green production technology on Kiwi's yield. The second-stage regression estimates the adoption of green production technology on Kiwi's income and household's income are not discussed due to space limitation, but they are presented in the Appendix (Tables A1–A2).

As shown in Table 3, the family size has a positive effect on the kiwi yield for farmers who adopt PCT<sub>1</sub>SMT<sub>0</sub> and those who only adopt PCT<sub>0</sub>SMT<sub>1</sub>, which are statistically significant at 10% and 5%, respectively. Compared with adopting PCT<sub>1</sub>SMT<sub>0</sub>, the size of the 'farmer's family that only adopted PCT<sub>0</sub>SMT<sub>1</sub> had a more significant impact on the kiwi yield. The kiwi scale has a positive impact on the kiwi yield of farmers who adopt PCT<sub>0</sub>SMT<sub>0</sub> and PCT<sub>1</sub>SMT<sub>0</sub> both are significant at 5% level. The effect on the kiwi yield of farmers who did not adopt technologies was higher than those who only adopted the pest control technology. Land fragmentation has a negative impact on the kiwi yield of farmers who adopt PCT<sub>0</sub>SMT<sub>0</sub> and who adopt PCT<sub>0</sub>SMT<sub>1</sub>, which are statistically significant at 1% and 10% respectively. For farmers who do not adopt technologies, the degree of land fragmentation has a more substantial restriction on the kiwi yield. The results of the

Variables	PCT <sub>0</sub> SMT <sub>0</sub>	PCT <sub>1</sub> SMT <sub>0</sub>	PCT <sub>0</sub> SMT <sub>1</sub>	PCT <sub>1</sub> SMT <sub>1</sub>	Multiple green
Gender	0.058 (0.237)	0.128 (0.285)	0.336 (0.311)	-0.723 (0.740)	technologies
Age	-0.104(0.250)	0.015 (0.279)	-0.440(0.386)	0.734 (0.577)	teennoiogies
Education	-0.028(0.151)	0.109 (0.311)	0.133 (0.327)	0.729 (0.487)	
Asset value	0.015 (0.054)	-0.044(0.086)	-0.110(0.099)	0.016 (0.156)	
Household size	0.051 (0.123)	0.266* (0.161)	0.456** (0.207)	0.172 (0.214)	
Migrant work	-0.015(0.037)	-0.006(0.043)	-0.043(0.046)	0.050 (0.057)	239
Cooperative	-0.352(0.435)	-0.314(0.269)	-0.407(0.317)	0.308 (0.240)	
Kiwi scale	0.268** (0.109)	0.209** (0.103)	0.112 (0.195)	0.187 (0.188)	
Land fragmentation	-0.064 * * * (0.017)	-0.029(0.018)	-0.074*(0.039)	0.024 (0.035)	
Land quality	-0.020(0.062)	-0.104(0.089)	0.082 (0.112)	0.229 (0.158)	
Annual watering	0.241*** (0.069)	0.293*** (0.081)	0.501*** (0.182)	0.071 (0.144)	
Credit constraints	-0.014(0.037)	0.015 (0.052)	-0.037(0.066)	-0.149(0.106)	
Township distance	-0.197 * * * (0.062)		-0.354 * * * (0.105)		
Technical training		0.151 (0.102)		0.320* (0.193)	
Technical guidance			0.588** (0.269)		
Government promotion	0.108*** (0.031)	0.071 (0.046)			
Constant	6.297*** (1.363)	6.209*** (1.828)	7.954*** (2.169)	1.645 (3.685)	
$\sigma^2$	0.358 (0.445)	0.301 (0.272)	0.790 (1.118)	1.470 (2.289)	
$\lambda_1$		0.277 (0.498)	0.832 (0.751)	-0.219(0.653)	
$\lambda_2$	-0.394(0.675)		-0.845(0.744)	0.918 (0.812)	
$\lambda_3$	-0.691(0.581)	-0.246(0.530)		-0.923** (0.378)	
$\lambda_4$	0.932* (0.548)	-0.042(0.711)	-0.415(0.385)		Table 2
Number of samples	242	162	135	111	Porrogaion regulta of
<b>Notes:</b> * <i>p</i> < 0.1; ** <i>p</i> < times are in parentheses	0.05; ***\$ <i>p</i> < 0.01. Re	obust standard erro	rs obtained by repeat	ing Bootstrap 100	the second stage of the MESR model

cultivated land fragmentation denote the increase in the labour force, input time and energy input of the planters. Due to negligence in the management of some scattered land, the output level of agricultural products has declined. The annual watering frequency has a positive impact on the kiwi yield of farmers who adopt  $PCT_0SMT_0$ ,  $PCT_1SMT_0$  and  $PCT_0SMT_1$ , all of which are statistically significant at 1%. Compared with the farmers who did not adopt the two technologies and only adopted the pest control technology, the farmers who only adopted the soil management technology had a greater impact on the kiwi yield.

In the second stage of estimation, the effective identification variables are the township distance, technical training, technology guidance and government promotion. The township distance has a negative impact on the kiwi yield of farmers who adopt  $PCT_0SMT_0$  and  $PCT_0SMT_1$ , and both are statistically significant at 1% level. The technical training has a positive effect on the kiwi yield adopted by the joint technology adopters, which is statistically significant at 10%. Whether technology guidance has a significant positive effect on the kiwi yield of farmers who adopt  $PCT_0SMT_1$ , is statistically significant at 5%. While government promotion has a positive impact on the kiwi yield who adopt  $PCT_0SMT_0$  and is significant at 1%. Based on the above results, it is shown that the identification variable selection is adequate.

# 4.2 Analysis of the treatment effect of green production technology joint adoption on the family welfare of growers

By employing equations 5–7, to further calculate the ATT and heterogeneous ATT of the impact of green production technology joint adoption on the household welfare of

**IICCSM** 13.3

240

welfare

and non-adopted growers

the growers (kiwi yield, kiwi income, household income). Due to space limitations, this paper does not discuss the positive ATT and the heterogeneous effect of adopting green production technology on the welfare of farmers, but it is listed in the Appendix (Tables A3–A4).

Regarding the treatment effect of the combined adoption of green production technology to increase the kiwi yield, the results in Table 4 show that under the construction of the "counterfactual" framework, ATT is positive in all three technology adoption combinations. It shows that for kiwi farmers who adopt green production technology if they adopt  $PCT_0SMT_0$ , the kiwi yield will be significantly reduced. Moreover, it also implies that the kiwi growers adopt the combination of green production technology, and the kiwi yield is higher than those who adopt PCT<sub>0</sub>SMT<sub>0</sub>. If the farmers who adopted PCT<sub>1</sub>SMT<sub>1</sub> did not adopt any technologies, their kiwi yield decreased by 53.81%. The adoption of PCT<sub>1</sub>SMT<sub>0</sub>,  $PCT_0SMT_1$  and  $PCT_1SMT_1$  had a significant positive effect on the yield. The farmers who adopted PCT<sub>1</sub>SMT<sub>1</sub> had the highest yield gain of kiwi yield (1159 Kg/mu), followed by adopted PCT<sub>0</sub>SMT<sub>1</sub> (284 Kg/mu) and PCT<sub>1</sub>SMT<sub>0</sub> (230 Kg/mu). Growers adopting  $PCT_1SMT_1$  has a higher effect on yield increase than adopting any single technology, indicating that there is a technical synergy between pest control technology and soil management technology. The kernel density function is used to predict the kernel density distribution of the kiwi yield of the technology adopters, and further analyze the effect of adopting green production technology on the kiwi yield (Figure 1). As shown in the figure, the kernel density function of the kiwi yield of the PCT<sub>1</sub>SMT<sub>1</sub> adopters is located to the right of the other technology adopting combinations (PCT<sub>0</sub>SMT<sub>0</sub>, PCT<sub>0</sub>SMT<sub>1</sub>, PCT<sub>1</sub>SMT<sub>0</sub>), which

			Adoption		
			Adopted $(j = 2, 3, 4)$	Not adopted $(j = 1)$	Treatment effect
		Technology adoption (j)	(1)	(2)	(3) = (1) - (2)
	Kiwi yield	PCT1SMT0(ATT) PCT0SMT1(ATT) PCT1SMT1(ATT)	1140 (34) 1493 (50) 2154 (93)	911 (28) 1209 (33) 995 (32)	230*** (19) 284*** (38) 1159*** (92)
	Kiwi income	PCT1SMT0(ATT) PCT0SMT1(ATT) PCT1SMT1(ATT)	7567 (114) 11786 (263) 15629 (408)	6767 (130) 9380 (236) 10115 (276)	800*** (111) 2405*** (218) 5513*** (395)
	Household income	PCT1SMT0(ATT) PCT0SMT1(ATT) PCT1SMT1(ATT)	28708 (1158) 48185 (933) 52420 (2210)	25372 (683) 29875 (903) 20711 (1212)	3336*** (780) 18310*** (856) 12700*** (2010)
	Kiwi yield	PCT1SMT1(ATU) PCT0SMT1(ATU)	1252 (24) 1045 (23)	962 (19) 962 (19)	291*** (19) 83*** (16)
	Kiwi income	PCT1SMT1(ATU) PCT1SMT0(ATU) PCT0SMT1(ATU)	1378 (32) 7675 (71) 7569 (115)	962 (19) 6339 (84) 6339 (84)	417*** (36) 1336*** (78) 1231*** (95)
Table 4.	Household	PCT1SMT1(ATU) PCT1SMT0(ATU) PCT0SMT1(ATU)	10795 (207) 26099 (613) 46855 (652)	6339 (84) 22328 (387) 22328 (387)	4456*** (177) 3771*** (534) 24527*** (670)
the ATT and ATU of the Joint adoption of	litcome	PCT1SMT1(ATU)	27060 (797)	22328 (387)	4732*** (794)
technology on the	<b>Notes:</b> $*p < 0$ average treatm	0.1; $**p < 0.05$ ; $***p < 0.01$ . nent effect corresponding to	standard errors are in the joint adoption of	parentheses. ATT an green production tech	d ATU indicate the mology by growers



indicates that the grower adopting  $PCT_1SMT_1$  has a higher increase in the yield than adopting any single technology or not adopting any technologies.

In terms of the joint adoption of green production technology to increase the treatment effect of increasing the kiwi income and the household income, the results in Column (3) of Table 4 show that under the framework of "counterfactual", for growers who adopt PCT<sub>1</sub>SMT<sub>1</sub>, if they do not adopt the green production technology, whether it is kiwi income or the household income will be significantly reduced by 35.27% and 25.66%, respectively. It means that the adoption of green production technology by kiwi growers can significantly increase the kiwi income as well as household income. Specifically, growers who adopt PCT<sub>0</sub>SMT<sub>1</sub> and PCT<sub>1</sub>SMT<sub>1</sub> have higher income advantages than those who adopt  $PCT_1SMT_0$ . The kiwi income for growers who adopt  $PCT_1SMT_0$  is the lowest (800 Yuan/ mu), and the household income is also the lowest (3336 Yuan). Similarly, the nuclear density function graph can also reflect the income effect of kiwi farmers adopted by different green production technologies (Figures 2 and 3). As shown in Figures 2 and 3, the kernel density function of kiwi income and the household income of the farmers adopting  $PCT_1SMT_1$  is located to the right of the kernel density function of the farmers adopting other technologies. It shows that kiwi income and household income of adopting joint technology are higher than that of adopting any single technology or not adopting any technology.

#### 5. Discussion and observation

In this paper, based on full consideration of the selective bias caused by observable factors and unobservable factors, using the survey data of 650 kiwi growers in 6 counties (cities) in Shaanxi and Sichuan provinces, multiple endogenous conversion regression models, and "counterfactual" framework is used to analyze the effect of the joint adoption of green production technology on the welfare of growers. The main observations are as follows:

- First, statistical analysis shows that the adoption rate of kiwi growers for pest control technology and soil management technology is 42% and 38%, respectively.
- Second, the adoption of pest control technology and soil management technology by kiwi growers significantly increased the kiwi yield, increased the average kiwi income and the household income, indicating that the joint adoption of green



production technology has a significant yield increase effect and income gain effect, which is also identical to the result of Ricker-Gilbert and Jones (2015) and Kpadonou *et al.* (2017).

• Third, under the "counterfactual" assumption, if the farmers who adopted the joint technology did not adopt the pest control technology and soil management technology, their kiwi yield, kiwi income and household income decreased by 53.81%, 35.27% and 25.66%, respectively. If the farmers who have not adopted the pest control technology and the soil management technology adopt the green production technology, their kiwi yield, kiwi income and household income increased by 43.35%, 70.29% and 21.19%, respectively. The study of Thirtle *et al.* (2003), Awotide *et al.* (2016) also support these findings.

• Fourth, the gender, age, education level, asset value, migrant work, cooperative, land fragmentation, cultivated land quality, annual watering and credit constraints all have significantly affected the adoption of green production technology by kiwi growers. For decision-making, growers with a high asset value in their homes, good land quality, weak credit constraints, more training and greater local government promotion tend to adopt both pest control technology and soil management technology. These findings also gain light with the findings of Singha and Baruah (2011), Diiro (2012) and Tiffin and Balcombe (2011).

### 6. Conclusion and enlightenment

This paper aims to explore the influencing factors of farmer's joint adoption of green production technology and analyze the impact of joint adoption technology on Farmers" welfare effect. The relationship between the adoption behaviour of combined green production technology and the welfare of farmers can be regarded as an essential supplementary research content of planned behaviour theory and welfare economics theory. On this basis, the study of farmer's joint adoption of green production technology rather than unique technology is helpful to deeply understand the practice of agricultural technology adoption of Chinese farmers and the impact path of Influencing Farmer's joint adoption of technology. It can provide feasible support and reference for local governments to promote green production technology, and also for the government to formulate green technology promotion policies and systems degree provides theoretical reference. Based on the above conclusions, the following policy implications could be suggested:

- First, the government and agricultural technology promotion department need to facilitate and provide continuous support for availing improve agricultural technology, promoting innovative methods and strengthen the training facilities to promote green production technology. Improved and innovative technical training methods and content should be facilitated based on the actual need of growers. They have to guide and encourage growers to participate in green production technology training actively. Moreover, initiatives should be taken to reduce the technical knowledge threshold and information barriers of kiwi growers and try to change the traditional technology application conceptions of kiwi growers for removing the "shortboard" of kiwi growers. Along with those, governments and the related authorities should highlight and promote the adoption of green production technology to availing a substantial increase in output and income as well.
- Second, more focusses should be given on the technical synergy among kiwi grower's green production technologies and promote the overall application of kiwi grower's green production technologies. The government should actively build an open technology platform and optimize the technology promotion environment, make full use of the synergy among technologies, promote the joint adoption of green production technology, effectively reduce the cost and the difficulty of technology promotion and enhance the kiwi farmers' initiative to adopt green production technology.
- Third, the design of green production technology policies and the crackdown on technical bottlenecks should be optimized. The government should encourage kiwi growers to adopt green production technology through financial subsidies; alleviate kiwi grower's financial, technical and information constraints in the application of

Multiple green production technologies

IJCCSM technology, focus on guiding growers with higher physical capital, human capital and financial capital to adopt green production technologies.

• Finally, the adoption of covered green production technology should be realized, and the efficiency of green production technology adoption of kiwi growers in the whole region should be improved as well.

We noticed that there are some limitations also associated with our current study. First, this  $\mathbf{244}$ study takes kiwi fruit growers in Shaanxi and Sichuan as examples, whereas we covered only small areas and small peasant groups, which cannot represent the technology adoption behaviour of all farmers in China. We believe and hope that to make the research results more meaningful and representative, future research studies will expand the research scope by including more research objects and coving up broad area. Second, for the measurement of farmer's welfare effect, the researcher's selected three variables: annual income, kiwi fruit vield and income. However, welfare is a multi-dimensional comprehensive index. There is no doubt that there is a particular bias to consider only from these three perspectives. We expect to evaluate it in future research. Finally, at present, the adoption of green agricultural production technology not only includes pest control technology and soil management technology, but there have strong involvements of complex technology packages including the replacement of organic fertilizer chemical fertilizer, healthy breeding, soil testing and formula fertilization and integrated pest control and management. Therefore, not including all the technologies in the research may lead to errors in the research results. The above limitation and possible extension should be considered as essential research directions for future researchers.

#### References

- Adnan, N., Nordin, S.M., Bahruddin, M.A. and Tareq, A.H. (2019), "A state-of-the-art review on facilitating sustainable agriculture through green fertilizer technology adoption: assessing farmers behavior", *Trends in Food Science and Technology*, Vol. 86, pp. 439-452.
- Aklin, M., Bayer, P., Harish, S.P. and Urpelainen, J. (2018), "Economics of household technology adoption in developing countries: evidence from solar technology adoption in rural India", *Energy Economics*, Vol. 72, pp. 35-46.
- Anang, B.T., Bäckman, S. and Sipiläinen, T. (2020), "Adoption and income effects of agricultural extension in Northern Ghana", *Scientific African*, Vol. 7, p. E00219.
- Awotide, B.A., Karimov, A.A. and Diagne, A. (2016), "Agricultural technology adoption, commercialization and smallholder rice farmers' welfare in rural Nigeria", *Agricultural and Food Economics*, Vol. 4, p. 3.
- Bandiera, O. and Rasul, I. (2006), "Social networks and technology adoption in Northern Mozambique", *The Economic Journal*, Vol. 116 No. 514, pp. 869-902.
- Barham, B.L., Chavas, J.P., Fitz, D., Rios-Salas, V. and Schechter, L. (2015), "Risk, learning, and technology adoption", *Agricultural Economics*, Vol. 46 No. 1, pp. 11-24.
- Bunclark, L., Gowing, J., Oughton, E., Ouattara, K., Ouoba, S. and Benao, D. (2018), "Understanding Farmers' decisions on adaptation to climate change: exploring adoption of water harvesting technologies in Burkina Faso", *Global Environmental Change*, Vol. 48, pp. 243-254.
- Chang, S.C. and Tsai, C.H. (2015), "The adoption of new technology by the farmers in Taiwan", *Applied Economics*, Vol. 47 No. 36, pp. 3817-3824.
- Das, S., Hittinger, E. and Williams, E. (2020), "Learning is not enough: diminishing marginal revenues and increasing abatement costs of wind and solar", *Renewable Energy*, Vol. 156, pp. 634-644.

- Diiro, G.M. (2012), "Impact of off-Farm income on agricultural technology adoption intensity and productivity evidence from rural maize farmers in Uganda", Ifpri Org.
- Duflo, E., Kremer, M. and Robinson, J. (2011), "Nudging farmers to use fertilizer: theory and experimental evidence from Kenya", *American Economic Review*, Vol. 101 No. 6, pp. 2350-2390.
- Feder, G. and Umali, D.L. (1993), "The adoption of agricultural innovations: a review", *Technological Forecasting and Social Change*, Vol. 43 Nos 3/4, pp. 215-239.
- Fernandez-Cornejo, J. (1998), "Environmental and economic consequences of technology adoption: Ipm in viticulture", Agricultural Economics, Vol. 18, pp. 145-155.
- Gómez, W., Salgado, H., Vásquez, F. and Chávez, C. (2014), "Using stated preference methods to design cost-effective subsidy programs to induce technology adoption: an application to a stove program in Southern Chile", *Journal of Environmental Management*, Vol. 132, pp. 346-357.
- Joffre, O.M., Poortvliet, P.M. and Klerkx, L. (2019), "To cluster or not to cluster farmers? Influences on network interactions, risk perceptions, and adoption of aquaculture practices", Agricultural Systems, Vol. 173, pp. 151-160.
- Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcántara, L., Jordán, A. and Cerdà, A. (2016), "Effects of soil management techniques on soil water erosion in apricot orchards", *Science of the Total Environment*, Vol. 551-552, pp. 357-366.
- Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F. and Kiema, A. (2017), "Advancing climate-smartagriculture in developing Drylands: joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel", *Land Use Policy*, Vol. 61, pp. 196-207.
- Kumar, A., Takeshima, H., Thapa, G., Adhikari, N., Saroj, S., Karkee, M. and Joshi, P.K. (2020), "Adoption and diffusion of improved technologies and production practices in agriculture: insights from a donor-led intervention in Nepal", *Land Use Policy*, Vol. 95, p. 104621.
- Liu, Y., Ruiz-Menjivar, J., Zhang, L., Zhang, J. and Swisher, M.E. (2019), "Technical training and rice farmers' adoption of low-carbon management practices: the case of soil testing and formulated fertilization technologies in Hubei", *Journal of Cleaner Production*, Vol. 226, pp. 454-462.
- Maertens, A. and Barrett, C.B. (2013), "Measuring social networks' effects on agricultural technology adoption", American Journal of Agricultural Economics, Vol. 95 No. 2.
- Mariano, M.J., Villano, R. and Fleming, E. (2012), "Factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines", *Agricultural Systems*, Vol. 110, pp. 41-53.
- Moyo, S. and Veeman, M. (2004), "Analysis of joint and endogenous technology choice for protein supplementation by smallholder dairy farmers in Zimbabwe", *Agroforestry Systems*, Vol. 60 No. 3, pp. 199-209.
- Narayanan, S. (2014), "Profits from participation in high value agriculture: evidence of heterogeneous benefits in contract farming schemes in Southern India", *Food Policy*, Vol. 44, pp. 142-157.
- Omotilewa, O.J., Ricker-Gilbert, J. and Ainembabazi, J.H. (2019), "Subsidies for agricultural technology adoption: evidence from a randomized experiment with improved grain storage bags in Uganda", *American Journal of Agricultural Economics*, Vol. 101 No. 3, pp. 753-772.
- Phibbs, B.C.S. (2002), "Managed care, technology adoption, and health care: the adoption of neonatal intensive care", *Rand Journal of Economics*, Vol. 33, pp. 524-548.
- Rahelizatovo, N.C. and Gillespie, J.M. (2004), "The adoption of best management practices by Louisiana dairy producers", *Journal of Agricultural and Applied Economics*, Vol. 36 No. 1, pp. 229-240.
- Ricker-Gilbert, J. and Jones, M. (2015), "Does storage technology affect adoption of improved maize varieties in Africa? Insights from Malawi's input subsidy program", *Food Policy*, Vol. 50, pp. 92-105.
- Rogers, J.K., Nichols, B., Biermacher, J.T. and Mosali, J. (2014), "The value of native, warm-season perennial grasses grown for pasture or biofuel in the Southern great plains", *Crop and Pasture Science*, Vol. 65 No. 6, pp. 550-555.

Multiple green production technologies

IJCCSM	Schiopu, I. (2015), "Technology adoption, human capital formation and income differences", Journal of Macroeconomics, Vol. 45, pp. 318-335.
10,0	Singha, A.K. and Baruah, M.J. (2011), "Farmers' adoption behaviour in rice technology: an analysis of adoption behaviour of farmers in rice technology under different farming systems in Assam", <i>Journal of Human Ecology</i> , Vol. 35 No. 3, pp. 167-172.
246	Smith, J.E. and Ulu, C. (2017), "Risk aversion, information acquisition, and technology adoption", <i>Operations Research</i> , Vol. 65 No. 4, pp. 1011-1028.
240	Thirtle, C., Lin, L. and Piesse, J. (2003), "The impact of research-led agricultural productivity growth on poverty reduction in Africa", Asia and Latin America. World Development, Vol. 31, pp. 1959-1975.
	Tiffin, R. and Balcombe, K. (2011), "The determinants of technology adoption by UK farmers using Bayesian model averaging: the cases of organic production and computer usage", <i>Australian</i> <i>Journal of Agricultural and Resource Economics</i> , Vol. 55 No. 4, pp. 579-598.
	Uddin, M., Mohi, B., Bernhard, P. and Johanes, K. (2014), "Technical efficiency and metatechnology ratios under varying resource endowment in different production systems: a stochastic metafrontier model in Bangladesh dairy farms", <i>China Agricultural Economic Review</i> .
	Wang, Y., Zhu, Y., Zhang, S. and Wang, Y. (2018), "What could promote farmers to replace chemical fertilizers with organic fertilizers?", <i>Journal of Cleaner Production</i> , Vol. 199, pp. 882-890.

- Wossen, T., Alene, A., Abdoulaye, T., Feleke, S. and Manyong, V. (2019), "Agricultural technology adoption and household welfare: measurement and evidence", *Food Policy*, Vol. 87, p. 101742.
- Wossen, T., Abdoulaye, T., Alene, A., Haile, M.G., Feleke, S., Olanrewaju, A. and Manyong, V. (2017), "Impacts of extension access and cooperative membership on technology adoption and household welfare", *Journal of Rural Studies*, Vol. 54, pp. 223-233.

## Multiple green production technologies

### Appendix

Variables	PCT <sub>0</sub> SMT <sub>0</sub>	$PCT_1SMT_0$	$PCT_0SMT_1$	$PCT_1SMT_1$	
Gender	0.034 (0.262)	0.043 (0.165)	0.120 (0.225)	0.009 (0.206)	247
Age	-0.065 (0.276)	0.051 (0.213)	-0.038(0.248)	0.196 (0.294)	241
Education	0.106 (0.144)	0.118 (0.153)	-0.062(0.189)	0.268 (0.192)	
Asset value	0.063 (0.048)	0.024 (0.055)	0.009 (0.055)	-0.087(0.096)	
Household size	0.331** (0.146)	0.127 (0.140)	0.307** (0.120)	-0.017 (0.115)	
Migrant work	-0.055(0.034)	-0.017(0.032)	-0.049(0.032)	0.023 (0.033)	
Cooperative	-0.284(0.392)	-0.002(0.201)	-0.002(0.192)	0.179 (0.123)	
Kiwi scale	-0.060(0.115)	0.118 (0.091)	0.026 (0.087)	0.009 (0.105)	
Land fragmentation	-0.023(0.015)	-0.024(0.014)	-0.004(0.018)	0.016 (0.015)	
Land quality	0.079 (0.072)	-0.063(0.067)	-0.075(0.080)	-0.022(0.091)	
Annual watering	0.113** (0.057)	0.057 (0.065)	0.126 (0.096)	0.186** (0.077)	
Credit constraints	-0.051*(0.037)	0.003 (0.032)	0.032 (0.037)	-0.064(0.055)	
Information accessibility	0.077** (0.037)	0.082** (0.035)	()	0.090** (0.039)	
Township distance	()	(,		(,	
Technical training				0.020 (0.095)	
Technical guidance	0.391** (0.186)		0.194 (0.222)	()	
Government promotion	0.057*(0.031)		)		
Ancillary	0.0001 (0.0001)				
$\sigma^2$	0.320 (0.683)	0 206 (0 154)	1 219** (0 569)	0 254 (0 404)	
λ1	0.020 (0.000)	0.436 (0.516)	1 182** (0 480)	-0.817(0.526)	Table A1
$\lambda_{2}$	-0.769(0.682)	0.100 (0.010)	-0.848(0.590)	0.892 (0.744)	Table A1.
$\lambda_{2}$	0.826(0.681)	-0.208 (0.508)	0.010 (0.000)	0.198 (0.545)	Marginal effect of
λ,	-0.246(0.537)	-0.376(0.622)	-0.355 (0.322)	0.100 (0.040)	joint adoption of
Number of observations	242	162	135	111	green production technologies on kiwi
<b>Notes:</b> * <i>p</i> < 0.1, ** <i>p</i> < 0.05	5, *** <i>p</i> < 0.01. Robust	standard errors are	in parentheses		income (MESR)

IJCCSM	Variables	PCT <sub>0</sub> SMT <sub>0</sub>	PCT <sub>1</sub> SMT <sub>0</sub>	PCT <sub>0</sub> SMT <sub>1</sub>	PCT <sub>1</sub> SMT <sub>1</sub>
10,0	Gender	-0.221(0.261)	-0.347(0.242)	0.084 (0.200)	0.084 (0.421)
	Age	-0.244(0.303)	0.041(0.262)	-0.146(0.227)	-0.482(0.512)
	Education	0.096 (0.159)	0.273 (0.166)	-0.153(0.263)	0.314 (0.438)
	Asset value	0.119* (0.064)	0.069 (0.079)	0.063 (0.055)	0.022 (0.122)
a ( a	Household size	-0.263(0.173)	0.111 (0.163)	-0.427 *** (0.150)	-0.430 ** (0.211)
248	Migrant work	0.071*(0.042)	0.033 (0.040)	0.031 (0.037)	-0.018(0.048)
	<ul> <li>Cooperative</li> </ul>	-0.172(0.448)	-0.268(0.260)	0.259 (0.237)	0.150 (0.212)
	Kiwi scale	0.080 (0.108)	0.549*** (0.136)	0.181 (0.149)	0.410** (0.162)
	Land fragmentation	-0.009(0.019)	-0.018(0.016)	0.021 (0.028)	-0.007(0.034)
	Land quality	0.071 (0.076)	0.102 (0.079)	-0.008(0.097)	0.014 (0.133)
	Annual watering	0.129* (0.078)	0.118 (0.078)	-0.169*(0.087)	-0.004(0.139)
	Credit constraints	-0.018(0.038)	-0.039(0.045)	0.047 (0.052)	-0.094(0.087)
	Information accessibility	0.083* (0.045)	0.083** (0.042)		
	Township distance		-0.168 ** (0.069)		-0.283*(0.159)
	Technical training		0.122 (0.099)		
	Technical guidance	0.409** (0.201)			-0.044(0.329)
	Government promotion	0.056 (0.037)		0.021 (0.046)	0.246*** (0.086)
	Ancillary				
Table A2.	$\sigma^2$	0.672 (0.742)	0.287 (0.237)	0.539 (0.704)	0.982 (1.476)
Marginal effect of	$\lambda_{1}$		0.270 (0.536)	-0.531(0.622)	0.106 (0.670)
ioint adoption of	$\lambda_2$	-0.340(0.653)		1.062** (0.497)	0.814 (0.808)
groon production	$\lambda_3$	1.231** (0.554)	0.378 (0.386)		-0.976 (0.695)
	$\lambda_4$	-0.884*(0.476)	-0.722(0.518)	-0.493(0.389)	
household income	Number of observations	242	162	135	111
(MESR)	<b>Notes:</b> * <i>p</i> < 0.1, ** <i>p</i> < 0.0	5, *** <i>p</i> < 0.01. Robu	ıst standard errors a	re in parentheses	

			Adoption status			
			(j = 2, 3, 4)	(j=1)	Treatment effect	
		Technology adoption (j)	(1)	(2)	(3) = (1) - (2)	
	Kiwi yield	$PCT_1SMT_0$	1285 (16)	1006 (14)	279*** (13)	
		$PCT_0SMT_1$	1204 (20)	1006 (14)	198*** (14)	
Table A3.		$PCT_1SMT_1$	1659 (33)	1006 (14)	653*** (32)	
Unconditional	Kiwi income	$PCT_1SMT_0$	8167 (62)	7722 (102)	445*** (73)	
average treatment		$PCT_0SMT_1$	9697 (131)	7722 (102)	1975*** (95)	
offect of the joint		$PCT_1SMT_1$	12174 (159)	7722 (102)	4451*** (126)	
	Household income	$PCT_1SMT_0$	33477 (701)	27622 (439)	5855*** (487)	
adoption of green		$PCT_0SMT_1$	49845 (527)	27622 (439)	22222*** (466)	
technology on the		PCT <sub>1</sub> SMT <sub>1</sub>	37107 (937)	27622 (439)	9484*** (812)	
welfare	<b>Notes:</b> * <i>p</i> < 0.1, ** <i>p</i>	< 0.05, ***p < 0.01. Robust st	andard errors are	in parentheses		

		Adoptic	on status		Multiple green production technologies
	Technology adoption $(j)$	Adopted (j = 2, 3, 4) (1)	Not adopted (j = 1) (2)	Treatment effect (3) = $(1) - (2)$	
Kiwi yield	E(4 2) vs $E(3 2)E(4 3)$ vs $E(2 3)E(2 4)$ vs $E(2 4)$	1418 (59) 2046 (87) 1424 (50)	1044 (31) 1450 (39) 1270 (26)	374*** (57) 596*** (88)	249
Kiwi income	$E(3 4) \lor S E(2 4)$ $E(4 2) \lor S E(3 2)$ $E(4 3) \lor S E(2 3)$ $F(3 4) \lor S E(2 4)$	1434 (59) 10862 (280) 13377 (319) 12323 (321)	9335 (237) 8961 (139) 9148 (164)	64 (43) $1528^{***} (325)$ $4416^{***} (246)$ $3174^{***} (281)$	Table A4. The average treatment
Household income	E(4 2) vs E(3 2) E(4 3) vs E(2 3) E(3 4) vs E(2 4)	30565 (1588) 49553 (2579) 60740 (1594)	48229 (1060) 38259 (1416) 50708 (2235)	$-17664^{***}$ (1446) 11294^{***} (2314) 10032^{***} (2141)	heterogeneity effect of the joint adoption of green production
Notes: *p < 0.1, **p	<0.05, ***p < 0.01. Robust st	andard errors are	in parentheses		welfare

**Corresponding author** Xianli Xia can be contacted at: xnxxli@163.com

For instructions on how to order reprints of this article, please visit our website: www.emeraldgrouppublishing.com/licensing/reprints.htm Or contact us for further details: permissions@emeraldinsight.com