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RESEARCH ARTICLE

Duration analysis on the adoption behavior of green control techniques

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Abstract

Based on field survey data of 366 traditional households (THs) and 364 family farms (FFs) from Huang-Huai-Hai Plain, a discrete-time cloglog model for parameter estimation was constructed to reveal factors that affect the two types of farms' duration from the awareness to the adoption of green control techniques (GCTs). Differences in the influencing factors affecting the duration of the two types of farmers were also discussed. The research results are as follows. First, the duration from awareness to adoption of GCTs is significantly shorter in FFs than that in THs. Second, a higher degree of education, risk preference, family financial status, perceived ease of use and usefulness of the technique, and extension of media and supervision of agricultural technique extension departments of local governments significantly reduce the duration from awareness to adoption of GCTs by THs and FFs, whereas a male head of household prolongs the duration. Third, the age, farm size, and number of laborers exert different impacts on the duration from awareness to adoption of GCTs by THs and FFs.

Keywords Farms differentiation · Green control techniques (GCTs) · Duration analysis · Discrete-time cloglog model

Introduction

The use of chemical pesticides has two apparently conflicting effects in agricultural production. On the one hand, chemical pesticides play an important role in preventing pests and producing a stable high yield. On the other hand, chemical pesticides can result in high production costs and increased agricultural residues when their application is inappropriate. Furthermore, excessive chemical pesticides enter the soil, rivers, and atmosphere through volatilization, causing agricultural non-point source pollution. The average amount of chemical pesticide use is 2.5–5 times higher in China than in developed countries (Jin et al. 2017). Moreover, farmers extensively practice the improper use and frequent application of chemical pesticides, with shortened intervals between applications (Wang et al. 2015a).

China's government is committed to promoting green control techniques (GCTs) to reduce and control the usage of chemical pesticides, ensure safe agricultural production, and provide ecological and environmental safety, thereby promoting the sustainable development of agriculture. GCT is the Chinese concept of integrated pest management (IPM) and prioritizes adopting resource-saving and environmentally friendly technical measures such as ecological regulation, biological control, physical control, and scientific pesticide use. However, the use of GCTs in China remains mainly experimental and implemented at a small scale; GCTs continue to face numerous difficulties in achieving popularity and being more widely applied (Wang et al. 2015b).

Demand from farmers, who constitute the micro decision-making body of agricultural production and operation, would be the basis for the successful application of GCTs. Scholars have conducted extensive and in-depth studies on the factors that influence the adoption behavior of GCTs by farmers. For example,

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Bola et al. (2016), Murage et al. (2015), Kabir and Rainis (2015), Korir et al. (2015), and Ward and Singh (2015) highlighted that gender, age, education degree, and risk preference affect GCT (IPM) adoption by farmers. Cavallo et al. (2014a), Allahyari et al. (2016), and Grabowski et al. (2016) discovered that the availability of large-scale cultivated land, a favorable capital position, and an abundant source of labor promote GCT (IPM) adoption by farmers. Gao et al. (2017a) and Verma and Sinha (2018) confirmed that farmers would likely adopt GCTs (IPM) when they perceive them to be useful and easy to implement. In addition, the influence of mass communication media and extension activities by the agricultural technique extension departments of local governments promoting GCTs (IPM) adoption by farmers cannot be ignored (Zamani-Miandashti et al. 2014; Jayasooriya and Aheeyar 2016; Sharma and Peshin 2016).

Existing researches have provided a valuable source of references for this paper, but the following two aspects of this issue remain to be studied. First, under the influence of the market economy and agricultural modernization, Chinese farmers are classified as either traditional households (THs), with multiple jobs and decentralized features, or as family farms (FFs, large THs), who are characterized by specialization, integration, systematization, and socialization (Guan 2018). These two types have coexisted for many years and will continue to coexist (Gao et al. 2017b). FFs are based on the family and integrate modern production factors such as science and technology, cutting-edge information, agricultural machinery, finance resources, and modern management concepts; FFs implement a new microeconomic organization with specialized production, socialized collaboration, and large-scale operations. FFs, formerly large THs, originated in the 1980s and formalized in 2005. At present, China has more than 870,000 FFs with an average area of more than 10 ha; in total, these encompass 11.7 million hectares of farmland and account for 13.4% of the country's total agricultural land. FFs are different from THs in terms of production factors such as land, capital and labor, the nature of labor, and the product attributes of the households (Gao et al. 2013). To be specific, first, in terms of land, whereas THs mainly rely on their own land, which they supplement with leased land, the land of FFs is primarily leased land supplemented by their own land. Second, in terms of financial status, THs rely on their own funds and often lack a clear return on capital, whereas FFs need outside investment combined with their own capital, and they have a clear goal regarding return on capital. Third, in terms of their views on labor, THs mainly rely on family members, with an occasional need for outside labor from neighbors, while FFs rely mainly on their own labor force. Fourth, in terms of the nature of the labor operating these types of farms, THs rely mainly on productive labor, while FFs make use of both productive and managerial labor. Finally, in terms of product attributes, the THs produce for the farmer's living needs, and the FFs produce mainly for profit. Thus, to promote the application of GCTs, the practical needs of THs and FFs should be considered separately. However, most existing studies on the Chinese agricultural system take THs as the example, and there are relatively few studies focusing on the needs of FFs; in addition, research that focuses on the differences between THs and FFs has not yet been reported. Therefore, this study aims to address this shortcoming and focuses on the differences in GCTs adoption behaviors between THs and FFs.

Second, the technology adoption behavior of farmers should be a dynamic process (Martins et al. 2011), but most of the existing researches use static analysis methods, such as Probit, Tobit, and sample selection models. These static models cannot explain the duration from the awareness to the adoption of GCTs by farmers nor can they estimate the aging of the farmers over time and its variable impact on the GCTs adoption behavior of farmers. Therefore, this study applied duration analysis (DA) to understand the dynamic changes in the GCTs adoption behavior of farmers.

Currently, adopting behavioral research based on DA is common for studies on farmers. For example, Alcon et al. (2011) argued that the duration between the awareness and adoption of soilless cultivation techniques by Spanish farmers is short when FFs are large. Nazli and Smale (2016) found that the duration from awareness to adoption by elite Pakistani farmers is short when the household head is educated and when they are engaged in more labor-intensive practices. Martins et al. (2011) highlighted that greater age and farming experience among heads of households in Kenyan farms significantly increase the duration of their knowledge and the adoption of soil fertility management techniques. The extension activities of non-governmental organizations significantly shorten the duration between awareness and adoption processes for rainwater harvesting technology (Willy and Kuhn 2016). Ahsanuzzaman (2015) confirmed that acquiring agro-technique extension services and participating in the technical training of farmers in Bangladesh would hasten IPM adoption time by 4% and 12%, respectively. The duration of the improvement of maize varieties from awareness to adoption by Tanzanian farmers is extended by 10% when each household head grows a year older (Beyene and Kassie 2015).

Current researches on farmers' technology adoption behavior based on continuous time analysis frequently uses the Cox proportional hazard model (CPHM) to perform parameter estimation. However, the duration from awareness to the adoption process of techniques by farmers is characterized by a discrete distribution. CPHM is incapable of dealing with multiduration node problems caused by the discrete random distribution of data (Hess and Persson 2010).[1] Therefore, this paper used the discrete-time model for parameter estimation. The discrete-time model can be subdivided into three forms, Probit model, Logit

[1] The CPHM cannot deal with unobserved heterogeneity and is prone to pseudo-duration dependence. Simultaneously, the CPHM may be subject to estimation bias caused by the error setting benchmark risk (Alandejani et al. 2017).

model, or Cloglog model depending on whether the data distribution functions are close to a normal distribution, a logistic distribution, and an extreme value distribution, respectively. Because the duration from the awareness to the adoption of GCT by farmers is asymmetrically distributed and closer to the extreme value distribution, this paper used the discrete-time cloglog model. The discrete-time cloglog model can effectively prevent the problems experienced by the CPHM, and more rigorous estimation results can be obtained.

Therefore, we used DA to process the data of 366 THs and 364 FFs in the Huang-Huai-Hai Plain. First, Kaplan–Meier estimates of the survival function model were constructed to describe the probability distribution characteristics of the GCTs and the duration from the awareness to the adoption of GCTs by the THs and FFs. Furthermore, to reveal the influencing factors and their different effects on the duration from the awareness to the adoption of GCTs by THs and FFs, based on the hazard function model, we constructed a discrete-time cloglog model for parameter estimation.

The contributions of this article are mainly reflected in three aspects. First, this paper fully considers the differences in the demand of farms and discusses the differences between THs and FFs in the factors that influence the GCT adoption behavior. Second, this paper focuses on the dynamic changes and reveals the factors that affect the duration from the awareness to the adoption of GCTs by farmers. Third, this paper uses the discrete-time cloglog model to obtain a more rigorous estimation result.

Research design and methodology

Model

The DA is based on conditional probability theory (Lancaster 1979), and the basic functional model includes survival and hazard functions (Jenkins 2005). This article first defines the non-negative discrete random variable T, which indicates duration from awareness to adoption process of GCTs by farmers, $T = 1, 2, \ldots, t-1, t$.

Let $S(t)$ be the survivor function, which is the probability that a farmer takes more than t years between awareness and adoption of GCTs.

$$S(t) = \Pr.(T > t) = 1-\Pr(T \le t) = 1-\int_0^t f(t)dt, 0 \le S(t) \le 1 \quad (1)$$

where $f(t) = \Pr(T = t)$ denotes the probability of the awareness of GCTs to the adoption process by farmers for t years. $S(t)$ monotonically decreases in its domain, $S(t) = 1$ when $t = 0$.

Furthermore, the Kaplan–Meier estimate of survival function is established to describe the probability distribution of the duration from awareness to adoption of GCTs.

$$S(t) = \prod_{T \ge t} \frac{n_t - d_t}{n_t} \quad (2)$$

where n_t represents the number of farmers whose duration from awareness to the adoption of GCTs is greater than or equal to t and d_t denotes the number of farmers whose duration from awareness to the adoption of GCTs is equal to t.

However, the Kaplan–Meier estimator is a non-parametric function and cannot address the factors that influence the duration of the period between awareness to the adoption of GCTs by farmers. Therefore, this study introduces the discrete-time cloglog model to estimate the impact of factors that influence T.

The discrete-time cloglog model uses the hazard function to represent the instantaneous probability of an event mutation. The hazard function is defined as $h(t)$, which means that the awareness of GCTs by farmers persists for $t-1$ years, and the probability of adoption in year t is as follows:

$$h(t) = \Pr(t-1 \le T < t | T \ge t-1) = 1-\frac{S(t)}{S(t-1)} \quad (3)$$

The formula for the discrete-time cloglog model is

$$Cloglog[1-h(t|X)] = \log(-\log[1-h(t|X)]) = \theta + \sum \beta X + u \quad (4)$$

where $h(t|X)$ refers to the awareness timing of farmers regarding GCTs after $t-1$ years, which is the probability of adopting GCTs in year t; X is the characteristic variable; u is the error term that controls unobservable heterogeneity; and θ and β represent the estimated parameters.

Variable selection and measurement

Farmers' duration from the awareness to the adoption of GCTs

The formal research for this article was conducted from January to March 2017. However, China started to promote GCTs in 2006. Therefore, the year at which farmers became aware of GCTs should be between 2006 and 2016. They were instructed to recognize that the duration of the adoption process ranged from 0 to 11 years, that is, T takes an integer value in the interval [0, 11].

Factors that influence farmers' duration from the awareness to the adoption of GCTs

The theory of farmers' behavior emphasizes that the family is the basic economic unit, that utility maximization is pursued

under the condition of limited endowment, and that the subjective attitude of farmers will affect their individual behavior (Becker 1965). The theory of planned behavior is based on the theory of farmers' behavior and emphasizes that farmers' behaviors are not all voluntary. Their behaviors are affected by other control factors, such as other individuals and social influences, i.e., subjective norms (Ajzen 1991). The technology acceptance model is derived from the theory of farmers' behavior, emphasizing that farmers' attitude toward technology will also affect their behavior (Davis 1989). The main conclusions from the theory of farmers' behavior, the theory of planned behavior, and the technology acceptance model were combined in our conceptual framework. The factors that influence the duration from awareness to adoption of GCTs were selected from four dimensions: household head, resource endowment, technique, and information characteristics.

In terms of household head characteristics, according to Murage et al. (2015), households may become more conservative about the adoption of new technologies as the age of the household head increases. Supriya and Ram (2013) found that female heads of households in India are more passive than male heads of households in terms of accepting IPM. According to Bola et al. (2016), heads of households will improve the planning and management of their production and operations and are more positive about new technologies when the educational level of the household head is high. Ward and Singh (2015) confirmed that risk-preferring heads of household are more likely to adopt new technologies than risk-averse ones are. Therefore, we selected household head characteristics, such as age, gender, educational level, and risk preference, as part of our analysis.

In terms of resource endowment characteristics, farm size has a significant positive impact on technology adoption by farmers (Margit and Ludwig 2017). Farmers with improved household finances adopt technology significantly more quickly (Murage et al. 2011). Farms are less motivated to invest in new technologies if they have invested more in labor (Nigussie et al. 2017). Therefore, we considered the characteristics of resource endowment through the farm size, financial status of families, and number of laborers as part of our analysis.

In terms of technique characteristics, in accordance with the technology acceptance model, the technique characteristics of GCTs are divided into perceived ease of use and perceived usefulness. Perceived ease of use refers to how difficult it is for farmers to adopt GCTs behavior, whereas perceived usefulness denotes farmers' recognition of the performance improvement when they adopt GCTs. Farmers' perceived of ease of use and usefulness of GCTs increases their willingness to adopt the techniques (Zeweld et al. 2016). Thus, we selected perceived ease of use and usefulness as specific indicators to measure the technique characteristics.

Subjective norms refer to the external pressure that farmers feel when making decisions, and these are composed of two parts: the individual (neighborhoods) and society (government and media). Willy and Kuhn (2016) argued that farmer–rural interaction could speed up the adoption of new agricultural technologies. Vidogbéna et al. (2015) highlighted that education and training by the agricultural technique extension departments of local governments have a significant positive impact on IPM adoption by farmers. Patrick et al. (2016) confirmed that the government's agricultural quality and safety supervision would promote the adoption of pathogen prevention techniques by California farmers. Cavallo et al. (2014b) found that media propaganda is a key factor that affects the adoption of technology by farmers. Therefore, we selected the frequency of communication with neighbors, the intensity of education and training, the intensity of government supervision, and the intensity of media propaganda to measure subjective norms.

In addition, each characteristic variable was assigned as follows: the age of the head of household was given as actual age in 2017. If the respondents had adopted the GCTs, then the actual age in the adopted year was treated as the actual age. The gender of the household head was treated as male = 1 and female = 0. The educational level of the household head was expressed by years of education. The farm size was measured by actual farmland area. The number of laborers was represented by actual family labor and total long-term employees. Other variables were measured using a 7-point Likert scale.

Data source and descriptive statistics

Data source

This study investigates the five provinces, namely, Hebei, Henan, Anhui, Shandong, and Jiangsu, in the Huang-Huai-Hai Plain. The main reasons for this selection are as follows. First, these five provinces are important food production bases in China, representing 34.2% of China's total output.[2] Second, the number of FFs that are registered in the abovementioned five provinces exceeds 10,000, and FFs have enjoyed an excellent momentum of development. Third, there are high incidences of pests and diseases in these five provinces, and the pest and disease control issue is serious (Gao et al. 2018). Fourth, GCT demonstration zones have been established in all five provinces, and certain areas have been set aside for the promotion and application of GCTs.

The investigation was divided into two stages. The first stage was the pre-survey. In December 2016, five THs and FFs were randomly selected from each province for household interviews, and their awareness and adoption of GCTs were

[2] Source: National Bureau of Statistics of China (eds): China Statistical Yearbook 2016, China Statistics Press, 2016.

investigated. The results of the pre-survey were used to correct any weaknesses in the questionnaire. The second stage was the formal research. A multistage random sampling method was adopted from January to March 2017. First, two prefecture-level cities were selected randomly in each province. Second, two counties (cities and districts) were randomly selected in each prefecture-level city. Third, 20 THs and 20 FFs were randomly selected in each county (city, district). Taking into account the education level of rural households, we conducted a door-to-door survey. The investigators were trained graduate students and senior undergraduates. We distributed a total of 800 questionnaires. Questionnaires missing key information, with obvious errors or with left-censored[3] data, were rejected. Finally, 730 valid questionnaires were obtained. The effective rate of the questionnaires was 91.25%. The sample sizes for THs and FFs were 366 and 364, respectively.

Descriptive statistics

In this paper, using Stata 14.0, the survey data are first tested for a normal distribution and homoscedasticity. Because the p values of the S–K test of the THs sample data and the FFs sample data are less than 0.01 and the Bartlett test p value is greater than 0.1, both sets of data pass the normal distribution test and the homogeneity test of variance. Furthermore, the mean difference of the two sets of data was tested by a two-sample t test, and the test results are shown in Table 1. The data show that FFs have younger heads of household, a higher proportion of males, more years of education, and a higher degree of risk preference than the THs do. Meanwhile, except for the intensity of government supervision and media propaganda, FFs have a lower financial status, acquire more laborers, perceive GCTs as easier and more useful, and have more education and training and more frequent exchanges with rural neighbors than the THs do. Media campaigns and extension activities by the agricultural technique extension departments of local governments also have strong effects. The above differences all passed the t test. THs' and FFs' average duration from awareness to adoption of GCTs is 3.97 and 2.93 years, respectively, i.e., the process was faster in FFs than it was in THs. Thus, THs and FFs differ in terms of average duration from awareness to adoption of GCTs, household head, resource endowment, and information characteristics. It is necessary to adopt a rigorous measurement method to explore the influencing factors and the differences in the duration from the awareness to the adoption of GCTs by THs and FFs. In addition, the results of the third National Agricultural Census are consistent with our results in terms of indicators such as the age of the household head, educational attainment, cultivated land size, and labor force.[4] Therefore, our samples in this survey are representative in China.

Results

Duration probability distribution characteristics

To utilize the full information from the right-censored[5] and non-censored data, the Kaplan–Meier estimate was used for non-parametric estimation to describe the probability distribution of the duration from awareness to adoption of GCTs by THs and FFs separately (Kaplan and Meier 1958). The estimation results in Fig. 1 show that the survival rate (Y) of THs and FFs follows a non-uniform decline along the increase in GCT awareness time (X), with the largest decline occurring in the first 6 years. In addition, the Kaplan–Meier curves of FFs are steeper than those of THs, and the logrank test results are significant, indicating the rapid adoption of GCTs by FFs. Moreover, a certain degree of difference is observed between the factors that affect the duration from awareness to adoption of GCTs by THs and FFs.

Factors that affect the duration

As shown in Table 2, the models for both THs and FFs passed the log likelihood test, i.e., the overall fitting degree of the models is high, and the estimated results are statistically significant. In terms of the specific impact of the hazard ratio for eigenvalues on the duration from awareness to adoption of GCTs by THs and FFs, a hazard ratio of less than 1 denotes that the eigenvalue has an extended effect on the duration of the awareness to adoption of GCTs by THs and FFs. If the hazard ratio is greater than 1, then the characteristic variable has a shortened impact. If the hazard ratio is equal to 1, then this feature variable has no effect. A specific discussion is as follows.

From the analysis of household head characteristics, gender had a significant effect on the duration from awareness to adoption of GCTs by THs and FFs. Moreover, a higher educational level and a risk-preferring household head tended to significantly shorten this duration. The reasons for these results are as follows. First, Yin et al. (2017) and Burton et al. (2003) noted that compared with male heads of households, female heads tend to pay more attention to chemical pesticide

[3] There were 11 THs and 16 FFs who knew the technology before the introduction of GCT in China. These samples were left-censored. Since there is no effective treatment method for left-censored data, this paper excludes these samples.

[4] China's third national agricultural census major data bulletin (no. 5) http://www.gov.cn/xinwen/2017-12/16/content_5247683.htm December 16, 2017.

[5] As of the end of the study, THs and FFs who knew of but did not adopt GCTs had a right-censoring problem, and T was processed to a maximum of 11 in the Kaplan–Meier estimate.

Table 1 Descriptive statistics of the characteristic variables of THs and FFs

Variable type	Variable	Description	TH		FF		*t*
			Mean	Std.	Mean	Std.	
Household head characteristics	Age	Age in 2017	49.872	19.149	43.476	11.634	5.450***
	Gender	Female = 0, Male = 1	0.754	0.441	0.824	0.457	− 2.106**
	Educational level	Years of education	9.941	1.639	11.697	3.487	− 8.715***
	Risk preference	Very risk averse = 1, Very risk preferring = 7	4.305	1.773	4.596	1.834	− 2.179**
Resource endowment characteristics	Farm size	The actual farm area (hectares)	0.941	0.755	9.254	4.642	− 33.814***
	Financial status	Very little = 1, very abundant = 7	3.921	1.247	3.632	1.492	2.840***
	Number of laborers	The actual family labor force and total long-term employees	2.618	1.009	5.969	4.350	− 14.354***
Technique characteristics	Perceived ease of use	Very difficult = 1, Very easy = 7	4.378	1.662	4.617	1.538	− 2.016**
	Perceived usefulness	Very useless = 1, very useful = 7	3.953	1.002	4.189	0.979	− 3.218***
Subjective norms	Frequency of neighbor communication	Very low = 1, Very high = 7	4.099	1.364	4.297	1.399	− 1.936*
	Media propaganda	Very low = 1, Very high = 7	4.341	1.782	4.536	1.889	− 1.435
	Education and training	Very low = 1, Very high = 7	4.292	1.782	4.577	1.798	− 2.151**
	Government supervision	Very low = 1, Very high = 7	4.119	1.802	4.249	1.884	− 0.953

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

overuse and its impact on human health as well as its threat to agricultural security and product quality. Therefore, female heads of household often adopt GCTs relatively quickly. Second, as heads of THs and FFs receive more education, their ability to collect GCTs information and discriminate among information is improved. As a result, they are likely to adopt GCTs more quickly (Murage et al. 2011). Third, GCTs will be adopted quickly to reduce costs and increase yields without chemical pesticides when THs and FFs have a high level of risk preference and are willing to be proactive (Gong et al. 2016). In addition, age has a different impact on the duration from awareness to adoption of GCTs between THs and FFs, and our findings are inconsistent with the findings of Cavallo et al. (2015). As far as THs are concerned, the older the head of household is, the more conservative his or her thinking and the less willing to change the existing methods of pest control, leading to a significant prolongation of duration based on the age of TH heads (Willy and Kuhn 2016). FFs' farmers in China tend to be young and active, and their age differences are not significant. Consequently, the influence of age on the duration from awareness to adoption of GCTs by FFs is non-significant.

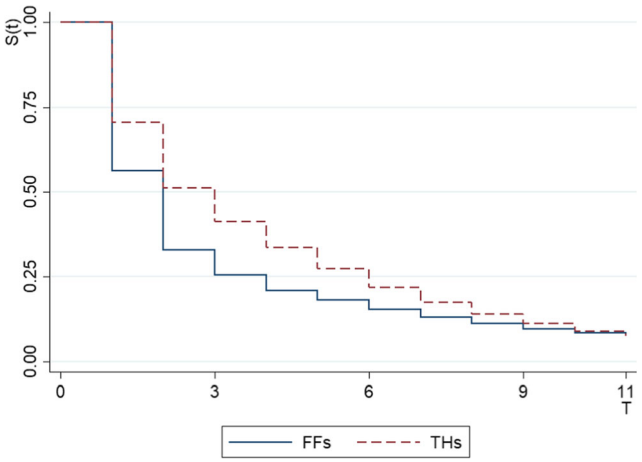

Fig. 1 Kaplan–Meier estimation curve

In terms of resource endowment characteristics, the state of household finances significantly shortens the duration between awareness and the adoption of GCTs by THs and FFs. This result is consistent with the conclusions of Bavorova et al. (2018). Understandably, the better the financial status of THs and FFs is, the less likely they are to worry about the costs and risks associated with implementing GCT, and thus they will often adopt GCT as soon as possible. However, farm size and labor force have different effects on the duration from awareness to adoption of GCTs by THs and FFs. On the one hand, in larger THs, GCTs are frequently adopted within a relatively short period of time (Kpadonou et al. 2017). Moreover, THs are less motivated to invest in GCTs when they employ many laborers (Nigussie et al. 2017). On the other hand, FFs have a standard size set by local governments in all localities and are relatively stable. The preference for GCTs implementation to ease labor cost pressure and maximize profits occurs when the size of the labor force is high (Irawan 2016). Therefore, farm size significantly shortens the duration from awareness to the adoption of GCTs by THs but has no significant impact on the corresponding duration of FFs. The size of the labor force significantly lengthens the

Table 2 Discrete-time cloglog model estimation results

Variable	THs		FFs	
	Hazard ratio	Std. error	Hazard ratio	Std. error
Age	0.871*	0.079	0.849	0.105
Gender	0.868*	0.074	0.872*	0.071
Educational level	1.375*	0.194	1.466**	0.197
Risk preference	1.107***	0.008	1.109***	0.009
Farm size	1.008**	0.004	1.082	0.308
Financial status	1.069**	0.033	1.073**	0.029
Number of laborers	0.855*	0.082	1.013*	0.007
Perceived ease of use	1.512**	0.231	1.563***	0.049
Perceived usefulness	1.449**	0.186	1.468***	0.162
Frequency of neighbor communication	1.039	0.251	1.083	0.084
Media propaganda	1.101**	0.047	1.012**	0.005
Education and training	1.403*	0.241	1.462**	0.182
Government supervision	1.062*	0.036	1.088	0.157
Log likelihood	− 417.812**		− 449.201**	
Samples	366		364	

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

duration from awareness to adoption of GCTs by THs but has a significantly reduced impact on the duration from awareness to adoption of GCTs by FFs.

From a technique characteristics perspective, the perceived ease of use and usefulness of the technology tend to shorten the duration from awareness to adoption of GCTs by THs and FFs. This result is consistent with the findings of Chen et al. (2017). Perceived ease of use and usefulness are subjective judgments of THs and FFs based on prior information and experience. When farmers perceive GCTs to be easy and useful, their duration from awareness to the adoption of GCTs will be shorter.

From the perspective of subjective norms, the intensity of media propaganda and the availability of education and training significantly shorten the duration from awareness to adoption of GCTs by THs and FFs for the following reasons. First, Chinese farmers enjoy watching news and agricultural programs during their free time (Xiao 2017). The reporting of GCT cases and typical experiences through the media stimulate the early adoption of GCTs by THs and FFs (Roesch-McNally et al. 2018). Second, education and training are important ways for THs and FFs to gain a deeper understanding of GCTs. Education and training activities such as technical introductions, technology demonstrations, technology investments, and income explanations conducted by the agricultural technique department can undoubtedly enhance the confidence of THs and FFs and enable them to adopt GCTs more quickly (Karidjo et al. 2018). Third, with the government's increasing supervision over the quality and safety of agricultural products, THs have increasingly felt the government and market penalties caused by excessive pesticide residues, so that they will adopt GCTs as quickly as possible. However, in the case of the FFs, the magnitude of the government regulations matters less than profit, which is their fundamental purpose. With their "consumer-oriented, market-oriented, facing the future" business strategy, GCT adoption occurs when the time is right to allow them to achieve the goal of saving costs and increasing benefits. Finally, the frequency of interactions with rural neighbors did not significantly affect the duration from awareness to adoption of GCTs by THs and FFs, in contrast with the findings of Bravo-Monroy et al. (2016). This result may be related to the fact that most of the exchanges between our neighbors in China are chat.

Conclusions and policy recommendations

Our investigation of 366 THs and 364 FFs in the Huang-Huai-Hai Plain used duration analysis with Kaplan–Meier estimates of the survival function model to describe the probability distribution characteristics for the duration from the awareness to adoption of GCTs by THs and FFs. Furthermore, based on the hazard function model, a discrete-time cloglog model was constructed to estimate the parameters, and a more rigorous estimation result was selected to reveal the influencing factors and their differences in the duration from awareness to adoption of GCTs by THs and FFs.

The main conclusions of this study are as follows. First, the duration from awareness to adoption of GCTs is significantly shorter in FFs than in THs. Second, the level of education, risk preference, family financial status, perceptions of the usefulness and ease of use of the technology, the intensity of media

propaganda, and the availability of education and training significantly shorten the duration from awareness to adoption of GCTs by THs and FFs, whereas having a male head of household tends to prolong the duration significantly. Third, age, farm size, number of laborers, and government supervision have different effects on the duration from awareness to adoption of GCTs by THs and FFs.

The main conclusions of this study suggest the following policy implications for formulating GCTs extension policies. First, the duration from awareness to adoption of GCTs is significantly shorter in FFs than in THs, and FFs play a leading role in the application of scientific and technological achievements as well as in green development (Ruan et al. 2017). Therefore, the development of FFs should be promoted through the establishment of a sound land transaction service platform, improved guidance for price assessments, improved risk prevention mechanisms, and the implementation of land transaction dispute mediation and arbitration measures. Additionally, GCT extension activities should first be targeted to FFs with higher levels of education and risk preference, better financial status, and better perceptions of the GCTs usefulness and ease of use. By encouraging these FFs to adopt GCTs first, they can lead the way for THs to adopt GCTs. Second, by improving the effectiveness of technical training, innovating the agricultural subsidies mechanism, broadening the channels for technology extension services, and strengthening the informatization and construction of grassroots by agricultural technique extension departments of local governments, the inherent conditions and external environment of THs and FFs will be improved, which will help eliminate obstacles to the early adoption of GCTs. Third, due to the relatively weak regulatory power over the quality and safety of grass-root agricultural products in China, "unbalanced" regulatory strategies should be applied. The government should concentrate its limited efforts on creating specializations to govern THs, intensifying routine inspections, and comprehensively strengthening supervision and spot checks to force THs to adopt GCTs as quickly as possible.

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