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SPEED OF HYBRID MAIZE ADOPTION IN THAILAND: AN APPLICATION OF DURATION ANALYSIS

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ABSTRACT

Hybrid maize was released in Thailand in 1980s, and has become widely adopted among maize growers. During the early years of introducing hybrid maize, the adoption was infinitesimal due to unsurpassing yield and high seed price. However, after a substantial increasing role of private seed companies in varietal development and seed commercialization during the early 1990s, the adoption of hybrid maize has been escalating. At present, hybrid maize covers nearly all maize production areas in Thailand making Thailand one of most adopted hybrid maize in developing countries. Despite the success of disseminating hybrid maize in Thailand, none of existing studies could answer the reasons why different farmers adopt hybrid maize at different at time. Thus, this paper aims a determining factors influencing the timing or speed of adoption by employing a duration model in a dynamic framework. The results showed that educated and younger farmers are among the early adopters. Being closer to input dealers and higher seed price would speed up the adoption, but the communication with public extension officers in fact decreased the speed of adoption while communication with the private seed companies did not influence the speed of hybrid maize adoption.

Key words: duration model, technology diffusion, modern varieties

INTRODUCTION

Maize is the cereal of the largest cultivation area, and production of maize has been increasing due to increasing demands for feed and biofuel. Maize also plays an important role for food security in many countries in Sub-Saharan Africa and Latin America where it is a staple crop. Hybrid maize varieties have shown to provide yield superiority over open-pollinated varieties (OPVs). Due to a remarkable yield advantage and uniformity characteristics, soon after the commercialization of hybrid maize in the early 1930s, it is vastly adopted in the Corn Belt of the U.S. (Griliches 1960). Adopting modern plant varieties has shown to improve farmers' income and food security in many developing countries (Beyene and Kassie 2015; Ghimire and Huang 2016; Khonje et al. 2015; Shiferaw et al. 2004). Thus, many development programs supported by international organizations such as the Rockefeller Foundation, USAID, Bill and Melinda Gates Foundation aim at introducing hybrid technology into developing countries throughout most of Africa, Latin America, and Asia. However, the adoption of hybrid varieties in many countries remains limited (Heisey et al. 1998). Although maize is not a traditional crop in Asia, it became important to Thailand's economy. Thailand is ranked the 20th largest maize producer in the world, and the 4th largest maize producer in Asia (FAO, 2016). Hybrid maize was first introduced in Thailand in 1982 by the National Corn and Sorghum Research Center in response to a drastic expansion of poultry and livestock industry. Compared to maize production in 1982 of 3.55 million tons (average yield of 2.113 tons/ha), in 2012 Thailand produced about 5.09 million tons of maize annually with the yield of 4.317 ton/ha (FAO, 2016), a 40% increase in production and double of yield. A remarkable increase in Thailand's maize output and yield is mainly attributable to the conversion of OPVs to hybrid varieties (Morris, 1998 cited Thomson, 1994). The adoption of hybrid maize was initially slow but after after the release of single-cross hybrids by private companies in the early 1990s, the adoption of hybrid maize considerably increased (Suwantaradon, et al. 2012), and after two decades, its adoption reached 90%, and nearly all maize cultivation in Thailand are hybrid varieties today (Napasintuwong, 2014). Over the past three decades, there have been several government policies to promote hybrid maize adoption such as direct subsidy programs for hybrid maize seed, corn production development program and seed exchange program during 1989/90 and 1993/94 that invited private companies to buy grain from farmers at a guarantee price or higher, extension programs to promote hybrid maize adoption by supplied single-cross hybrid seed and other inputs at no cost to farmers, and privatization of maize seed industry (Ekasingh and Thong-Ngam, 2008; Napasintuwong 2014; Pongsroypech 1994). These changes have influenced the adoption hybrid maize in Thailand.

Hybrid maize in Thailand is an example of a successful modern varieties adoption in a developing country. A review of the history of maize seed industry in Thailand by Napasintuwong (2017) emphasizes different roles of public universities, public research institutes, private companies and collaborative efforts with international organizations. There have been limited studies described the adoption of hybrid maize in Thailand in a static framework (Jamroonpong, 1996; Ekasing et al., 2004) but no earlier study using a dynamic framework to capture the rate and process of the adoption of hybrid maize through time. Recent exceptions are Poolsawas and Napasintuwong (2012) who showed that characteristics such as farm and farmers' characteristics in Thailand describe their innovativeness which in turn affect the timing of hybrid maize adoption, and Beyene and Kassie (2015) who found that the speed of adopting improved maize varieties in Tanzania is influenced by social and environmental factors, and government support during crop failure.

Numerous economic studies have analyzed the determinants of agricultural technology adoption decisions; however, most of them employ micro-level cross-sectional data at a particular point of time that cannot explain the timing of the adoption decision. Technology diffusion studies, on the other hand, evaluate the timing of adoption and adoption rate at the aggregate level (Arora and Bansal, 2012; Batz et al. 1999; Frisvold et al. 2009; Griliches, 1960; Poolsawas and Napasintuwong, 2012), but fail to address specifically why individual farmers adopt a technology earlier than the others. Understanding the timing of adoption provides important information, particularly when it is considered to be linked with specific events (Beyene and Kassie, 2015; Matuschke, and Qaim, 2008). Understanding the speed of technology adoption which is subject to policy choices allows for understanding the economic development process (Feder and Umali, 1993). Through the process of adoption which affects economic performance, resource availability, and environmental quality, understanding the adoption process will also help better planning for input supply and resource management (Castillo et al. 2018).

To address what make individual farmers adopt a technology at a particular point in time, limited number of recent studies employs a duration model. A duration model was initially applied to biomedical research, called survival analysis, where the duration of interest is the survival time of a subject. It was first applied to social sciences by Lancaster (1978) to study factors influencing unemployment spells, and became widely used in labor economics, mainly in the analysis of unemployment duration (Arranz and García-Serrano, 2014; Arranz and Muro, 2004; Lancaster, 1978; De Una-Alvarez *et al.*, 2003). Recently, it has been applied to capture the dynamic aspects of technology adoption in agricultural sector (Abdulai and Huffman, 2005; Beyene and Kassie, 2015; Burton *et al.*, 2003; Dadi *et al.*, 2004; D'Emden *et al.*, 2006; Fuglie and Kascak, 2001; Matuschke and Qaim, 2008; Nazli and Smale, 2016).

Because there have been several changes in policy instruments and social and economic conditions that affect the dynamic of hybrid maize adoption in Thailand, the main objective of this study is to identify both time-varying and time-invariant factors on the duration farmers waited before they first adopted hybrid maize varieties. There has been no other study that employs duration analysis for the adoption of hybrid maize varieties in developing countries, and particularly in the situation that the adoption is nearly complete the production area.

MATERIALS AND METHODS

Building upon Keifer (1988) and Lancaster (1990) on the hazard function, individual farmers have different time origin for durations they experience. For the adoption of hybrid maize, the time that hybrid variety became available or the time individual farmers first started cultivating maize might not be the same. Burton *et al.* (2003) defined technology adoption as the start or entrance date can be set either at the time when the first adoption of an innovation took place or at the time of its creation. The exit date, or the end of a spell, is the time the adoption of innovation takes place. The duration or a spell length for an individual wait to adopt hybrid varieties is given as T*, a random variable. The start date in this study would be set either at the time when the hybrid maize was first available or the time of farmer's entry if the farmer entered after the hybrid maize was released. The end of a spell is the time when a farmer adopted the hybrid maize. However, this time spell, may possibly be censored if at the time of survey, the farmers still have not adopted hybrid maize at the time of data collection. For these farmers the ends of their spells are unknown although they might occur in the future so the duration is right-censored at the end of the observation period.

Let T be a non-negative continuous variable and represents the length of time farmers waited before the adoption. The cumulative distribution function of T is defined as

$$F(t) = P(T \leq t), t \geq 0. \quad (1)$$

It demonstrates that the probability that duration time T is smaller or equal to some value t. Thus, the probability density function of T can be derived as

$$f(t) = \frac{\partial F(t)}{\partial t}. \quad (2)$$

In the case of farmer waiting before adoption, the survival function is the probability of an individual not adopts the technology until or beyond time t is defined as

$$S(t) = 1 - F(t) = \Pr(T > t). \quad (3)$$

The hazard function indicates the instantaneous rate of leaving per unit time period at t (Lancaster, 1990) or represent the probability that farmers adopt the new technology at time $t + \Delta t$. The hazard function for T is defined as

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t \mid T \geq t)}{\Delta t}$$
$$= \lim_{\Delta t \to 0} \frac{f(t)}{1 - F(t)} \quad (4)$$

Therefore, $$h(t) = \frac{f(t)}{S(t)} \quad (5)$$

given that the hazard rate $(\frac{\partial h}{\partial t})$ may be constant, positive or negative.

The hazard function can be separate into two components: the first part that is dependent on individual farmer's characteristics and the other one that is not. The latter is sometimes called a baseline hazard which can be semi-parametric following Cox proportional hazards model (Cox, 1972). However, parametric models are more efficient in their use of data because they do not reject what happens to covariates where adoptions occur. Therefore, functional forms that have been used for parametric duration models include the exponential, Weibull, Gompertz, logistic, lognormal and log logistic probability distribution (Cleves et al. 2008). Among all of them, the two most commonly used are the exponential and Weibull distributions.

The exponential distribution is characterized by a hazard function with a constant rate, $h(t) > \lambda$ where $\lambda > 0$, implying that the duration time (length of spells) does not affect the hazard rate. The baseline hazard is given as:

$$h_0(t) = \lambda \text{ , } \lambda = \exp(\beta_0)$$

$$\text{or } h_0(t) = \exp(\beta_0) \tag{6}$$

where β_0 is the only parameter to be estimated. The result of this model is the expected remaining time to adoption and is independent of prior survival times.

The Weibull distribution is characterized by the hazard function,

$$h(t) = \lambda p t^{p-1} \text{ ; } \lambda > 0 \text{ and } p > 0 \text{ .} \tag{7}$$

It exhibits an increasing hazard rate when $p > 1$ while the hazard rate would be decreasing if $p < 1$. When $p = 1$, it exhibits a constant hazard rate and collapses to the exponential distribution model.

The explanatory variables can be introduced in a number of ways, and the most common is to assume a proportional hazard model in estimating the distribution of durations. The simplest ways to include covariates are those which do not change over time, such as farm location and farm size may be assumed to be time-invariant.

$$h(t, X) = h_0(t)\exp(\beta, X) \tag{8}$$

Where $h_0(t)$ denotes the baseline hazard which is independent of covariates X and a second term $\exp(\beta, X)$ exhibits multiplicatively on the baseline hazard models.

Based on the literatures, the factors influencing the speed of adoption of new crop varieties are divided into two components; time-invariant and time varying factors as shown in Table 1.

Table 1. Summary of explanatory variables (n=335)

Variable	Description
Time-invariant factors	
Edu	Number of year for formal education received (years)
HH size	Number of people in household (persons)
Distance	Distance from farm to the nearest input market or input dealer (km)
Meet pub	Number of times farmer meet with public officers/researchers /breeders (times per year)
Meet priv	Number of times farmer meet with private staff/researchers/sale persons (times per year)
Res center pub	Public research center exists in the district
Res center priv	Private research center exists in the district
Ext pub	Farmers received hybrid maize information from public officers/ research center at time of adoption. = 1 if yes; = 0 otherwise
Ext priv	Farmers received hybrid maize information from private companies/ sale persons at time of adoption. = 1 if yes; = 0 otherwise
Credit pub	The farmer's accessibility to credit at adoption year from public organization or public research center. = 1 if yes; = 0 otherwise
Credit priv	The farmer's accessibility to credit at adoption year from private companies or private research center. = 1 if yes; = 0 otherwise
Time varying factors	
Age	Age of farmer when first adopted hybrid varieties (years)
Size	Total maize cultivated land when first adopted hybrid varieties (hectare)
Seed price*	Price of hybrid maize seed when first adopted hybrid varieties (baht per kg)
Output price**	Price of maize grain when first adopted hybrid varieties (baht per kg)

Remarks: *, ** The real price of hybrid maize seed and maize grain were calculated based on consumer price index from Bureau of Trade and Economic Indices, Ministry of Commerce (2016).

The empirical model of the speed of hybrid maize adoption employing duration model can be specified as follows:

$$h(t,X) = \beta_0 + \beta_1 Edu + \beta_2 HHSize + \beta_3 Distance + \beta_4 Meetpub + \beta_5 Meetpriv + \beta_6 Rescenterpub + \beta_7 Rescenterpriv + \beta_8 Extpub + \beta_9 Extpriv + \beta_{10} Creditpub + \beta_{11} Creditpriv + \beta_{11} Age(t) + \beta_{12} Size(t) + \beta_{13} Seedprice(t) + \beta_{14} Outputprice(t) + \alpha \quad (9)$$

The factors that are static over time are defined as time-invariant factors includes education of farmers, size of household, distance from farm to input market and attitude of farmers toward hybrid maize traits. Farmers with higher education levels are hypothesized to adopt earlier (Burton et al. 2003; Dadi et al. 2004; Matuschke and Qaim, 2008) while the farmer with larger size of household member are hypothesized to have a negative effect on the adoption (Hintze et al. 2003). A distance from farm to input market which represents input accessibility and infrastructure effort, is hypothesized to negatively affect the adoption therefore the farmers who has farm close to input market tend to adopt earlier (Matuschke and Qaim, 2008; Ahsanuzzaman, 2015). Moreover, some factors related to public and private sector are included in the study. Rogers (2003) discussed the important roles of social communication as a mean to stimulate technology adoption. The relationship between social meetings and adoption of new crop varieties, districts with public or private research center located are in the study of Matuschke and Qaim (2008) and Dadi et al. (2004) with the positive effect hypotheses. The farmers who participated in field trials or have crop visits both formal and informal meetings are hypothesized to adopt earlier. Furthermore, extension services by public and private research center and credit are also included to be the important factors of technology adoption with positive impact (Sain and Martinez, 1999; Ahsanuzzaman, 2015).

The factors that change value over time are included as time varying factors. Age of maize farmers when they adopted hybrid varieties is hypothesized to have negative impact on the adoption, it represents that the younger farmers tend to adopt new technology or innovation earlier (Dadi et al. 2004). The size of farm at the first adoption which represents wealth of farmers and possibly accessibility to credits and is hypothesized to have a positive impact to the speed of adoption (Sain and Martinez, 1999; Dadi *et al.*, 2004). Price of hybrid maize seed at the first adoption and farm price of maize grain are also hypothesized to have an impact on the adoption (Matuschke and Qaim, 2008; Mugisha and Diiro, 2010). In this study, we estimated the real price in each timing period based on consumer price index from Bureau of Trade and Economic Indices, Ministry of Commerce (2016).

Since this research involves farmers who adopted hybrid maize varieties, the start year ($t = 0$) is 1979 when the first hybrid maize was in the field-trial and its information was first available. Because there were two groups: farmers who started maize cultivation before 1979 and farmers who started maize cultivation after 1979, the time to adoption was defined by applying the study of Matuschke and Qaim (2008). For farmers who started maize cultivation before 1979, the spell was the time difference between 1979 and the year they first adopted hybrid maize. For farmers who started maize cultivation after 1979, the spell was calculated from the time difference between the first year of maize cultivation and the year of hybrid maize adoption. The farmers who used hybrid varieties in the first year when they started maize cultivation, the spell comprise to one. It was assumed that the farmers received the information of those hybrid varieties one year before the maize cultivation. Once an appropriate parameterization is selected, maximum-likelihood estimation was used for parameters estimates.

A three-stage stratified sampling technique was adopted in data collection. Because the different in intensities of maize production may suggest different levels of extension services, access to information and social activities of maize farmers which were hypothesized to be important factors for the adoption decision, in the first stage, the intensity of maize planted area (proportion of maize area to total crop area) was used as a proxy for the levels of production capacity in each province. Thirteen maize producing provinces were classified into major maize production zone where the intensity of maize production area is more than 10.08% and minor maize production zone cover fifteen provinces where the intensity is less than 10.08%. In the second stage, the existence of research center, either public and private, was used to stratify provinces following the hypothesis that farmers who stayed closer to research center can get more access to information and might adopt faster (Matuschke and Qaim 2008). Five provinces were randomly selected: three were major maize zone where public research center, private research center and none of research center was located, and two were minor maize zone where public research center and none research center located (no private research center was located in the minor maize zone). The last stage, one district from each province was randomly selected (Table 2). The number of respondents were 341 samples based on Krejcie and Morgan (1970) sampling technique and a five percent statistical significance level was assumed.

Table 2. Three stage stratified sampling and sample size of the study

Stage I: Intensity of maize area	**Stage II: The establishment of research center**	**Stage III: Sample districts**	**Total Maize farming households**	**Expected Sample size**	**Expected sample proportion**	**Actual sample size**	**Actual sample proportion**
Major maize province	*Public*: Nakhon Ratchasima	Pak Chong	169	19	0.05	22	0.06
	Private: Lopburi	ChongSarika	735	84	0.25	76	0.23
	None: Petchabun	Namron	949	108	0.32	106	0.32
Minor maize province	*Public*: Nakhon Sawan	Suksamran	832	95	0.28	101	0.30
	Private: -	-	-	-	-	-	-
	None : Kampangphet	Angthong	312	35	0.10	30	0.09
		Total	2,997	341	1.00	335	1.00

RESULTS AND DISCUSSIONS

The statistics of explanatory variables which hypothesized to have an influence on the speed of adoption are summarized in Table 3. On average, farmers have only five years of formal education, and age around 37 years at the time of adoption. The average farm size is approximately seven hectares considered relatively large compared with other crop production. About 37% of maize farms are in the provinces where the public research center is located, 23% in the provinces where private research center is located, and the rest are in the provinces where neither public nor private centers exist. The survey found increasing prices of maize seed and grain during the past three decades. At the time of adoption, the real price of hybrid maize seed was approximately 134.24 baht/kg, about 23 times that of maize grain which was about only 5.82 baht/kg. A larger number of farmers receive information or extension service from the private seed companies than from the public institutes while a much larger proportion of farmers gets credit loan from public sector than from the private sector. It showed that maize production information and knowledge was more accessible from the private sector whereas the financial support was more available from the public organizations.

Table 3. Summary statistics of explanatory variables (n=335)

Variable	Mean	S.D.	Percentage
Time-invariant factors			
Edu	5.31	3.30	-
HH size	4.08	1.54	-
Distance	9.00	7.67	-
Meet pub	1.91	2.91	-
Meet priv	0.26	0.60	-
Res center pub	-	-	36.72%
Res center priv	-	-	22.69%
Ext pub	-	-	13.43%
Ext priv	-	-	28.06%
Credit pub	-	-	45.97%
Credit priv	-	-	3.88%
Time varying factors			
Age	36.90	11.75	-
Size	7.19	13.02	-
Seed price*	134.24	1.55	-
Output price**	5.82	0.18	-

Remarks: *, ** The real price of hybrid maize seed and maize grain are calculated based on consumer price index from Bureau of Trade and Economic Indices, Ministry of Commerce (2016).

The attitudes toward the advantages of hybrid maize over OPVs and local varieties are shown in Table 4 and were measured using a 5-point Likert scale approach with 1 if strongly disagree, 2 if disagree, 3 if neutral, 4 if agree and 5 if strongly agree. Hence, the summed scores ranged from 8 – 40 points. The farmers who gave responses less than 24 points were allocated into unfavorable attitudes and the farmers who gave responses equal to or greater than 24 points were allocated to favorable attitudes. The majority of the maize farmers have positive attitudes toward hybrid varieties with regard to high yielding, grain weight and shape, tolerance to drought, ease of harvesting, and resistance to diseases.

Table 4. Attitudes toward the advantage of hybrid maize over OPVs and local varieties.

Statement	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
- Higher yielding	0.60	6.27	8.36	38.81	45.97
- Earlier maturity	5.07	32.84	12.84	35.22	14.03
- Better grain weight & shape	1.19	6.57	10.45	37.01	44.78
- More drought tolerant	2.09	17.31	11.04	36.72	32.84
- More pesticide and chemical resistance	1.19	20.90	27.76	42.39	7.76
- Easier to harvest	0.90	17.61	13.73	36.72	31.04
- More rust or downy mildew resistant	1.49	12.54	27.76	36.42	21.79
- Higher maize grain price	7.46	42.99	11.94	21.49	16.12

Table 5 describes the characteristics of current hybrid maize production. From our study, all farmers adopted hybrid varieties produced by private companies that OPVs information was not included for comparison. Average hybrids yields were 7,384.87 kg/hectare and 112 days maturing period. Seed used, on average, was 20.39 kg/hectare with 127.74 baht/kg at current price while current grain price was 5.65 baht/kg.

Table 5. Production characteristics of hybrid maize in Thailand

Variables	Mean	Standard Deviation	Min	Max
Yield (kg/hectare)	7,384.87	2,381.36	1331.25	14,062.50
Maturity (days)	111.80	7.79	90	150
Seed used (kg/hectare)	20.39	3.80	9.37	41.25
Current seed price (baht/kg)	127.74	13.51	50	180
Current grain price (baht/kg)	5.65	1.37	2.64	12.36

Figure 1 presents a non-parametric, Kaplan-Meier estimator, of the survival function. It illustrates the relationship between proportion of non-adopters and the adoption spell, which is the time difference between the year of first maize cultivation and the year of hybrid varieties adoption. More than 40% of farmers adopted hybrid varieties within one year, and the rate of non-adoption constantly decreased after two years. For the parametric estimation, we assume that the baseline hazard has a Weibull distribution. The Akaike information criterion (AIC) is employed to choose the best fit model (Akaike, 1974), and can be defined as $AIC = -2\ln L + 2(k+c)$, where k is the number of independent variables, c is the number of model-specific distribution parameters (=1 for exponential and = 2 for Weibull distribution). Based on our samples, the AIC for the exponential distribution is 1,045.961 and the Weibull distribution is 1045.133. Therefore, the Weibull distribution has the lower AIC and fits the model better. Thus, we adopted the Weibull distribution for hazard model estimation (equation 8), and coefficient estimates are reported as hazard ratios ($\exp(\beta, X)$). A value greater than one is interpreted as a positive impact on the hazard rate of adoption, implying faster adoption process, and vice versa for the value less than one.

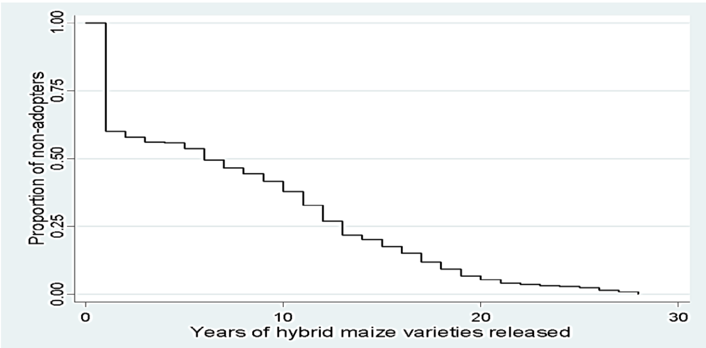

Fig. 1. Kaplan-Meier estimator of the survival function

For time-invariant factors, it was found that the formal education of farmers has significant impact on the speed of hybrid maize adoption with the hazard ratio at 1.055 (Table 6). More educated farmers have higher probability of adopting earlier, conforms to previous studies from Dadi *et al.* (2004). Farmers who have their farms closer to input markets or seed dealers were easy to access technologies and tended to adopt earlier similar to Ahsanuzzaman (2015) and Sain and Martinez (1999).

In terms of the public and private roles in adoption process, frequent meeting with public researchers and farm locating in the districts where public research centers exist, have a negative influence to the hazard rate. It showed that a unit increase in numbers of meeting with public staff and existence of public research center in the district decreased the hazard at 0.956 and 0.659, respectively. Fewer meeting with the public staff may actually increase the hybrid maize adoption as the information from public staff may complicate the technologic choice especially in this situation when public sector does not provide hybrid seeds to the market. All of the expected variables related to the private sector had no significant impact on the speed of adoption compared to previous study by Matuschke and Qaim (2008).

Table 6. Coefficient estimates of Weibull distribution hazard model for the adoption of hybrid maize varieties (N=335)

Variables	Hazard ratio	Standard Error	Z	p-value
Edu	1.074	0.021	3.60	0.000***
HH size	0.983	0.038	-0.43	0.670
Distance	0.977	0.007	-2.81	0.005***
Meet pub	0.956	0.020	-2.13	0.033**
Meet priv	0.967	0.044	-0.73	0.468
Res center pub	0.659	0.095	-2.86	0.004***
Res center priv	0.908	0.149	-0.59	0.557
Ext pub	0.884	0.157	-0.69	0.490
Ext priv	0.975	0.128	-0.19	0.849
Cre pub	0.968	0.116	-0.27	0.788
Credit priv	1.340	0.398	0.99	0.324
Age	0.972	0.005	-4.70	0.000***
Size	0.999	0.001	-0.78	0.438
Seed price	1.005	0.002	2.32	0.020***
Output price	1.027	0.022	1.24	0.213
Log-likelihood	-505.56			
Chi^2	85.96			

Remarks: ***, **, ands * indicates statistically significant at 1%, 5%, and 1% levels respectively.

This implies that while public communication and access to public research information may inversely influence the speed of hybrid maize varieties, the communication with the private companies did not appear to be significant factor to the speed of hybrid maize adoption as expected. One possible explanation is that the hybrid maize varieties were well-accepted among farmers from significant yield improvement, compared to OPVs. Even without public extension services or private seed companies' promotion, the speed of hybrid maize adoption most likely depended on the expected benefit (i.e. relative advantage of producing hybrid maize rather than the OPVs) and availability of seeds in the seed market. This can be seen from the impact of accessibility to inputs (located near input dealers) on the speed of adoption discussed above. In addition, public institutes still produced hybrid varieties together with OPVs in the earliest stage. Through public communication of these hybrids that had higher relative price but not perceived as higher yield than existing OPVs could be a cause of decrease in the speed of adoption. Although private companies started commercial trials of hybrid maize varieties in 1981, but the adoption of hybrid varieties was slow at the beginning. Only until the release of CP-DK 888 by Charoen Pokphand in 1991 that provided more access to uniform and high yielding hybrid varieties and highly demanded by its integrated feed industry (e.g. orange-yellow color), the adoption of hybrid maize significantly increased (Napasintuwong 2017) as well as the number of adopters (Fig 1). In this case, the attributes of technology (trialability and observability of relative benefits) could be more important than social communication. Private companies' communication at the time that farmers decided to adopt hybrid varieties varied depending on the seed companies' strategies and the period of adoption. Private companies' extension evolved from farmer's field demonstration, seed exhibition, to agrodealer promotion. Our results show that these do not have significant influenced on the speed of adoption (not the adoption per se), and might be more influenced by perceived relative advantage and the availability and affordability of hybrid seeds (i.e. influenced by agrodealers) rather than direct communication with private seed companies.

For time-varying factors, the age at the time of adoption had negative impact at 0.972 times, whereas younger farmers tended to adopt hybrid maize earlier (Dadi et al 2004). Seed price also positively increased the rate of adoption whereby a unit increase in seed price increased the hazard by 1.005; this is different than earlier study by Mugisha and Diiro (2010). This could be because the share of seed cost was relatively lower than other cost of inputs, and it continuously increased over time so even if it increased, farmers still see more benefits of adopting hybrid varieties. Farm size and grain price were expected to positively shift the probability of adoption but both factors had no effect on the speed of adoption in our study which is contrary to a previous study by Sain and Martinez (1999) and Dadi et al. (2004). On average, most Thai maize farmers had small farm area which offers less risk from adopting new technology. Regarding the insignificant effect of grain price, it was determined that hybrid grain and OPVs grain were sold at the same price because there were no significant difference in grain characteristics therefore it did not affect the adoption.

CONCLUSIONS

The findings from the duration analysis of a farm survey from five major maize provinces of Thailand suggested that to increase the speed of hybrid maize adoption, policy makers may promote new crop varieties to the young and educated farmers. Increasing input accessibility would also increase the adoption. Increasing the price of hybrid seed or other new technology may still increase more adoption when the price of output increases correspondingly. However, the communication from public sector may not necessarily increase the speed of adoption particularly in this case where the technology is provided by the private companies. The availability of technology could be more important factor to speed up the adoption like in this case where perceived benefits (i.e. significant yield improvement) is prominent.

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