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Enhancing adoption of agricultural technologies requiring high initial investment among smallholders

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ABSTRACT

Low and slow adoption of improved agricultural technologies among smallholders often frustrate technology development and promotion efforts in the developing world. That is especially true for technologies requiring high initial investment. This study investigates how increasing farmers' awareness and exposure to new agricultural technologies through the creation of systematic linkages in the research-to-development continuum affect adoption. The double hurdle and duration analysis models were applied to a sample of 820 smallholder households producing wheat and barley in Syria. The results show that increasing exposure and awareness of the zero tillage technology through organized field days and demonstration trials, complemented with providing free access to costly zero tillage seeders for first-time users, increases the propensity, speed, and intensity of adoption. The intensity of adoption is also positively influenced by wheat acreage and farmers' access to credit. The findings of this study highlight the importance of facilitating farmers' initial exposure and ease of trying out new agricultural technologies, especially those requiring high initial investment, at low or no cost in ensuring fast and large-scale adoption.

1. Introduction

In the developing world, new agricultural technologies are predominantly characterized by low and slow adoption adding to the frustration of researchers, development practitioners, policy makers and donors alike. Any new innovation carries both risks and opportunities and farmers are more likely to try out a new technology that is less risky and with higher expected benefits relative to the prevailing technology (Pannell et al., 2006). The decision on whether to adopt is even more challenging when the new technology involves high initial investment.

The decision to adopt a new technology, such as zero tillage (ZT), may be affected by several factors including farmer and farm household characteristics, farm biophysical characteristics, farm financial and management characteristics and exogenous factors beyond the control of the farmer. Among farmer characteristics, empirical evidence finds that the sex, age, education, and perceptions of farmers about inherent features of new technologies as important determinants of adoption (Baumgart-Getz et al., 2012; Vitale et al., 2011; Knowler and Bradshaw, 2007). Farm characteristics such as the size, location, soil properties, slope, proximity to homestead, access to irrigation water and the agro-ecological conditions of the area where the farm is located have also been found to affect adoption (D'Emden et al., 2008; Gedikoglu and McCann, 2012).

The adoption process involves a sequence of sub-decisions on when to try out the new technology, when to adopt, the intensity of adoption, and whether or not to fully replace the old with the new technology (Astebro, 2004; Jha et al., 1990; Smale et al., 1991). The ease with which the new innovation can be tested to confirm its advantages enhances farmers' tendency and speed to adopt and this may depend on the extent to which it may be tested at low or no cost (Pannell et al., 2006). The innovation's compatibility with existing set of resources,

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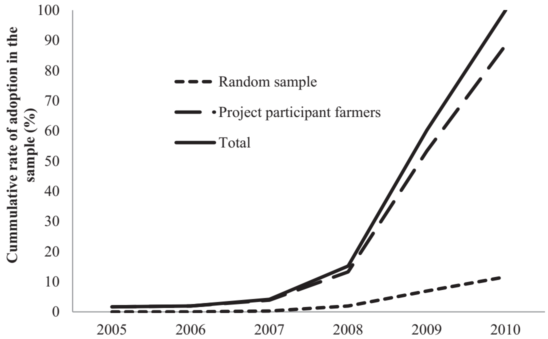

Fig. 1. Trend in the adoption of ZT among sample farmers.

practices and technologies may also influence the intensity of adoption. For instance, Zentner and Lindwall (1978) and Malhi et al. (1988) show that incompatibility with existing technologies and required high initial investments are contributing factors to low adoption of conservation agriculture (CA) in general, and zero tillage (ZT) in particular (Fig. 1).

In 2005, the International Center for Agricultural Research in the Dry Areas (ICARDA) launched a project to introduce and promote zero tillage (ZT), one of the 'pillars' of conservation agriculture (CA), to farmers in Iraq and Syria. The project adopted participatory methods to increase farmers' exposure to the new technology to encourage them to try it out and eventually adopt. Farmers were encouraged to carry out demonstration trials on their own farms by availing locally-made low cost ZT seeders to first-time users at no cost for up to two years while providing technical assistance and extension services. After the two years, farmers were left to decide whether they want to adopt the technology using their own or rented ZT seeders. Farmers were also encouraged to adopt other CA practices such as early sowing, use of low seed rates and residue retention. The detailed strategies used by the project to enhance ZT adoption is well documented (Loss et al., 2014; Piggin et al., 2015). By 2010/11 the total area under ZT had increased to about 15,000 ha and reached 50,000 ha by 2014/15. This rapid adoption is partly attributed to the shortage of fuel due to prevailing political instability in the country, necessitating the need to adopt the new technology.

El-Shater et al. (2015) investigated the economic benefits of the adoption of ZT among Syrian wheat farmers. The study found that after controlling for all confounding factors, adoption of the ZT technology led to a 25% (US$187/ha) increase in net crop income and a 34% (26.4 kg) gain in per capita wheat consumption per year (adult equivalent), which represent meaningful changes in the livelihoods of small and medium-scale wheat farmers. Numerous empirical studies have investigated the economic impact of adoption of new agricultural innovations. However, studies that document the efficacy of new innovation promotion strategies, especially those that require high initial investment, to enhance the speed, propensity, and intensity of adoption are sparse.

This study investigates the efficacy of promotion strategies in enhancing the decisions on the speed, propensity, and intensity of adoption of ZT among smallholder wheat and barley producers in Syria. The study makes two novel contributions to the existing literature. First, we show the importance of integrating research with development by allowing farmers to hold demonstration trials on their own farms as a pathway to promote uptake of new innovations and agricultural development. Second, we demonstrate the importance of providing risk-free environment to promote uptake on new technologies that require high initial investment.

The remainder of the paper is organized as follows. Section 2 provides an overview of the history of ZT in Syria followed by a description of the data used for this study in Section 3. Section 4 presents the methodologies used for the analysis. Estimation results are presented and discussed in Section 5. Section 6 concludes the paper with presentation of the major findings and their policy and extension implications.

2. Zero tillage and its promotion in Syria

Zero tillage (ZT) was little-known or tested in Syria before ICARDA introduced it via a project funded by Australian Agency for International Development (AusAid) through the Australian Center for International Agricultural Research (ACIAR) in 2005. The project discussed and demonstrated various ZT seeding technologies and requirements with local manufacturers in 2007 to 2008. Various prototype ZT seeders were developed with modifications to suit local conditions. To promote ZT in the region, the project purchased 10 ZT seeders from the local manufacturers and made them available for cost-free trial by interested farmers who wanted to try out the technology for the first-time on their own fields. While the project provided extension and advisory services to the first-time users, the farmers had to use their own tractors, fertilizers and other inputs. The project also organized and held field days on some of these demonstration sites to effectively promote the technology in a participatory approach.

The focus of the project in promoting the ZT technology was to demonstrate to farmers the immediate cost savings and potential yield increases as compared to conventional tillage practices (Loss et al., 2014). The gains in yields were expected to come from two sources. First, moisture being a major limiting factor in Syria, ZT helps the conservation of moisture which leads to yield gains. Second, given the amount of tillage needed and pressure on labor and machinery, farmers in Syria normally wait until after mid-October to plant wheat. The introduction of ZT would reduce the pressure on labor and machinery and adopters of ZT would be able to plant earlier without waiting for the first rains. Consequently, by 2010 the total area under ZT had reached about 15,000 ha with 70% of this estimated to be actual adoption by farmers using their own, rented, or borrowed ZT seeders. The remaining 30% was sown with local ZT seeders freely provided to first-time users without charge by the project implementers (ICARDA, Aga Khan Foundation and Aleppo Agricultural Machinery Center).

3. Data

The data used for this analysis comes from a farm survey conducted in 2011 by ICARDA scientists and the national extension program of Syria. The survey covered 28 randomly selected villages distributed across 17 districts and 7 main wheat-growing governorates. Cluster sampling procedure was used to collect the data with the different administrative units used as clusters. Using power analysis (Cohen, 1988), the minimum sample size required under the simple random sampling technique for ensuring 95% confidence and 3% precision levels in capturing up to 10% adoption was determined to be 374. Accounting for the design effect, the minimum sample size under the cluster sampling technique required for ensuring the same levels of confidence, precision and adoption levels was estimated to be 459, with an optimal cluster size of 17. The primary sampling units (PSUs) were the villages. Accordingly, a decision was made to take a random sample of 500 farmers uniformly distributed across all the 28 sample villages (about 18 farmers in each village).

Given the short history of ZT in the study area, the number of adopters in the random sample was found to be only 42, which was not considered adequate for statistical analysis. Therefore, in addition to the random sample of 500 farmers, 320 additional farmers, who had previously tested ZT on their own farms through the project's participatory development and extension program, were added, making the total sample size to be 820 farm households. Details of the sampling design are summarized in Table 1. All the 320 farmers had tried the ZT technology at least once, in tests or 'demonstrations' involving ZT and conventional tillage comparisons and were still using the technology

Table 1
Sampling design for the surveys conducted in Syria in 2011.

Governorates	District	Districts included in the survey			
		Number of villages	Total population in the villages	Sample size	
				Total	Randomly selected
Aleppo	Al Bab	1	650	36	18
	Ein Al Arab	2	700	40	36
	Sama'an	2	800	26	36
	Sfiera	1	900	43	18
Al-haska	Kamshly	4	347	96	70
	Tel-Hamis	1	66	31	18
	Malkia	1	190	25	18
	Amoda	1	270	21	18
	Hasaka	1	700	62	18
	Ras-Alain	1	600	22	18
Edleb	Khan-Shikon	1	400	23	18
	Almara	4	3270	174	70
Hamah	Slmiah	3	2400	94	54
	Sabora	2	1200	50	36
Homs	Ksier	1	380	26	18
Deraa	Alshajra	1	410	25	18
Alswieda	Salked	1	800	26	18
Total		28	14,083	820	500

after the project withdrew its support.

The sampled farmers cultivated small to medium farms, ranging from 1.4 ha to 401 ha, with an average size of 5.43 ha. The typical farmer in the sample had 3.3 years of schooling and 25 years of farming experience. Among the 820 sampled farm households, 214 (26%) hosted on-farm demonstrations trials, 89 (11%) participated in field days, and 76 (9%) engaged in both promotion activities. Thus, 441 of the sampled farmers neither hosted demonstration trials nor participated in field days. Out of the 820 total sampled farmers, 362 (44%) were adopters of the new ZT technology while the remaining 458 (56%) were non-adopters. The average number of years the typical adopter had used the ZT, after the withdrawal of project support, was 2.1 years which is not surprising as the technology was only relatively new in the region (Table 2).

4. Methodology

4.1. Theoretical framework

We assume that the decision to adopt ZT is a two-staged process. The farmers will first choose whether to adopt zero tillage or not before they decide how much acreage of available arable land to commit to zero tillage production. They do so by maximizing an underlying utility function from the production and consumption of farming activities. We assume that consumption and production decisions are inseparable because of imperfection in both product and factor markets in Syria. Therefore, a farmer's willingness to adopt zero tillage depends on the magnitude of the expected change in utility. Assuming that the expected utility from adoption is represented by U^a and from non-adoption by U^{na}, a producer will only decide to adopt, and thereafter allocate land for zero tillage production, if the expected utility (benefit) from adoption is greater than from non-adoption, i.e., $B = U^a - U^{na} > 0$. However, the gains in utility due to adoption, B, are not observable and can only be expressed as a function of observed socio-demographic elements that affect the decision to adopt (Z) in a latent variable model. The change in utility from the adoption of ZT is heterogeneous across individual decision makers. Thus, each farm household will have different perceptions about the expected benefits of adoption. Therefore, instead of observing utility, the researcher can only observe a dichotomous variable B with a value of 1 if the farmer is an adopter and therefore expect a positive change in utility from

Table 2
List and summary of explanatory variables included in the models.

Variables		Unit	Adopters	Non-adopters	Total
Number of farmers		Number	362	458	820
Total number of purposively selected elite farmers		Number	320	0	320
Total number of randomly selected farmers		Number	42	458	500
Number of farmers who only hosted demonstration trials	Elite	Number	197	0	197
	Random	Number	11	6	17
	Total	Number	208	6	214
Number of farmers who only participated in field days	Elite	Number	48	0	48
	Random	Number	0	41	41
	Total	Number	48	41	89
Number of farmers who participated in field days and also hosted demonstration trials	Elite	Number	75	0	75
	Random	Number	1	0	1
	Total	Number	76	0	76
Number of farmers who did not participate in either or both of field days & demonstration trials	Elite	Number	0	0	0
	Random	Number	31	410	441
	Total	Number	31	410	441
Proportion of farmers who are in zone one[b]		%	77.1	72.3	74.4
Total cultivated area		ha	28.5	9.73	18
Age of household head		years	50.8	51	50.9
Farming experience of household head		years	24.6	25.7	25
Level of education of household head		Year	3.8	2.9	3.3
Value of total assets in '000 Syrian pounds		1000 SP[a]	1561	1577	1570
Number of extension contacts related to ZT		Number	3.5	1.5	2.3
Farmers who used credit to fund production in 2010/11		%	22.6	11.6	16.5
Farmers who are members of the cooperative		%	68.6	44.8	58.0

[a] The currency conversion rate at the time of the study was 1US$ = 50 Syrian pounds (SP).

[b] Syria is divided into five agro-ecological zones where Zone 1 represents the relatively wetter areas with average annual precipitation of about 350 mm but with a 33% probability to be < 350 mm and Zone 2 represents areas with average annual rainfall of about 250 mm with > 33% probability of falling below 250 mm.

adoption and 0 otherwise:

$$B_i^* = \beta' Z_i + \varepsilon_i$$

$$B_i = \begin{cases} 1 \text{ if } E(U^a - U^{na}) > 0 \Rightarrow \text{adopter} \\ 0 \text{ if } E(U^a - U^{na}) > 0 \Rightarrow \text{non-adopter} \end{cases} \quad (1)$$

Prior to adoption, the farmer has to make choice of the optimal time, t^*, to adopt after the technology has been introduced and made readily available. At time of adoption, it is assumed that the farmer will expect that ZT technology to yield better benefits (more utility) relative to conventional tillage technology. Therefore, the optimal time to invest in ZT technology will vary across farmers. Nevertheless, this will occur when a farmer perceives that the gains from adoption outweigh the value of waiting any longer for more information or any other triggers to adopt. It is assumed that time until adoption (i.e., continued use of conventional tillage) is influenced by different factors, including farmer, farm, and economic factors as well as information and farmer's own perception of innovation-specific characteristics. A duration function can be used to empirically model the key determinants of the probability waiting time until adopt given that the new technology had not been adopted before.

4.2. Decision and intensity of adoption

Adoption of a new innovation in agriculture at an individual farmer level is defined as the degree of use of the new technology in the long-run when the farmer has full information about the technology and its potential (Feder et al., 1985). Zero tillage was promoted in Syria through on-farm demonstration trials conducted by farmers and a series of field days organized to achieve maximum exposure. In this study, adoption is defined as the use of the ZT technology for at least two consecutive years. Thus, on-farm demonstration trials are considered as pre-testing and not real adoption.

The double hurdle (DH) model is used to analyze the decision to adopt zero tillage and the intensity of adoption. The approach permits the joint modelling of the decision to adopt and the decision regarding the acreage of farmland to put under zero tillage. The micro-level data analyzed comprise of a random sample and a purposive sample collected from smallholder producers. Therefore, the variable that is used to measure intensity of adoption, i.e., farm acreage under zero tillage, is censored to the left. This problem is arising because some producers had decided not to adopt zero tillage for personal preferences. However, among those who are classified as adopters, some may have decided not to commit any land to zero tillage during the study period. Therefore, the observed data for acreage under zero tillage is continuous but censored at zero. The Tobit regression analysis would have been the ideal statistical model to use. However, a limitation of the Tobit model is that the decision to participate in zero tillage promotion program and how much land to allocate to zero tillage are assumed to be determined by the same variables. Thus, a variable that increases the probability to participation also increases the farm acreage allocated to zero tillage. This is a restrictive assumption that may lack any empirical evidence. Moreover, in the Tobit model the relative marginal effects of two continuous covariates on the probability of participation and the unconditional expected acreage under ZT are assumed to be identical, a fairly restrictive (Wooldridge, 2010). Therefore, the double hurdle model initially developed by Cragg (1971) is preferred to jointly model the two decisions. The model allows for the separation of the variables that determine the adoption decision from those of the intensity of adoption and is estimated in two steps (Burke, 2009).

The farmland acreage that adopters choose to put under zero tillage is represented by $y = c \cdot a$ where c and a respectively are the binary consideration decision (adopt ZT or not) and a continuous choice of acreage put under zero tillage given that it is not zero.

The latent variable underling a household's decision to commit farmland to zero tillage (c^*) is specified as:

$$c^* = X\beta + e$$
$$c = \begin{cases} 1 \text{ if } c^* > 0 \\ 0 \text{ if } c^* = 0 \end{cases} \tag{2}$$

where X is a vector of determinants of farmland allocated to zero tillage, β is a vector of parameters to be estimated and e is a normally distributed error term with zero mean and constant variance. The land area (acreage) variable a is indicated by a latent variable a* and cornered at zero such that:

$$a = \max[0, a^*]$$
$$a^* = \exp(Z\alpha + \mu)$$
$$y = \begin{cases} a^* \text{ if } c = 1,\ a > 0 \\ 0 \text{ otherwise} \end{cases} \tag{3}$$

where Z is a vector of determinants of acreage under zero tillage, α is a vector of parameters to be estimated and μ is the random error term which is log-normally distributed with zero mean and constant variance. The disturbance terms u and e are assumed to be independent of each other (Wooldridge, 2010).

The decision on whether to adopt ZT or not (first hurdle) is modeled using a Probit model in which the dependent variable is binary (1 = adopt, 0 = not adopt). The acreage to commit to zero tillage (second hurdle) given that a farmer is an adopter is estimated using a truncated regression where the dependent variable is the logarithm of acreage under zero tillage. In this case, the decision not to cultivate land using ZT, given that the farmer is already a non-adopter, is an optimal choice and not missing value. Therefore, the zero acreage under ZT is treated as observed. Following Pannell et al. (2006), El-Shater et al. (2015), Alwang and Sowell (2010), Knowler and Bradshaw (2007) and Winters et al. (2004) we hypothesize that the decision to adopt zero tillage by Syrian farmers is influenced by household characteristics, farm characteristics and exposure to zero tillage through field days, demonstration trials or both.

The double hurdle model has been widely used in the literature as an improvement to the commonly used Tobit model for analyzing the decision and intensity of adoption of agricultural technologies (Cooper and Keim, 1996; Gebregziabher and Holden, 2011; Mal et al., 2012; Miranda, 2010; Ricker-Gilbert et al., 2011; Shiferaw et al., 2008). The model can be estimated assuming the dependent variable in the second hurdle model follows truncated normal or lognormal distribution. We choose to use the lognormal double-hurdle model as it has an easier economic interpretation compared to the truncated normal model; the estimated parameters α is a measure of the semi-responsiveness of y with respect to Z, conditional on $y > 0$ (Hsu and Liu, 2008).

It is common practice to impose some exclusion restrictions on the variables used to estimate the participation and intensity equations in order to adequately identify the parameter estimates. However, the choice of which variables to exclude is often arbitrary as theory is not precise as to which variable to exclude, and choice of those variables depends on context of study. Therefore, in this study we include in the participation equation the variables that relate to exposure to the technology. Those include whether farmer attended ZT promotion field days, ZT demonstration trials or both. Those might influence decision to participate in ZT program but not that of how much acreage to put under ZT production. The ZT participation equation and acreage equation are assumed to be independent and estimated using maximum likelihood (ML). Detailed information about the estimation method is documented in Burke (2009).

The list and summary statistics of the explanatory variables included in the lognormal double-hurdle model estimated in this study are provided in Table 2. The variables that measure the effect of risk-free access[1] to ZT technology are included in the first hurdle (Probit model) equation as explanatory variables but excluded in the second hurdle (truncated regression) equation because these variables may be important in deciding whether or not to adopt the ZT technology, but not so much on the decision regarding the area of land to be devoted to the ZT technology. The exclusion of these variables will also help in overcoming the identification problem that might be introduced during simultaneous estimation of the two equations mainly due to the non-linearity in the participation equation (Sartori, 2003).

4.3. Speed of adoption

Duration analysis (DA) is concerned with the timing of events where the event variable represents the transition from one state to another (Henry and Butler, 2012). The purpose of DA is to statistically identify those factors which have a significant effect on the length of a spell, in our case the length of time taken before adoption of ZT given that the technology has already been made available. A spell starts at the time of entry into a specific state and ends at a point when transition is made into a new state (Dadi et al., 2004).

Duration analysis has been applied to study the adoption or dis-adoption of new technologies such as sustainable land management practices in Brazil (De Souza Filho et al., 1999), conservation tillage in

[1] Whether or not the household has hosted an on-farm demonstration trial with free access to a ZT seeder; whether or not the household has participated in field days organized to popularize ZT; and whether or not the household has participated in both the demonstration trials with free access to a ZT seeder and field days.

Australia (D'Emden et al., 2006), organic agriculture in the UK (Burton et al., 2003) and recombinant bovine Somatotropin (rbST) in cattle production in California (An and Butler, 2012). When applied to the analyses of technology adoption, DA is used to identify the factors that determine the time lag (T) between the moment when the innovation becomes available to farmers, or when they are first exposed to it, until when they actually adopt the technology. In this study, we use DA to analyze the determinants of delay in the adoption of ZT by Syrian wheat and barley producers.

Let T represent the duration before adoption, $f(t)$ the probability density function of T and $F(t)$, the cumulative distribution function T. Given those functions, the probability that non-adoption will last at least until time t, i.e. the survival function, $S(t)$, and the corresponding probability that the farmer adopts the technology at time t, given that he or she had not adopted before, $h(t)$, i.e. the hazard function, are expressed as:

$$S(t) = \Pr(T \geq t) = 1 - F(t)$$
$$h(t) = \lim_{\Delta t \to \infty} \left(\frac{\Pr(t \leq T < t + \Delta t \mid T \geq t)}{\Delta t} \right) = \lim_{\Delta t \to \infty} \frac{F(t + \Delta t) - F(t)}{\Delta S(t)} = \frac{f(t)}{S(t)} \tag{4}$$

In parametric duration models the hazard rate may assume a particular shape, i.e., time dependency. The common shapes include the logistic, Weibull, exponential, lognormal, log-logistic and Gompertz probability distributions (Cleves et al., 2008; Kiefer, 1988; Mudholkar and Hutson, 1996).

Apart from the time variable, the distribution of duration can be influenced by a set of other covariates such as household and farm characteristics. The individual covariates can be introduced in a number of ways but the most common is to assume proportional hazards where the impact of a covariate on the hazard is proportional to the baseline hazard $h(t)$. Therefore, the hazard function can be redefined as being conditional on time (t), a matrix of covariates (X) and a vector of parameters characterizing the covariates (β) as follows:

$$h(t, X, \theta, \beta) = \lim_{\Delta t \to \infty} \left(\frac{\Pr(t \leq T < t + \Delta t \mid T \geq t, X)}{\Delta t} \right) = \lim_{\Delta t \to \infty} \frac{F(t + \Delta t, X, \beta) - F(t, X, \beta)}{\Delta S(t, X, \beta)} = \frac{f(t, X, \beta)}{S(t, X, \beta)} \tag{5}$$

In PH specification covariates are related multiplicatively with the baseline hazard and can be formulated as:

$$h(t, X, \theta, \beta) = h(t, X) \times g(X, \beta) = h(t, X) \exp(X, \beta) = \exp(\theta) \exp(X, \beta). \tag{6}$$

In the above equation $g(X,\beta)$ is the hazard that depends on covariates determined by economic theory, β is a vector of unknown parameters of X and θ is a vector of parameters that characterize the distribution function of the hazard rate. The estimated exponential parameter is known as the hazard ratio and shows how much a unit increase in a covariate will increase the baseline hazard.

An alternative specification of the duration model is the accelerated failure time (AFT) model. Unlike the PH model that assumes a non-linear relationship between the survival time T and covariates, this model assumes a linear relationship:

$$\ln T = X'\beta + z \tag{7}$$

where z is the generalized error term that is a product of a scaling factor (σ) and error term, i.e., $z = \sigma\varepsilon$. The error term in this model can follow a Weibull, log-normal, exponential or log-logistic distribution. Unlike the PH model that measures the effects of the relative hazard, the AFT model measures the direct effects of the covariates on survival time. The parameters of the AFT model relate proportional change in survival time to a unit change in a given regressor, holding all else constant. The estimated exponential parameter is known as the time ratio and shows how much a unit increase in a covariate will increase the survival time. Therefore, the AFT model is preferred in this study to the PH model.

Following Karshenas and Stoneman (1993) and Abdulai and Huffman (2005), we also assume duration follows a Weibull distribution because it is suitable for modelling data where hazard is duration-dependent and particularly when data exhibit hazard rates that increase or decrease exponentially with time. The Weibull distribution characterizes the hazard function as:

$$h(t, X) = \lambda p t^{p-1} | \lambda = \exp(X'\beta) > 0 \tag{8}$$

where β is a vector of parameters characterizing the baseline hazard and λ is the location parameter. The function exhibits increasing hazard when the Weibull parameter shape $p > 1$, decreasing hazard when $p < 1$, and collapses to the exponential distribution with constant hazard when $p = 1$; this later case indicates that the passage of time does not influence the hazard rate. Therefore, the Weibull model is an important generalization of the exponential model with two positive parameters (Weibull, 1939). By introducing a second parameter in the model, the Weibull distribution allows for great flexibility of the model and different shapes of the hazard function. The convenience of the Weibull model for empirical work stems from this flexibility and from the simplicity of the hazard and survival functions. A major limitation of the exponential model is that the expected remaining time to adoption is given by the inverse of the hazard, and is independent of prior survival times, thus failing to capture history. The scaling factor in Eq. (7) is a reciprocal ($\sigma = 1/p$) of the Weibull shape parameter p that determines whether the hazard is increasing, decreasing, or constant over time. Following Abdulai and Huffman (2005), the parameters of the PH and AFT models are estimated using the maximum likelihood procedure. The parameters of the PH model and AFT model are linked in the following way: $\widehat{\beta}_{PH} = \frac{-\widehat{\beta}_{AFT}}{\widehat{\sigma}}$.

The dependent variable in the analysis is the time farmers waited before adopting the ZT technology, which is measured by the number of years since 2005 when the ZT technology was first introduced in Syria. For those farmers who had not as yet adopted the technology, the duration is right-censored (i.e., assumed to have adopted ZT) at the year of data collection (2010). The covariates which are included in the model to explain variation in the duration of adoption are presented in Table 2.

5. Results and discussion

The results of the decision to participate in ZT program and acreage to commit to ZT once the adoption decision is made are reported in Table 3. The reported values for hurdle 1 are the estimated coefficients and average partial effects (APE) of each variable on the probability to adopt ZT. The values for hurdle 2 are estimated coefficients, the marginal effects of each explanatory variable (conditional APE (CAPE)) on acreage under ZT conditional on adoption of ZT. The unconditional APE (UAPE) captures the joint impact of a variable on the probability of ZT adoption and intensity of adoption as measured with ZT acreage. Those of the duration until adoption once the technology is made available are reported in Table 4.

5.1. Adoption and acreage enrolment decisions

The APE estimates from the first stage of the double hurdle model (Table 3) show that participation in hosting demonstration trials with free access to ZT seeders and in field days increases the propensity of adoption by 0.60 and 0.26 respectively – both at high significance level ($p < 0.01$). The joint effect of participation in field days and demonstration trials increases the propensity to adopt ZT substantially to 1.00

Table 3
Parameter estimates of the lognormal double-hurdle model.

Independent variables	Hurdle 1		Hurdle 2 (log normal)		(5)
	ZT participation		ZT acreage		UAPE
	(1)	(2)	(3)	(4)	
	Coef	APE	Coef	CAPE	
Education (years)	0.155***	0.023***	0.050	0.020	0.0426
	(0.055)	(0009)	(0.083)	(0.035)	(0.036)
Farmer age (years)	0.005	0.000	−0.278*	−0.110*	−0.109
	(0.008)	(0.001)	(0.162)	(0.061)	(0.070)
Extension (contact numbers)	0.164***	0.239***	−0.185***	−0.074***	−0.050
	(0.051)	(0.008)	0.050	(0.026)	(0.024)
Credit (1 = yes,0 = no)	0.186	0.027	0.270***	0.107***	0.134
	(0.294)	(0.043)	(0.094)	(0.040)	(0.055)
Coop member (1 = yes, 0 = no)	−0.393**	−0.057**	−0.402***	−0.159***	−0.217
	(0.185)	(0.029)	(0.100)	(0.039)	(0.055)
Field day (1 = yes, 0 = no)	1.772***	0.258***			0.258***
	(0.201)	(0.032)			(0.032)
Demonstration (1 = yes, 0 = no)	4.119***	0.600***			0.600***
	(0.457)	(0.195)			(0.195)
F. day & demo (1 = yes, 0 = no)	7.204***	1.049***			1.049***
	(0.330)	(0.122)			(0.122)
Farm assets (SL)	−0.000	−0.000	−0.001	−0.000	−0.000
	(0.000)	(0.000)	(0.056)	(0.019)	(0.022)
Farm size (ha)	0.052	0.008	0.127	0.050	0.058
	(0.037)	(0.006)	(0.198)	(0.083)	(0.074)
Wheat area (ha)	−0.106	−0.015	0.853***	0.339***	0.323
	(0.092)	(0.015)	(0.225)	(0.087)	(0.097)
Zone (1 = yes, 0 = no)	0.764**	0.111***	−0.155*	−0.061	0.050
	(0.299)	(0.040)	(0.089)	(0.037)	(0.059)
Duration using ZT (years)			0.044	0.018	0.018
			(0.291)	(0.118)	(0.118)
Constant	0.155***		1.459		
	(0.055)		(1.220)		
Observations	820		820		

Note 1: Robust standard errors in parentheses.
Note 2: APE, CAPE and UAPE are average partial effects, conditional average partial effects and unconditional average partial effects. Standard errors are reported in parenthesis and are obtained by bootstrapping with 100 replications using the delta method.
*** Indicate the level of significance at $p < 0.01$.
** Indicate the level of significance at $p < 0.05$.
* Indicate the level of significance at $p < 0.1$.

and this is also highly significant ($p < 0.01$).

As expected, the number of contacts with extension agent related to ZT has a positive and significant effect ($p < 0.01$) on the decision to adoption. It increases the propensity of adoption by 0.24. However, it has a negative and significant effect ($p < 0.01$) on the intensity of adoption which is contrary to theoretical expectation. The positive and significant coefficient on the wheat area variable on the intensity of adoption indicates that farmers cultivating larger wheat areas, assuming that they are already adopters, are more likely to have a higher intensity of adoption relative to those cultivating smaller wheat areas.

The APE for the education variable is positive and significant ($p < 0.01$) in the first hurdle indicating that an increase in year of education would only increase the propensity of adoption by 0.023. This variable is positive but insignificant in the second hurdle model suggesting that education does not influence intensity of adoption once the first hurdle is overcome. This result is as expected because adoption of ZT technology may require a good understanding of crop physiology and soil management practices making educated farmers at a better position to adopt compared to non-educated farmers. Age of the head of the farm household is found to have negative and weakly significant ($p < 0.1$) effect in the intensity of adoption while it does not have significant effect on the decision on whether to adopt or not.. This suggests that farmers will reduce acreage under ZT as they become older although age does not seem to affect the decision to adopt. We find that farmers who took credit in 2010 increased their ZT acreage relative to those who did not. The credit variable is positive and statistically significant ($p < 0.01$) for the second hurdle equation and not for the first hurdle equation. Contrary to expectation, we find that membership to a cooperative group reduces both the propensity and intensity of ZT adoption. This is possibly because membership to cooperatives might create easy and cheap access to inputs thereby reducing the incentive to save on costs of production.

5.2. Time until adoption

For the duration model, the dependent variable is the natural logarithm of the duration between the time ZT technology became available for the first-time in Syria to when the farmer first adopted it. The estimated coefficients, time ratio and percentage change are reported in Table 4. Percentage change indicates the change in the logarithm of survival time (time until adoption) for a unit change of a given covariate. Therefore, a negative coefficient for a covariate implies faster adoption as it indicates negative marginal effect on duration. The estimated model as a Weibull parameter (α) that is positive (5.65) and statistically significant indicates a positive duration dependency on the covariates. This implies that the probability of adopting ZT technology for a typical farmer increases with the number of years since ZT was introduced and become available.

The reported results indicate that education, credit, cooperative membership, field day, demonstration trials and joint effect of field

Table 4
Parameter estimates of the accelerated failure time model.

Variables	Coef	Time ratio	Percentage change
Education (years)	−0.024*** (0.006)	0.976	−2.419
Farmer age at adoption time (years)	−0.002* (0.001)	0.998	−0.182
Extension (contact numbers)	0.001 (0.003)	1.001	0.115
Credit (1 = yes, 0 = no)	0.069*** (0.025)	1.071	7.144
Coop member (1 = yes, 0 = no)	−0.049** (0.022)	0.952	−4.826
Field day (1 = yes, 0 = no)	−0.454*** (0.047)	0.635	−36.471
Demonstration (1 = yes, 0 = no)	−0.776*** (0.045)	0.460	−53.966
F. day & demo (1 = yes, 0 = no)	−0.804*** (0.047)	0.447	−55.249
Farm assets (SL)	−0.000 (0.000)	1.000	0.000
Farm size (ha)	0.009* (0.005)	1.010	0.927
Wheat area (ha)	−0.024* (0.013)	0.977	−2.330
Zone (1 = yes, 0 = no)	−0.040 (0.024)	0.961	−3.885
Constant	2.532*** (0.072)		

Note 1: Robust standard errors in parentheses.
Note 2: Percentage change for each parameter is computed as $100 \times [\exp(\beta_k) - 1]$.
*** Indicate the level of significance at $p < 0.01$.
** Indicate the level of significance at $p < 0.05$.
* Indicate the level of significance at $p < 0.1$.

days and demonstration trials have a negative and strong statistically significant association with the logged duration until adoption ($p < 0.01$). Hosting on-farm demonstration trials, participation in field days and involvement in both activities decreases the duration to adoption by 36.5, 54 and 55% respectively. A unit increase in education decreases the duration to adoption by 2.42% while belonging to a co-operative reduced the duration to adoption by 4.83%. Contrary to expectation, having had access to credit in 2010 increased the duration to adoption by 7.1%, suggesting that farmers who obtained credit were indeed credit constrained and therefore delayed decision to adopt. A unit increase in farm size weakly ($p < 0.1$) increases duration to adoption by 0.93% while an increase in wheat area reduce the duration by 2.3%. This implies that the relative acreage of farmland dedicated to wheat production is key determinant of duration to adopt rather than the mere total farm acreage. Farmers with large wheat acreage are likely to adopt ZT earlier relative to those with small wheat areas.

6. Conclusions

This paper investigated the role of integrating research with development in promoting ZT technology uptake by availing free-access to ZT seeders that require high initial investment to first time ZT users to carry out demonstration trials on their own farms and exposure through field days. We investigate the key determinants of time until adoption, propensity to adopt and intensity of adoption. The lognormal double-hurdle model was used to identify important factors which determine the propensity and intensity of adoption as measured by acreage under ZT. The duration model was used to investigate factors that determine the duration of time taken to make the adoption decision from the time when the technology becomes readily available and exposed to farmers.

Our main findings is that the promotion strategy employed by ICARDA to promote ZT adoption in Syria - enhancing farmers' exposure to ZT through field days and hosting of demonstration trials on their own farms while providing free access to ZT seeders to first time users for utmost for two years, had positive and significant effects on decisions on how soon to adopt and propensity to adopt. Participation in both field days and demonstration trials decreased the duration to adopt by 55% while increased the propensity of adoption by almost 100%. This underscores the importance of increasing exposure to new technologies and creating of low or risk-free environment to allow farmers to try out new technologies in increasing the speed and propensity of adoption.

Consistent with the empirical evidence from the extant literature on adoption, we find that farm and household characteristics such as education attainment, access to extension services related to ZT and belonging to social networks such as cooperative memberships are important determinants of adoption decisions.

These results reinforce the common belief that in general people are more likely to accept and practice what they see and try than what they just hear about or what is recommend to them by others. This is even more so when it comes to new agricultural technologies like ZT that require high initial investment. For centuries, farmers in the Middle East have prepared their fields for planting with multiple tillage operations. Therefore, our study makes contribution to existing literature by reinforcing the importance of increasing exposure of farmers to new agricultural innovations in enhancing the likelihood and speed of adoption, and the importance of linking research to development efforts through participatory methods. Apart from creating free access of the ZT seeders for first-time users, hosting demonstration trials and organizing field days, Piggin et al. (2015) argue that the success of the project in enhancing the adoption of ZT can be attributed to: 1) the local research verification and adaption of ZT; 2) project support for local production of appropriate ZT seeders suited for the local environment at affordable prices; and 3) project flexibility in allowing demonstration farmers to choose the adoption of ZT separately or in combination with other improved crop management options such as early sowing and low seed rates, and encouraging (and not imposing) the retention of as much residue as possible.

Our results have policy implications for efforts to promote and diffuse new technologies such as ZT. First, the packaging of new technologies should be done in a manner that makes it easy for would-be adopters to draw lessons from past trials and apply them on their own. Second, projects should create a risk-free environment that allows farmers to try the new innovations at low or no cost and results from those trials should be observable by interested farmers and extension personnel. Third, both the government and the private sector should invest in intensive extension services and create mechanisms that enhance farmers' awareness through both formal and informal exchange of information. Fourth, the current approach which allows farmers to test the ZT technology for one or two years at no cost and then have to buy one of their own seeders to continue using it does not seem to be equally effective among large and smallholders. Testing other modalities of promotion of the technology including, the development of seeders appropriate for small farmers, creation of easy access to credit for smallholders, establishment of companies which provide ZT service, determining the maximum service fee that smallholders are willing to pay, and analyzing if that service fee will enable the companies to remain profitable would be subjects for future research.

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