Modeling the factors affecting farmers' timing of adoption of in-field conservation cropping practices

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Introduction

The diffusion of agricultural technologies is a gradual process; it takes time for information and knowledge about these practices to be widespread within the farming community (Jabbar et al., 2003; Jaffe et al., 2002). Differences in farmers’ and farm management characteristics make farmers likely to adopt at different points in time (Fuglie and Kascak, 2001). Thus, studying the timing of the adoption process is important (Hoppe, 2002). Farmers’ interaction with other adopters and the process of knowledge accumulation, which takes place over time, are important determinants in the diffusion of agricultural technologies (Fischer et al., 1996; Jabbar et al., 2003; Llewellyn, 2007). Another important factor is the adaptability of conservation practices into farmers’ production systems, which are likely to evolve over time as their production systems adjust to changing conditions (Hudson and Hite, 2003). Knowing the factors that play a role in the timing of adoption is important for agricultural educators and policymakers. Knowledge about the factors that accelerate or slow adoption for particular practices can be useful in identifying target populations with lower likelihood of adoption, allowing for the development of programs that tackle the barriers faced these farmers.

The purpose of this study is to examine factors affecting the timing of adoption of continuous no-till, cover crops, and variable rate application (VRA) of inputs for Kansas farmers to gain insight regarding the time-path diffusion of these conservation practices since their introduction into the agricultural community. A duration analysis was used to account for the dynamics of the adoption process and the factors affecting farmer’s likelihood of adoption. In addition, this study seeks to investigate how previous adoption efforts affect the speed of adoption of additional conservation practices.

Literature review

There is a large body of literature examining the adoption of conservation practices (Feder and Umali, 1993; Knowler and Bradshaw, 2007; Prokopy et al., 2008). Many adoption studies rely on approaches that model adoption at a given point in time, are static in nature and are not able to account for the timing (speed)[1] of adoption. Thus, these studies do not consider the process of adoption over time and how some factors may not only affect the decision to adopt, but also the timing of adoption. For example, some factors may not directly restrict the adoption of conservation practices, but may delay their adoption (Fuglie and Kascak, 2001).

Given that farmers adopt a conservation practice based on their knowledge or expectations about the benefits of the practice, the timing of information collection (learning) and formation of expectations is important (Au and Kauffman, 2003), and may not be captured in traditional binary adoption models (Burton et al., 2003). Diffusion studies, while accounting for the dynamic nature of the diffusion of agricultural technologies, have done so at the aggregate level and have not been able to capture farm-level characteristics that affect the adoption process at the individual level (Fuglie and Kascak, 2001).

Some studies have employed duration analysis to examine the time path of adoption and to account for the dynamic nature of the adoption process of agricultural technologies. In the adoption literature, duration models have been applied to the study of organic farming (Burton et

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[1] Timing and speed of adoption are used interchangeable in this study and they indicate the time it takes for a farmer to adopt a certain agricultural practices

al., 2003); conservation tillage (D'Emden et al., 2006; Fuglie and Kascak, 2001); soil nutrient testing and integrated pest management (Fuglie and Kascak, 2001); weed control practices (Murage et al., 2011); fertilizer and herbicide (Dadi et al., 2004); drip irrigation (Alcon et al., 2011); and other production technologies (Abdulai and Huffman, 2005).

Burton et al. (2003) studied the adoption of organic horticulture in the United Kingdom using duration analysis. They found that the probability of adopting organic farming methods declines after the farmer has been farming for five years. In addition, attitudinal factors were important determinants of the timing of organic adoption, while factors such as education, farm size, household size, and income from farming were not found to be significant factors. Dadi et al. (2004) studied the adoption of fertilizer and herbicides by farmers in Ethiopia. Their findings suggest that the speed of adoption of fertilizer was more rapid than the speed of adoption of herbicides. Factors that accelerated adoption in their study were the availability of credit, output prices, and closeness to markets. Factors such as farmers’ education, awareness of technologies, and farm size were not significant determinants of the speed of adoption. Murage et al. (2011) studied the timing of adoption of weed control technologies in corn production in Kenya using a duration model. They found that education, farm size and household size increased the speed of adoption. Their results also suggested that field days were a more effective method for accelerating the decision to adopt.

Alcon et al. (2011) investigated the adoption of drip irrigation in Spain from 1975 to 2005. They found that factors such as credit availability, water availability, the price of water, information sources and trialing of prior technologies were significant determinants of the rate of adoption. The adoption of water conservation practices in Kenya and the Philippines was also analyzed by Oostendorp and Zaal (2012) using duration analysis. They found that land ownership was an important factor affecting adoption. Their findings also suggested that the likelihood of adoption decreased over time.

Fuglie and Kascak (2001) used duration analysis to examine the dynamics of the adoption of conservation tillage, soil nutrient testing, and integrated pest management using data from a USDA survey conducted from 1991 to 1993, covering different watersheds in the High Plains, Iowa-Illinois, Central Nebraska basins, Mississippi Embayment, Upper Snake River Basin, Susquehanna River Basin, and White River Basin. In this study, the authors investigated the effect of farmer and farm characteristics, and natural resource characteristics (e.g. soil quality and rainfall) on adoption. They found a faster rate of adoption for conservation tillage during the late 1980s. Education, farm size, source of farm income, and soil characteristics were important factors in explaining the timing of adoption in their study. They also found that farmers with better soil quality adopted more rapidly than farmers with poor soil quality. Duration analysis was also applied by D'Emden et al. (2006) to study the adoption of conservation tillage by grain producers in Australia from 1983 to 2003. They found that the decrease in the price of glyphosate was an important factor accelerating adoption and that lower precipitation levels increased farmers' likelihood of adoption.

The study presented here uses duration analysis to examine the timing of adoption of continuous no-till, cover crops and VRA of inputs. While previous studies have examined the adoption of these practices, they have done so from a static point of view. The time it takes farmers to adopt a practice and the factors that accelerate or slow the adoption process have not been extensively evaluated.

Methods and data

Conceptual framework

The adoption of conservation practices is a dynamic process. Farmers evaluate a practice and decide to adopt at a point in time when introducing the practice into their production systems maximizes their utility (Pannell et al., 2011). Different components may be evaluated as part of the utility farmers derive from adopting a particular technology, including economic, social and/or environmental benefits (Pannell et al., 2006; Pannell et al., 2011). For example, if farmers are profit maximizers, they would adopt a technology if they find it profitable (Hoppe, 2002). Commonly, farmers have multiple goals or objectives (Pannell et al., 2006). Farmers may also seek to maximize their utility through environmental stewardship. In this case, in addition to profits, the farmer would want to adopt a technology if doing so achieves their environmental objectives. If a practice does not maximize farmers' utility at a particular point in time, farmers may delay adoption until new information about the suitability of the practice for meeting their economic, social and environmental goals becomes available (Hoppe, 2002).

An important temporal aspect in the adoption process is a technology's suitability. At the beginning, the uncertainty from adopting a new practice is high, however, with time the uncertainty is reduced (Pannell et al., 2006). In some cases, farmers may find it optimal to delay adoption until the practice becomes viable for their cropping system. That is, the new technology or practice can most easily be assimilated into their current cropping system with the lowest transaction cost, while meeting their objectives for adopting the practice (Ghadim and Pannell, 1999; Pannell et al., 2006). In some cases, this point is reached when sufficient information has been gathered to make an optimal decision (Fischer et al., 1996; Jabbar et al., 2003). Some factors that may affect the adaptability of a practice or technology and knowledge acquisition could be farm size, physical capital requirements, human capital requirements, weather, geography, and complementarity with other agricultural practices already used on the farm (Ghadim and Pannell, 1999; Jabbar et al., 2003).

The compatibility of a conservation practice, which concerns the stage of development of the technology, is another factor that can affect the adoption of a new technology or practice. For example, in the case of VRA of inputs, constraints to adoption have been linked to equipment and software issues (Robertson et al., 2012). External factors such as the complexity of the practice, the extent of trialability, social network interactions, and farmer's characteristics can influence farmers' perceptions of the adaptability and compatibility of a new practice, affecting the decision of when to adopt (Pannell et al., 2011). For example, risk averse farmers may delay adoption to avoid uncertainty and minimize the cost of information, which may become available as more farmers adopt a practice (Sassenrath et al., 2008).

The conceptual framework examines the timing of adoption of conservation practices by farmers, building on the framework used by Abdulai and Huffman (2005). Consider a farmer, indexed by *i*, who is considering the adoption of a conservation practice. Let $\pi_{it}^{E}(x_{it})$ represent the expected profit when adopting the conservation practice at time period *t* as a function of a set of explanatory factors that can vary across individuals and time (x_{it}). While profit is a strong motivation to adopt a practice, it may not be the only objective. That is, farmers may be environmental stewards or want to provide security for the farm for future generations. Thus, a utility framework is used to capture these multiple objectives. Let farmer *i*'s expected utility from farming in time period *t* be represented by $U_{it}^{E} = U_{i}^{E}[I_{it}, \pi_{it}^{E}(x_{it}), z_{it}, w_{it}, r_{i}, \Gamma_{it}]$. It is assumed that farmers' expected utility is increasing in π_{it}^{E} such that $\partial U_{it}^{E} / \partial \pi_{it}^{E} \geq 0$. I_{it} is an indicator function taking a value of 1 if the farmer adopts the conservation practice in time period *t* and zero otherwise. The other arguments of farmer *i*'s expected utility are farmer demographics (z_{it}); farm and farm management characteristics (w_{it}); attitudinal factors (r_i); and site-specific characteristics Γ_{it}. These different factors play an important role in farmers' motivation to adopt a conservation practice as shown in prior research (Robison et al., 1984; Skaggs et al., 1994).

The goal of the farmer is to maximize expected utility over time, i.e. $\max \sum_t U_{it}^E(\cdot)$. Letting t^* represent the optimal time to adopt the conservation practice, the utility maximization problem implies the following condition: $\sum_{t=1}^{t^*-1} U_{it}^E(I_{it}=0,\cdots) + \sum_{t=t^*}^{T} U_{it}^E(I_{it}=1,\cdots) \geq \sum_{t=1}^{T} U_{it}^E(I_{it}=0,\cdots)$, where the indicator variable denotes adoption at time *t**. The utility is maximized over the indicator variable and adoption occurs when the above condition is met. That is, a farmer will adopt in time period t^* if the stream of utilities over time after adopting a conservation practice at time t^* is greater or equal to the sum of utilities when the practice is not adopted (or adopted at a different time). This suggests that a conservation practice is adopted not only when its expected benefit is positive, but by choosing t^*, we ensure that the adoption occurs at the point in time when that benefit is maximized (Abdulai and Huffman, 2005). Operationalizing this model requires that what is observed for the farmer is the actual point of adoption t^*. Thus, we can look at the timing of adoption empirically from a probabilistic framework.

Empirical model

Duration analysis will be used to study the length of time it takes a farmer to adopt a conservation practice. Let the time of adoption be represented by a random variable T. Then the probability distribution of the length of time to adoption can be represented by the distribution function

$F(t) = \text{Prob}(T < t)$. That is, the probability of adopting a conservation practice before time period *t* is given by $F(t)$, where *t* is a particular realization of T. Associated with this distribution, is its corresponding density function $f(t) = dF(t)/dt$, which provides the relative frequency of adopting at time period *t* (Greene, 2012; Kiefer, 1988). The probability that a farmer adopts after time *t* can be represented by the survival function $S(t) = 1 - F(t) = \text{Prob}(T \geq t)$. Using $F(t)$ and $S(t)$, the probability that a farmer would adopt in a given interval of time Δt can be modeled using the hazard rate (or function):

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\text{Prob } (t \leq T \leq t + \Delta t \ \mid T \geq t)}{\Delta t} = \frac{f(t)}{S(t)} \tag{1}$$

The hazard rate represents the rate at which a farmer would adopt after he has farmed for *t* years, or alternatively, after the practice has been available for *t* years, whichever is latest. The hazard rate can be allowed to be a function of a vector of explanatory variables x such that $\lambda_i(t; x) = \lambda\phi(x, \beta)$, where λ is a constant or baseline hazard. A commonly adopted functional form for $\phi(\cdot)$ is $\phi(\cdot) = \exp(x'\beta)$.

Different parametric specifications for the hazard function can be used, namely, exponential, Weibull, log-logistic, lognormal, and inverse normal (Kalbfleisch and Prentice, 2011; Lancaster, 1992). A graphical nonparametric assessment of the proper functional form to utilize to model $F(t)$ can be done using the Kaplan-Meier estimator, which can be used to assess the shape of the distribution graphically and to determine the distributional form of the survival and hazard functions (Kalbfleisch and Prentice, 2011; Lancaster, 1992). Based on the analysis of the Kaplan-Meier estimator of the survival curve (discussed later in the results section), the Weibull model, which is widely used to model monotonically increasing or decreasing hazard functions, was chosen to model the duration of adoption in this study (Greene, 2012).

The hazard function assuming a Weibull distribution for $F(t)$, is given by $\lambda_i(t;x) = p(\gamma t)^{p-1}\exp(x'\beta)$, where γ and p are distributional parameters (Greene, 2012). When $p = 0$, the distribution reduces to the exponential case, where the probability of adopting is the same in any year after the operator begins farming. The explanatory variables enter the adoption rate in a linear fashion. The explanatory variables do not affect duration dependence, which is given by the parameter *p*, the explanatory variables affect the Weibull hazard multiplicatively (Kalbfleisch and Prentice, 2011). For more details on how the model is derived, see Greene (2012).

Survey data

A survey was administered during a series of workshops held across 10 locations spanning the state of Kansas from December 2013 to March 2014. Workshop locations were selected based on different weather, landscape and farm demographic characteristics. Prior to administering the survey, the instrument was field tested during two focus groups with farmers. The sample of farmers contacted for the survey was obtained from the Kansas Farm Management Association (KFMA). A total of 1,513 farmers were mailed letters to attend face-to-face workshops. Of the farmers contacted, 432 responded to the letter, and 250 were able to attend the workshops, yielding an adjusted response rate of 30% and an attendance rate of 17%. Workshop attendees were compensated for their time and travel expenses.

Participating farmers were asked to complete a survey with questions covering their farming history, farm operation, and conservation on their farm. The survey required respondents to provide information on the practices adopted and the date in which these practices were adopted. Farmers also provided information on the date in which they started operating any part of their farm. The average farm size (including CRP land) of the respondents was 2,508 acres with an average sales value of $400,000 to $599,999. The average farm size was larger than the average farm size reported in the 2012 Census of Agriculture as the study focuses on medium to large farms, excluding small hobby farmers, retired farmers, and very large operations which represented a significant share of the total farms in Kansas (Lambert et al., 2007; NASS-USDA, 2014).

Model estimation

This study examined the timing of adoption of continuous no-till, cover crops and VRA of inputs. For the purpose of this research, the conservation practices examined are defined as follows:

- Continuous no-till: Consists of planting crops directly into the crop residue without disturbing the soil with tillage, for all the crops in a rotation within a particular field.
- Cover crops: Planting a single or multiple cover crop species between regular cash crops to protect the soil and improve soil organic matter.
- VRA of inputs: This practice consists in using site-specific information for input application rates within a field. Methods used could be sensor-based and/or map-based.

These practices were selected because they are cropping practices commonly known and adopted at different degrees in the region of study. Given that farmers did not provide information regarding the date of adoption for some practices, the number of observations for each practice modeled varied. The start of the time period to adoption ($T = 0$) begun at different years for each farmer. The beginning of the duration for each farmer was estimated as either the year in which the farmer started operating the farm, or alternatively, the year at which the practice was commercially introduced if the farmer started operating the farm prior to the introduction of the practice (Alcon et al., 2011; Burton et al., 2003; D'Emden et al., 2006).

For no-till practices, the year used as the initial year of farmers' exposure to the practice was 1962. While no-till practices were used since the existence of ancient cultures (Triplett and Dick, 2008), its use in mechanized farms occurred in the last century. No-till experiments were conducted as early as 1951 in the U.S., however the practice was not adopted and field trials conducted until 1961 (Derpsch et al., 2010; Doraszelski, 2004). Successful introduction of no-till practices in mechanized farms was reported in 1962 (Derpsch, 2004). Specifically, the development of this practice in corn started in 1960 (Triplett and Dick, 2008). For VRA, 1993 was used as the date in which farmers had initial access to precision technologies. By 1993, the introduction of GPS made it possible for the development of crop monitoring and yield mapping (Taylor and Whelan, 2005), technologies that had been commercially available since the early 1990s (Daberkow and McBride, 2003). For cover crops, there was not an identifiable date when the practice was introduced since different types of cover crops have been used prior to the time spam of this research.

In some cases, conservation practices could have been adopted on a farm by previous operators. This represents a case of left truncation if information on the adopter and the path of adoption are unknown. In this study, observations with left truncation were omitted following Alcon et al. (2011). The exit or date of adoption was estimated as the year when adoption took place for adopters ($T = t$). For right censored observations, where adoption had not taken place by the date of the survey, the survey date was taken as the exit time (Kiefer, 1988). For censored observations, the process is still ongoing and adoption could take place sometime after t, but it is not observed. The parameters of the duration model are estimated using Maximum Likelihood estimation, and accounting for the censored nature of the data.

Explanatory variables used in the analysis

Multiple factors can affect farmers' adoption of agricultural technologies. These factors differ by the type of technology adopted and the region where adoption takes place. Some of the determinants of adoption for conservation practices identified in the literature are farm and farm management characteristics; biophysical factors or site-specific characteristics; economic factors; attitudinal factors; and market factors such as input and output prices (Knowler and Bradshaw, 2007). The factors evaluated in this study are: profitability factors, farmer demographics (age and education), farm and farm management characteristics (crop acreage, on-farm income, crop income, previous adoption of conservation practices on the farm), attitudinal factors (risk aversion, profit motivations, and if the farmer is an early adopter of technology), and site-specific characteristics (regional variables). Descriptive statistics of the data are reported in Table 1.

Profitability is a discrete variable that takes a value of 1 if the farmer indicated that they would adopt a conservation practice only if the practice increased profits, and zero otherwise. This variable was used to control for the profitability of the practice at the time of adoption. If farmers indicated that they would adopt these practices only if these resulted in higher profits, then it follows that they adopted the practice at a particular point in time when expected profits were higher with the practice than without it. Conversely, if farmers have yet to adopt these practices, then it indicates that they do not perceive these practices as being economically profitable (i.e. production, opportunity or transaction costs could be too high).

Age of the farm operator is expected to be negatively correlated with the speed of adoption. Older farmers have a shorter planning horizon and are thought to be more averse to change. While some studies have found that younger farmers are more likely to adopt conservation practices (Davey and Furtan, 2008; Hudson and Hite, 2003; Larson et al., 2008; Soule et al., 2000), other studies have found no statistical relationship (Abdulai and Huffman, 2005; Finger and El Benni, 2013). *College* is a discrete variable taking a value of 1 if the farmer has a college degree, and zero otherwise. Education was included to evaluate the effect of human capital in the timing of adoption. Farmers with a higher level of education are thought to have better access to information and to be able to make more efficient and informed decisions (Rahm and Huffman, 1984). The effect of education is expected to be larger for more complex technologies like cover crops and VRA application of inputs. Highly educated farmers have been found to be more likely to adopt various VRA technologies (Adrian et al., 2005; Larson et al., 2008; Robertson et al., 2012). In duration analysis applications, education has been found to speed the adoption of agricultural technologies (Alcon et al., 2011; Fuglie and Kascak, 2001; Murage et al., 2011).

Crop Acreage represent the number of acres dedicated to crop production and was included in the models to evaluate the effect of operation size. Given that some of these practices may require human/capital investment and may have transaction costs, farmers that operate at a larger scale may be able to distribute the costs of adoption among more acres or enterprises, reducing the unit cost due to economies of scale. Therefore, total acres is expected to be a positive factor in the timing of adoption. For practices where the required investment is larger (e.g. VRA of inputs), the presence of economies of scale could be more significant. Evidence in the literature suggests that VRA of inputs is more likely to be adopted on larger farms (Adrian et al., 2005; Daberkow and McBride, 2003; Hudson and Hite, 2003; Larson et al., 2008; Robertson et al., 2012).

Farm Income is the percentage of income derived from the farm operation and is used as a proxy for the time devoted to work on the farm. A higher percentage of on-farm income is expected to speed the adoption of conservation practices. The adoption of agricultural practices require time and investment in the development of new skills (Llewellyn, 2007), which could represent a constraint to adoption for farmers whose main activity is not farming. Another variable included in the analysis was *Crops*, the percentage of farm income from crop production. This variable is expected to have different effects on each practice. Farmers with more livestock are expected to be more likely to adopt cover crops because these can be used for a dual purpose, such as feeding livestock. On the other hand, farmers whose income primarily comes from livestock and who allow their livestock to graze crop residues may be less likely to adopt conservation tillage (Vitale et al., 2011).

Previous adoption of conservation practices on the farm at the time of adoption was also included to examine that effect of complementarity or substitionability of conservation practices. A dummy variable was included to indicate if the farmer was using continuous no-till (*CNT*), conservation crop rotations (*CCRot*), cover crops (*CCrop*), or VRA of inputs (*VRA*) prior to adopting the practice being examined. Adopting different conservation practices on the farm could also indicate an attitude towards conservation and it is expected to speed the timing of adoption. However, a study by Bergtold and Molnar (2010) did not find evidence that the adoption of one practice influenced the adoption of other practices.

Risk Aversion is a discrete variable indicating if the farmer is risk averse. Risk affects the adoption of agricultural technologies in different ways and has been found to reduce the adoption of agricultural technologies (Ghadim et al., 2005; Marra et al., 2003). Risk affects farmers' willingness to try new practices and the process of knowledge accumulation (Greiner et al., 2009). Risk averse farmers are thought to adopt practices more slowly than risk-neutral or risk-loving farmers to avoid the cost of uncertainty and the cost of learning a new technology (Sassenrath et al., 2008). For example, Krause and Black (1995) suggested that risk averse farmers adopt conservation tillage slower because of the learning costs. In the case of no-till, at initial stages of the diffusion of the technology, studies found the practice to be riskier, and risk aversion was found to be negatively associated with adoption (Bultena and Hoiberg, 1983). However, as no-till technologies improved and improved herbicides were introduced, the risk associated with the practice decreased (Bosch and Pease, 2000). Generally, farmers with higher risk tolerance adopt practices more rapidly than risk averse farmers (Chatterjee and Eliashberg, 1990).

Stewardship is an attitudinal factor indicating that environmental stewardship is more important than farm profit to the farm operator. This variable is expected to speed the adoption of the conservation practices. Farmers with conservation motivations were found to be more likely to adopt best management practices in previous empirical studies (Greiner et al., 2009). *Innovator* is a discrete variable indicating if the farmer is an early adopter of technologies. Innovators are expected to adopt more rapidly. However, as discussed by Pannell et al. (2011), innovators are not always the first to adopt conservation practices. In some cases, they may become later adopters if the practice is not attractive or suitable to their production system.

Regional indicators, *Western* and *Central*, were included to account for differences in the adoption across regions. The eastern region was used as the baseline. Due to heterogeneity in land quality and weather, weed pressure and other factors that are not accounted for in the set of explanatory variables, it is important to capture the effect of geographical differences affecting the adoption of agricultural technologies (Green et al., 1996).

Given the way the variables enter the model and method of data collection, it is implicitly assumed that the explanatory variables do not vary over time, which can be a strong assumption for many covariates. Education may not change significantly over time as it is likely that the level of education attained at the time farmers started operating their farm stayed the same. While attitudinal factors and risk aversion may be affected by knowledge and experience, they could also be related to farmers' personality and it could be argued that, in general, they are relatively constant over time. However, farm size may have been affected by the adoption of the practices and other exogenous factors, and may not be constant.

Results and Discussions

Kaplain Meier survival estimates for the three practices are illustrated in Figure 1. The survival function represents the likelihood that a farmer continues farming without adopting the conservation practice. It can be noted that the survival curve for the three practices decreases over time, indicating that the likelihood that a farmer would adopt any of these practices increases over time. The three survival estimates decrease over time, indicating positive duration dependence. That is, the likelihood of adoption increases with the number of years of farming or the number of years the practice has been available (Greene, 2012). It can be noted that the adoption of these practices is more rapid during the first years of farming (or introduction of the practice) and later years are characterized by a slower pace of adoption. It can also be noted from the graphs that the adoption of VRA has been slow. Under some conditions, farmers may have an incentive to delay adoption until a technology is improved or more information becomes available (Chatterjee and Eliashberg, 1990). Since the survival function for the exponential distribution is constant, and first increasing and then decreasing for the lognormal and logistic distributions, the Weibull distribution, characterized for being monotonically increasing (or decreasing), was a good fit for the data in this study (Greene, 2012). The Weibull distribution is appropriate as the probability of adoption is not expected to be constant over time, but to gradually increase.

The results of the models estimated are reported in Table 2. The parameter *p*, is greater than one for all the conservation practices, indicating positive duration dependence. That is, the likelihood that a farmer would adopt any of these practices increases with the number of years of farming, or the number of years exposed to the practice. Over time, the cost of technologies tends to decrease (Jaffe et al., 2002). In addition, over time, farmers acquire more farming experience and accumulate knowledge and capital. These factors may increase the likelihood that a farmer adopts a conservation practice. Given that the adoption of conservation practices by farmers creates an important source of information to assist with the diffusion of the technology, the longer a farmer operates a farm, the more they are in contact with an increasing number of adopters, potentially reducing their uncertainty about the benefits and costs of using a particular practice. There are other external factors that overtime ease the adoption of some practices. For example, the development and improvement of technologies and equipment that facilitate the implementation of a practice. In the case of no-till, it has been suggested that the introduction of herbicides made it possible to speed adoption rates (Doraszelski, 2004).

The parameter estimates for each model are reported in accelerated failure-time metric and represent the effect of an explanatory variable on the conditional probability of adoption at time period *t*. While the magnitude of the coefficients cannot be readily interpreted, the sign of the parameters can be interpreted as speeding or slowing adoption. A negative coefficient indicates that the effect of a particular variable is to accelerate adoption. On the other hand, a positive coefficient would indicate a factor that would delay adoption. A highly significant factor in the adoption of all conservation practice models was a farmer’s age. Younger farmers were found to adopt the three practices faster than older farmers. A potential implication of this result is that, as farmers start operating their farms at a younger age, efforts should be directed towards encouraging those farmers to adopt environmentally sound conservation practices, because as they grow older, they are less likely to adopt.

Farmers who adopt practices only when there is a corresponding increase in profit were found to lag behind those farmers for whom profitability of the practice is not the main driver for adoption. This result was found statistically significant for both continuous no-till and cover crops. This result may indicate that some farmers do not always perceive these practices as being profitable. In addition, farmers for whom profit maximization was more important than stewardship were found to adopt VRA of inputs at a higher speed. This result could indicate that adoption of VRA of input is driven by profit motives and not environmental motives.

A surprising result was that farmers who adopted VRA of inputs adopted continuous no-till and cover crops at a slower pace than farmers who had not adopted this practice. Similarly, the adoption of cover crops was found to slow the adoption of VRA of inputs. It has been previously suggested that while farmers may consider the adoption of various conservation practices, when it comes time to adopt additional practices, the higher cost of conservation intensification may make farmers less likely to adopt more practices (Ma et al., 2012). In addition, Cattaneo (2003) found that conservation contracts with a larger bundle of conservation practices in the EQIP program were more likely to be withdrawn. It is possible that farmers see some of these practices as substitutes. They may obtain some benefits from a particular practice, and as a result, the likelihood of adopting an additional practice that provides the same or similar benefits may decrease.

Risk aversion was found to delay the adoption of cover crops and VRA of inputs. It has been previously suggested that risk averse farmers may find it optimal to delay adoption to avoid the cost of learning. Risk aversion was not found to significantly affect the speed of adoption of continuous no-till. As expected, farmers who considered themselves innovators were found to adopt the three conservation practices at a faster rate than their counterparts.

The speed of adoption of cover crops and VRA of inputs in the western region of Kansas was found to be slower than in the eastern part of the state. Differences in the time of adoption across regions could indicate differences in climatic and soil conditions, as well as the profitability of the practices. In cases such as with the adoption of VRA of inputs, this could be related to the availability of custom options for precision services. A slower rate in the adoption of cover crops in the western region of Kansas could be the result of dryer weather. During the workshops, some farmers expressed concern about the use of water by cover crops and the availability of water for subsequent cash crops.

The speed at which conservation practices are adopted are subject to various factors as the results of this study suggest. While some factors cannot be controlled, information and knowledge generation are important sources of change. For farmers who are not innovators, knowledge acquisition is an important step and precedes their decision to adopt (Jabbar et al., 2003). It has been suggested that the slow rate of adoption for some practices could be related to slow rates of information acquisition (Fischer et al., 1996). Hence, extension plays an important role, not only in the levels of adoption, but also in the time of adoption. For practices with a potential to provide large environmental benefits to society, a critical role for extension services then may be to help accelerate the rate of adoption of these practices (Marsh et al., 2000). In addition, since farmers may delay the adoption of conservation practices until they find it optimal, an important element to conservation efforts could be helping farmers to adapt practices to the conditions of their farming operation. Education efforts could focus on providing farmers with tools to successfully adapt conservation practices in a way that the perceived risks can be mitigated and synergies in the cropping system can be explored.

Conclusions

This study examined the factors affecting the timing of adoption of continuous no-till, cover crops, and variable rate application of (VRA) of inputs for Kansas farmers using a duration analysis to account for the dynamics of adoption and changing factors that affect farmer's likelihood of adoption. Some of the factors examined are profitability factors, farmers' demographics, farm and farm management characteristics, attitudinal factors, and geography.

Findings in this study suggest that the adoption of certain practices delay the adoption of other conservation practices. For example, the adoption of conservation crop rotation and VRA of inputs were found to delay the adoption of continuous no-till, and the adoption of cover crops delayed the adoption of VRA of inputs. In addition, the findings in this study suggest that risk aversion is not a significant factor delaying the speed of adoption of continuous no-till. However, risk aversion was found to delay the adoption of cover crops and VRA of inputs. In addition, the results in this study suggest that farmers who considered themselves innovators adopt the three conservation practices at a faster rate than their counterparts. Given that profitability factors and risk aversion seem to be important factors delaying the adoption of cover crops and VRA of inputs, information about the benefits obtained by these practices and how they may mitigate soil degradation and/or may increase profits may be an important message to deliver by extension educators.

Limitations and future research

Given the cross section nature of the data used in this study, the timing of adoption was modeled under the assumption that some of at factors measured at the time of the survey were the same at the time of adoption, which can be a strong assumption for some of the factors evaluated. For example, the size of the operation may have significantly changed since the date farmers started operating their farms to the date they adopted the conservation practice and finally to the date the survey data was collected. A natural extension to this study is to include time-varying covariates to evaluate how changing factors affect the point in time at which farmers decide to adopt new conservation practices. Obtaining such data, however, can be difficult if the researcher does not have access to historical data at the farm level. If the data is collected from farmers it can be unreliable if based on recall (Burton et al., 2003).

References

Abdulai, Awudu and Wallace E. Huffman. 2005. "The Diffusion of New Agricultural Technologies: The Case of Crossbred-Cow Technology in Tanzania." *American Journal of Agricultural Economics* 87 (3): 645-659.

Adrian, Anne Mims, Shannon H. Norwood, and Paul L. Mask. 2005. "Producers’ Perceptions and Attitudes Toward Precision Agriculture Technologies." *Computers and Electronics in Agriculture* 48 (3): 256-271.

Alcon, Francisco, María Dolores de Miguel, and Michael Burton. 2011. "Duration Analysis of Adoption of Drip Irrigation Technology in Southeastern Spain." *Technological Forecasting and Social Change* 78 (6): 991-1001.

Au, Yoris A. and Robert J. Kauffman. 2003. "What do You Know? Rational Expectations in Information Technology Adoption and Investment." *Journal of Management Information Systems* 20 (2): 49-76.

Bergtold, Jason S. and Joseph J. Molnar. 2010. "Limited Access to Conservation: Limited-Resource Farmer Participation in the Conservation Security Program in the Southeast." *Journal of Agricultural & Applied Economics* 42 (2): 211.

Bosch, Darrell J. and James W. Pease. 2000. "Economic Risk and Water Quality Protection in Agriculture." *Review of Agricultural Economics* 22 (2): 438-463.

Bultena, Gordon L. and Eric O. Hoiberg. 1983. "Factors Affecting Farmers' Adoption of Conservation Tillage." *Journal of Soil and Water Conservation* 38 (3): 281-284.

Burton, Michael, Dan Rigby, and Trevor Young. 2003. "Modelling the Adoption of Organic Horticultural Technology in the UK using Duration Analysis." *Australian Journal of Agricultural and Resource Economics* 47 (1): 29-54.

Cattaneo, Andrea. 2003. "The Pursuit of Efficiency and its Unintended Consequences: Contract Withdrawals in the Environmental Quality Incentives Program." *Review of Agricultural Economics* 25 (2): 449-469.

Chatterjee, Rabik Ar and Jehoshua Eliashberg. 1990. "The Innovation Diffusion Process in a Heterogeneous Population: A Micromodeling Approach." *Management Science* 36 (9): 1057-1079.

Daberkow, Stan G. and William D. McBride. 2003. "Farm and Operator Characteristics Affecting the Awareness and Adoption of Precision Agriculture Technologies in the US." *Precision Agriculture* 4 (2): 163-177.

Dadi, Leggesse, Michael Burton, and Adam Ozanne. 2004. "Duration Analysis of Technological Adoption in Ethiopian Agriculture." *Journal of Agricultural Economics* 55 (3): 613-631.

Davey, Kelly A. and W. Hartley Furtan. 2008. "Factors that Affect the Adoption Decision of Conservation Tillage in the Prairie Region of Canada." *Canadian Journal of Agricultural Economics/Revue Canadienne D'Agroeconomie* 56 (3): 257-275.

D'Emden, Francis H., Rick S. Llewellyn, and Michael P. Burton. 2006. "Adoption of Conservation Tillage in Australian Cropping Regions: An Application of Duration Analysis." *Technological Forecasting and Social Change* 73 (6): 630-647.

Derpsch, Rolf. 2004. "History of Crop Production, with and without Tillage." *Leading Edge* 3 (1): 150-154.

Derpsch, Rolf, Theodor Friedrich, Amir Kassam, and Hongwen Li. 2010. "Current Status of Adoption of no-Till Farming in the World and some of its Main Benefits." *International Journal of Agricultural and Biological Engineering* 3 (1): 1-25.

Doraszelski, Ulrich. 2004. "Innovations, Improvements, and the Optimal Adoption of New Technologies." *Journal of Economic Dynamics and Control* 28 (7): 1461-1480.

Feder, Gershon and Dina L. Umali. 1993. "The Adoption of Agricultural Innovations: A Review." *Technological Forecasting and Social Change* 43 (3): 215-239.

Finger, Robert and Nadja El Benni. 2013. "Farmers’ Adoption of Extensive Wheat production–Determinants and Implications." *Land use Policy* 30 (1): 206-213.

Fischer, AJ, AJ Arnold, and M. Gibbs. 1996. "Information and the Speed of Innovation Adoption." *American Journal of Agricultural Economics* 78 (4): 1073-1081.

Fuglie, Keith O. and Catherine A. Kascak. 2001. "Adoption and Diffusion of Natural-Resource-Conserving Agricultural Technology." *Review of Agricultural Economics* 23 (2): 386-403.

Ghadim, Amir K. Abadi and David J. Pannell. 1999. "A Conceptual Framework of Adoption of an Agricultural Innovation." *Agricultural Economics* 21 (2): 145-154.

Ghadim, Amir K. Abadi, David J. Pannell, and Michael P. Burton. 2005. "Risk, Uncertainty, and Learning in Adoption of a Crop Innovation." *Agricultural Economics* 33 (1): 1-9.

Green, Gareth, David Sunding, David Zilberman, and Doug Parker. 1996. "Explaining Irrigation Technology Choices: A Microparameter Approach." *American Journal of Agricultural Economics* 78 (4): 1064-1072.

Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Greiner, Romy, Louisa Patterson, and Owen Miller. 2009. "Motivations, Risk Perceptions and Adoption of Conservation Practices by Farmers." *Agricultural Systems* 99 (2): 86-104.

Hoppe, Heidrun C. 2002. "The Timing of New Technology Adoption: Theoretical Models and Empirical Evidence." *The Manchester School* 70 (1): 56-76.

Hudson, Darren and Diane Hite. 2003. "Producer Willingness to Pay for Precision Application Technology: Implications for Government and the Technology Industry." *Canadian Journal of Agricultural Economics/Revue Canadienne D'Agroeconomie* 51 (1): 39-53.

Jabbar, Mohammad A., MA Mohamed Saleem, Solomon Gebreselassie, and Hailu Beyene. 2003. "Role of Knowledge in the Adoption of New Agricultural Technologies: An Approach and an Application." *International Journal of Agricultural Resources, Governance and Ecology* 2 (3-4): 312-327.

Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins. 2002. "Environmental Policy and Technological Change." *Environmental and Resource Economics* 22 (1-2): 41-70.

Kalbfleisch, John D. and Ross L. Prentice. 2011. *The Statistical Analysis of Failure Time Data*. Vol. 360 John Wiley & Sons.

Kiefer, Nicholas M. 1988. "Economic Duration Data and Hazard Functions." *Journal of Economic Literature* 26 (2): 646-679.

Knowler, Duncan and Ben Bradshaw. 2007. "Farmers' Adoption of Conservation Agriculture: A Review and Synthesis of Recent Research." *Food Policy* 32 (1): 25-48.

Krause, M.A., and J.R. Black "Optimal adoption strategies for no-till technology in Michigan." *Review of Agricultural Economics* 17 (1995):299-310.

Lambert, Dayton M., Patrick Sullivan, Roger Claassen, and Linda Foreman. 2007. "Profiles of US Farm Households Adopting Conservation-Compatible Practices." *Land use Policy* 24 (1): 72-88.

Lancaster, Tony. 1992. *The Econometric Analysis of Transition Data* Cambridge university press.

Larson, James A., Roland K. Roberts, Burton C. English, Sherry L. Larkin, Michele C. Marra, Steven W. Martin, Kenneth W. Paxton, and Jeanne M. Reeves. 2008. "Factors Affecting Farmer Adoption of Remotely Sensed Imagery for Precision Management in Cotton Production." *Precision Agriculture* 9 (4): 195-208.

Llewellyn, Rick S. 2007. "Information Quality and Effectiveness for More Rapid Adoption Decisions by Farmers." *Field Crops Research* 104 (1): 148-156.

Ma, Shan, Scott M. Swinton, Frank Lupi, and Christina Jolejole-Foreman. 2012. "Farmers' Willingness to Participate in Payment-for-Environmental-Services Programmes." *Journal of Agricultural Economics* 63 (3): 604-626.

Marra, Michele, David J. Pannell, and Amir Abadi Ghadim. 2003. "The Economics of Risk, Uncertainty and Learning in the Adoption of New Agricultural Technologies: Where are we on the Learning Curve?" *Agricultural Systems* 75 (2): 215-234.

Marsh, SP, DJ Pannell, and RK Lindner. 2000. "The Impact of Agricultural Extension on Adoption and Diffusion of Lupins as a New Crop in Western Australia." *Animal Production Science* 40 (4): 571-583.

Murage, AW, G. Obare, J. Chianu, DM Amudavi, J. Pickett, and ZR Khan. 2011. "Duration Analysis of Technology Adoption Effects of Dissemination Pathways: A Case of 'push–pull'technology for Control of Striga Weeds and Stemborers in Western Kenya." *Crop Protection* 30 (5): 531-538.

Oostendorp, R.H., and F. Zaal "Land acquisition and the adoption of soil and water conservation techniques: a duration analysis for Kenya and the Philippines." *World Development* 40 (2012):1240-54.

Pannell, David J., Graham R. Marshall, Neil Barr, Allan Curtis, Frank Vanclay, and Roger Wilkinson. 2011. "Understanding and Promoting Adoption of Conservation Practices by Rural Landholders." *Changing Land Management: Adoption of New Practices by Rural Landholders*: 11.

———. 2006. "Understanding and Promoting Adoption of Conservation Practices by Rural Landholders." *Animal Production Science* 46 (11): 1407-1424.

Prokopy, LS, K. Floress, D. Klotthor-Weinkauf, and A. Baumgart-Getz. 2008. "Determinants of Agricultural Best Management Practice Adoption: Evidence from the Literature." *Journal of Soil and Water Conservation* 63 (5): 300-311.

Rahm, Michael R. and Wallace E. Huffman. 1984. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *American Journal of Agricultural Economics* 66 (4): 405-413.

Robertson, MJ, RS Llewellyn, Roger Mandel, Roger Lawes, RGV Bramley, Lara Swift, Nigel Metz, and C. O'Callaghan. 2012. "Adoption of Variable Rate Fertiliser Application in the Australian Grains Industry: Status, Issues and Prospects." *Precision Agriculture* 13 (2): 181-199.

Robison, Lindon J., Peter J. Barry, James B. Kliebenstein, and George F. Patrick. 1984. "Risk Attitudes: Concepts and Measurement Approaches." In *Risk Management in Agriculture*, edited by PJ Barry, 3-30. Ames IA: Iowa State University Press.

Sassenrath, GF, P. Heilman, E. Luschei, GL Bennett, G. Fitzgerald, P. Klesius, W. Tracy, JR Williford, and PV Zimba. 2008. "Technology, Complexity and Change in Agricultural Production Systems." *Renewable Agriculture and Food Systems* 23 (04): 285-295.

Skaggs, Rhonda K., RE Kirksey, and Wilmer M. Harper. 1994. "Determinants and Implications of Post-CRP Land use Decisions." *Journal of Agricultural and Resource Economics*: 299-312.

Soule, Meredith J., Abebayehu Tegene, and Keith D. Wiebe. 2000. "Land Tenure and the Adoption of Conservation Practices." *American Journal of Agricultural Economics* 82 (4): 993-1005.

Taylor, James and Brett Whelan. 2005. "A General Introduction to Precision Agriculture." *Australian Center for Precision Agriculture*.

Triplett, GB and Warren A. Dick. 2008. "No-Tillage Crop Production: A Revolution in Agriculture!" *Agronomy Journal* 100 (Supplement_3): S-153-S-165.

Vitale, JD, C. Godsey, J. Edwards, and R. Taylor. 2011. "The Adoption of Conservation Tillage Practices in Oklahoma: Findings from a Producer Survey." *Journal of Soil and Water Conservation* 66 (4): 250-264.

Table 1. Descriptive statistics of Dependent and Explanatory Variables

	Continuous no-till	Cover Crops	VRA of inputs	Definition
Adoption time	24.172 (14.687)	30.908 (14.676)	17.556 (5.942)	Dependent variable. Time measured in years that it took for farmers to adopt.
Profitability	0.616 (0.488)	0.618 (0.487)	0.620 (0.487)	The farmer would adopt the practice only if it increases net returns $(1 = yes, 0 = no)$.
Age	47.355 (14.469)	53.787 (13.726)	54.185 (13.826)	Farmer's age in years.
College	0.517 (0.501)	0.517 (0.501)	0.517 (0.501)	Farm operator has a college degree (1=*yes*, 0=*no*).
Crop Acreage	2,538 (2,044)	2,565 (2,046)	2,576 (2,047)	Total crops acres (including crops, grazing).
Farm Income	74.260 (29.706)	73.753 (30.096)	74.106 (29.924)	Percentage of household income derived from the farming operation.
Crops	73.463 (26.981)	73.362 (26.851)	74.595 (26.411)	Percentage of farm income from crop production.
CNT	---	0.551 (0.499)	0.576 (0.495)	Farmers was using continuous no-till before adopting this practice (1=*yes*, 0=*no*).
CCRot	0.438 (0.497)	0.556 (0.498)	0.585 (0.494)	Farmers was using crop rotation before adopting this practice (1=*yes*, 0=*no*).
Ccrops	0.079 (0.270)	---	0.254 (0.436)	Farmers was using cover crops before adopting this practice (1=*yes*, 0=*no*).
VRA	0.084 (0.278)	0.198 (0.400)	---	Farmers was using VRA of inputs before adopting this practice (1=*yes*, 0=*no*).
Risk Aversion	0.734 (0.443)	0.734 (0.443)	0.727 (0.447)	Risk taking behavior in farm management decisions (1=*risk averse*, 0=*otherwise*).
Stewardship	0.478 (0.501)	0.483 (0.501)	0.488 (0.501)	Maximizing farm profit is more important than environmental stewardship to the farm's operator (1=*yes*, 0=*no*).
Innovator	0.532 (0.500)	0.517 (0.501)	0.522 (0.501)	Farm operator usually adopts new technology before neighbors (1=*yes*, 0=*no*)
Western	0.192 (0.395)	0.208 (0.407)	0.210 (0.408)	If the farm is located in Western Kansas (1=*yes*, 0=*no*)
Central	0.404 (0.492)	0.411 (0.493)	0.405 (0.492)	If the farm is located in Central Kansas (1=*yes*, 0=*no*)
No. Obs.	203	207	205	

Standard deviation in parenthesis.

Table 2. Model estimates for the timing of adoption of continuous no-till, cover crops and VRA of inputs

	Continuous no-till		Cover Crops		VRA of inputs	
	Coefficient	Std. Dev.	Coefficient	Std. Dev.	Coefficient	Std. Dev.
Intercept	0.233	(0.263)	1.016***	(0.312)	2.189***	(0.468)
Profitability	0.133*	(0.080)	0.27***	(0.098)	0.02	(0.146)
Age	0.064***	(0.004)	0.053***	(0.004)	0.042***	(0.006)
College	-0.155**	(0.079)	-0.101	(0.097)	0.023	(0.155)
Crop Acreage	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)
Farm Income	0.001	(0.001)	-0.004**	(0.002)	-0.002	(0.002)
Crops	-0.001	(0.001)	0.001	(0.002)	-0.009**	(0.004)
CNT	---	---	-0.142	(0.105)	-0.111	(0.147)
CCRot	0.135	(0.085)	-0.109	(0.097)	0.076	(0.147)
Ccrops	-0.235	(0.183)	---	---	0.418**	(0.186)
VRA	0.633***	(0.231)	0.3***	(0.110)	---	---
Risk Aversion	0.066	(0.084)	0.215**	(0.089)	0.416***	(0.143)
Stewardship	0.009	(0.082)	-0.036	(0.089)	-0.297**	(0.148)
Innovator	-0.207**	(0.081)	-0.313***	(0.100)	-0.441***	(0.163)
Western	0.099	(0.112)	0.601***	(0.187)	1.005***	(0.371)
Central	0.083	(0.089)	0.126	(0.100)	0.071	(0.142)
p	2.206***	(0.254)	2.925***	(0.299)	2.453***	(0.191)
	---------------------------------- Fit Statistics ----------------------------------					
No. observations		203		207		205
Log likelihood		-134.49		-92.57		-91.92
AIC		300.983		217.141		215.834

*,**,*** statistically significant at the 1%, 5% and 10% level.

Figure 1. Kaplan Meier survival estimates