# Factors that affect the adoption decision of conservation tillage in the Prairie Region of Canada

**K.A. Davey[1] and W.H. Furtan[2]**

[1]Canadian Wheat Board
[2]University of Saskatchewan

The authors thank SSHRC, Biocap, the AAFC Innovation Network, and Statistics Canada for financial support. K Davey is the corresponding author at Kelly_Davey@cwb.ca, H. Furtan can be reached at Hartley.Furtan@usask.ca.

# Abstract

The adoption of conservation tillage technology since the 1970s has been one of the most remarkable changes in the production of crops on the Canadian Prairies. The decision whether to adopt conservation tillage technology or not requires the producer to go through a thorough decision making process. In Canada there has been little economic research on the question of what farm, regional, and environmental characteristics affect the adoption decision. Using 1991, 1996, and 2001 Census of Agriculture data together with other data sources we estimate a probit model explaining the adoption decision. We find that important variables include, farm size, proximity to a research station, type of soil, and weather conditions.

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## Introduction

One of the most remarkable changes in the production of crops on the Canadian Prairies since the 1970s has been the adoption of conservation tillage technology. In this paper conservation tillage is defined as tillage that retains most of the previous crop residue on the soil surface; this includes zero tillage. Conservation tillage is also referred to as minimum tillage. Conventional tillage is defined as tillage that incorporates most of the previous crop's residue into the soil (Agricultural Census Questionnaire, 2001). Conservation tillage has not been adopted by all Prairie producers even though its conservation benefits are thought to be economically important and universal. Depending upon the type of soil and rainfall one would expect that benefits differ substantially between producers. This motivates the question addressed in this paper: why have some producers adopted the technology and others not.[1]

Conservation tillage systems provide a number of benefits to the quality of the soil, including increased soil organic matter and an increase in favorable types of microbial activity. Soils that are under conservation tillage management are less compact than those under conventional tillage practices, which helps the soil to maintain moisture for a longer period of time when there is a shortage of precipitation. An additional feature of conservation tillage is that it allows for continuous cropping in some of the drier regions of the Prairies because the crop stubble traps snow, which improves spring soil moisture conditions. Conservation tillage requires a minimum level of moisture before the continuous cropping benefits can be realized e.g. in terms of nitrogen response.

This is part of the explanation as to why summerfallow is still a common practice in the driest part of the prairies.

Land degradation from soil erosion and the depletion of soil organic matter is a concern to many Prairie producers. The continuous cultivation of the land disturbs the soil, leaving it open and susceptible to wind and water erosion, whereas conservation tillage maintains the soil so that it is more capable of water retention and has a higher level of organic matter (Zentner et al, 2002). Some of the early economic analyses indicated that conservation tillage was not economically competitive with conventional tillage, at least in the short run (Smith et al, 1996). However, a more comprehensive review of the literature by Mooney and Williams (2007) shows that under some circumstances conservation tillage is indeed profitable.

To date there have been no studies that use a technology adoption model to explain the adoption of conservation tillage by farmers in Canada. This is in itself a surprising result given the importance and prevalence of the technology on the Canadian Prairies. In addition, Canadian policymakers are concerned with the process of innovation and are encouraging the agriculture industry to adopt new technologies that improve farm profitability and protect the environment. Because of the policy interest it is important to know which economic, physical, and technological factors affect the adoption decision.

To start to understand the producer adoption decision regarding conservation tillage we address two issues in this paper. First, why did farmers adopt the tillage technology when many of the economic studies indicated that it may not be profitable for them to do so (see Fox et al., 1991, Smith et al., 1996, Jaffe et al., 2002, and Kurkalova et al., 2006). We suggest that by incorporating environmental stress into a lexicographical utility function it is possible to explain the adoption decision given the potential short term non-profitability of the technology. Second, we want to determine the farm, regional, and industry characteristics that explain the adoption of conservation tillage on Prairie farms. We use a large pooled data set with over 43,000 observations from three census periods to determine which characteristics affect this decision. We found that important characteristics include farm size, soil type, proximity to research farms, and short term weather patterns. Our model was able to correctly predict the adoption decision for over 80% of the farmers in the sample.

## Literature Review

The decision as to whether to adopt conservation tillage technology requires the producer to go through a thorough decision making process.[2] The first factor that a farmer will consider is the impact the new technology has on both the short-term and the long-term profitability of the farm enterprise (Åstebro, 2004). A second consideration is the impact the new technology has on the variability of profit. As many farmers are risk averse any new technology that increases the variance of profit, *ceteris paribus* is unlikely to be adopted.

There are some useful stylized facts about firms that aid our understanding of how they make the decision to adopt new technologies (Åstebro, 2004). The most common of these is that large firms are more likely to adopt new technology as compared with small firms.  Large firms have a greater output over which to spread the cost of the new technology; therefore it is economically more viable for them to adopt earlier as compared with a small firm, *ceteris paribus*.  The adoption decision will differ among producers because of the heterogeneity of the farming population. The characteristics of the adoption decision may be the same, but the magnitudes of these characteristics differ across producers, implying a different adoption decision.

The adoption of a new technology takes place over a period of time because both the developers and the users of the technology learn about the short comings in the design and then modify the product (Jaffe et al., 2002). This process occurs in many industries and can take a number of years to complete. The evolution of conservation tillage technology is a good illustration of this process. The early conservation tillage seeders were often a converted cultivator. They had small seed storage capacity and little or no fertilizer application ability. Over time the conservation seeders have been designed to both plant and fertilize large acres without the need to refill the machine. All of these changes illustrate how the manufacturers made the machines more useable by improving the machine design. As a result more farmers have adopted the technology.

The economic characteristics of the new technology will have an influence on whether the technology will be adopted, as well as the rate and speed of adoption (Batz et al, 1999). In particular, technologies which reduce the perceived risk level compared to traditional technologies (i.e. the financial and yield risk which the farmer expects to occur as a result of adopting the new technology) tend to be adopted. In line with this and likely applicable to farmers, Batz et al (1999) assumes that technology adoption decisions are based on the following four technology characteristics: relative profitability, relative risk, initial costs, and relative complexity.

The more competitive an industry is, the more likely the firms in that industry are to adopt innovative technology (Goel and Rich, 1997). In order to succeed in a competitive industry a firm must quickly adopt and capture any competitive advantage that is created by the new technology. There may be first-mover advantages associated with the adoption. This is particularly important to farmers who must bid for cropland over which to spread the cost of the new technology. Thus we expect some farmers to adopt the technology as soon as it is available.[3]

Finally, the decision to adopt conservation tillage has been examined from the point of view of a market failure. If conservation of the soil resource has public good attributes and farmers do not adopt conservation tillage because of economic or informational constraints then it may be optimal to subsidize the adoption costs (Kurkalova et al, 2006). The approach taken by Kurkalova (2006) is to calculate the level or amount of subsidy that is required to reach the socially optimal level of conservation tillage.

**The Utility Function for Conservation Tillage Adopters**

Utility functions can be expressed as a lexicographic ordering of elements that provide the decision maker with utility (DeJanvry, 1973). The individual ranks the elements in the utility function by order of importance and then chooses a particular action depending upon a satisfying criterion. Each element of the utility function must be satisfied in order of rank so that highest level of utility is achieved when the greatest number of elements has been satisfied.

Little is known about the structure of a farmer's lexicographic utility function when they are considering the decision to adopt a new technology. We hypothesize that when faced with the decision to adopt conservation tillage technology there are at least three elements in an agricultural producer's utility function. The elements are expected profits, risk aversion and a third element environmental stress. Environmental stress occurs because of the decline in soil productivity arising from the continued use of conventional tillage technologies. One of the puzzles of conservation tillage adoption is that farmers adopt the technology even though it does not appear to have a higher expected income or lower risk (variance) at least in the short run. For example, the von Neumann–Morgenstern (1944) expected utility hypothesis calculates the mean-variance tradeoff of income from a particular action. [4] Producers view a decline in soil quality as a precursor to lower farm productivity and thus falling profitability.

The notion that a producer may react to stress when making the decision to adopt a new technology was well summarized by Rosenberg (1969, p.23)…

> … It is possible, furthermore, that threats of deterioration or actual deterioration from some previous state are more powerful attention-focusing devices than are vague possibilities for improvement. There may be psychological reasons why a worsening state of affairs, or its prospect, galvanizes those affected into a more positive and decisive response than do potential movements to improved states…

Environmental stress leads to a decline in profitability due to the loss of soil quality. In this paper we associate environmental stress with the potential loss in soil quality due to adverse weather conditions in some previous time period. Farmers can reduce environmental stress by adopting conservation tillage, and thus stress reduction becomes a motivator in whether or not to adopt the new technology.

The lexicographic utility function is written as:

$$LU\left[\Pr(\pi \geq 0) = \alpha, E(\pi) \geq 0, \max E(\pi)\right] \qquad 1.0$$

where $\Pr(\pi \geq 0) = \alpha$ is the probability of profits being positive and equal to alpha (a risk parameter), $E(\pi) \geq 0$ is the need to reduce environmental stress, and $\max E(\pi)$ the maximization of profits. One aspect of the decision to adopt a new technology that the producer must consider is the future stream of benefits and costs associated with the decision. The profit element includes the discounted stream of net benefits over the life of the new technology. [5]

## Modeling the Adoption Decision

When producers are faced with the decision as whether to adopt a new technology, in this case conservation tillage technology, they have less than full information about the future, i.e. they face uncertainty. In such a case producers are assumed to make the adoption decision by choosing the technology that maximizes their individual utility. In our model we assume that a discrete variable *T* is used to denote if the producer adopts the new technology, such that *T*=1 if the producer adopts, and *T*=0 if the producer does not adopt.

Suppose we have a utility function $U(P_{Ti}, C_{Ti})$, which is strictly increasing and quasi concave that ranks the $i^{th}$ firm's preference for the technology, where $P_T$ represents the distribution of discounted profit margins from adoption of the new technology, and $C_T$ are other characteristics of the new technology such as the soil quality benefits of using conservation tillage. In the data the values of $P_{Ti}$ and $C_{Ti}$ when T=0 are not observable because the technology has not yet been adopted by the producer.

In the case where some producers have adopted the technology, and others not, it is possible to select a set of variables that are observable for all producers. We can then utilize the information in these variables to calculate a probability that producers with certain characteristics will adopt the new technology. Furthermore if we can identify such variables, they can be used to predict which producers will adopt the new technology and which will not adopt. Following the literature (Rahm and Huffman, 1984) we specify a function:

$$U_{Ti} = X_i\alpha_T + e_{Ti} \qquad 2.0$$

where $X_i$ is a vector of pre-selected observable farm characteristics such as, farm size, education and age for both adopters $T=1$ and non-adopters $T=0$, $i = 1, 2, \ldots, n$ (farms), $\alpha_T$ is a vector of parameters, and $e_{Ti}$ a vector of error terms. [6]

It is assumed that producers will adopt and use the technology which allows them to achieve the highest level of utility. Thus the $i^{th}$ firm will choose to adopt conservation tillage if $U_{1i}$ is greater than $U_{0i}$ (calculated from equation 2). Using our knowledge as to what affects the probability of firm *i* adopting the new technology we find a vector of regressors $X_i$, which is specific to each producer (i) that can be used to predict the adoption choice. We specify a probit function using the above regressors to explain the adoption decision. The accuracy of the probit model is determined by the degree to which the pre-selected variables capture the essence of the adoption decision.

In order to calculate the impact of a per unit change in one of the independent variables we need to calculate what is known as the marginal effects. The marginal effect of any variable must be calculated after the parameters for the variables have been estimated. The marginal effect of variable $X_j$ on the probability of adopting (i.e. $P_i$ for firm *i*) conservation tillage is $\partial P_i / \partial X_{ij} = f(X_i\beta).\beta_j$, where $f(.)$ is the marginal probability density function of $\mu_i$. $\mu_i$ is the error term for the non-adopters less the error term for the adopters. The direction of the marginal effect is determined by the sign of $\beta_j$; $\beta_j$ represents coefficient differences $\alpha_{1j} - \alpha_{0j}$ where $\alpha_{1j}$ is the coefficient on the variable j for the adopters and $\alpha_{0j}$ is the coefficient for the non adopters on variable j. Thus, $\beta_j$ is expected to be positive (negative, or zero) if $\alpha_{1j}$ is positive (negative, or zero) and greater than (less than, or equal to) $\alpha_{0j}$.

**Model Specification and Data**

The probit model estimated to explain the adoption decision is:

$$
\begin{gathered}
F[\Pr ob(MinTill_{t,i,k})] = F[P(Y=1|X)] = F[\beta_0 + \beta_1 AB_t + \beta_2 SK_t + \beta_3 Labor_{t,i} + \beta_4 Young_{t,i} + \\
\beta_5 Male_{t,i} + \beta_6 Post_{t,i} + \beta_7 NFWork_{t,i} + \beta_8 \operatorname{Re} sid_{t,i} + \beta_9 Sfallow_{t,i} + \beta_{10} \ln Age_{t,i} + \beta_{11} \ln TFArea_{t,i} + \\
\beta_{12} \ln Own_{t,i} + \beta_{13} \ln ValMch_{t,i} + \beta_{14} \ln ValBOwn_{t,i} + \beta_{15} \ln ValBRnt_{t,i} + \beta_{16} RFarm_{t,k} + \\
\beta_{17} \ln Black_{t,k} + \beta_{18} \ln Brown_{t,k} + \beta_{19} \ln DarkGray_{t,k} + \beta_{20} \ln DarkBrown_{t,k} + \beta_{21} \ln Gray_{t,k} + \\
\beta_{22} OpStruc_{t,i} + \beta_{23} \ln Age_{t,i}{}^2 + \beta_{24} \ln TFArea_{t,i}{}^2 + \beta_{25} Time + \beta_{26} \ln AprMax_{t-1,k} + \\
\beta_{27} \ln Apr \Pr ecip_{t-1,k} + \beta_{28} \ln MayMax_{t-1,k} + \beta_{29} \ln May \Pr ecip_{t-1,k} + \beta_{30} \ln JunMax_{t-1,k} + \\
\beta_{31} \ln Jun \Pr ecip_{t-1,k} + \beta_{32} \ln JulMax_{t-1,k} + \beta_{33} \ln Jul \Pr ecip_{t-1,k} + \beta_{34} \ln \Pr ecip_{t-1,k} + \varepsilon_{ik}]
\end{gathered}
$$

……3.0

where: $t$ = time period, $i$ = farm/producer, and $k$ = census division. The variables used in equation (3.0) follow the reviewed literature. We use a number of variables to measure financial constraints (farm assets), profits (sales), risk (age), and environmental stress (weather patterns) etc. The ability to mirror the exact set of variables used in previous research was constrained by our data set.

The primary data source for this study was the Canadian Agriculture Census for the years 1991, 1996, and 2001. A representative sample of individual farm files for each census division in Alberta, Manitoba, and Saskatchewan was drawn by Statistics Canada. The Census of Population was used to match education achievement to the farm files.

Agriculture and Agri-Food Canada (AAFC) provided weather data by census division, and the Soil Science Department at the University of Saskatchewan supplied data on the proportion (i.e. percentage) of land that was of the various soil types by census division. The combination of these data sources allow for the inclusion of producer, farm, and regional characteristics in the analysis. A summary of the data broken out by adopters and non-adopters are in table 1.

The Agriculture and Population Censuses are conducted by Statistics Canada every five years. The Agriculture Census is completed by everyone who has, or has the potential to have farm income; this includes hobby farmers with less than a quarter section of land up to corporate farmers with hundreds of quarter sections of land. If there is more than one producer on a farm only the primary operator completes the Agriculture Census, thus each operation is only reported once. The Population Census has two forms, a short form and a long form. The short form is completed by 80% of households in Canada, while the remaining 20% fill out the long form. Linkages between the Agriculture Census and the long form of the Population Census were required for this analysis; therefore the data set represents 20% of all farms in Alberta, Saskatchewan, and Manitoba. Farm level data cannot be linked from one census year to another due to government confidentiality restrictions. For this reason farm specific variables cannot be lagged from one census year to another. However, some variables, such as total farm sales are lagged one year (i.e. not a census year) because respondents are asked about their sales in the previous year.

Weather data were obtained from the Prairie Farm Rehabilitation Administration of AAFC. This data contained average maximum temperature and total precipitation for the months of April, May, June, and July for the years: 1990, 1995, and 2000. The data were collected by weather station and often there is more than one weather station in each census division (CD). In this case the raw weather data were modified with the use of Geographic Information Systems (GIS). An average weather observation was found for each CD using all weather stations within the CD. Due to government confidentiality restrictions with the Census data, soil data cannot be linked with each producer's land, therefore soil type percentages were used for each CD. For each CD the percentage of gray, dark gray, dark brown, brown, black, and unknown soils were calculated. The location of Federal research farms were obtained from AAFC.

The Agriculture and Population Census data were 'cleaned' by eliminating those farms that had an unusual operating structure, such as Hutterite colonies and First Nations reserves. Farms that were less than 160 acres (i.e. one-quarter section) in size were also eliminated from the data set. The hypothesized sign together with an explanation is given for each variable of the model (i.e. equation 3) in table 2.

## Model Results and Some Interpretation

The identical specification was estimated for each of the years 1991, 1996, and 2001. We then estimated a pooled model over all three years. [7] The dependent variable for all four models is the 'use' of conservation tillage technology. One problem with this variable is that producers who are using conservation tillage in the current time period, but adopted the technology in a previous time period, will not have the same set of characteristics that they had at the time of adoption. For example, if they adopted the technology ten years prior they would have been ten years younger, possibly had a smaller land base, less total farm sales, and so forth. Notwithstanding this problem the model fit the data well using the measure of 'percent correctly predicted'.

The 'percent correctly predicted' is a measure of how often the model correctly predicts the adoption or non-adoption decision (see table 3). In addition, weighted averages of the percent correctly predicted were calculated to eliminate the effects of when a model incorrectly predicts an outcome of zero. [8] As expected the weighted averages of the percent correctly predicted is the lower of the two measures. The 'percent correctly predicted' and weighted average 'percent correctly predicted' are more useful in terms of evaluating the accuracy of the different model specifications and sensitivity analyses as compared to the log likelihood value, particularly when the same data set is not always used.

Using the measure of the 'percent correctly predicted' the 1991 data fit the model the best, followed by the 1996 and the pooled data set, and finally the 2001 data set. One reason the 1991 fit the best may be the way the dependent variable is measured i.e. 'use of conservation tillage'. If a farmer used the tillage in 1991 he probably did so in 2001, which may reduce the ability of the model to correctly predict the outcome. The percent correctly predicted for all four models ranged between 75% and 88%. From these initial results, the pooled model was chosen to be used in the calculation of the marginal effects. This decision was made because the pooled model contains all the data and thus the results are the most meaningful and relevant. If only the 1991 data were used the results would be 15 years old and their impact on current and future decisions would be more limited.

As expected, gross farm sales and total farm area are highly correlated. To prevent multicollinearity total acres farmed and total gross sales were not included in the same equation. We estimated the same model using each of the size measures and the results did not vary significantly (the preferred equation uses gross sales as an explanatory variable because it is a better measure of farm size). Before any equations were estimated correlation tables for all independent variables were created and if two variables were highly collinearity (over .9), one was deleted. Heteroscedasticity was not a problem in the equations, possibly due to the large sample size. However, even though it was not a problem the robust command in STATA was used. Results between SAS and STATA were identical. [9]

**Discussion of Results**

Using the pooled data set and different equation specifications, the range of 'correctly predicted' producers using conservation tillage went from a low of 81.63% to a high of 82.07%. The specification using the pooled data is presented in Table 4. The significant variables in the equations also had significant t-statistics when comparing the mean of adopters and non-adopters (Table 1). However, there were four exceptions: gender, residence, summerfallow, and total precipitation for the period April to July of the previous year. A total of twelve different specifications were run using the panel data set. [10]

The Alberta dummy variable is a significant explanatory variable in all the equations. The dummy variable for Saskatchewan was deleted because it was not significant in the probit model. A dummy variable for Manitoba was not included to avoid perfect collinearity. It is a conundrum as to why Alberta farmers would be less likely to adopt the new technology: Alberta producers are 8.45% less likely to adopt conservation tillage technology and practices compared with producers living in Saskatchewan or Manitoba.

There are a number of possible explanations for the observed difference between Alberta and the other two Prairie Provinces. One explanation is that moisture is not as constraining in Alberta and thus the farmers can continuous crop without adopting conservation tillage. A second explanation is that spring temperatures in the Peace River region and along the Foothills may be cooler and not suited to increased crop trash left from year to year. This explanation would indicate that the adoption of conservation tillage has more to do with continuous cropping and moisture affects than controlling for wind and water erosion. Finally, the explanation may be that Alberta farmers receive more total government subsidies than either Saskatchewan or Manitoba farmers which may reduce financial stress levels (AAFC, 2006). Whatever the explanation, Alberta farmers have been slower to adopt conservation tillage than farmers in either Manitoba or Saskatchewan.

The number of farm operators present had no impact on the technology adoption decision. The decision to adopt is negatively impacted if the operator was male. It is difficult to interpret this variable given only 4% of the sample are women operators. Perhaps women are more sensitive to the environment, but other factors need to be considered before any conclusion is drawn. The post secondary education variable is not significant in any of the equations, which was also found by Westra and Olson (1997) and Uri (1998). The adoption of conservation tillage technology may be based on a neighbor effect rather than the level of the producers' education, which is consistent with a knowledge spillover. In Canada farm managerial ability is very important, but it is not well established that it is correlated with education achievement levels.

The age and age squared variables are significant in the preferred model. When only the age variable is included in the estimated equation the coefficient is negative, meaning that as a producer's age increases the probability of adopting conservation tillage decreases. However, when age squared is added to the equation the age coefficient becomes positive while the age squared variable is negative. In this case, the adoption of conservation tillage increased up to the age of 19 years at which time it begins to decrease. This is hardly important as most individuals under 19 years are not full time farmers. Some researchers have found the age variable to be significant while other researchers found the age of the operator to be not significant. In Westra and Olson (1997), Adesina and Zinnah (1993), and Uri (1998) age was not significant in explaining tillage adoption. However, age was a significant explanatory variable in Feder and Umali (1993) and Lapar and Pandey (1999).

The adoption decision is not affected by off-farm employment; however the producer who resides on the farm is less likely to adopt conservation tillage compared with a producer whose residence is not on the agricultural operation. This was an unexpected result. We provide two possible explanations as to why farmers who reside away from their farms are more likely to adopt conservation tillage technology. First, a producer who does not live on the operation is more likely to be using custom operators to carry out the farm operations (even though an individual who employs custom operators is not disqualified from being a farmer). Custom operators manage a large number of acres, thus they have the resources to adopt the latest technology if it is beneficial to their operation.  Second, an operator who lives in town may have a larger off-farm income and thus be more financially able to purchase the new conservation tillage technology. Whatever the reason for this result (which really warrants more investigation) any innovation strategy must be careful to target farmers who live on their operations. If we knew the reason for the difference in adoption between these two groups then those reasons could be targeted by policy intervention, but for now it appears that the place of residence is an important proxy for some constraint to technology adoption.

The use of conservation tillage can eliminate the need for summerfallow in the crop rotation. In this sense some conservation cropping practices are a substitute for fallowing. Conservation technology often requires more fertilizer which may not be required if the producer follows the practice of summerfallow. Thus, there may be some endogeniety between summerfallow and conservation tillage usage, which would make the interpretation of this variable difficult.

A producer who includes summerfallow in their crop rotation is 4.32% less likely to adopt conservation tillage.  Because summerfallow is most prevalent in the driest region of the Prairies the lack of conservation leaves the soil open to wind and water erosion. It has been reported that summerfallow in the brown soil zone is more effective at retaining moisture for crops when compared with conservation tillage (Alberta Agriculture, Food and Rural Development, 2006).  This may be a case where the socially optimal level of conservation tillage is not used and farmers may need a subsidy in order to adopt the new technology. This is an interesting question but work for another study.

The variable representing total farm sales is significant when determining whether a producer will adopt conservation tillage. Feder and Umali (1993) obtained a similar result. Producers who use conservation tillage had average total sales of $150,694, while the average total sales of non-adopters were $86,372. As total farm sales increase so does the ability of the producer to purchase new equipment. For every one unit increase in total farm sales the probability of adopting conservation tillage technology increased 4.35%. This may indicate that larger farms have an advantage in the land market due to economies of scale that are present in much of the conservation tillage (seeders and sprayers for example).

The result that larger farmers are more likely to adopt conservation tillage is not surprising to anyone familiar with the sector but is nevertheless important. If Canadian policy makers are concerned with developing an innovation and adoption strategy then they may consider aiming such a policy at larger farms. To the extent that climate change can be mitigated by farm practices such as conservation tillage, larger farmers may play a key role in the adoption and spread of climate improving agricultural innovations.

Farmers who use a corporate operating structure are more likely to adopt conservation tillage. For large profitable farms there is a tax incentive to incorporate as earnings are taxed at a lower rate. Another incentive with incorporation is limited liability; that is the individual farmer will lose only those assets which are part of the company in the case of bankruptcy. Finally, incorporation might also be an indicator of managerial ability. Few farmers do incorporate but it may be a proxy for more effective management particularly financial management; at any rate the effect is small with a marginal effect of 1.92%.

The variables which measure the value of machines and buildings capture the effect of wealth on the adoption decision. The marginal effects are very small although significant for the value of owned and rented buildings. This variable picks up the effect of how well established the farmer is in terms of his farmyard site. If the farmer has invested in buildings it could be argued they will be wealthier, given sales etc have been controlled. If so, increased wealth has little impact on the adoption of conservation tillage.

Producers who farm in a CD (census division) where a research farm is located are able to observe the benefits of new technology and practices first hand. In addition, farmers in a CD with a research farm have less distance to travel to attend research field days were the effects of new technologies are demonstrated and thus have less cost to access the information. Those who reside in a CD with a research farm are 8.37% more likely to adopt conservation tillage technology as compared to those whose farm is in a CD with no research station farm.

This result is particularly important for policy makers in a period when governments are encouraging the adoption of new technology. Provincial governments have cut back on the number of agricultural extension professionals and public extension activities. The goal to increase adoption of technology is not consistent with the reduction in extension expenditures. Making the effects of new technology apparent to farmers is one issue that the governments need to carefully reconsider. Perhaps the reduced emphasis on extension has come at a higher cost than first considered.

Three of the five soil zone variables are significant in predicting whether a producer would adopt conservation tillage. Soil zones reflect the very long term weather and vegetation patterns, which are in part responsible for the type of soil.

The proportion of black and dark gray soil in a CD increased the probability of conservation tillage being adopted, while having a large proportion of brown soil in a CD decreased the probability of adoption. Changing the proportion of soil type within a CD is not possible in the short run. Also one cannot change the proportion of one soil color in a CD without changing the proportion of other soils. Because we did not know which soil color would increase we did not change any other proportion. Thus our results for soil type are a gross marginal effect rather then the desired net marginal effect. Moisture is not as constraining in the black and dark gray soil zones therefore the use of conservation tillage is more prevalent. For a 1 unit increase in the proportion of black soil in a CD the probability of adopting conservation tillage increased by 1.87%, and 0.65% for dark gray soils. [11] Gould et al. (1989) also found land quality to be a significant variable in determining tillage adoption.

In the brown soil zone the lack of soil moisture is a severe problem. Conservation tillage increases soil moisture some years, however it is not sufficient to make it profitable for farmers to adopt conservation technology. For a 1 unit increase in the proportion of brown soil in a CD the probability of adopting conservation tillage technology decreased 3.4%. In some years farms located in the brown soil zone are exposed to severe wind and water erosion problems, yet this was not important enough to reverse the negative effects of the moisture constraint. This result is consistent with the conjecture that conservation tillage is more about water management than wind and water erosion.

The dark brown soil variable is not significant in any of the equation specifications. This was an expected result. The dark brown soil is a transition zone between black and brown soils. It is in the dark brown soil zone that the use of the new technology is just break-even in the producer's utility function; thus this variable has no direct influence on the likelihood of adoption.

A number of the weather variables were significant. The probability of adopting conservation tillage technology increases as the average maximum temperature for April increases. As the air temperature rise the soil temperature also increases; thus the soil will be warm enough for the seed to properly germinate and develop. Therefore, the increased residue, from conservation tillage, on the soil surface is not considered a hindrance to crop development. For every one unit increase in the April (that is a warmer spring) average maximum temperature the probability of adopting conservation tillage technology increased 7.55%. This marginal effect is large and suggests that a warmer April significantly encourages the adoption of conservation tillage.

The probability of adopting conservation tillage technology increases as the average maximum temperature for the previous month of June (that is the June of the previous year) increases. The increased residue on the soil surface is beneficial to good crop development because it prevents the soil from drying up. As well, in a drought period the residue provides protection for the crop. A one unit increase in the average maximum daily temperature in June of the previous year results in the probability of adopting conservation tillage technology increasing by 19.97%. This variable (and certainly the size of the marginal effect) may reflect some learning on the part of the farmer. If they experience a hot June farmers will observe their crops under moisture stress. This will re-enforce the benefits of conservation tillage and increase the probability they will benefit from using the technology in the next year.

As total previous June (that is, June the previous year) precipitation increases the probability of adopting conservation tillage technology decreases. In this case the farmer will observe that conservation tillage has limited benefits if there is increased rainfall in June. [12] If a crop has adequate moisture because of precipitation for plant development there is little incentive for a producer to adopt conservation tillage (from the perspective of a moisture constraint) because their crop will not yield significantly more or obtain a better grade to justify the capital cost of adopting conservation tillage. For every one unit increase in the previous June's precipitation the probability of adopting conservation tillage technology decreased 4.07%. The marginal effect of temperature is much higher than moisture, suggesting that hot temperatures in June have more impact than increased June moisture (if there is a correlation between June temperature and moisture was not explored).

Earlier in the paper it is suggested that the producer's adoption decision is related to the mitigation of stress. If in the previous year the farmer observes adverse spring and summer weather conditions that can be partially mitigated by conservation tillage, the probability of adopting soil conservation technology increases. It is interesting to note that the weather variables have the largest marginal effects which indicate their importance in determining the adoption decision.

Finally, the time trend is significant indicating that there is a systematic increase in the use of conservation tillage not explained by the other variables. For example, farmers may become more aware of the benefits of conservation tillage as they observe their neighbors. There may be an advertising effect by machine companies that is being picked up by the trend. Finally, the manner in which the dependent variable is measured leads to the expectation that the trend variable will be positive.

## Sensitivity Analysis

### *Total Acres Farmed*

The probit equations were not sensitive to using total acres farmed in place of gross sales. The larger the number of acres farmed the more likely the farm is to use conservation tillage. The average farm size of adopters is 1,521 acres, while the average farm size of non-adopters is 967 acres. It is likely there are economies of scale with the adoption of conservation tillage making it more profitable for farmers with a larger acreage.

Finally, the census data came with weights for each observation because the data represents a 20% sample of Prairie farms. The weight represents the number of farms in the entire sample (100% of Prairie farms) with those particular characteristics. A sensitivity analysis was conducted to determine if the weights of each sample affected the estimated parameters. The log likelihood value increased when the weight was not included in the equation however, there was no change in the percent correctly predicted. Since results between the equations with and without the weight did not differ we concluded that the weight did not play a significant role in determining the value of the model parameters.

## Conclusion

It is possible to select a set of observable farm, regional, and environmental variables that can be used to correctly predict if a farmer will adopt (or not adopt) conservation tillage technology on the Canadian Prairies. In the case of conservation tillage weather and soil conditions play the largest role in the adoption decision. This is not surprising given that conservation tillage is primarily aimed at these variables. The results that proximity to a research farm increases adoption and the lack of the importance of formal education in the adoption decision are significant. From our analysis it appears farmers may learn about the effects of new technology through observation. If correct, then governments must be careful when they reduce the support for extension activities. If governments want farmers to adopt new technologies more quickly they should consider expanding the resource base of extension activities.

This data set is extremely rich and much remains to be done to understand the adoption decision. For example, it may be possible to develop a panel data set which links farmers across census years with the aid of Statistics Canada. This would open up research possibilities to address questions of how networks affect adoption as well as analyzing the entry and exit decision. Knowing the factors which affect technology adoption is important. Little economic research has examined this important topic in Canada. As governments become more focused on innovation policy and place greater emphasis on farmers adopting new technologies, the factors which affect technology adoption will be central to the success of their policy initiatives.

## Endnotes

1. For this research we have a pooled sample of 43,573 farmers of which 7,903 reported they used conservation tillage and 34,670 said they did not use the technology. The sample was drawn by Statistics Canada to be representative of the population. The data are described in detail later in the paper.

2. The literature on technology adoption is large. In this paper we only briefly review the more recent literature. For a more complete review of the literature of technology adoption by farmers see Sunding and Zilberman 2000.

3. By way of comparison farmers who adopt new seed varieties will have done so after three years of its first release. This is a very rapid rate of adoption.

4. We build a model that includes the farmer's attitude toward environmental degradation as one reason for adoption.

5. Although not explicitly mentioned in the objective function, the impact of the dynamic nature of the adoption decision is included.

6. This section follows the model developed by Rahm and Huffman (1984). See Rahm and Huffman for the probability function need to specify the probit model.

7. A number of different exogenous variables were used in the probit model; because of the size of the regression equations in terms of number of variables we only report the equation that fit the best. The log likelihood value was calculated for each estimated equation.

8. If $F(\alpha + \beta X_{ij}) \geq 0.5$ then set it equal to 1; if $F(\alpha + \beta X_{ij}) < 0.5$ set it equal to 0. Then the weighted average percent correctly predicted can be found by using the following formula:

$$[[(\Pr(Y_i = 1)/N) * \Pr(Y_i = 1 | F(.) \geq 0.5) + (\Pr(Y_i = 0)/N) * \Pr(Y_i = 0 | F(.) < 0.5)]/N] * 100.$$

9. STATA and SAS are statistical packages which were used to estimate the parameters.

10. The results of other specifications are available from the authors upon request.

11. The proportion of black soil in a particular CD was logged; however, the value should not have been logged because values of proportions of 0 and 1 were then treated the same. Of the total data set 0.7% of the observations are affected, thus this is not a significant problem for the final results. The result of using the logged value is that the significance of black soil in the decision to adopt conservation tillage will be understated, but since the variable is significant the problem is not of major concern. Given this data had to be used only at Statistics Canada we did not have the opportunity to change the specification of the variable.

12. June rains make a large difference in the yield of a crop produced on the Prairies.

## REFERENCES

**Adesina, Akinwumi A. and Moses M. Zinnah. 1993.** *Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone.* Agricultural Economics. Volume 9. pp. 297 – 311.

**Agriculture and Agri-Food Canada (AAFC). 2006.** Farm Income, Financial Conditions and Government Assistance, (December), Ottawa.

**Alberta Agriculture, Food and Rural Development. 2006.** Accessed at:. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex980

**Åstebro, Thomas. 2004.** *Sunk Costs and the Depth and Probability of Technology Adoption*. The Journal of Industrial Economics. Volume LII. Issue 3. pp. 381 – 399.

**Batz, F.J., K.J. Peters, and W. Janssen. 1999.** *The influence of technology characteristics on the rate and speed of adoption.* Agricultural Economics. Volume 21. pp. 121 – 130.

**De Janvry, A. 1973.** "A Socioeconomic Model of Induced Innovations for Argentine Agricultural Development." *Quarterly Journal of Economics,* Vol. 87, No. 3, pp: 410–435

**Feder, Gershon and Dina L. Umali. 1993.** *The Adoption of Agricultural Innovations A Review.* Technological Forecasting and Social Change. Volume 43. pp. 215 – 239.

**Fox, G.A., A. Weersink, G. Sarwar, S. Duff and B Deen. 1991.** Comparative economics of alternative agricultural production systems: A review. *Northeastern Journal of Agricultural and Applied Economics.* Vol. 20. pp:124-142.

**Goel, Rajeev K. and Daniel P. Rich. 1997.** *On the Adoption of New Technologies*. Applied Economics. Volume 29. pp. 513 – 518.

**Gould, Brian W., William E. Saupe, and Richard M. Klemme. 1989.** *Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion.* Land Economics. Volume 65. Number 2. pp. 167 – 182.

**Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins. 2002.** *Environmental Policy and Technological Change*. Environmental and Resource Economics. Volume 22. pp. 41 – 69.

**Lapar, Ma. Lucila A. and Sushil Pandey. 1999.** *Adoption of soil conservation: the case of the Philippine uplands.* Agricultural Economics. Volume 21. pp. 241-256.

**Kurkalova, L., C. Kling and J. Zhao. 2006.** Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior. *Canadian Journal of Agricultural Economics,* Vol. 54. No. 2, pp: 247-268.

**Mooney, S. and J. Williams 2007. "**Private and Public Values of Soil Carbon Management", in Kimble J., C. Rice, D. Reed, S. Mooney, R. Follet, and R. Lal (eds.) Soil Carbon Management: Economic Environmental and Societal Benefits. Talyor and Francis Group, LLC.

**PFRA 2006.** Prairie Farm Rehabilitation Act, Historical weather data for the Prairies. Regina.

**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. Number 66. pp. 405 – 413.

**Rosenberg, N. 1969.** *The Direction of Technological Chang: Inducement Mechanisms and Focusing Devices.* Economic Development and Cultural Change. Number 18. pp. 1 – 24, quote on pp. 23.

**Smith E.g., T.L. Peters, R.E. Blackshaw, C.W. Lindwall, and F.J. Larney. 1996.** "Economics of reduced tillage fallow-crop systems in the Dark Brown soil zone of Alberta", *Canadian Journal of Soil Science,* 76:411-416.

**STATA,** StataCorp Lp. College Station, Texas.

**Statistics Canada.** Census Data for 1991, 1996, and 2001.

**Sunding, D., and D. Zilberman. 2000.** The agricultural innovation process: Research and technology adoption in a changing agricultural sector. In *Handbook of Agricultural Economics,* edited by B. Gardner and G. Rausser. Amsterdam: Elsevier Science Publishers.

**University of Saskatchewan, Soil Science GIS Lab.** Soil Data.

**Uri, Noel D. 1998.** *Conservation Tillage and the Use of Energy and Other Inputs in US Agriculture.* Energy Economics. Volume 20. pp. 389 – 410.

**Von Neumann, J. and Morgenstern, O. 1944.** *Theory of Games and Economic Behavior.* Princeton University Press. Princeton, NJ.

**Westra, John and Kent Olson. 1997.** *Farmers' Decision Processes and Adoption of Conservation Tillage.* Department of Applied Economics, College of Agricultural, Food, and Environmental Sciences, University of Minnesota, Staff Paper P97-9.

**Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B.G. McConkey, S. A. Brandt, G.P. Lafond, A.M. Johnston and D.A. Derksen. 2002.** Economics of Crop diversification and Soil Tillage Opportunities in the Canadian Prairies, *Agronomy Journal,* Vol. 94, pp: 216-230.

## Table 1 Comparison of Adopter and Non-Adopter Means: Pooled Sample

| **Variable name**<br>Variable units**<br>*Variable Mnemonic* | **Adopters** | | **Non-Adopters** | | **t-value*** |
|---|---|---|---|---|---|
| | **Mean** | **Standard Deviation** | **Mean** | **Standard Deviation** | |
| **Alberta** *(AB)****<br>=1 if is Alberta | 0.18 | 0.84 | 0.29 | 1.00 | 20.10 |
| **Labor** *(Labor)****<br>=0 if one operator | 0.31 | 1.01 | 0.27 | 0.98 | 6.94 |
| **Young farmer** *(Young)****<br>=1 if a second operator < 36 | 0.20 | 0.87 | 0.18 | 0.84 | 4.85 |
| **Male** *(Male)****<br>=1 if operator is male | 0.96 | 0.44 | 0.96 | 0.44 | 1.06# |
| **Post Secondary Education** *(Post)****<br>=1 if operator post secondary education | 0.50 | 1.09 | 0.53 | 1.10 | 4.18 |
| **Non-Farm Work** *(NFWork)****<br>=1 if operator worked off farm | 0.25 | 0.95 | 0.26 | 0.97 | 2.05 |
| **Age** *(Age)*<br>years of the operator | 48.5 | 29.7 | 50.9 | 31.80 | 13.81 |
| **Residence** *(Resid)****<br>=1 if operator lived on farm | 0.79 | 0.89 | 0.80 | 0.89 | 1.27# |
| **Summerfallow** *(Sfallow)****<br>=1 if some land fallowed | 0.61 | 1.06 | 0.61 | 1.07 | 0.42# |
| **Total Farm Area** *(TFArea)*<br>acres of the farm | 1,521 | 2853 | 967 | 2,130 | 42.58 |
| **Total Sales** *(TFSales)*<br>dollars in sales | 150,694 | 360,745 | 86,372 | 273,554 | 38.65 |
| **P'ion of Owned Land** *(Own)*<br>Percent | 0.68 | 0.71 | 0.74 | 0.71 | 14.75 |
| **Machinery Value** *(ValMch)*<br>machinery investment $ | 220,618 | 487,491 | 141,285 | 356,868 | 36.17 |
| **Value of Owned Buildings** *(ValBOwn)*<br>buildings owned $ | 410,127 | 1,021,349 | 280,998 | 827,437 | 26.12 |
| **Value of Rented Buildings** *(ValBRnt)*<br>buildings rented $ | 197,404 | 875,910 | 107,905 | 672,432 | 21.96 |
| **Research Farm** *(RFarm)****<br>=1 if a research farm CD | 0.34 | 1.03 | 0.24 | 0.9440 | 17.80 |
| **Proportion of Black Soil** *(Black)*<br>proportion | 0.31 | 0.70 | 0.37 | 0.7355 | 14.80 |
| **Proportion of Brown Soil** *(Brown)*<br>proportion | 0.23 | 0.74 | 0.13 | 0.62 | 25.98 |
| **Proportion of Dark Gray Soil** *(DarkGray)*<br>proportion | 0.05 | 0.23 | 0.10 | 0.29 | 26.36 |
| **Proportion of Dark Brown Soil** *(DarkBrown)* | 0.31 | 0.68 | 0.19 | 0.62 | 32.35 |

| | | | | | |
|---|---|---|---|---|---|
| proportion | | | | | |
| **Proportion of Gray Soil** *(Gray)* proportion | 0.10 | 0.42 | 0.19 | 0.58 | 31.07 |
| **Operating Structure** *(OpStruc)****<br>=1 if farm was incorporated | 0.14 | 0.77 | 0.07 | 0.56 | 21.15 |
| **Time** *(Time)*<br>Trend for each year | 2.19 | 1.72 | 1.84 | 1.75 | 35.09 |
| **Average Maximum** *(AprMax)*<br>Temperature of Previous April: Celsius | 9.39 | 5.15 | 8.76 | 5.38 | 20.92 |
| **Total Precipitation of Previous April** *(AprPrecip)*<br>millimeters | 29.10 | 21.94 | 29.87 | 23.84 | 5.75 |
| **Average Maximum Temperature of Previous May** *(MayMax)*<br>Celsius | 17.57 | 2.29 | 17.35 | 2.50 | 15.94 |
| **Total Precipitation of Previous May** *(MayPrecip)*<br>millimeters | 45.69 | 50.54 | 44.51 | 51.68 | 4.03 |
| **Average Maximum Temperature of Previous June** *(JunMax)*<br>Celsius | 22.25 | 4.35 | 22.39 | 4.24 | 5.75 |
| **Total Precipitation of Previous June** *(JunePrecip)*<br>millimeters | 76.21 | 56.59 | 80.30 | 65.84 | 11.17 |
| **Average Maximum Temperature of Previous July***(JulMax)*<br>Celsius | 24.83 | 3.06 | 24.10 | 3.24 | 40.14 |
| **Total Precipitation of Previous July** *(JulPrecip)*<br>millimeters | 74.60 | 71.94 | 79.37 | 68.58 | 12.09 |
| **Total Precipitation for April to July of Previous year** *(Precip)*<br>(millimeters) | 225.57 | 114.15 | 234.05 | 116.41 | 1.28# |

* The difference between the adopters and non-adopters mean value is reported using a t-statistic.
** The dollar values are deflated to 1991.
*** Signifies a dummy variable which otherwise takes on a value of zero.
\# Indicates variables which were not significantly different at the 5% level.
**Source:** Statistics Canada, AAFC (PFRA), and University of Saskatchewan Soil Science Department

## Table 2: Expected Relationships between the Adoption of Conservation Tillage and Explanatory Variables

| Variable | Expected Sign | Explanation |
|---|---|---|
| *AB* | - | Alberta farmers were less likely to adopt conservation tillage because they have fewer moisture constraints. Also Alberta farmers receive more subsidies than Manitoba or Saskatchewan farmers and have less financial reason to adopt. |
| *Labor* | + | The more operators an operation has the more opinions and thoughts that go into a decision making process. Therefore, if conservation tillage technology is beneficial to an operation it is more likely they will adopt it. |
| *Young* | + | Younger operators are more likely to act favorably towards new technology, therefore they are more likely to adopt. In addition, young farmers have longer planning horizons in order to spread the capital cost over. |
| *Male* | ? | There was no expectation for this variable. |
| *Post* | ? | As education attainment levels increase, producers are able to make more informed decisions. Since conservation tillage is not suitable under all scenarios, the expected sign is unknown. |
| *NFWork* | - | As the number of hours a producer spends at off-farm employment increases the less likely they are to be dependent on farm income. Also they want to adopt labor saving technology. |
| *Age* | - | As the age of the primary farm operator increases it is expected that the probability of adopting conservation tillage technology and practices decreases, since the adoption of conservation tillage technology is a long term planning decision. |
| *Resid* | + | A producer who lives on their operation sees it everyday and may be more aware of the operation. As well, they may be more reliant on the farm for household income. |
| *Sfallow* | - | A negative relationship is expected between the adoption of conservation tillage technology and summerfallow. Conservation management does not incorporate summerfallow into the crop rotation. |
| *TFArea* | + | The greater the number of acres farmed the more likely an operator is to adopt conservation tillage technology. A larger farm has more acres to spread the capital cost over. As well they have to replace their equipment more often because of wear. |
| *TFSales* | + | An increase in gross farm sales is expected to increase the probability of adopting conservation tillage technology and practices, since producers now have a larger income to afford the capital cost of new technology. |
| *Own* | + | Land owners benefit from an increase in land quality when they sell or rent their land. Since conservation tillage technology and practices maintain or increase the quality of soil a positive relationship is expected. |
| *ValMCH* | + | As the value of capital assets increases, so does collateral and the ability to borrow money for future capital purchases. |
| *ValBOwn* | + | As the value of capital assets increases, so does collateral and the ability to borrow money for future capital purchases. |
| *ValBRnt* | + | As the value of capital assets increases, so does collateral and the ability to borrow money for future capital purchases. |
| *Rfarm* | + | If a research farm is located within the same CD as a producer's operation the more likely the producer is to learn of new |

| | | |
|---|---|---|
| | | developments, both in terms of technology and practices. |
| *Black, Dark Gray DarkBrown, Gray* | + | Most years farms located in the black, dark brown, gray, and dark gray soil zones receive an adequate amount of precipitation during the growing season to grow a crop; however, the increase in the amount of residue on the soil surface can benefit the crops by providing extra moisture to grow a better crop. In addition, these soils are able to maintain higher levels of soil organic matter, which is beneficial to crop development. |
| *Brown* | - | Farms located in CD's with a large proportion of brown soil are prone to water shortage problems. These problems are so great that even the benefits provided by conservation tillage technology and practices are not enough to offset the water shortage. |
| *OpStruc* | + | Operations that are incorporated are expected to have less capital restraints, thus they will keep up to date on the latest technology and practices and adopt whenever it is beneficial for them to do so. |
| *AprMax, MayMax, JunMax, JulMax* | + | As average maximum temperatures increase, the adoption of conservation tillage technology will also increase. This is because the increased residue on the soil surface will keep the soil cooler, which is beneficial to crop development. |
| *AprPrecp, MayPrecip, JunPrecip, JulPrecip* | - | It is expected that as precipitation over the growing season increases the adoption of conservation tillage technology and practices will decrease. This is because soil moisture is not a significant concern when adequate precipitation is received. In addition, too much moisture is bad for proper crop development. |
| *Precip* | - | It is expected that as total precipitation increases farmers are less likely to adopt conservation tillage. |
| *Time* | + | As time goes on (measured by year in this model) more producers will have adopted conservation tillage technology, 1991=1, 1996=2, and 2001=3. |

**Table 3: Comparison of Different Data Sets**

| | Correctly Predicted (%) | Weighted Average Correctly Predicted (%) | Log Likelihood Value |
|---|---|---|---|
| **1991** | 88.5 | 79.6 | -24,638 |
| **1996** | 81.1 | 67.6 | -29,787 |
| **2001** | 75.2 | 54.9 | -29,623 |
| **Pooled** | 81.8 | 68.0 | -85,832 |

Source: Author's Calculations

**Table 4: Preferred equation parameter estimates and marginal effects at sample mean**

| Variable | Coefficient | Marginal Effect | Standard Error | Pr>Chi-Square |
|---|---|---|---|---|
| Intercept | -2.8665 | n/a | 1.5109 | 0.0803 |
| *AB* | -0.3931 | -0.0844 | 0.0307 | <0.0001 |
| *Labor* | 0.0070 | 0.0017 | 0.0173 | 0.6979 |
| *Young* | 0.0267 | 0.0063 | 0.0261 | 0.3348 |
| *Male* | -0.1258 | -0.0315 | 0.0384 | 0.0017 |
| *Post* | -0.1040 | -0.0246 | 0.0746 | 0.1833 |
| *NFWork* | 0.0060 | 0.0014 | 0.0200 | 0.7735 |
| *Age* | 1.0706 | 0.2527 | 0.5361 | 0.0682 |
| $(Age)^2$ | -0.1972 | -0.0466 | 0.0750 | 0.0156 |
| *Resid* | -0.0505 | -0.0121 | 0.0195 | 0.0142 |
| *Sfallow* | -0.1794 | -0.0432 | 0.0171 | <0.0001 |
| *TSales* | 0.1843 | 0.0435 | 0.0110 | 0.5530 |
| *Own* | 0.0093 | 0.0022 | 0.0152 | <0.0001 |
| *ValMch* | -0.0022 | -0.0005 | 0.0053 | 0.6824 |
| *ValBOwn* | 0.0065 | 0.0015 | 0.0031 | 0.0394 |
| *ValBRnt* | 0.0063 | 0.0015 | 0.0019 | 0.0010 |
| *RFarm* | 0.3279 | 0.0837 | 0.0806 | 0.0001 |
| *Black* | 0.0792 | 0.0187 | 0.0085 | <0.0001 |
| *Brown* | -0.1448 | -0.0342 | 0.0134 | <0.0001 |
| *DarkBrown* | -0.0071 | -0.0017 | 0.0050 | <0.0001 |
| *DarkGray* | 0.0276 | 0.0065 | 0.0058 | 0.1989 |
| *Gray* | -0.0248 | -0.0059 | 0.0102 | 0.0234 |
| *OpStruc* | 0.0788 | 0.0192 | 0.0255 | 0.0028 |
| *AprMax* | 0.3198 | 0.0755 | 0.0472 | <0.0001 |
| *AprPrecip* | 0.0222 | 0.0052 | 0.0239 | 0.3734 |

| | | | | |
|---|---|---|---|---|
| *MayMax* | -0.3316 | -0.0783 | 0.1717 | 0.0646 |
| *MayPrecip* | 0.0654 | 0.0154 | 0.0205 | 0.0028 |
| *JunMax* | 0.8456 | 0.1997 | 0.2306 | 0.0003 |
| *JunPrecip* | -0.1723 | -0.0407 | 0.0291 | <0.0001 |
| *JulMax* | -0.9295 | -0.2194 | 0.3142 | 0.0039 |
| *JulPrecip* | -0.0390 | -0.0092 | 0.0237 | 0.1201 |
| *Precip* | -0.1041 | -0.0246 | 0.0389 | 0.0120 |
| *Time* | 0.3575 | 0.0844 | 0.0455 | <0.0001 |

Source: Author's Calculations