

The Subsidy for Adopting Conservation Tillage: Estimation from Observed Behavior

Lyubov A. Kurkalova, Catherine L. Kling, and Jinhua Zhao

Working Paper 01-WP 286
September 2001

**Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu**

*This paper was a selected paper presented at the American Agricultural
Economics Association 2001 annual meeting in Chicago.*

Lyubov Kurkalova is associate scientist at the Center for Agricultural and Rural Development (CARD), Iowa State University. Catherine Kling is professor of economics and head of the Resource and Environmental Policy Division at CARD. Jinhua Zhao is assistant professor of economics, Iowa State University.

The authors thank seminar participants at the Resources Workshop at Iowa State University and at the American Agricultural Economics Association 2001 annual meeting in Chicago for their helpful comments. The usual disclaimer applies.

This publication is available online on the CARD website: www.card.iastate.edu. Permission is granted to reproduce this information with appropriate attribution to the authors and the Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa 50011-1070.

For questions or comments about the contents of this paper, please contact Lyubov Kurkalova, 560A Heady Hall, Iowa State University, Ames, IA 50011-1070; Ph: 515-294-7695; Fax: 515-294-6336; E-mail: lyubov@iastate.edu.

Iowa State University does not discriminate on the basis of race, color, age, religion, national origin, sexual orientation, sex, marital status, disability, or status as a U.S. Vietnam Era Veteran. Any persons having inquiries concerning this may contact the Director of Affirmative Action, 318 Beardshear Hall, 515-294-7612.
--

Abstract

Due to payoff uncertainties combined with risk aversion and/or real options, farmers may demand a premium in order to adopt conservation tillage practices, over and above the compensation for the expected profit losses (if any). We propose a method of directly estimating the financial incentives for adopting conservation tillage and distinguishing between the expected payoff and the premium of adoption based on observed behavior. We find that the premium may play a significant role in farmers' adoption decisions. Even for non-adopters, conservation tillage provides a higher payoff than does conventional tillage on average, as agronomists have argued. However, non-adopters do not use conservation tillage because the expected profit gain alone does not fully compensate them for the uncertainties. To induce additional adoption, subsidies could be used. We find that in Iowa on average, the mean subsidy needed is \$2.40 per acre per year for corn and \$3.50 per acre per year for soybeans.

Key words: adoption subsidies, risk premium.

THE SUBSIDY FOR ADOPTING CONSERVATION TILLAGE: ESTIMATION FROM OBSERVED BEHAVIOR

Significant quantities of topsoil are lost annually due to erosion (USDA/NRCS). This fact was a primary motivation for the establishment of the Soil Conservation Service in 1935, and for many years, government programs have been targeted at reducing erosion levels (Claassen et al.). McConnell's important 1983 paper led to a clear understanding of the role of private (on-farm) versus external (off-farm) costs of soil erosion, and much of the literature in agricultural economics since then has focused on off-farm damages related to the runoff of nutrients, chemicals, and soils.

More recently, increased concerns about water quality degradation from nonpoint sources and the implementation of Total Maximum Daily Load (TMDL) regulations has generated interest in a variety of policies for environmental improvements in agriculture and mechanisms to encourage the adoption of conservation practices such as low-tillage methods. Careful economic analysis of the efficiency of these policies requires an understanding of the costs of achieving gains in environmental quality due to the adoption of conservation practices.

Adopting conservation practices does not always lead to profit losses for farmers. In fact, even without any government subsidy, on average over 36 percent of U.S. farmers use conservation tillage, and in Iowa the percentage is even higher (CTIC). Nevertheless, to the extent that an individual farmer ignores the social benefits of conservation practices, the adoption rate is likely to be lower than socially optimal. Further, even when conservation practices can raise farmers' expected profit, they may be reluctant to adopt because the practices may be riskier. Farmers may require a premium to adopt because they are risk averse and/or because adoption involves sunk investments (e.g., in human or physical capital) while other real options are available (Arrow and Fisher). If so, the farmer adopts only if the additional profit of conservation practices overcomes the premium.

A large amount of literature has studied the incentives of farmers to adopt conservation practices and new technologies in general (Sunding and Zilberman provide a review). The incentives are found to depend qualitatively on soil quality, crops grown, and farmer characteristics such as age and education. In spite of the amount of literature, there exists little empirical evidence on the payments (or subsidies) that would be needed to induce farmers to adopt conservation practices (and new technologies in general). The reason for this omission is that most of the studies employ discrete choice methods, which allow coefficient estimates to be recovered only up to a multiplicative constant. Thus, though probabilities of adoption can be estimated, these estimates cannot be readily converted into dollar compensation levels.¹

This paper contributes to the literature in several ways. First, we present a new modeling strategy that allows for full recovery of the structural coefficients and hence the ability to directly compute the subsidies needed for adoption. Pautsch et al. apply a simple version of this model to examine the potential for carbon sequestration in agricultural soils. Here, we apply a richer version of the model and fully investigate the effects of various farm and farmer characteristics on the size of the subsidy. Further, we decompose the subsidy into the profit loss (or gain) from adoption and the adoption premium due to uncertainties. Our results confirm the arguments of agronomists and extension agents that conservation tillage pays: on average farmers gain from adoption. However, the adoption premium may exceed the profit gain, and consequently farmers still may demand a subsidy in order to adopt. Finally, based on the estimated subsidies, we calculate the “supply curve” of conservation tillage for a sample of Iowa farmers and analyze the role of the subsidies in improving environmental performance and as a tool for income transfers to farmers. In Iowa, where the existing adoption rate of conservation tillage is already high (over 60 percent), we find that a significant part of the subsidy (or conservation payments) will be income transfers to existing and low-cost adopters.

One important previous effort to estimate the premium for conservation tillage adoption relies on stated preference methods (Cooper; Cooper and Keim) and provides a useful empirical comparison to our results. These works relied on contingent valuation surveys that elicit directly from farmers the per acre payments they would need to induce adoption. In this paper, we estimate the premium based on observed behavior, noting that

farmers who have already adopted conservation tillage must have received high enough additional returns from doing so to compensate for the presence of any increased risk or real options.

In the next section, we present the behavioral model and derive the econometric specification from it, specifically noting the innovation that allows recovery of the structural coefficients. In the third section, the data used for estimation are described, and in the following section, the model is applied to the data set. The size and distribution of the premium payments are further studied in the fifth section, followed by conclusions and additional discussion.

The Adoption Model

We begin by briefly describing the theoretical justification for the existence of an adoption premium and why the premium relates directly to payoff uncertainties. Let \mathbf{p}_1 be the expected annual net return from using conservation tillage, \mathbf{p}_0 be that from using conventional tillage, and \mathbf{s}_1^2 and \mathbf{s}_0^2 be the variances of the two returns. Consider first a simple case where every year farmers are free to change their farming practices between the two choices. If farmers are risk averse, standard utility theory indicates that they use conservation tillage if and only if $\mathbf{p}_1 - R_1(\mathbf{s}_1^2) \geq \mathbf{p}_0 - R_1(\mathbf{s}_0^2)$ or $\mathbf{p}_1 - \mathbf{p}_0 \geq R_1(\mathbf{s}_1^2) - R_1(\mathbf{s}_0^2)$, where $R_1(\square)$ is the risk premium associated with each practice. Typically $\mathbf{s}_1^2 > \mathbf{s}_0^2$, either because farmers have more experience with conventional till or because of the agronomic characteristics of the two practices. Then \mathbf{p}_1 must exceed \mathbf{p}_0 by a strictly positive premium for farmers to adopt conservation tillage.

More realistically, adopting a new tillage practice requires certain sunk investments in physical and human capital. Moreover, conservation tillage usually leads to lower yields in early years before soil nutrients build up. The lost profit in these years is sunk because it cannot be recovered by reverting back to conventional till. Given the uncertainties and the lost profits, farmers may be reluctant to adopt conservation till and will adopt only when they are especially “sure” that adoption will be profitable. Particularly, there is a value of delaying the adoption until the likelihood of unprofitable

adoption is sufficiently low. Then farmers adopt only when \mathbf{p}_1 exceeds \mathbf{p}_0 by the option value or premium $R_2(\mathbf{s}_1^2, \mathbf{s}_0^2)$, where $R_2(\cdot)$ is increasing in both arguments. This reasoning does not depend on the risk attitude of farmers and is a standard result in the real options literature (Arrow and Fisher; Dixit and Pindyck).

Note that both sources of the adoption premium (R_1 and R_2) depend on the existence of uncertainties in the returns of conventional and conservation tillage practices. For example, the existence of sunk costs of adopting alone does not generate a premium. If farmers know with certainty the future streams of returns under the two practices, their decision will depend only on the two net present values (NPVs). In this case, the sunk costs simply enter the streams of returns and affect the NPV alone; thus, they will not lead to any additional adoption premium.

In summary, due either to risk aversion or to real options, farmers typically demand a premium for adopting conservation tillage. That is, they adopt if and only if $\mathbf{p}_1 - \mathbf{p}_0 \geq P(\mathbf{s}_1^2, \mathbf{s}_0^2)$, where $P(\mathbf{s}_1^2, \mathbf{s}_0^2) = [R_1(\mathbf{s}_1^2) - R_1(\mathbf{s}_0^2)] + R_2(\mathbf{s}_1^2, \mathbf{s}_0^2)$. The premium is zero when both variances are zero.

We turn now to the modeling strategy for describing farmers' decisions to adopt conservation tillage. In the standard setting (Soule, Tegene, and Wiebe; Uri; Rahm and Huffman), farmers are predicted to adopt conservation tillage if the expected profit from adoption exceeds that from continuing with conventional practices, i.e., when $\mathbf{p}_1 \geq \mathbf{p}_0$. Farmers' profit functions are assumed to be known to the farmers but are unobservable to the researcher. An additive error is incorporated to reflect the researcher's omission of relevant variables or misspecification of the net return functions. An expression for the probability of adoption from the researcher's perspective can be then written as

$$\Pr[\text{adopt}] = \Pr[\mathbf{p}_1 \geq \mathbf{p}_0 + \mathbf{s}\mathbf{e}], \quad (1)$$

where \mathbf{e} is typically a standard normal or logistic error and \mathbf{s} is the associated standard deviation multiplier. We write the error term in this somewhat nonstandard way to more easily explain the limitation of this form of the model. The next step is to specify a functional form for the difference in the net returns, typically linear in explanatory

variables, e.g., $\mathbf{p}_1 - \mathbf{p}_0 = \mathbf{d}\mathbf{y}$, where \mathbf{y} is a vector of explanatory variables and \mathbf{d} is a vector of coefficients.

There are two limitations of this model for fully understanding adoption decisions. First, there is no explicit formalization of the existence of the premium needed to induce adoption. Second, and even more critical for estimating the financial incentives needed to induce adoption, the coefficients on the net return expression can only be estimated up to the multiplicative constant, \mathbf{s} . To see this, write the probability of adoption as

$$\begin{aligned} \Pr[\text{adopt}] &= \Pr[\mathbf{p}_1 \geq \mathbf{p}_0 + \mathbf{s}\mathbf{e}] \\ &= \Pr[\mathbf{d}\mathbf{y} \geq \mathbf{s}\mathbf{e}] \\ &= \Pr[\mathbf{e} \leq \frac{\mathbf{d}\mathbf{y}}{\mathbf{s}}]. \end{aligned} \tag{2}$$

This formulation makes clear the point that is well known among practitioners of discrete choice models: only estimates of the ratios of the coefficients to the standard deviation can be recovered. Consequently, the changes in net returns associated with adoption of conservation tillage cannot be estimated. Analysts must be satisfied with predictions of qualitative changes such as identifying what characteristics of farmers will increase the likelihood of adoption.

Here we propose and implement a new conceptual model that both explicitly incorporates an adoption premium to reflect risk aversion and real options and allows recovery of an estimate of \mathbf{s} , thereby allowing recovery of the individual parameter values. Specifically, we assume that an individual farmer will adopt conservation tillage when $\mathbf{p}_1 \geq \mathbf{p}_0 + P$, where P is the premium. Again, an additive error is used to represent omitted variables or misrepresentation of the net return statement by the researcher, and \mathbf{p}_1 is assumed linear in explanatory variables. However, we assume that the expected net returns from conventional tillage are known to the farmer and focus on modeling the returns to conservation tillage as a function of explanatory variables. Thus, we write the probability of adoption as

$$\begin{aligned}
\Pr[adopt] &= \Pr[\mathbf{p}_1 \geq \bar{\mathbf{p}}_0 + P + \mathbf{s}\mathbf{e}] \\
&= \Pr[\mathbf{B}\mathbf{x} \geq \bar{\mathbf{p}}_0 + P + \mathbf{s}\mathbf{e}] \\
&= \Pr[\mathbf{e} \leq \frac{\mathbf{B}\mathbf{x}}{\mathbf{s}} - \frac{\bar{\mathbf{p}}_0}{\mathbf{s}} - \frac{P(\mathbf{z})}{\mathbf{s}}],
\end{aligned} \tag{3}$$

where $P(\mathbf{z})$ represents the premium as a function of its explanatory variables, and the bar on $\bar{\mathbf{p}}_0$ denotes that this variable is known. Note that $\mathbf{B}\mathbf{x}$ represents the expected net returns to conservation tillage and not the difference in returns between the two practices (represented by $\mathbf{d}\mathbf{y}$ above).

In this formulation, recovery of the standard deviation multiplier \mathbf{s} is straightforward as it will be simply the inverse of the coefficient estimated on $\bar{\mathbf{p}}_0$. Thus, by adding information to the model in the form of the expected net profits from conventional tillage, it is possible to estimate the standard error, in turn allowing recovery of the specific parameter values for \mathbf{B} .²

Further, it seems reasonable to assume that farmers fully understand the expected return for conventional tillage, as this practice has been used widely over a long period. Thus, farmers have substantial experience both in using conventional tillage and in predicting its mean profitability (e.g., in making annual planting decisions).

Turning now to the premium function, note that the theoretical basis for the presence of an adoption premium requires the presence of profit uncertainties of the two tillage practices. Although these uncertainties may affect the premium differently under risk aversion and real options, we focus on the magnitude of the premium and how it depends on the uncertainties rather than attempting to identify the source. Because the data set we use is cross-sectional and because agricultural input and output markets are well established, we see no reason why the farmers in our study region would face varying price uncertainty. Thus, only yield uncertainties vary across the sample and are modeled in this study. This observation provides important guidance in specifying the empirical model, as it implies that the adoption premiums should depend on variables related to yield uncertainty as well as farmer characteristics that may define how uncertainty translates into adoption premiums.

Data and Notation

The study region consists of the state of Iowa. The crops in the analysis are corn, soybeans, wheat, and hay. Summary statistics and definitions of the explanatory variables are given in Table 1. The variable I_j is an indicator function for crops: $j=cn$ (corn), sb (soybeans), oth (other). That is, $I_j=1$ if a farmer grows crop j and $I_j=0$ otherwise. The primary data source is a random sample drawn from the National Resource Inventory (NRI) (USDA/SCS; Nusser and Goebel). For each NRI point, information is collected on the natural resource characteristics of the land, the farming practices used by the producer, and weather characteristics. To form our complete data set, we supplement the NRI data with constructed net returns, climate, and farm operator characteristics data.

All data are for the 1992 growing season. As seen from Table 1, 63 percent of farmers use conservation tillage. The expected net returns from conventional tillage (\bar{p}_0) are distinguished by crop in Table 1 and are those realized in 1992. Since returns data are not available from the NRI data, we assigned the net returns data to each sample point based on the production region and 1991 and 1992 crop information. To construct the regional returns data, we combined county-specific average yield data (USDA/NASS 1994), state-specific price data (USDA/NASS 1999a), and the region-, tillage-, and rotation-specific cost data from Mitchell. The sample average net return to conventional tillage in corn production is about \$145/acre, in soybeans, about \$110/acre, and for all other crops, about \$92/acre. A dummy variable indicating a crop other than corn or soybeans (“other crops”) is included to account for the somewhat idiosyncratic nature of these other choices (over 90 percent of Iowa is planted in corn or soybeans).

Climatic data (TMAX, TMIN, PRECIP, and s_{precip}) were constructed from the 1975-94 temperature and precipitation data collected by the National Climatic Data Center (Earthinfo) for the usual crop growing seasons as reported in USDA/NASS (1997). The standard deviation of precipitation s_{precip} was calculated as the standard deviation of the daily precipitation during the growing season over the years 1975-94.

County average indicators of farm operator characteristics (OFFFARM, TENANT, AGE, and MALE) were constructed from the 1992 Census of Agriculture data (USDA/NASS 1999b).³ The remaining variables used in the model are indicators of land

TABLE 1. Definition of variables and summary statistics

Notation	Description	Units	Sample Mean	Sample St. Dev.
Adopt	Conservation tillage (1=yes, 0=no)	Number	0.63	0.48
I_{cn}	Corn (1=corn, 0=soybeans or other crop)	Number	0.57	0.50
$\bar{p}_{0,cn}$	Net returns to conventional tillage, corn ^a	\$ per acre	145	23
$\bar{p}_{0,sb}$	Net returns to conventional tillage, soybeans ^b	\$ per acre	109	14
$\bar{p}_{0,oth}$	Net returns to conventional tillage, other crops ^{c,d}	\$ per acre	93	43
SLOPE	Land slope	Percent	4.1	3.9
PM	Soil permeability	Inches per Hour	1.7	2.2
AWC	Soil available water capacity	Percent	18.5	2.8
TMAX	Mean of daily maximum temperature during the corn growing season	Fahrenheit	78.7	1.8
TMIN	Mean of daily minimum temperature during the growing season	Fahrenheit	55.6	2.0
PRECIP	Mean of daily precipitation during the growing season	Inches	0.141	0.012
s_{precip}	Standard deviation of daily precipitation during the growing season	Inches	0.331	0.027
OFFFARM	Proportion of operators working off-farm to the total number of farm operators in the county	Number	0.471	0.055
TENANT	Proportion of harvested cropland operated by tenants to the total county harvested cropland	Number	0.199	0.050
AGE	County average farm operator age	Years	50.2	1.8
MALE	Proportion of male operators to the total number of farm operators in the county	Number	0.9774	0.0096

Note: Total observations are 1,339.

^a 762 observations.

^b 475 observations.

^c Wheat, or hay.

^d 102 observations.

characteristics that are agronomically either favorable or unfavorable to conservation tillage practices. Because an increase in the amount of crop residue cover on the soil surface tends to keep soils cooler, wetter, less aerated, and denser (e.g., Allmaras and Dowdy), conservation tillage is favored on sloping and better-drained soils.

Model Specification and Estimation Results

The probability of adopting conservation tillage practices for corn, soybeans, and other crops is specified as

$$\Pr[adopt] = \Pr[p_{1,j} \geq \bar{p}_{0,j} + P_j], \quad j = cn, sb, oth,$$

where

$$p_{1,j} = b_{0,cn} \cdot I_{cn} + b_1 \cdot SLOPE + b_2 \cdot PM + b_3 \cdot AWC + b_4 \cdot TMAX + b_5 \cdot TMIN + b_6 \cdot PRECIP \\ + b_7 \cdot TENANT + s_e \cdot e,$$

and

$$P_j = s_{precip} (a_{1,j} + a_{2,j} \cdot \bar{p}_{0,j} + a_{3,j} \cdot OFFFARM + a_{4,j} \cdot TENANT + a_{5,j} \cdot AGE + a_{6,j} \cdot MALE).$$

The parameters to be estimated are the b 's, the a 's, and s_e . Table 2 presents the results of estimation. Estimates of the effect of soil and climatic conditions on the net returns to conservation tillage appear reasonable: land slope (the amount of inclination of the soil surface from the horizontal expressed as the vertical distance divided by the horizontal distance), soil permeability (the rate at which water can pass through a soil material), and available water capacity (the amount of water that a soil can store in a form available for plant use) are all positively related to better drainage of the soil. Improved soil drainage, in turn, is found to positively affect yields under conservation tillage systems (see, for example, Allmaras and Dowdy). Thus, the strong positive effects of these variables on conservation tillage adoption are consistent with agronomy and soil science. Our statistically significant positive relationship between the slope and the probability of adoption is likewise consistent with earlier studies by Rahm and Huffman, Norris and Batie, Wu and Babcock, and Uri.

TABLE 2. Maximum likelihood estimates of the adoption model

Variable(s)	Parameter	Estimate	St. Error of Estimation ^a
Net returns to conservation tillage			
I_{cn}	$b_{0,cn}$	41	11 [*]
$SLOPE$	b_1	0.22	0.12 ^{***}
PM	b_2	0.63	0.31 ^{**}
AWC	b_3	0.73	0.29 ^{**}
$TMAX$	b_4	2.57	0.68 [*]
$TMIN$	b_5	-2.48	0.72 [*]
$PRECIP$	b_6	76	69
$TENANT$	b_7	194	92 ^{**}
	s_e	6.0	1.6 [*]
Premium			
$s_{precip} \cdot I_{cn}$	$a_{1,cn}$	1400	411 [*]
$s_{precip} \cdot I_{sb}$	$a_{1,sb}$	1123	432 [*]
$s_{precip} \cdot I_{oth}$	$a_{1,oth}$	770	557
$s_{precip} \cdot \bar{p}_{0,cn}$	$a_{2,cn}$	-2.79	0.11 [*]
$s_{precip} \cdot \bar{p}_{0,sb}$	$a_{2,sb}$	-3.32	0.19 [*]
$s_{precip} \cdot \bar{p}_{0,oth}$	$a_{2,oth}$	-3.00	0.22 [*]
$s_{precip} \cdot OFFFARM \cdot I_{cn}$	$a_{3,cn}$	-103	47 ^{**}
$s_{precip} \cdot OFFFARM \cdot I_{sb}$	$a_{3,sb}$	-131	59 ^{**}
$s_{precip} \cdot OFFFARM \cdot I_{oth}$	$a_{3,oth}$	-53	94
$s_{precip} \cdot TENANT \cdot I_{cn}$	$a_{4,cn}$	607	274 ^{**}
$s_{precip} \cdot TENANT \cdot I_{sb}$	$a_{4,sb}$	682	264 [*]
$s_{precip} \cdot TENANT \cdot I_{oth}$	$a_{4,oth}$	442	339
$s_{precip} \cdot AGE \cdot I_{cn}$	$a_{5,cn}$	-5.1	1.8 [*]
$s_{precip} \cdot AGE \cdot I_{sb}$	$a_{5,sb}$	-4.0	2.0 ^{**}
$s_{precip} \cdot AGE \cdot I_{oth}$	$a_{5,oth}$	-2.9	4.1
$s_{precip} \cdot MALE \cdot I_{cn}$	$a_{6,cn}$	-763	302 ^{**}
$s_{precip} \cdot MALE \cdot I_{sb}$	$a_{6,sb}$	-605	338 ^{***}
$s_{precip} \cdot MALE \cdot I_{oth}$	$a_{6,oth}$	-301	469
Fraction of correct predictions		0.70	
Log (likelihood)		-779.3	

^a The standard errors are computed from analytic second derivatives; *, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels respectively.

The effect of climatic variables on conservation tillage adoption is also consistent with agronomic science. With reduced tillage, the soils tend to stay cooler and wetter; thus, conservation tillage results in better yields in warmer regions. The strong positive effect of the average daily maximum temperature and the opposite one of the average daily minimum temperature agree with this expectation. The positive effect of precipitation is also consistent with rainfall generally acting as a limiting factor of crop production (Kaufmann and Snell; Hansen).

Several alternative model specifications were considered but were found to provide inferior fits. Specifically, we initially modeled the error term as heteroskedastic across crops, but the generalized likelihood ratio test failed to reject the hypothesis that the error term is homoskedastic (the computed test statistic, 3.72, does not exceed the critical value of 5.99 corresponding to the 5 percent level of significance). Initially, the intercept term, b_0 , also was allowed to vary for every crop, but the estimates were not significant for soybeans and for other crops.

Notice that the variable TENANT can influence both the profitability of conservation tillage and the premium required. We also investigated other socioeconomic variables to explain the magnitude of the profitability, but their effect on the expected net returns to conservation tillage was not significant.⁴

Analysis of the Adoption Premium

Agronomic studies indicate that a major variable that affects yield uncertainties under both conservation and conventional tillage is the variability of climatic conditions during a crop's growing season (Kaufmann and Snell; Hansen; Thompson). In this study, we model the climatic variability via variability of precipitation. While the variability of temperature is also important, it often affects the yield variability in conjunction with precipitation variability (Runge). Also, in our study region, areas with higher precipitation variability tend to have higher temperature variability during the crucial periods of the growing season; the sample correlation coefficients between precipitation variability and measures of temperature variability are as high as 0.25. Thus, only the precipitation variability is included in the premium estimation. The functional form

assumed for the adoption premium guarantees that there is zero premium without the weather variability, as theoretically required.

The size of the premium also is affected by the personal characteristics of the farmer, such as operator age, off-farm employment, tenancy, and gender. While this is not an exhaustive list, it encompasses most of the standard characteristics hypothesized to affect the adoption decision in the literature (Feder and Umali; Sunding and Zilberman).⁵

Farmer's age is found to negatively affect the adoption premium and thus to positively affect the adoption of conservation tillage. Previous studies have yielded mixed and inconclusive results on the effect of age and experience on adoption. Rahm and Huffman observed a positive though statistically insignificant association between human capital and adoption of conservation tillage for Iowa farmers growing corn in 1977. Fuglie found a positive effect of the years of farming experience on the adoption of reduced till in the Corn Belt in 1991-92. Uri used 1987 farm-level data and found no statistically significant effect of age on adoption of conservation tillage. Korsching et al. surveyed farmers in three central Iowa watersheds in 1980 and found that adopters were younger on average than were non-adopters. Norris and Batie found a statistically significant negative effect of age on conservation tillage acreage of cotton producers in Virginia. Featherstone and Goodwin found that older farmers invested less in conservation improvements. Finally, Soule, Tegene, and Wiebe found a statistically significant negative effect of age on the adoption of conservation tillage by corn producers.

These mixed results may be due to the possibility that age affects risk aversion and option values differently. In particular, risk aversion, and consequently risk premium, has been shown to rise with age (Bakshi and Chen; Palsson). The risk-aversion argument has often been supplied as an explanation for the estimated negative effect of age on the adoption of new, uncertain technologies (e.g., Dimara and Skuras). However, if age is positively related to accumulated knowledge and experience about the suitability of conventional and/or conservation till, a farmer of older age may have less incentive to gather further information. Thus, older farmers may demand a smaller option value compensation for their adoption. Our estimation results indicate that the option value effect of age does indeed dominate the risk-aversion effect.

Off-farm employment is found to reduce the adoption premium, thereby increasing the adoption rate. Since those working off-farm have more diversified sources of income, they may be less risk averse and demand a smaller premium for adoption. This result is consistent with previous findings. Korsching et al. found a higher, though statistically insignificant, off-farm employment involvement by adopters of minimum tillage in Iowa in 1980. Fuglie, who analyzed a sample of midwestern farmers observed in 1991-92, also found a higher adoption of no-till by farmers working off-farm.

The consensus in the literature on the gender effect is that women are in general more risk averse than men (e.g., Jianakoplos and Bernasek; Barsky et al.). Thus, one would expect the risk premium to be smaller for men than for women. Our estimates suggest a negative effect of the proportion of males on the adoption premium. This result is consistent with the higher rate of adoption of soil conservation structures by male operators estimated by Young and Shortle.

We find that tenancy increases the expected net returns to conservation tillage but also raises the adoption premium. Its overall effect on adoption is negligible, as these two effects roughly cancel each other out. The positive effect of tenancy on profitability may be explained by a very strong profit-maximizing motivation among tenants. In particular, tenancy leaves no room for recreational farming. However, renters may have a shorter planning horizon (possibly due to tenure insecurity) and a greater risk-aversion coefficient, leading to a higher risk premium. To the extent that tenants may have less historical knowledge of the land parcel compared to owners (Surjandari and Batte), they may also have a higher option value. In addition, because of tenure insecurity, a renter may have little incentive to maintain soil fertility or control erosion, or to enjoy the positive long-run effects of conservation tillage. All these factors imply a higher adoption premium. Further, tenants may be prohibited from adopting conservation practices because absentee landowners are not willing to make any changes in the way land is operated.

The empirical literature on the effects of tenancy has been mixed (see, for example, Fuglie and the discussion in Soule, Tegene, and Wiebe). Soule, Tegene, and Wiebe point out that lease arrangements may influence renters' conservation decisions. They also find that, while cash-renters are less likely, share-renters are not less likely than owner-operators to use conservation tillage. Share-renters, they explain, may behave more like

owner-operators than cash-renters because they bear only a share of the costs, and landlords tend to participate more actively in the management of farms rented under share leases. Our estimates suggest yet another explanation for the mixed effects of tenancy: the relative dominance of either the effect of payoff or of the premium.

We used returns to conventional tillage as a proxy to farmer's income in the analysis of the premium. This variable does not account for either accumulated wealth or total farmer's income, yet it gives a good indication of the income from farming activity. The estimated strong negative effect of this variable on the premium is consistent with the presumption of decreasing absolute risk aversion that has found support in many studies of farmers' behavior (Moschini and Hennessy). However, similar to the effect of tenancy, the overall effect of this variable on the probability of adoption is about zero at the data means.⁶ This finding is in agreement with the common absence of income variables in conservation tillage adoption models and with the inconclusive findings on the effect of income on the adoption of erosion-control practices (Young and Shortle; Norris and Batie; Belknap and Saupe; Uri).

Finally, the top part of Table 3 presents the estimated adoption premiums for the entire sample. The premium accounts for about 17 percent of the annual returns to conventional tillage for corn and soybeans.

Adoption Subsidies and Policy Implications

Based on the estimated results, we can calculate the subsidies that are needed to induce farmers to adopt conservation tillage. Given the farmer, soil, and weather characteristics, we calculate the expected net return from conservation tillage, \hat{p}_1 , and the required adoption premium, \hat{P} . Let S be the minimum subsidy required for a farmer to adopt conservation tillage. If a farmer has already adopted conservation tillage, the required subsidy is zero. Otherwise, the minimum subsidy must satisfy $\hat{p}_1 + S = p_0 + \hat{P}$. Then we know

$$S = \max \{ \hat{P} + (p_0 - \hat{p}_1), 0 \}. \quad (4)$$

TABLE 3. Estimated adoption premium

Variable	Corn	Soybeans	Other Crops
Whole sample			
Premium, \hat{P} (\$)	22 (12)***	16 (12)	30 (14)**
Expected net returns to conservation tillage, \hat{p}_1 (\$)	171 (13)*	130 (13)*	120 (14)*
Percentage of the premium in the expected net returns to conventional tillage (%)	14.9 (8.5)***	15 (11)	32 (16)**
Expected net returns to conventional tillage, \bar{p}_0 (\$) ^a	145.1	108.6	93.0
Predicted subsidies for adoption for current non- adopters ^b			
Profit loss due to adoption, $\bar{p}_0 - \hat{p}_1$ (\$)	-11 (12)	-35 (13)*	-22 (14)
Premium, \hat{P} (\$)	13 (13)	38 (14)*	27 (15)***
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{p}_0 - \hat{p}_1)$ (\$)	2.35 (0.93)**	3.5 (1.3)*	4.9 (2.2)**

Note: Estimates are reported at the means of the corresponding samples; standard errors in parenthesis; *, **, and *** indicate statistical significance at a 1%, 5%, and 10% level respectively. The standard errors are computed using the Delta method under the assumption of asymptotic normality. We used the subroutine ANALYZE of TSP to compute the standard errors.

^a Sample means.

^b 144 observations for corn, 68 observations for soybeans, and 80 observations for other crops.

When S is positive, it can be decomposed into two parts. One part (equal to \hat{P}) is used to remove the “hesitancy” of farmers by compensating for their adoption premium, and the remaining part is the monetary transfer to compensate for the profit loss.

The second half of Table 3 presents estimates of the mean premium and mean subsidy for the subsample of farmers who have not adopted conservation tillage and therefore are not predicted to adopt without any government subsidy. In general, consistent with the extensive agronomic studies, the expected profit of conservation tillage is higher than that of conventional tillage. For example, the predicted average profit gain of conservation tillage is \$10.60 per acre for corn and \$34.80 per acre for soybeans. Then what is the reason that these farmers have not adopted conservation tillage in spite of the profit gains? The

answer lies with the adoption premium. The average premium is \$13.10 per acre for corn and \$38.40 for soybeans, both of which are higher than the profit gain from conservation tillage. Therefore, either because of risk aversion or real options, these farmers stayed with conventional tillage. That is, the potential gain was not high enough to offset the presence of risk aversion and/or real options.

To induce adoption, the mean subsidy, which equals the difference between the mean profit gain and the adoption premium, is \$2.35 per acre per year for corn and \$3.50 for soybeans. The median subsidies are lower for both crops. That is, these subsidies will induce more than half of the current non-adopters to switch to conservation tillage. Our estimate of the required subsidies is much lower than that of Cooper, who estimated the median subsidy to be about \$23. Our lower estimate seems reasonable in our study application given that, without any subsidies, about 64 percent of farmers have adopted conservation tillage for corn and 68 percent have adopted for soybeans.

Applying equation (4) to each sample point, we calculate the required minimum adoption subsidies for the entire sample. Extrapolating our sample to the state as a whole, we obtain the state's intensity of adoption at each subsidy level, or the "supply curve" of conservation tillage, presented in Figure 1. Over 14 million acres (about 63 percent of all agricultural land in Iowa) are already in conservation tillage without any subsidy. The acreage increases as the subsidy level rises. At a subsidy of \$11.50 per acre, about 90 percent of farmland would be in conservation tillage.

The supply curve allows us to analyze the nature of a conservation tillage subsidy, in particular, its role as a tool for environmental efficiency or for income transfer. Suppose the government decides to subsidize conservation tillage at \$11.50 per acre, for new and existing adopters alike.⁷ The subsidy acts as a pure income transfer for existing adopters, for they do not need any additional incentive to adopt. Even for the new adopters, part of the subsidy is in fact an income transfer (similar to producer surplus) due to the heterogeneity of the adoption costs. Only the area under the supply curve captures the required compensation for conservation tillage or serves the single purpose of generating environmental benefits from conservation tillage. From Figure 1, it is obvious that the income transfer portion of the subsidy far exceeds the efficiency payment component. Of the \$236 million total subsidy needed to achieve 90 percent adoption, about \$204 million,

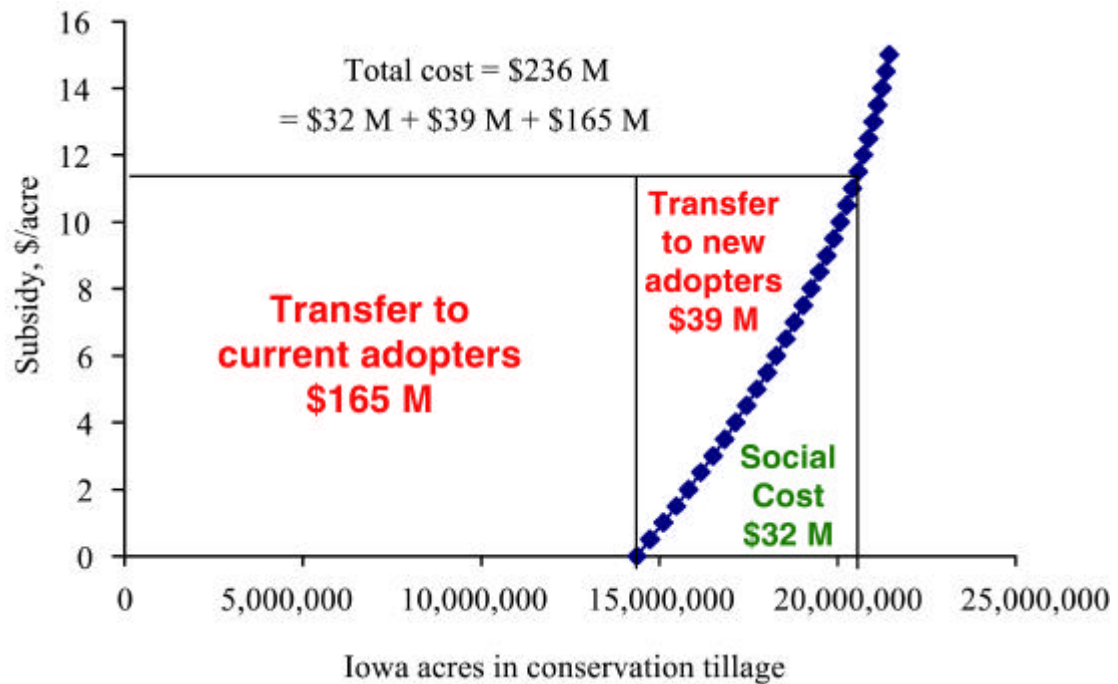


FIGURE 1. Total predicted cost of the subsidy to achieve 90 percent adoption in Iowa

or over 86 percent of the total subsidies, comprises income transfers, a major part of which goes to existing adopters. Of course, the income transfer will be less important in states where the existing adoption is low and the adoption costs are less heterogeneous.

Further, by relating the required subsidy to farmer characteristics, we can analyze how the level and structure of the subsidy varies by farmer groups. For example, Table 1 and the discussion in the previous section on the adoption premium indicate that the required subsidy decreases in off-farm employment. Thus, a low level of subsidy is likely to attract farmers with off-farm employment to adopt conservation tillage. As the subsidy rises, farmers without off-farm employment will increasingly adopt.

Conclusions

We propose a method of directly estimating the financial incentives for adopting conservation tillage and distinguishing between the expected payoff and premium of adoption based on observed behavior. We find that the adoption premium may play a significant role in farmers' adoption decisions (accounting for about 17 percent of their annual profits on average). Non-adopters do not use conservation tillage because the

expected profit gain alone does not fully compensate them for the increased risk and possibility of irreversible lost profits associated with conventional tillage practices. To induce adoption, government subsidies are needed to overcome the adoption premium net of the expected gain from adoption. We find that on average the mean subsidy needed is \$2.4 per acre per year for corn and \$3.5 per acre per year for soybeans.

Farmer characteristics can affect the adoption decision either by influencing the expected payoff of adoption or by changing the adoption premium. The two effects may work in opposition. For example, we find that while tenancy in general increases the expected profitability of adoption, it also raises the premium. The two effects roughly cancel each other out so that, in aggregate, tenancy does not change the adoption rate significantly. Given that the subsidies needed are mainly used to overcome the adoption premium, identifying the different effects of these characteristics is important for policy design and for evaluating impacts of the subsidies across geographic and socioeconomic groups.

In this study, we do not distinguish between the forces of risk aversion and real options underlying the adoption premium. However, the distinction is important for policy design because the two possibilities may suggest different optimal policy responses. For example, if it is risk aversion that generates the bulk of the premium, a proper government response may be to offer stabilization policies such as green insurance. However, if it is irreversibility of sunk investments that primarily generates the premium, measures to reduce the option value are more efficient, such as providing better information about conservation tillage or reducing the sunk cost of adoption (e.g., by subsidizing conservation tillage in early years).

Endnotes

1. In an alternative approach, Caswell and Zilberman estimate the premium for adopting new irrigation technologies by relating the costs of technologies to well depth and electricity rates.
2. Readers familiar with the contingent valuation literature immediately will see the similarity between this model and the Cameron bid function approach commonly used to estimate the willingness to pay for an environmental quality change from discrete choice data. In the contingent valuation models, the bid offered to respondents in the survey varies across respondents in the same way that the expected net returns from conventional tillage will vary across a sample of farmers. It is this variability that allows identification of the variance of the error in both types of application.
3. The AGE variable turned out to be highly correlated with another variable available in the Census of Agriculture, PRESENCE, the average years present on the farm (coefficient of correlation 0.67 with a p-value of less than 0.0001). The model estimated with the PRESENCE variable is neither quantitatively nor qualitatively different from the one presented here. Therefore, only AGE is included in our model.
4. Specifically, we compared three models: (i) the completely unrestricted model where the explanatory variables OFFFARM, AGE, and MALE appear on both the payoff side (the β 's) and on the premium side (the α 's); (ii) the restricted model in which the explanatory variables OFFFARM, AGE, and MALE appear on the payoff side only; and (iii) the restricted model as presented, in which the explanatory variables OFFFARM, AGE, and MALE appear on the premium side only. Using the generalized likelihood ratio tests, we reject model (ii) in favor of model (i) (the computed test statistic 28.2 is greater than the critical value of 16.92 corresponding to the 5 percent level of significance) and fail to reject model (iii) in favor of model (i) (the computed test statistic 1.13 is clearly less than the critical values at any conventional level of significance). Full model and test results are available from the authors.
5. We do not include farm size and farmer's education, two factors sometimes considered as affecting the adoption decisions, because of lack of data.
6. The derivative of the probability of adoption with respect to \bar{p}_0 is proportional to $1 + s_{precip} \cdot (a_{2,cn} \cdot I_{cn} + a_{2,sb} \cdot I_{sb} + a_{2,oth} \cdot I_{oth})$.
7. The government may choose to subsidize new adopters only, but the feasibility of such a policy is questionable, as some have argued that it punishes "good stewards" of farmland.

References

- Allmaras, R.R., and R.H. Dowdy. 1985. "Conservation Tillage Systems and Their Adoption in the United States." *Soil and Tillage Research* 5: 197-222.
- Arrow, K., and A. Fisher. 1974. "Environmental Preservation, Uncertainty, and Irreversibility." *Quarterly Journal of Economics* 88: 312-19.
- Bakshi, G.S., and Z. Chen. 1994. "Baby Boom, Population Aging, and Capital Markets." *Journal of Business* 67(2, April): 165-202.
- Barsky, R.B., F.T. Juster, M.S. Kimball, and M.D. Shapiro. 1997. "Preference Parameters and Behavioral Heterogeneity: An Experimental Approach in the Health and Retirement Study." *Quarterly Journal of Economics* 112(May): 537-79.
- Belknap, J., and W.E. Saupe. 1988. "Farm Family Resources and the Adoption of No-Plow Tillage in Southwestern Wisconsin." *North-Central Journal of Agricultural Economics* 10(January): 13-23.
- Caswell, M.F., and D. Zilberman. 1986. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." *American Journal of Agricultural Economics* 68(4, November): 789-811.
- Cameron, T. 1988. "A New Paradigm for Valuing Non-market Goods Using Referendum Data: Maximum Likelihood Estimation by Censored Logistic Regression." *Journal of Environmental Economics and Management* 15: 355-79.
- Claassen, R., L. Hansen, M. Peters, V. Breneman, M. Weinberg, A. Cattaneo, P. Feather, D. Gadsby, D. Hellerstein, J. Hopkins, P. Johnston, M. Morehart, and M. Smith. 2001. "Agri-Environmental Policy at the Crossroads: Guideposts on a Changing Landscape." Washington, D.C.: U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 794. <http://www.ers.usda.gov/publications/aer794/>, January (Accessed May 2001).
- Conservation Tillage Information Center (CTIC). 2000. *2000 Crop Residue Management Survey*. West Lafayette, IN: National Association of Conservation Districts. <http://www.ctic.purdue.edu/CTIC/CTIC.html> (Accessed May 2001).
- Cooper, J.C. 1997. "Combining Actual and Contingent Behavior Data to Model Farmer Adoption of Water Quality Protection Practices." *Journal of Agricultural and Resource Economics* 22(1, July): 30-43.
- Cooper, J.C., and R.W. Keim. 1996. "Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices." *American Journal of Agricultural Economics* 78(February): 54-64.
- Dimara, E., and D. Skuras. 1998. "Adoption of New Tobacco Varieties in Greece: Impacts of Empirical Findings on Policy Design." *Agricultural Economics* 19: 297-307.
- Dixit, A., and R. Pindyck. 1994. *Investment Under Uncertainty*. Princeton, N.J.: Princeton University Press.
- Earthinfo. 1995. *NCDC Summary of the Day*. Boulder, CO: Earthinfo.

- Feder, G., and D.L. Umali. 1993. "The Adoption of Agricultural Innovations: A Review." *Technological Forecasting and Social Change* 43(May/June): 215-39.
- Featherstone, A.M., and B.K. Goodwin. 1993. "Factors Influencing a Farmer's Decision to Invest in Long-Term Conservation Improvements." *Land Economics* 69(1, February): 67-81.
- Fuglie, K.O. 1999. "Conservation Tillage and Pesticide Use in the Cornbelt." *Journal of Agricultural and Applied Economics* 31(1, April): 133-47.
- Hansen, L. 1991. "Farmer Response to Changes in Climate: The Case of Corn Production." *Journal of Agricultural Economics Research* 43(Fall): 18-25.
- Jianakoplos, N.A., and A. Bernasek. 1998. "Are Women More Risk Averse?" *Economic Inquiry* 36(October): 620-30.
- Kaufmann, R.K., and S.E. Snell. 1997. "A Biophysical Model of Corn Yield: Integrating Climatic and Social Determinants." *American Journal of Agricultural Economics* 79(February): 178-90.
- Korsching, P.F., C.W. Stofferahn, P.J. Nowak, and D.J. Wagener. 1983. "Adopter Characteristics and Adoption Patterns of Minimum Tillage: Implications for Soil Conservation Programs." *Journal of Soil and Water Conservation* 38: 428-30.
- McConnell, K. 1983. "An Economic Model of Soil Conservation." *American Journal of Agricultural Economics* 65: 83-89.
- Mitchell, P.D. 1997. "Cost of Production Systems Budgets." CARD Technical Report 97-TR 37, Center for Agricultural and Rural Development, Iowa State University.
- Moschini, G., and D.A. Hennessy. 2000. "Uncertainty, Risk Aversion and Risk Management for Agricultural Producers." Chapter 3 in *Handbook of Agricultural Economics*, Vol. 1A: *Agricultural Production*, edited by B.L. Gardner and G.C. Rausser. Amsterdam: Elsevier Science Publishers.
- Norris, P.E., and S.S. Batie. 1987. "Virginia Farmers' Soil Conservation Decisions: An Application of Tobit Analysis." *Southern Journal of Agricultural Economics* 19(July): 79-90.
- Nusser, S.M., and J.J. Goebel. 1997. "The National Resources Inventory: A Long-Term Multi-Resource Monitoring Programme." *Environmental and Ecological Statistics* 4: 181-204.
- Palsson, A.M. 1996. "Does the Degree of Relative Risk Aversion Vary with Household Characteristics?" *Journal of Economic Psychology* 17(6, December): 771-87.
- Pautsch, G., L.A. Kurkalova, B.A. Babcock, and C.L. Kling. 2001. "The Efficiency of Sequestering Carbon in Agricultural Soils." *Contemporary Economic Policy* 19: 123-34.
- Rahm, M.R., and W.E. Huffman. 1984. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *American Journal of Agricultural Economics* 66(November): 405-13.
- Runge, E.C.A. 1968. "Effects of Rainfall and Temperature Interactions During the Growing Season on Corn Yield." *Agronomy Journal* 60(September): 503-7.
- Soule, M.J., A. Tegene, and K.D. Wiebe. 2000. "Land Tenure and the Adoption of Conservation Practices." *American Journal of Agricultural Economics* 82(4, November): 993-1005.

- Sunding, D., and D. Zilberman. 2000. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." Chapter 5 in *Handbook of Agricultural Economics*, Vol. 1A: *Agricultural Production*, edited by B.L. Gardner and G.C. Rausser. Amsterdam: Elsevier Science Publishers.
- Surjandari, I., and M.T. Batte. 2000. "Adoption of Variable Rate Technology: A Multinomial Logit Analysis." Poster presented at the American Agricultural Economics Association annual meeting, Tampa, FL, August.
- Thompson, L.M. 1969. "Weather and Technology in the Production of Corn in the U.S. Corn Belt." *Agronomy Journal* 61(May): 453-56.
- U.S. Department of Agriculture, National Agricultural Statistics Service (USDA/NASS) 1994. USDA-NASS Crops County Data 1991-92: Data files. USDA/NASS, Washington, D.C.
<http://usda.mannlib.cornell.edu/usda/usda.html> (Accessed May 2001).
- . *Usual Planting and Harvesting Dates for U.S. Field Crops*. 1997. Agricultural Handbook No. 628, USDA/NASS, Washington, D.C.
- . 1999a. *Crop Values: Final Estimates 1992-97*. Agricultural Handbook No. 963, USDA/NASS, Washington, D.C.
- . 1999b. 1997 Census of Agriculture, vol. 1, Geographic Area Series. USDA/NASS, Washington, D.C.
- U.S. Department of Agriculture, National Resources Conservation Service (USDA/NRCS). 2001. *National Resources Inventory Highlights*. USDA/NRCS, Washington, D.C.
<http://www.nhq.nrcs.usda.gov/land/pubs/97highlights.pdf>, January (Accessed May 2001).
- U.S. Department of Agriculture, Soil Conservation Service (USDA/SCS). 1994. The 1992 National Resources Inventory Database. USDA/SCS, Washington, D.C.
- Uri, N.D. 1998. "Conservation Tillage and the Use of Energy and Other Inputs in US Agriculture." *Energy Economics* 20: 389-410.
- Wu, J., and B.A. Babcock. 1998. "The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications." *American Journal of Agricultural Economics* 80(3, August): 494-511.
- Young, C.E., and J.S. Shortle. "Investment in Soil Conservation Structures: The Role of Farm Operator and Operation Characteristics." *Agricultural Economics Research* 36(2, Spring): 10-15.