Adoption of Conservation-Tillage Methods and Genetically Modified Cotton

Roland K. Roberts
Professor
The University of Tennessee
308 B Morgan Hall
2621 Morgan Circle
Knoxville, TN 37996-4518
Phone: (865) 974-7482
E-mail: rrobert3@utk.edu

Burton C. English
Professor
The University of Tennessee
308 C Morgan Hall
2621 Morgan Circle
Knoxville, TN 37996-4518
Phone: (865) 974-7482
E-mail: benglish@utk.edu

Qi Gao
Graduate Student
200 Charles Halton Ave., Apt 10E
College Station, TX 77840
Phone: (979) 845-5222
E-mail: gaoqia1106@yahoo.com

James A. Larson
Associate Professor
The University of Tennessee
308 G Morgan Hall
2621 Morgan Circle
Knoxville, TN 37996-4518
Phone: (865) 974-6361
E-mail: jlarson2@utk.edu

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Abstract: Adoption of herbicide-tolerant cotton and conservation tillage may be simultaneously related. Bayes' theorem and a two-equation logit model were used to test the simultaneity hypothesis. Evidence for Tennessee suggests that adoption of these technologies reduced residual herbicide use and soil erosion more than if adoption of these technologies were independent.

Key Words: Bayes' theorem, conservation tillage, cotton, genetically modified crops, herbicide tolerant crops, simultaneous logit model, technology adoption

JEL Classifications: Q12, Q16, Q24, O33

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Monsanto claims that adoption of herbicide-tolerant seed facilitates adoption of conservation tillage, which “sustains the environment”. Yet, Fernandez-Cornejo and McBride found no evidence that soybean farmers who had adopted herbicide-tolerant seed had a higher probability of adopting no-tillage practices than farmers who had not adopted herbicide-tolerant seed. They found evidence supporting the converse, however; farmers who had adopted no-tillage practices had a higher probability of adopting herbicide-tolerant soybean seed than farmers who had not adopt no-tillage practices. Fernandez-Cornejo and McBride used data from the 1997 USDA Resource Management Study Survey (ARMS) and a two-equation simultaneous probit model to perform their analysis. The data were cross sectional for the year after herbicide-tolerant soybean seed was first introduced, leaving little time for adjustment in tillage practices. Also, the field evidence from the ARMS survey was biased against genetically modified crops because it may have identified some partial adopters as non-adopters if the selected field was in conventional seed (Marra). Marra, Piggott, and Sydorovych found that 76% of all crop acreage in herbicide-tolerant seed in North Carolina was produced with conservation-tillage practices in 2001, while only 64% of crop acreage in conventional seed was produced with conservation-tillage practices. Their specific results for cotton were different, with these two percentages being about the same at close to 73%.

Findings from the aforementioned cross-sectional analyses suggest a simultaneous relationship may exist between adoption of herbicide-tolerant seed and adoption of conservation-tillage practices, but the evidence is inconclusive, especially for cotton. Sufficient annual time series data are now available to investigate the relationship between adoption of these two technologies over time. The Conservation Tillage Information Center (Fawcett and Towery) used a limited time series sample of percentages of acres in glyphosate-tolerant crops by tillage method for 1998 through 2000 and a 2001 survey by the American Soybean Association to suggest a simultaneous relationship between adoption of glyphosate-tolerant crops and conservation-tillage practices in the United States. Our article uses time series data from 1992 through 2004, along with Bayes' theorem and a two-equation simultaneous logit model, to examine the relationship between the adoption of herbicide-tolerant seed and the adoption of conservation-tillage practices in Tennessee cotton production. If adoption of herbicide-tolerant seed influences adoption of conservation-tillage practices, adoption of herbicide-tolerant seed may indirectly lead to greater soil conservation and, if adoption of conservation-tillage practices influences adoption of herbicide-tolerant seed, adoption of conservation-tillage practices may indirectly lead to reduced residual herbicide use and increased farm profits as farmers increase their adoption of herbicide-tolerant seed (Marra, Pardy, and Alston).

The choice of tillage method is a major decision for farmers because of its potential impacts on soil erosion and farm profit. Erosion of agricultural top soils has been recognized as a problem for decades. Federal mandates have encouraged production practices to curb erosion. Anderson and Magleby, and Himlich provide a comprehensive overview of U.S. Government policies designed to encourage conservation of our nation's top soils. For example, Conservation Compliance, established in the 1985 Farm Bill, resulted in farms with highly erodible lands being required to alter cropping patterns and tillage practices to reduce erosion as a requirement for receiving government payments, and in 1991, the Crop Residue Management Action Plan was developed to assist producers in implementing conservation systems. Tennessee has the most erodible cultivated cropland in the United States (Denton) with cotton being produced on some of those erodible soils. The adoption of conservation-tillage practices in cotton production has lagged behind the adoption of conservation tillage in other row crops (Tennessee Department of Agriculture, July 23, 2004). Exploring the relationship between the adoption of herbicide-tolerant seed and the adoption of conservation-tillage practices in Tennessee cotton production could lead to improved and additional policies for reducing soil erosion.

Farmers who adopt conservation-tillage practices may benefit if adopting herbicide-tolerant cotton seed allows them to use more effective herbicide treatment systems (Shoemaker et al.). Weed control is a vital component of conservation tillage. Failure to control weeds with conservation tillage can result in decreased quantity and quality of output. Besides preventing yield loss from weed competition, weed control is particularly important in cotton production because weed trash can stain lint resulting in price discounts (Moore). Herbicide-tolerant seed provides farmers with effective weed control programs that eliminate some of the problems associated with conservation programs (Fawcett and Towery). For example, the introduction of herbicide-tolerant cotton seed has led to a reduction in the number of herbicide applications made by cotton farmers (Carpenter and Gianessi). Investigating the relationship between the adoption of conservation-tillage practices and herbicide-tolerant seed could increase our understanding of ways to increase farm profit and reduce residual herbicide use (Marra, Pardey, and Alston), while conserving soil.

The objectives of this research were: 1) to evaluate the relationship between the adoption of herbicide-tolerant seed and conservation-tillage cotton technologies over time and 2) to quantify the effects of input prices on the adoption of herbicide-tolerant seed and conservation-tillage practices for cotton production in Tennessee.

Methods and Data

Two methods were used to evaluate the relationship between the adoption of herbicide-tolerant cotton seed and conservation-tillage practices in Tennessee. The first method was a comparison of conditional probabilities using Bayes' theorem (Render, Stair, and Hanna) and the second was estimation of a two-equation simultaneous logit model (Amemiya). Both methods assume the probability that a farmer will choose to produce an acre of cotton using a particular technology is equal to the share of cotton acreage produced with that technology.

Bayes' Theorem

Consider two events: 1) event H occurs when an acre of Tennessee cotton is produced with herbicide-tolerant seed and 2) event C occurs when an acre of Tennessee cotton is produced with conservation-tillage practices. The complement of event H ($\overline{H}$) occurs when an acre is produced with conventional cotton seed and the complement of C ($\overline{C}$) occurs when an acre is produced with conventional-tillage practices. Let the probability of an event occurring be represented by the share of total Tennessee cotton acreage in that event. When events H and C are not independent, Bayes' theorem states that the conditional probability of event H occurring given that event C has occurred, P(H|C), is equal to the joint probability of events H and C occurring, P(HC), divided by the marginal probability of event C occurring, P(C), or mathematically (Render, Stair, and Hanna):

(1) $$P(H \mid C) = \frac{P(HC)}{P(C)}.$$

If events H and C are independent, $P(H \mid C) = P(H)$ (Render, Stair, and Hanna). Bayes' theorem can be stated conversely as:

(2) $$P(C \mid H) = \frac{P(HC)}{P(H)},$$

where $P(C \mid H)$ is the conditional probability of event C occurring given that event H has occurred. If events H and C are independent, $P(C \mid H) = P(C)$.

Two other probabilities of interest are the conditional probability of one event occurring given that the complement of the other event has occurred:

(3) $$P(H \mid \overline{C}) = \frac{P(H\overline{C})}{P(\overline{C})} = \frac{P(H) - P(HC)}{1 - P(C)}, \text{ and}$$

(4) $$P(C \mid \overline{H}) = \frac{P(\overline{H}C)}{P(\overline{H})} = \frac{P(C) - P(HC)}{1 - P(H)}.$$

When events H and C are independent, $P(H \mid \overline{C}) = P(H)$ and $P(C \mid \overline{H}) = P(C)$. Independence implies that the conditional probabilities in Equations (1) and (3) are equal, the conditional probabilities in Equations (2) and (4) are equal, and these conditional probabilities equal their respective marginal probabilities. Alternatively, if $P(H \mid C) > P(H \mid \overline{C})$, the adoption of conservation-tillage practices has increased the probability of adopting herbicide-tolerant cotton seed and, if $P(C \mid H) > P(C \mid \overline{H})$, the adoption of herbicide-tolerant seed has increased the probability of adopting conservation-tillage practices. We calculated and compared the conditional probabilities in Equations (1) through (4) using data for 1998 through 2004 (Doane Marketing Research, Inc.) on the percentages of Tennessee cotton acres in herbicide-tolerant seed, P(H), conservation-tillage practices, P(C), and in both technologies, P(HC).

Logit Analysis

Following Garrod and Roberts, assume cotton production can be accomplished using herbicide-tolerant or conventional-seed technologies and that cotton acreage is constrained to a fixed level by exogenous or predetermined events. Let p_H and $p_{\overline{H}}$ represent average profit functions for herbicide-tolerant and conventional-seed technologies, so that the problem faced by farmers is:

(5) Maximize $\sum_i q_i p_i$, subject to $\sum_i q_i = Q$, and $q_i \geq 0$, $i = H$ and $\overline{H}$,

where q_H is cotton acreage in herbicide-tolerant seed; $q_{\overline{H}}$ is cotton acreage in conventional seed; Q is total cotton acreage; and p_i is conditional upon the level of activity q_i ($i = H$ and $\overline{H}$), prices of outputs, and prices of inputs. Our hypothesis is that adoption of herbicide-tolerant seed is not independent of adoption of conservation-tillage practices. If they are not independent, p_i also includes conservation-tillage cotton acreage as an argument.

An equivalent expression for Equation (5) is:

(6) Maximize $\sum_i k_i p_i$, subject to $\sum_i k_i = 1$, $0 \leq k_i \leq 1$, $i = H$ and $\overline{H}$,

where $k_H = q_H / Q$ and $k_{\overline{H}} = q_{\overline{H}} / Q$ are acreage shares of the respective technologies, which are interpreted as the probabilities of adopting the respective technologies. Assuming that k_H and $k_{\overline{H}}$, and therefore q_H and $q_{\overline{H}}$, are dependent on the conditional profits of both technologies, their quantities and shares can be defined as:

(7) $q_i = f_i(p_H, p_{\overline{H}}, Q)$, $i = H$ and $\overline{H}$, and $k_i = f_i \Big/ \sum_i f_i$, $i = H$ and $\overline{H}$.

If we further assume that:

(8) $f_i = e^{g_i(p_H, p_{\overline{H}}, Q)}$, $i = H$ and $\overline{H}$,

then k_i is defined as a universal logit function (Amemiya). Taking $\overline{H}$ as the numeraire gives the following expressions:

(9) $k_H = e^{z_H}/(1+e^{z_H})$ and $k_{\overline{H}} = 1/(1+e^{z_H})$,

where $z_H = g_H - g_{\overline{H}}$. A convenient expression is then derived by taking the natural logarithm of the probability ratio, or odds ratio:

(10) $\mathrm{Ln}(k_H/k_{\overline{H}}) = \mathrm{Ln}(q_H/q_{\overline{H}}) = z_H = g_H - g_{\overline{H}}$.

Equation (10) can be estimated using standard econometric methods if it is stochastic and linear in its arguments, and an estimate of the probability of adopting herbicide-tolerant cotton seed can be obtained. Also, the conditional elasticities of q_H and $q_{\overline{H}}$ with respect to an explanatory variable other than Q can be calculated as (Roberts and Garrod):

(11) $E(q_H, x \mid Q) = x(1-k_H)\partial z_H/\partial x$ and $E(q_{\overline{H}}, x \mid Q) = x(1-k_{\overline{H}})\partial z_{\overline{H}}/\partial x$,

where x is an explanatory variable other than Q and $z_{\overline{H}} = g_{\overline{H}} - g_H$. These conditional elasticities approach zero as k_i (i=H or $\overline{H}$) approaches unity, suggesting that as the choice becomes limited to one alternative, that alternative cannot change in the short run because $q_i = Q$ is fixed. Also, because $\partial z_H/\partial x = \partial g_H/\partial x - \partial g_{\overline{H}}/\partial x$ and $\partial z_{\overline{H}}/\partial x = \partial g_{\overline{H}}/\partial x - \partial g_H/\partial x$, the signs and magnitudes of the respective elasticities depend on the relative marginal acreage responses of farmers to x in using herbicide-tolerant and conventional cotton seed. The weighted sum of these two conditional elasticities equals zero, where the weights are the acreage shares in each seed technology; thus, in the short run, cotton acreage in herbicide-tolerant seed cannot increase (or decrease) without decreasing (or increasing) acreage in conventional seed. If acreage in conservation-tillage practices is an argument of z_H, the influence of conservation-tillage adoption on the adoption of herbicide-tolerant seed and its complement can be evaluated through Equations (11).

If Q is allowed to vary, the elasticities of q_H and $q_{\bar{H}}$ with respect to Q are:

(12) $E(q_H, Q) = Q(1 - k_H)\,\partial z_H/\partial Q + 1$, and $E(q_{\bar{H}}, Q) = Q(1 - k_{\bar{H}})\,\partial z_{\bar{H}}/\partial Q + 1$,

where the weighted sum of these elasticities is unity.

A similar model and elasticities can be hypothesized for the choice between the use of conservation-tillage (C) and conventional-tillage ($\bar{C}$) practices:

(13) $Ln(k_C/k_{\bar{C}}) = Ln(q_C/q_{\bar{C}}) = z_C = g_C - g_{\bar{C}}$,

where $k_j = q_j/Q$ ($j = C$ and $\bar{C}$); q_j is acreage in technology j ($j = C$ and $\bar{C}$); and $Q = q_C + q_{\bar{C}}$. We hypothesize that adoption of conservation-tillage practices is not independent of herbicide-tolerant cotton seed adoption, suggesting that acreage in herbicide-tolerant seed is an argument of z_C. If indeed acreage in conservation-tillage practices is an argument in Equation (10) and acreage in herbicide-tolerant seed is an argument in Equation (13), these two equations form a system of simultaneous equations that must be estimated with appropriate econometric methods that account for simultaneity.

For empirical estimation, Equations (10) and (13) were specified as:

(14) $$Ln\left(\frac{HAC}{100 - HAC}\right) = \beta_0 + \beta_1 CAC + \beta_2 RUPR/COPR + \beta_3 RSPR/CSPR + \beta_4 D + \beta_5 CTAC + e_H,$$

(15) $$Ln\left(\frac{CAC}{100 - CAC}\right) = \gamma_0 + \gamma_1 HAC + \gamma_2 CHPR/FUPR + \gamma_3 RAIN + \gamma_4 DRAIN + \gamma_5 CTAC + e_C,$$

where HAC is the percentage of Tennessee cotton acres in herbicide-tolerant seed; CAC is the percentage of Tennessee cotton acres in conservation tillage practices; RUPR is the Roundup price ($/pint); COPR is the Cotoran price ($/pint); RSPR is the Roundup-Ready cotton seed price

($/lb); CSPR is the conventional cotton seed price ($/lb); D is a binary variable equal 1 for 1999 through 2004 and 0 otherwise; CTAC is Tennessee cotton acres (100,000s); CHPR is the U.S index of prices paid by farmers for chemicals (2002=100); FUPR is the U.S index of prices paid by farmers for fuel (2002=100); RAIN is county average cumulative rainfall for April and May for the five highest cotton producing counties in Tennessee (inches); DRAIN is a binary variable equal to RAIN if the change in RAIN from the previous year was greater than 0 inches and 0 otherwise; the βs and γs are parameters to be estimated; and e_H and e_C are random errors.

Equations (14) and (15) were estimated with Tennessee annual time-series data for the 1992-2004 period, and the elasticities in Equations (11) and (12) and similar ones for tillage practices were calculated at the means of the data. Roundup (RUPR), Cotoran (COPR), Roundup-Ready seed (RSPR), and conventional seed (CSPR) prices were taken from annual Tennessee field crop and cotton budgets (Johnson, 1992-1994; Gerloff, 1995-1999; Gerloff, 2000-2003). U.S. indexes of prices paid by farmers for chemicals (CHPR) and fuel (FUPR) were taken from the Council of Economic Advisors. Data for the rainfall variables were received from the National Climatic Data Center. Tennessee cotton acreage in herbicide-tolerant seed and conventional seed were received from Doane Marketing Research, Inc., and conservation-tillage, conventional-tillage, and total Tennessee cotton acres were found in Tennessee Department of Agriculture (1996-2003; 2004). Price ratios were used in Equations (14) and (15) to preserve degrees of freedom and reduce multicollinearity. National indexes of prices paid by farmers were used as proxies for Tennessee prices because time series data were not available for Tennessee.

Economic theory and other attributes of the variables in Equations (14) and (15) allowed formation of *a priori* hypotheses about the signs of the parameters. The motivating hypothesis for this research was that the adoption of conservation-tillage practices positively influences the adoption of herbicide-tolerant cotton seed and that the adoption of herbicide-tolerant seed positively influences the adoption of conservation-tillage practices; thus, β_1 and γ_1 were both expected to be positive, indicating that a change in the probability of adopting conservation-tillage cotton (CAC) positively influences the probability of adopting herbicide-tolerant cotton seed and that a change in the probability of adopting herbicide-tolerant cotton seed (HAC) positively influences the probability of adopting conservation-tillage practices.

Roundup (RUPR) and Cotoran (COPR) prices were included in Equation (14) as proxies for the prices of herbicides used to produce herbicide-tolerant and conventional-seed cotton, respectively. These herbicide prices were chosen because herbicide-tolerant cotton is produced almost entirely with Roundup-Ready seed and Cotoran was a herbicide consistently recommended for conventional-seed cotton in the University of Tennessee cotton budgets (Johnson, 1992-1994; Gerloff, 1995-1999; Gerloff, 2000-2003). With Roundup being an input in the production of herbicide-tolerant cotton, a change in RUPR was expected to negatively influence the probability of adopting herbicide-tolerant cotton seed and positively influence the use of conventional cotton seed. Conversely, a change in COPR was expected to negatively influence the use of conventional cotton seed and positively influence the probability of adopting herbicide-tolerant cotton seed; thus, β_2 was expected to be negative. Similarly, Roundup-Ready cotton seed and conventional cotton seed are inputs in the production of herbicide-tolerant cotton and conventional-seed cotton, respectively; therefore, β_3 was expected to be negative.

Although Roundup-Ready cotton seed became commercially available in 1997, insufficient supply was available to meet farmer demand. After 1998 most farmers were able to purchase Roundup-Ready cotton seed if they wanted it at the prevailing price. The binary variable D was included in Equation (14) to account for differences in years when sufficient Roundup-Ready seed was available to meet demand compared with years when Roundup-Ready seed was not available or not available in quantities sufficient to meet demand. Thus, β_4 was expected to be positive.

The sign of γ_2 was expected to be negative because chemicals are a more important input in the production of conservation-tillage cotton and fuel is a more important input in the production of conventional-tillage cotton. A decrease in the price of chemicals (CHPR) relative to the price of fuel (FUPR) would decrease the cost of producing conservation-tillage cotton relative to the cost of producing conventional-tillage cotton, encouraging farmers to move away from conventional-tillage towards conservation-tillage cotton production.

Conservation-tillage practices reduce the risk of late planting because fewer machinery operations are required and crops can generally be planted when conditions are too wet for conventional-tillage operations (Bates and Denton; Harper). Consequently, heavy rainfall during April and May, when farmers are potentially tilling their soil and planting their cotton, was hypothesized to encourage cotton farmers to retrofit their planters for no-till planting. Conversely, light rainfall during these months might encourage farmers to engage in what some call "recreational tillage" because many farmers feel they should be out working in the field when the weather is good (e.g., Alesii and Bradley, personal communication; Delta Farm Press; Fletcher). Our hypothesis was that γ_3 is positive; however, a positive γ_3 implies that increases in rainfall encourage adoption of conservation-tillage practices by the same amount as decreases in rainfall encourage abandonment of conservation-tillage practices. DRAIN was included in Equation (15) to test the hypotheses that increases in rainfall from the previous year encourage adoption of conservation-tillage practices more than decreases in rainfall from the previous year encourage their abandonment; thus, γ_4 was expected to be positive.

Theoretically, cotton is produced on the "best" cotton land in terms of potential profit compared with other crops. Consequently, increases in cotton acreage would typically occur on marginal cotton land that may be more erodible than land already in cotton production. We hypothesized that farmers are more likely to use conservation-tillage practices on this marginal land than on the less erodible land already in cotton production; thus, γ_5 was expected to be positive. Farmers who increase cotton acreage or who produce cotton for the first time may be less risk averse than those who do not, and they may be more likely to adopt new technologies. If this hypothesis were correct, β_5 would be positive, and the positive expectation for γ_5 would be reinforced.

Results

Bayes' Theorem

Shares of Tennessee cotton acreage produced with each technology and with both technologies for 1998 through 2004 and the conditional probabilities in Equations (1) through (4) are reported in Table 1. Except in 2003, the conditional probability of using herbicide-tolerant seed given conservation-tillage practices, P(H|C), is greater than the conditional probability of using herbicide-tolerant seed given conventional-tillage practices, $P(H|\bar{C})$, which indicates that cotton farmers who had adopted conservation-tillage practices had a higher probability of adopting herbicide-tolerant cotton seed than those farmers who had not adopted conservation-tillage practices. This finding suggests that diffusion of herbicide-tolerant seed technology was faster among farmers who used conservation-tillage practices than among those who did not. Also, the gap between $P(H|C)$ and $P(H|\bar{C})$ narrows over time, and in 2003 and 2004 these conditional probabilities are almost equal to each other and equal to the marginal probability of adopting herbicide-tolerant seed (P(H), suggesting that differences in tillage practices had less influence on the probability of adopting herbicide-tolerant seed in later years because almost all Tennessee cotton acreage was in herbicide-tolerant seed in 2003 and 2004 regardless of tillage method.

Results also suggest that adoption of herbicide-tolerant cotton seed influenced the probability of adopting conservation-tillage practices (Table 1) as indicated by $P(C|H)$ being greater than $P(C|\overline{H})$ every year except 2003. In this case, however, the gap between the two conditional probabilities does not narrow over time, indicating that adoption of herbicide-tolerant seed continued to have an influence through time on the probability of adopting conservation-tillage practices. The conditional probability of 1 in 2003 resulted from the data reporting only 1,088 Tennessee cotton acres being produced with conventional cotton seed in that year, all of which were produced with conservation-tillage practices.

The Bayes' results suggest a simultaneous relationship between adoption of herbicide-tolerant cotton seed and adoption of conservation-tillage practices. These results bode well for the simultaneity hypothesis in the logit analysis.

Logit Analysis

Results from the simultaneous logit model estimated with three-stage least squares are presented in Table 2. Three-stage least squares (3SLS) was used for estimation because the cross-equation correlation coefficient from the 2SLS residuals (-0.77) was significantly different from zero at the 5% level (t_{11df} = -3.94). All coefficients but two have their hypothesized signs and the high system weighted-average R^2 suggests a good fit to the data. The coefficient for DRAIN in Equation (15) has an unexpected negative sign but is not significantly different from zero at the 5% level. Multicollinearity diagnostics (Belsley, Kuh, and Welsch) indicated collinearity between the intercept and CTAC in both equations. Thus, multicollinearity may have seriously degraded the standard errors of the coefficients for CTAC in both equations, rendering the results from hypothesis testing inconclusive for those coefficients (Belsley, Kuh, and Welsch).

Results from the estimation of Equation (14) in Table 2 suggest that the probability of adopting conservation-tillage practices (CAC) significantly influenced the probability of adopting herbicide-tolerant cotton seed and results from the estimation of Equation (15) indicate that the probability of adopting herbicide-tolerant seed (HAC) significantly influenced the probability of adopting conservation-tillage practices for Tennessee cotton production. As suggested by the conditional probability results and the mean elasticities in Table 2, these influences are not symmetric. While both elasticities are positive, the number of cotton acres in herbicide-tolerant seed increases (decreases) by 4.29% for a 1% increase (decrease) in the probability of adopting conservation-tillage practices (CAC), while the number of cotton acres in conservation-tillage practices increases (decreases) by only 0.26% for a 1% increase (decrease) in the probability of adopting herbicide-tolerant seed (HAC).

Results for the ratio of Roundup Ready to conventional seed prices (RSPR/CSPR) in Table 2 indicate that the short-run supply of Tennessee cotton acreage in herbicide-tolerant seed increases (decreases) by 1.18% when the Roundup Read cotton seed price decreases (increases) by 1% relative to the conventional cotton seed price. Similarly, the short-run supply of Tennessee acreage in conservation-tillage cotton increases (decreases) by 1.6% when the price of chemicals decreases (increases) by 1% relative to the price of fuel (CHPR/FUPR).

The finding that the coefficient for RAIN is statistically significant while the coefficient for DRAIN is not (Table 2) suggests that symmetry exists in cotton farmers' response to increases or decreases in spring rainfall. The elasticity for RAIN indicates that conservation-tillage cotton acreage increases by 0.71% when spring rainfall increases by 1% and it decreases by the same amount when rainfall decreases by 1%, other things constant.

Conclusions

Results suggest that the introduction of herbicide-tolerant cotton seed in Tennessee increased the probability that farmers would adopt conservation-tillage practices. Along with the direct benefits of substituting none residual herbicides for residual herbicides and increasing profit potential, the introduction of herbicide-tolerant cotton seed may have indirectly contributed to increased conservation of Tennessee soils. Also, farmers who had previously adopted conservation-tillage practices were more likely to adopt herbicide-tolerant cotton seed, indirectly reducing their use of residual herbicides and increasing their profit potential as they reduced erosion. The simultaneous relationship between adoption of herbicide-tolerant cotton seed and adoption of conservation-tillage practices for cotton production likely contributed to reduced soil erosion, reduced residual herbicide use, and increased profit during a period of low cotton prices.

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Table 1. Probabilities Showing the Relationships between Adoption of Herbicide-Tolerant Cotton Seed and Conservation-Tillage Cotton Production Practices, 1998-2004

Probability	1998	1999	2000	2001	2002	2003	2004
Proportion of Cotton Acreage [a]							
Herbicide-Tolerant, P(H)	0.091	0.677	0.845	0.934	0.959	0.998	0.995
Conservation-Tillage, P(C)	0.364	0.549	0.670	0.777	0.709	0.735	0.782
Herbicide-Tolerant and Conservation-Tillage, P(HC)	0.061	0.410	0.625	0.732	0.696	0.733	0.781
Conditional Probability [b]							
$P(H \mid C)$	0.169	0.747	0.932	0.968	0.981	0.997	0.999
$P(H \mid \overline{C})$	0.047	0.593	0.668	0.817	0.905	1.000	0.981
$P(C \mid H)$	0.674	0.605	0.740	0.805	0.726	0.735	0.785
$P(C \mid \overline{H})$	0.333	0.431	0.294	0.377	0.331	1.000	0.143

[a] Source: Doane Marketing Research, Inc.

[b] $P(H \mid C)$ and $P(H \mid \overline{C})$ are the conditional probabilities of a Tennessee cotton acre being produced with herbicide-tolerant seed (H) given that it is produced with conservation-tillage practices (C) or conventional-tillage practices ($\overline{C}$), respectively. $P(C \mid H)$ and $P(C \mid \overline{H})$ are the conditional probabilities of a Tennessee cotton acre being produced with C given that it is produced with H or conventional cotton seed ($\overline{H}$), respectively.

Table 2. Three-Stage Least Squares Regression and Elasticities for Cotton Acreage Logit Model

Herbicide-Tolerant Seed, Equation (14)			Conservation-Tillage Practices, Equation (15)		
Variable[a]	Parameter Estimate	Elasticity	Variable[a]	Parameter Estimate	Elasticity
INTERCEPT	-0.752 (5.332)[b]		INTERCEPT	-0.328 (1.194)	
CAC	0.142*** (0.040)	4.29[c] [-3.19]	HAC	0.013*** (0.002)	0.26[d] [-0.29]
RUPR/COPR	-0.254 (0.886)	-0.34[e] [0.25]	CHPR/FUPR	-1.603** (0.602)	-0.81[e] [0.89]
RSPR/CSPR	-1.791** (0.571)	-1.18[e] [0.88]	RAIN	0.150*** (0.043)	0.71 [-0.79]
D	1.703 (0.1.877)	0.45 [-0.34]	DRAIN	-0.019 (0.015)	0.62[f] [-0.69]
CTAC	-0.649 (0.756)	-1.14 [2.60]	CTAC	0.048 (0.157)	1.13 [0.86]
System Weighted R^2		0.97	System Degrees of Freedom		14

[a] Variables are defined in Table 1.
[b] Numbers in parentheses below parameter estimates are asymptotic standard errors.
[c] These elasticities show the percentage change in cotton acres in herbicide-tolerant seed for a 1% change in the variable in the row and the elasticities in brackets are for conventional seed.
[d] These elasticities show the percentage change in the number of cotton acres in conservation-tillage practices for a 1% change in the variable in the row and the elasticities in brackets are for conventional-tillage practices.
[e] These elasticities are for the ratio of the variables in the row, for the variable in the numerator holding the denominator constant, or for the variable in the denominator holding the numerator constant with the latter having the same magnitude but opposite sign.
[f] These elasticities are for the sum of the coefficients for RAIN and DRAIN at the mean of RAIN.
, * Significantly different from zero at the 5% and 1% levels, respectively.