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Adoption of Conservation-Tillage Practices and Herbicide-Resistant Seed in Cotton Production

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Agricultural Resource Management Survey data for 2003 were used to estimate logit models for adoption of conservation-tillage practices and herbicide-resistant/stacked-gene cottonseed in the United States. The specification allowed for the possibility that adoption of one technology could influence adoption of the other. However, the null hypothesis that the technologies are adopted independently could not be rejected. The coefficient for herbicide-resistant cotton adoption was positive in the conservation-tillage adoption equation, but significant only at the 5.1% (10.2%) level in one- (two-) tailed tests. The coefficient for conservation-tillage adoption was positive in the herbicide-resistant seed adoption equation, but significant only at the 7% (14%) level in one- (two-) tailed tests. Prior adoption of no-till had a significant, positive impact on the conservation-tillage adoption. Compared to Delta states, Southern Plains and Western states were less likely to adopt either technology. Some practical limitations of analyzing complex survey data with limited research access are discussed.

Key words: conservation tillage, cotton, genetically modified seed, herbicide-resistant cotton, stacked-gene cotton, simultaneous logit model, single-equation logit model, technology adoption, jackknife.

The Natural Resources Conservation Service (NRCS) defines conservation tillage as a tillage system that leaves enough crop residue to adequately protect the soil from erosion throughout the year. The percent of cover required varies by field according to soil type, slope, crop rotation, winter cover crops used and other factors (NRCS website). Conservation tillage in general and no-till practices in particular have increased over the past few years (Figures 1 and 2). Yet, despite the apparent advantages of conservation tillage in reducing soil erosion, soil degradation, runoff, and in improving soil quality (Edwards, 1995; Sandretto, 1997), some farmers adopt no-till or minimum-till while others do not.

The use of conservation-tillage (CT) practices may be even more important in cotton production than other row-crop production because of the minimal amount of residue left on the soil surface. Crop residues after planting average 3% for cotton compared with 29% for corn (US Department of Agriculture Economic Research Service [USDA ERS], 1997). Yet adoption of conservation tillage is lower for cotton than for other crops in the United States. Additionally, it has been suggested that the adoption of CT practices impacts the adoption of herbicide-resistant (HR)[1] cotton and vice versa (Fawcett & Towery, 2005; Roberts, English, Gao, & Larson, 2006). Therefore, if CT practices impact HR cotton[2] adoption, then those practices can indirectly reduce residual herbicide use and affect farm profits; and conversely, if HR cotton adoption impacts CT practices, then HR cotton adoption may indirectly reduce soil erosion (Marra, Pardey, & Alston, 2003) through provision of effective and inexpensive weed control (Carpenter & Gianessi, 1999; Fawcett & Towery, 2005).

Broadly speaking, there are three reasons a study on conservation tillage in cotton is important. First, conservation tillage (either no-till or reduced-tillage practices) may reduce soil erosion caused by wind or water by maintaining crop residue on the soil surface (Harper, 1996), increasing water filtration and moisture retention, and reducing surface sediment, water runoff, and chemical runoff. This is especially important in cotton production where farmers make extensive use of fertilizers and chemicals. Second, with the use of HR or stacked-gene (SG) seed technology, CT practices indirectly reduce the use of residual herbicides and may

1. *The term "herbicide-resistant" (HR) is sometimes used in recent literature to replace the term "herbicide-tolerant."*
2. *For the purpose of this study, HR cotton was defined to include both HR and stacked-gene (SG) varieties. SG cotton includes the characteristics of both HR and insect-resistant (Bt) technologies.*

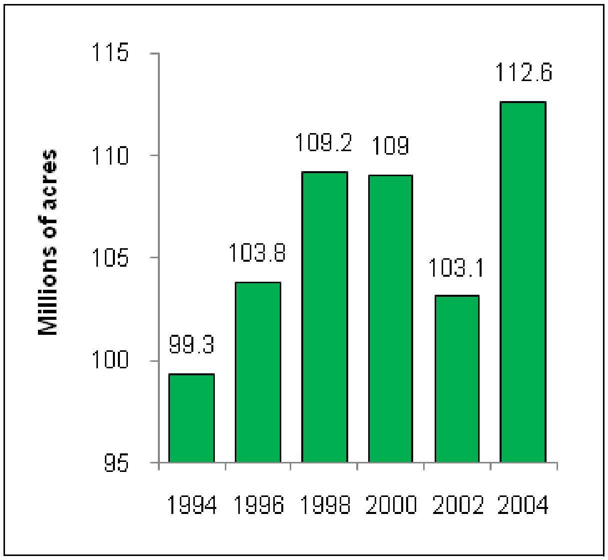

Figure 1. Conservation-tillage adoption in the United States, 1994-2004.
Source: Conservation Technology Information Center.

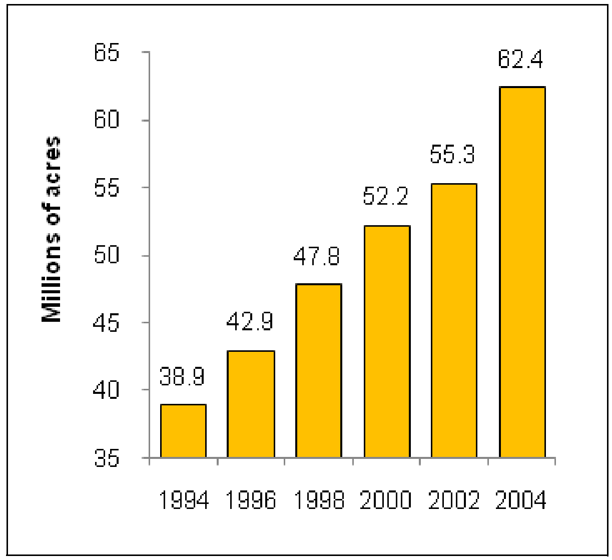

Figure 2. No-till adoption in the United States, 1994-2004.
Source: Conservation Technology Information Center.

increase profit potential (Marra et al., 2003). Third, notwithstanding its apparent benefits—especially cost savings from reduced labor, fuel, and machinery costs (Harper, 1996)—CT practices have been adopted by some farmers, but not all (Martin, 2002). Cooke (2002, pp. 26) contends that "lack of information on the economic benefits has inhibited a large number of farmers in the Mid-south from considering such practices ... not only for cotton but other crops" as well.

Technology adoption literature in general has studied different aspects of adoption, including the costs of adoption (Kurkalova, Kling, & Zhao, 2003), impact of adoption on efficiency (Langemeier, 2005), different stages of adoption (Barham, Jackson-Smith, & Moon, 2002), reversible technology adoption (Baerenklau & Knapp, 2005), role of human capital (Foster & Rosenzweig, 1995; Rahm & Huffman, 1984), risk (Marra & Carlson, 1987), and simultaneous adoption of technology and productivity (McBride & El-Osta, 2002; Zepeda, 1994).

Past studies have examined the benefits and costs of CT and HR technologies (Marra, Piggott, & Sydorovych, 2005) and the simultaneous adoption of those technologies (Fernandez-Cornejo & McBride, 2002; Frisvold & Boor, 2005; Marra et al., 2005; Roberts et al., 2006). For example, Fernandez-Cornejo and McBride (2002) used cross-sectional data for 1997 from the USDA's Agricultural Resource Management Survey (ARMS) to investigate a potential simultaneous relationship between HR soybean seed and CT practices using two simultaneously estimated binomial probit models, and compared those results with two single-equation probit models. Fernandez-Cornejo and McBride's (2002) study suggested that accounting for simultaneity was important for the no-till decision, but not for the seed-use decision. However, the study was conducted only one year after HR soybean seed was introduced. Thus, insufficient time might have transpired for adequate adjustment in tillage practices. Using data for later years may reveal that HR seed does impact tillage practices.

In a more recent study with time-series data for 1992-2004, Roberts et al. (2006), using Bayes' theorem and a two-equation simultaneous logit model, found the introduction of HR cotton in Tennessee increased the probability that farmers would adopt conservation tillage and farmers who had previously adopted CT practices were more likely to adopt HR cotton. They concluded that the simultaneous adoption of conservation tillage and HR cotton reduced soil erosion and residual herbicide use, and increased profit.

Currently, some information exists on the adoption of CT and HR technologies for some crops, but except for the Roberts et al. (2006) study for Tennessee, little information exists on the adoption of these technologies in US cotton production. This study attempted to fill that void by identifying the factors that influence the adoption of CT and HR technologies in cotton production. The overall objective of this research was to identify the factors that lead to adoption of conservation tillage in

US cotton production. More specifically, the study sought to identify the farm and farmer characteristics that drove the adoption of CT practices (i.e., no-till and reduced till: ridge-till, strip-till, and mulch-till) and the impact of conservation tillage on the adoption of HR cotton across the United States.

Several alternative procedures, such as probit and logit models, have been described by Maddala (1983) to handle discrete choices such as adoption. If the issue at hand is one of simultaneous adoption of multiple decisions, multinomial logit or multinomial probit models are generally used to evaluate such decisions. Wu and Babcock (1998) used multinomial logit and ordinary least squares (OLS) in a two-stage polychotomous-choice selectivity model (Lee, 1983) to account for selection bias in simultaneously analyzing the choice of alternative crop management practices/plans, and Dorfman (1996) used multinomial probit to model multiple adoption decisions. Binomial logit adoption models are used for binary choices. Soule, Tegene, and Wiebe (2000), for example, used a binary logit adoption model with 1996 ARMS data to analyze the influence of land tenure on the adoption of conservation practices in US corn production.

Testing of simultaneous adoption of conservation tillage and genetically engineered cotton has generated interest in recent crop-production literature. It is believed, when considered together, conservation tillage and HR cotton seem to increase potential environmental benefits while decreasing certain costs to producers. That is, the diffusion of conservation tillage positively influences the diffusion of HR cotton and vice versa. To test this hypothesis, Frisvold and Boor (2005) used state-level data on HR cotton diffusion and CT diffusion from 16 US states to compare estimates from OLS, two-stage least squares (2SLS), and three-stage least squares (3SLS) in a simultaneous-equation estimation framework. Based on results from the 3SLS model, they rejected the null hypothesis that diffusion of each technology was independent of diffusion of the other.

Data and Methods

The USDA's 2003 ARMS data were used to characterize farm households that adopted CT and HR seed technologies in cotton production. The ARMS is a collection of annual surveys focusing on farm enterprise and specific crops. The 2003 ARMS focused on cotton. The target population of the ARMS is any farm business that produces at least $1,000 worth of agricultural production during the calendar year (McBride & El-Osta, 2002). It is essentially the only annual source of data on the finances and practices of a nationally representative sample of US farms that includes information on the characteristics of farm operators and their households (Lambert, Sullivan, & Claasen, 2007). Though some questions asked in the survey are field-level, they apply for the farm as well. Moreover, the technology questions are currently asked in terms of the farm, thus eliminating the potential biases in data collected in earlier years. Therefore, the terms "field" and "farm" may be read synonymously for the purpose of this analysis.

Confidentiality issues limit access to the ARMS data and make analyses on them difficult and painful. For the current study, upon request and promise of pre-publication review, the USDA Economic Research Service in Washington, DC, sent the data on a compact disc to the Jackson, MS, office of the USDA's National Agricultural Statistics Service (NASS), in which office the data were accessed and analyzed under surveillance. Results and all analyzed data were thoroughly scrutinized before departing the NASS office during each visit. Raw data were not allowed to be carried out of the NASS office under any circumstances. This article brings to light the possible effects of these restrictive conditions coupled with some of the problems encountered with the analysis of cross-section data from a complex survey.

Following Fernandez-Cornejo and McBride (2002),[3] a system of simultaneous binomial logit models (Amemiya, 1981), using the 3SLS procedure, as well as two single-equation logit models (Maddala, 1983) were estimated for CT practices and HR cotton, respectively. Data from the 2003 ARMS, with samples of cotton farms across the United States, were used to estimate the adoption models. The explanatory variables for each equation included demographic information of the survey respondents (age, college education, annual gross farm income, length of tenure in cotton farming), farm characteristics (farm size, farm labor, percentage of cotton in total acres harvested, if cotton was grown in the previous year [2002], if the surveyed field was declared "highly erodible land" [HEL] by NRCS, if no-till was practiced in 2002), and region-specific dummy variables, one for each cotton-producing region.

The logit equation is written as (Greene, 1993)

3. *In particular, Fernandez-Cornejo and McBride (2002) used probit estimation for CT practices in soybean production, but essentially the results for logit and probit are comparable (Greene, 1993; Maddala, 1983).*

$$\Pr(Y=1)=\frac{e^{\beta' x}}{1+e^{\beta' x}}, \tag{1}$$

with the cumulative distribution function given by:

$$F(\beta' x)=\frac{1}{1+e^{\beta' x}}, \tag{2}$$

where β' represents the vector of parameters associated with the factors x.

Assuming the probability that farmer n will choose to produce cotton using a particular technology (CT practices or HR seed) is equal to the proportion of cotton farmers using that technology, the individual empirical models to be estimated may be specified as

$$\begin{aligned} CONSTILL = {} & \beta_0 + \beta_1 HRCOTT + \beta_2 LABEXP + \beta_3 CTA \\ & + \beta_4 CTP + \beta_5 HEL + \beta_6 CROP02 + \beta_7 PNT \\ & + \beta_8 AGE + \beta_9 EDU + \beta_{10} TEN + \beta_{11} GFI \\ & + \sum_{\substack{i=12 \\ j}}^{15} \beta_i REGION_j + \varepsilon_T, \end{aligned} \tag{3}$$

$$\begin{aligned} HRCOTT = {} & \gamma_0 + \gamma_1 CONSTILL + \gamma_2 LABEXP + \gamma_3 CTA \\ & + \gamma_4 CTP + \gamma_5 HEL + \gamma_6 CROP02 + \gamma_7 PNT \\ & + \gamma_8 AGE + \gamma_9 EDU + \gamma_{10} TEN + \gamma_{11} GFI \\ & + \sum_{\substack{i=12 \\ j}}^{15} \gamma_i REGION_j + \varepsilon_G, \end{aligned} \tag{4}$$

where *CONSTILL* is a dummy variable indicating whether or not CT practices were adopted; *HRCOTT* is a dummy variable indicating whether or not HR cottonseed was planted; *LABEXP* is the total labor expense on the farm ($100,000); *CTA* denotes the total harvested cotton acres (dryland and irrigated) on the farm (100 acres); *CTP* is the percentage of cotton acres on the farm; *HEL* is a dummy variable indicating whether NRCS classified any part of the field surveyed as HEL; *CROP02* is a dummy variable indicating whether cotton was the crop grown in the prior year, 2002; *PNT* is a dummy variable indicating whether no-till was used in the surveyed field in the year before the survey, 2002; *AGE* is the age of the principal farm operator; *EDU* is a dummy variable indicating the surveyed farm operator's education level (whether or not college graduate); *TEN* is the length of tenure (in years) of the operator household for the surveyed field; *GFI* is the gross farm income in 2003 ($100,000); *REGION* is a set of four dummies with *REGION1* including Alabama, Florida, and Georgia; *REGION2* includes North Carolina, South Carolina, and Virginia; *REGION4* includes Texas, Oklahoma, and Kansas; and *REGION5* includes Arizona, California, and New Mexico, with *REGION3* (Arkansas, Louisiana, Mississippi, Missouri, and Tennessee) excluded as the reference region; ε_T and ε_G are random error terms; and the subscript n for the n^{th} farmer is suppressed for clarity.

The adoption of conservation tillage was expected to positively influence the adoption of HR cotton. Fields in states with more HEL acres would likely demonstrate a higher probability of adoption of conservation tillage and/or HR cotton than states with less HEL acres. However, due to the classification of states into regions, no *a priori* signs could be assigned to the regional dummies. All other variables except *AGE* were expected to have positive coefficients. Table 1 provides detailed definitions of all explanatory variables and summary statistics (frequencies, means, and standard deviations of regular variables).

To determine the quantitative effects of one technology's diffusion on the other, marginal effects were calculated. Marginal effects measure changes in the probability of adopting each of the technologies from changes in the explanatory variables (Greene, 1993; Liao, 1994; Long, 1997; Maddala, 1983). Marginal effects of continuous variables were calculated at the means of the data.[4] For dummy variables, a value of 0 was used if the mean was less than 0.5 and a value of 1 if the mean was greater than or equal to 0.5 (Obubuafo, Gillespie, Paudel, & Kim, 2006; Schlotzhauer, personal communication, May 12, 2006).[5]

Assuming asymptotic normality of the error terms, the Hausman (1978) test was conducted to test for specification errors and endogeneity. Under the null hypothesis of no measurement error and no endogeneity

4. *In sufficiently large samples, marginal effects calculated by averaging the individual marginal effects at each observation (Bell, Roberts, English, & Park, 1994; Neter, Wasserman, & Kutner, 1983; Pindyck & Rubinfeld, 1976) would give the same results as obtained here from the means of the data (Greene, 1983, pp. 876) by adding an observation with all means and calculating the marginal effects at that point.*

5. *Anderson and Newell (2003) have developed a novel way of simplifying the calculation of marginal effects in logit and probit models (making them a function of only the estimated constant term) and their associated asymptotic variances by normalizing the explanatory variables at any desired value.*

Table 1. Summary of variables used in the logit models.[a]

Explanatory variable	Definition (Frequency used In regression)[b]	Mean (Std. dev.)[c]
	Farm characteristics	
CONSTILL	If practiced conservation tillage (no-till, ridge-till, strip-till, and mulch-till), i.e., if used one or more conservation-tillage equipment (Yes="1"=474 in sample=4,977 in population; No="0"=779 in sample=15,020 in population)	0.25
HRCOTT	If used herbicide-resistant and/or stacked-gene seed (Round-up Ready plus Liberty Link) (Yes="1"=935 in sample=13,277 in population; No="0"=318=6,720 in population)	0.66
LABEXP	Labor expense per cotton farm in 2003 in US dollars, scaled by $100,000s	0.54 (0.06)
CTA	Cotton acres (dryland and irrigated) harvested in farm on average in 2003, scaled by 100s	5.66 (0.30)
CTP	Percentage of cotton acres harvested in farm in 2003	0.58 (0.03)
HEL	If NRCS[d] classified any part of the field surveyed highly erodible land (Yes="1"=154 in sample=3,626 in population; No="0"=1,099 in sample=16,371 in population)	0.18
CROP02	If planted 'prior' (continuous) cotton crop in Spring/Summer 2002 (Yes="1"=902 in sample=12,144 in population; No="0"=351 in sample=7,853 in population)	0.61
PNT	If previously 'no-tilled' (i.e., soil and previous crop residue left undisturbed from harvest to planting) in Spring/Summer 2002 (Yes="1"=309 in sample=2,895 in population; No="0"=944 in sample=17,102 in population)	0.14
	Farmer characteristics	
AGE	Age (during survey in 2003) in years	54.52 (0.53)
EDU	If college graduate (Yes="1"=343 in sample=5,237 in population; No="0"=910 in sample=14,760 in population)	0.26
TEN	Length of tenure (in field surveyed in 2003) of principal operator in years	17.60 (1.05)
GFI	Estimated pre-tax gross farm income of respondent in 2003 in US dollars, scaled by $100,000s	5.81 (0.36)
	Farm location (*REGION*)[e]	
REGION1	If farm is located in Region 1 (Yes="1"=144 in sample=3,123 in population; No="0"=932 in sample=16,874 in population)	0.16
REGION2	If farm is located in Region 2 (Yes="1"=204 in sample=2,078 in population; No="0"=872 in sample=17,919 in population)	0.10
REGION4	If farm is located in Region 4 (Yes="1"=203 in sample=9,394 in population; No="0"=873=10,603 in population)	0.47
REGION5	If farm is located in Region 5 (Yes="1"=109 in sample=1,813 in population; No="0"=967=18,184 in population)	0.09

[a] *Total number of observations, n=1,253 respondents in sample=19,997 farms in the population (using the NASS "full-sample weight" variable).*

[b] *Except age and location, all other variables were hypothesized to have positive signs on their estimated coefficients. Age was expected to have a negative sign, and the signs of the location variables could not be hypothesized a priori, since it was difficult to speculate on reasons for differences among regions.*

[c] *Standard deviation of 'continuous' variable. Means are from the expanded full sample, and standard deviations use the NASS delete-a-group jackknife procedure.*

[d] *Natural Resources Conservation Service (citation).*

[e] *The dummy variable for Region 3 (AR, LA, MS, MO, TN), with 495 observations in sample=3,589 observations in population of "yes" (population mean=0.18), was omitted. This facilitates comparison of adoption probabilities in Region 3 with the other four regions: Region 1 (AL, FL, GA), Region 2 (NC, SC, VA), Region 4 (KS, OK, TX), and Region 5 (AZ, CA, NM).*

(Greene, 1993), the null hypothesis could not be rejected, suggesting that a single-equation estimation would be more appropriate, resulting in efficient estimates. Any supposed endogeneity among the regressors would not have deleterious effects on the least-squares estimators (Baum, Schaffer, & Stillman, 2007) or, in this case, single-equation estimates. Therefore, the results from only the single-equation logits are discussed in the "Results" section below.

Because the survey data are cross-sectional, all that the Hausman (1978) test implies about the timing of adoption is that some farmers adopted CT practices first and then HR seed, while others adopted HR seed first and then CT practices. Yet others might have adopted them at the same time, but the test indicates that, if they did adopt them at the same time, the statistical properties of the estimators from the binary logit models are not adversely affected. It is not difficult to imagine how farmers who had already adopted CT practices before HR seed was introduced might have a greater probability of adopting HR seed when it was introduced or at some time during or before 2003. Similarly, it is easy to imagine how farmers who had not adopted CT practices before HR seed was introduced might adopt HR seed first and then decide that they could improve efficiency even more by adopting CT practices sometime during or before 2003.[6]

The ARMS uses a complex stratified, multiphase, nonrandom survey design that may render naïve standard errors obtained by classical statistical algorithms invalid insofar as inferences on point estimates are concerned. Each observation in the ARMS represents a number of similar farms based on factors such as land use, farm size, etc., with the particular number being the survey weight or survey expansion factor. In effect, this is the inverse of the probability that the surveyed farm is selected to be surveyed (El-Osta, Mishra, & Morehart, 2007).

In order to alleviate the possibility of such a bias in measurement, the USDA NASS has established standards that allow valid inferences based on the entire population. These standards were used in this analysis. In particular, "full-sample weights" were used to calculate means, parameter estimates, and marginal effects, and "replicate weights" were used in what is called the "delete-a-group jackknife" procedure to calculate variances and, hence, standard deviations of all point estimates (Ahearn, El-Osta, & Deewbre, 2006; Dubman, 2000; El-Osta, Mishra, & Ahearn, 2004; El-Osta, Mishra, & Morehart, 2007; Kott, 1997a; Kott, 1997b; Lambert et al., 2007; Lohr, 1999). The sample used in the analysis included 1,253 respondents, which when properly expanded using survey weights yielded a population of 19,997 farm operator households (Table 1).

6. *Also due to the use of cross-sectional nature of our data, instead of establishing causality, effects, determinants, or impacts, our regression results may be read as implying correlations, relationships, and associations. The "correlations" presented, however, assume ceteris paribus conditions.*

Results

Multicollinearity diagnostics (Belsley, Kuh, & Welsch, 1980) diagnosed no serious degradation of standard errors among the explanatory variables. For the CT equation (Equation 3), logit estimation revealed a statistically significant constant. The main variable of interest in this equation, *HRCOTT,* was not significant even at the 10% level in a two-tailed test. With a *t* ratio of 1.637, the coefficient for *HRCOTT* was significant at the 5.1% (10.2%) level for a one- (two-) tailed test. However, Fernandez-Cornejo and McBride (2002) found HR (soybean) seed adoption to be a significant explanatory factor in the single-equation no-till model, though this variable was not significant in their study with the simultaneous model. In the simultaneous equation setup, Fernandez-Cornejo and McBride's (2002) cross-sectional ARMS data for 1997 showed that while farmers using no-till had a higher probability of adopting HR seed, using HR seed did not significantly affect no-till adoption. Their conclusion was that HR seeds were still a "new technology," and "an impact of HR seed adoption on no-till adoption in the future" might be experienced (Fernandez-Cornejo & McBride, 2002, pp. 60). With our cross-sectional ARMS data for 2003, we do not observe diffusion in HR cottonseed to the extent that the latter significantly affected the probability of adoption of CT practices in a decision taken separately from the decision to adopt HR seed technology. In addition, even after six years, these technologies are observed not to simultaneously affect each other. One possible reason for this is that herbicide resistance is often bundled with insect resistance. Further, the bundled insect- and herbicide-resistance characteristics are often placed in the best-yielding varieties. Farmers may choose to buy the best-yielding varieties even if they may not necessarily want the insect- or HR characteristics (Bryant et al., 2003).

In addition, the variables *PNT*, *REGION4*, and *REGION5* in the tillage equation were significantly different from zero at the 1% level. The variables for labor expense on farm (*LABEXP*) and total harvested farm acres in cotton (*CTA*) had the unexpected negative sign, but neither of them was significant (Table 2).

For the HR seed equation (Equation 4), *CONSTILL*, the main variable of interest, was not significant even at the 10% level, although it had the expected positive sign. The coefficient for *CONSTILL* was significant at the 7% (14%) level in one- (two-) tailed tests. This indicates that farmers practicing conservation tillage did not have a significantly higher probability of adopting HR

Table 2. Parameter estimates and marginal effects from the single-equation logit models for conservation-tillage (CT) practices and herbicide-resistant/stacked-gene (HR) cottonseed.

CT practices, Equation 3			HR cottonseed, Equation 4		
Explanatory variable[a]	Parameter estimate	Marginal effect[b]	Explanatory variable[a]	Parameter estimate	Marginal effect[b]
Constant***	-2.541 (0.666)[c]		Constant	0.719 (0.581)[c]	
HRCOTT	0.628 (0.384)	0.143 (0.087)[d]	*CONSTILL*	0.615 (0.412)	0.104 (0.070)[d]
LABEXP	-0.031 (0.122)	-0.007 (0.028)	*LABEXP*	-0.022 (0.182)	-0.004 (0.031)
CTA	-0.014 (0.024)	-0.003 (0.005)	*CTA*	<0.001 (0.027)	<0.001 (0.005)
CTP	0.491 (0.400)	0.112 (0.091)	*CTP*	0.070 (0.472)	0.012 (0.080)
HEL	0.464 (0.654)	0.105 (0.149)	*HEL*	-0.434 (0.360)	-0.073 (0.061)
CROP02	0.142 (0.446)	0.032 (0.010)	*CROP02*	0.023 (0.319)	0.004 (0.054)
*PNT****	2.205 (0.212)	0.501 (0.048)	*PNT*	0.471 (0.339)	0.079 (0.057)
AGE	0.011 (0.012)	0.003 (0.003)	*AGE*	0.013 (0.014)	0.002 (0.002)
EDU	0.104 (0.293)	0.024 (0.067)	*EDU*	-0.134 (0.298)	-0.023 (0.050)
TEN	0.012 (0.014)	0.003 (0.003)	*TEN*	-0.009 (0.016)	-0.002 (0.003)
GFI	0.020 (0.031)	0.005 (0.007)	*GFI*	-0.002 (0.040)	<-0.001 (0.007)
REGION1[e]	0.034 (0.417)	0.008 (0.095)	*REGION1*[e]	0.048 (0.469)	0.008 (0.079)
REGION2	-0.111 (0.292)	-0.025 (0.066)	*REGION2*	0.280 (0.311)	0.047 (0.053)
*REGION4****	-1.743 (0.408)	-0.396 (0.093)	*REGION4****	-1.019 (0.294)	-0.172 (0.050)
*REGION5****	-3.726 (0.576)	-0.846 (0.131)	*REGION5***	-1.467 (0.583)	-0.248 (0.099)
Likelihood ratio = 7,012.3633			Likelihood ratio = 2,831.0985		
McFadden R^2 = 0.3125			McFadden R^2 = 0.1109		
Adjusted McFadden R^2 = 0.3118			Adjusted McFadden R^2 = 0.1103		
Prediction success: Concordant 82.8% Discordant 17.0% Tied 0.2%			Prediction success: Concordant 69.8% Discordant 29.8% Tied 0.4%		
Number of observations=1,253 in sample=19,997 farms in expanded full sample			Number of observations=1,253 in sample=19,997 farms in expanded full sample		
Number of CT practices adopters=474 in sample=4,977 farms in expanded full sample			Number of HR seed adopters=935 in sample=13,277 farms in expanded full sample		

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

[a] *Explanatory variables are defined in Table 1.*

[b] *A marginal effect indicates the change in predicted probability of adopting the relevant technology for a unit change in an explanatory variable. Marginal effects of continuous variables were calculated at the means of the data. For dummy variables, a value of 0 was used if the mean was less than 0.5 and a value of 1 if the mean was greater than or equal to 0.5.*

[c] *Numbers in parentheses below parameter estimates are respective asymptotic delete-a-group jackknife standard errors of those estimates. Parameter estimates were obtained using the NASS "full-sample weight" variable.*

[d] *Numbers in parentheses below marginal effects are respective asymptotic delete-a-group jackknife standard errors of those effects. Marginal effects were obtained using the NASS "full-sample weight" variable.*

[e] *Regional dummy variables compare adoption relative to cotton farmers in Region 3 (AR, LA, MS, MO, TN).*

seed than those who were not. This contradicts Fernandez-Cornejo and McBride's (2002) results for US soybean production in 1997. The significant variables in this equation were only the regional dummies *REGION4* and *REGION5* at the 1% and 5% levels, respectively. The variables for labor expense on farm (*LABEXP*), highly erodible land declaration by NRCS (*HEL*), college education (*EDU*), tenure (*TEN*), and gross farm income (*GFI*) each had the unexpected negative sign, but none was significant (Table 2). Surprisingly, the prior no-till (*PNT*) variable also was not significant even at the 10% level in the HR seed equation.

In both Equations 3 and 4, the negative coefficients on Regions 4 and 5 indicate these regions had a lower probability of adoption of either technology relative to Region 3. Regions 4 and 5 are relatively arid compared to Region 3 and possibly contained large ranches (producing relatively large quantities of livestock and other non-cotton commodities), rendering adoption of each of these technologies less alluring in those regions.

Marginal effects—considered in isolation—on the main variables of interest (the HR and CT technologies in the tillage and seed-use equations, respectively) would suggest farmers using HR cottonseed (*HRCOTT*) were 14.3% more likely to adopt CT practices (*CONSTILL*) than those who were not. Similarly, farmers adopting CT practices were 10.4% more likely to also adopt HR cottonseed, *ceteris paribus* (Table 2). However, these variables not being significant even at the 10% level does not allow making these assertions with much confidence.

As evident from the tillage equation, having prior experience with no-till (*PNT*) raised the probability of adopting CT practices by 50.1%.

Regional dummies 4 and 5 figured 'significantly' in both equations with negative signs, with marginal effects approximating -0.396 and -0.846, respectively, for the tillage equation, and -0.172 and -0.248, respectively, for the seed-use equation. Thus, estimated in isolation, Regions 4 and 5 were 39.6% and 84.6% less likely to adopt CT practices, and 17.2% and 24.8% less likely to adopt HR cottonseed, respectively, in relation to Region 3 (Table 2).

Table 3 compares standard errors from the otherwise-used, standard technique with those from the delete-a-group jackknife technique used to handle complex data from surveys such as the ARMS. The bias in using the standard technique is apparent from the fact that standard errors are higher by approximately four to ten times using the more appropriate jackknife technique.

Summary, Conclusions, and Lessons Learned

Adoption of CT practices for cotton production is often studied in conjunction with HR cottonseed adoption. A simultaneous-equation system of logit equations for adoption of CT practices and HR cottonseed was estimated along with single-equation logit equations containing the same variables. In each adoption equation, the adoption of the other technology was used as an explanatory variable. These technology variables formed the core of this study. However, the Hausman (1978) specification test indicated no endogenous relationship between the adoption of CT practices and HR cottonseed, due to lack of significance in correlation of errors between the logit models. Therefore, results from only the single-equation logit models were reported.

As apparent from the regression results of both equations, each technology did not seem to significantly impact the other independently, thus indicating no significant diffusion in technology with time. This is in addition to the fact that the decision to simultaneously adopt those technologies was also not evidenced. Apart from these main variables of interest, the variable for prior experience with no-till was observed to have a significant, positive impact on CT adoption. Hence, efforts to increase adoption of the CT technology would more likely be successful if directed towards farmers with prior experience in no-till.

Additionally, as for regional variation, captured by the "region" dummies, Region 4 (Southern Plains) and Region 5 (New Mexico, Arizona, and California) produced significant, negative coefficients in both equations. Thus, cotton farmers in these regions were less likely to adopt HR cotton than those in Region 3 (the Delta).

Considered in isolation, labor expense, total or percentage of cotton acres, highly erodible land classification, continuous cropping, farmer age, college education, tenure, and gross farm income were not significant factors in determining either technology.

One limitation of this study is that the data are cross-sectional and might not appropriately capture farmers' adjustments of tillage practices in response to their adoption of genetically modified cotton and vice versa. This makes inference/assessment on causality of variables difficult. Therefore, discussion of regression results should be carried out in terms of correlations, relationships, or associations instead of effects, determinants, or impacts. Time-series and/or panel data, if available, might reveal different results with regard to simultaneity and the factors on which these technologies are dependent. Unfortunately, the survey (ARMS) for a given crop takes place once in every few years. Hence, the data collected over time would not necessarily be from the same farms or farmers or even the same crop on a given farm.

Coupled with the above, the study brings to light the problem of degrading standard errors due to the com-

Table 3. Comparison of standard errors obtained from standard and delete-a-group jackknife techniques for conservation-tillage (CT) practices and herbicide-resistant/stacked-gene (HR) cottonseed.

CT practices, Equation 3			HR cottonseed, Equation 4		
Explanatory variable[a] & parameter estimate[b]	Standard error: Standard	Standard error: Jackknife[c]	Explanatory variable[a] & parameter estimate[b]	Standard error: Standard	Standard error: Jackknife[c]
Constant -2.541	0.127***	0.666***	**Constant 0.719**	0.101***	0.581
***HRCOTT* 0.628**	0.052***	0.384	***CONSTILL* 0.615**	0.051***	0.412
***LABEXP* -0.031**	0.027	0.122	***LABEXP* -0.022**	0.013*	0.182
***CTA* -0.014**	0.004***	0.024	***CTA* <0.001**	0.004	0.027
***CTP* 0.491**	0.085***	0.400	***CTP* 0.070**	0.067	0.472
***HEL* 0.464**	0.062***	0.654	***HEL* -0.434**	0.042***	0.360
***CROP02* 0.142**	0.050***	0.446	***CROP02* 0.023**	0.038	0.319
***PNT* 2.205**	0.055***	0.212***	***PNT* 0.471**	0.068***	0.339
***AGE* 0.011**	0.002***	0.012	***AGE* 0.013**	0.002***	0.014
***EDU* 0.104**	0.049**	0.293	***EDU* -0.134**	0.037***	0.298
***TEN* 0.012**	0.002***	0.014	***TEN* -0.009**	0.001***	0.016
***GFI* 0.020**	0.005***	0.031	***GFI* -0.002**	0.003	0.040
***REGION1*[d] 0.034**	0.059	0.417	***REGION1*[d] 0.048**	0.069	0.469
***REGION2*[d] -0.111**	0.066*	0.292	***REGION2*[d] 0.280**	0.079***	0.311
***REGION4*[d] -1.743**	0.061***	0.408***	***REGION4*[d] -1.019**	0.055***	0.294***
***REGION5*[d] -3.726**	0.220***	0.576***	***REGION5*[d] -1.467**	0.072***	0.583**
Likelihood ratio=7,012.3633			**Likelihood ratio=2,831.0985**		
McFadden R^2=0.3125			**McFadden R^2=0.1109**		
Adjusted McFadden R^2=0.3118			**Adjusted McFadden R^2=0.1103**		
Prediction success: Concordant 82.8% Discordant 17.0%; Tied 0.2%			**Prediction success: Concordant 69.8% Discordant 29.8%; Tied 0.4%**		
Number of observations=1,253 in sample=19,997 farms in expanded full sample			**Number of observations=1,253 in sample=19,997 farms in expanded full sample**		
Number of CT practices adopters=474 in sample=4,977 farms in expanded full sample			**Number of HR seed adopters=935 in sample=13,277 farms in expanded full sample**		

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*
[a] *Explanatory variables are defined in Table 1.*
[b] *Parameter estimates were obtained using the NASS "full-sample weight" variable.*
[c] *This column shows respective asymptotic delete-a-group jackknife standard errors of parameter estimates.*
[d] *Regional dummy variables compare adoption relative to cotton farmers in Region 3 (AR, LA, MS, MO, TN).*

plex sampling design of the ARMS data, and hence the lack of significance in several variables. A preferred path to take would be to conduct a preliminary analysis before selecting variables to go into the multiple regression model(s). For example, it was noted during the review process that several explanatory variables had very low coefficients of variation (and thus were essentially constants). Researchers should be aware that during the review process they may likely be asked to re-specify their model(s), but the "luxury" of doing that may be limited by confidentiality restrictions limiting access to ARMS data.

References

Ahearn, M., El-Osta, H.S., & Deewbre, J. (2006). The impact of coupled and decoupled government subsidies on off-farm labor participation of U.S. farm operators. *American Journal of Agricultural Economics*, *88*, 393-408.

Amemiya, T. (1981). Qualitative response models: A survey. *Journal of Economic Literature*, *19*, 1483-1536.

Anderson, S., & Newell, R.G. (2003, December). Simplified marginal effects in discrete choice models. *Economics Letters*, *81*(3), 321-326.

Baerenklau, K.A., & Knapp, K.C. (2005, July). *A stochastic-dynamic model of costly reversible technology adoption*. Paper presented at the American Agricultural Economics Association Annual Meeting, Providence, RI.

Barham, B.L., Jackson-Smith, D., & Moon, S. (2002). *The dynamics of agricultural biotechnology adoption: Lessons from rBST use in Wisconsin, 1994-2001*. Paper submitted for the AAEA-WAEA Annual Meeting, Long Beach, CA.

Baum, C.F., Schaffer, M.E., & Stillman, S. (2007). *IVENDOG: Stata module to calculate Durbin-Wu-Hausman endogeneity test after ivreg*. Statistical Software Components S494401 (revised 4 Feb 2007). Boston College Department of Economics.

Bell, C.D., Roberts, R.K., English, B.C., & Park, W.M. (1994). A logit analysis of participation in Tennessee's Forestry Stewardship Program. *Journal of Agricultural and Applied Economics*, *26*, 463-472.

Belsley, D.A., Kuh, E., & Welsch, R.E. (1980). *Regression diagnostics, identifying influential data and sources of collinearity*. New York: John Wiley and Sons, Inc.

Bryant, K.J., Nichols, R.L., Allen, C.T., Benson, N.R., Bourland, F.M., Earnest, L.D., et al. (2003). Transgenic cotton cultivars: An economic comparison in Arkansas. *Journal of Cotton Science*, *7*(4), 194-204.

Carpenter, J., & Gianessi, L. (1999). Herbicide tolerant soybeans: Why growers are adopting Roundup Ready varieties. *AgBioForum*, *2*(2), 65-72. Available on the World Wide Web: http://www.agbioforum.missouri.edu/v2n2/v2n2a02-carpenter.htm.

Cooke Jr., F.T. (2002, January). *Whole farm economic analysis of cotton production systems—Mississippi cotton farms*. Proceedings of the 5th Annual National Conservation Tillage Cotton and Rice Conference, Tunica, MS.

Dorfman, J.F. (1996). Modeling multiple adoption decisions. *American Journal of Agricultural Economics*, *78*, 547-558.

Dubman, R. (2000). *Variance estimation with USDA's farm costs and returns surveys and agricultural resource management survey* (USDA Staff Report AGES 00–01). Washington, DC: US Department of Agriculture Economic Research Service (USDA ERS).

Edwards, W.M. (1995). Effects of tillage and residue management on water for crops. In R.L. Blevins, & W.C. Moldenhauer (Eds.), *Crop residue management to reduce erosion and improve soil quality: Appalachia and Northeast region* (USDA Conservation Research Report No. 41). Washington, DC: USDA ERS.

El-Osta, H.S., Mishra, A.K., & Ahearn, M. (2004). Labor supply by farm operators under 'decoupled' farm program payments. *Review of Economics of the Household*, *2*(4), 367-385.

El-Osta, H.S., Mishra, A.K., & Morehart, M.J. (2007). Determinants of economic well-being among U.S. farm operator households. *Agricultural Economics*, *36*, 291-304.

Fawcett, R., & D. Towery. (2005). *Conservation tillage and plant biotechnology*. West Lafayette, IN: Conservation Technology Information Center. Available on the World Wide Web: http://www.conservationinformation.org/?action=learningcenter_publications_contillbiotechnology.

Fernandez-Cornejo, J., & McBride, W.D. (2002). *Adoption of bioengineered crops* (Agricultural Economic Report No. 810). Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/publications/aer810/.

Foster, A.D., & Rosenzweig, M.R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy*, *103*, 1176-1209.

Frisvold, G., & Boor, A. (2005). *Adoption of conservation tillage and herbicide tolerant seeds: State-level and national impacts* (Cotton Incorporated Final Report No. 05-658). Cary, NC: Cotton, Inc.

Greene, W.H. (1993). *Econometric analysis* (3rd ed.). New York: Macmillan Publishing Company.

Harper, J.K. (1996). *Economics of conservation tillage* (Conservation Tillage Series Number 6). University Park: Pennsylvania State University College of Agricultural Sciences Cooperative Extension. Available on the World Wide Web: http://pubs.cas.psu.edu/FreePubs/pdfs/uc130.pdf.

Hausman, J.A. (1978). Specification tests in econometrics. *Econometrica*, *46*(6), 1251-1271.

Kott, P.S. (1997a, May). *Statistical analysis with a delete-a-group jackknife* (NRED Seminar Series). Washington, DC: USDA National Agricultural Statistics Service (NASS).

Kott, P.S. (1997b). *Using the delete-a-group jackknife variance estimator in NASS surveys*. Washington, DC: USDA NASS.

Kurkalova, L., Kling, C., & Zhao, J. (2003, April). *Green subsidies in agriculture: Estimating the adoption costs of conservation tillage from observed behavior* (Working Paper 01-WP 286). Ames, IA: Center for Agricultural and Rural Development, Iowa State University.

Lambert, D.M., Sullivan, P., & Claasen, R. (2007, April). Working farm participation and acreage enrollment in the Conservation Reserve Program. *Journal of Agricultural and Applied Economics*, *39*(1), 151-169.

Langemeier, M. (2005, February). *Impact of the adoption of less tillage practices on overall efficiency*. Paper presented at the Southern Agricultural Economics Association Annual Meetings, Little Rock, AR.

Lee, L.-F. (1983, March): Generalized econometric models with selectivity. *Econometrica*, *51*, 507-512.

Liao, T.F. (1994). *Interpreting probability models: Logit, probit, and other generalized linear models, 07-101*. Thousand Oaks, CA: Sage Publications.

Lohr, S. (1999). *Sampling: Design and analysis*. Cincinnati, OH: Duxbury Press.

Long, J.S. (1997). *Regression models for categorical and limited dependent variables*. Thousand Oaks, CA: Sage Publications.

Maddala. G.S. (1983). *Limited-dependent and qualitative variables in econometrics*. Cambridge, UK: Cambridge University Press.

Marra, M.C., & Carlson, G.A. (1987). The role of farm size and resource constraints in the choice between risky technologies. *Western Journal of Agricultural Economics*, *12*, 109-118.

Marra, M.C., Pardey, P.G., & Alston, J.M. (2003). The payoffs to transgenic field crops: An assessment of the evidence. *AgBioForum*, *5*, 43-50. Available on the World Wide Web: http://www.agbioforum.org/v5n2/v5n2a02-marra.htm.

Marra, M.C., Piggott, N.E., & Sydorovych, O. (2005, March/April). *The impact of herbicide tolerant crops on North Carolina farmers* (N.C. State Economist). Raleigh: Department of Agricultural and Resource Economics, College of Agriculture and Life Sciences, North Carolina Cooperative Extension Service.

Martin, S.W. (2002, January). *Economics of no-till cotton production*. Proceedings of the 5th Annual National Conservation Tillage Cotton and Rice Conference, Tunica, MS.

McBride, W.D., & El-Osta, H.S. (2002, April). Impacts of the adoption of genetically engineered crops on farm financial performance. *Journal of Agricultural and Applied Economics*, *34*(1), 175-191.

Neter, J., Wasserman, W., & Kutner, M.H. (1983). *Applied linear regression models*. Homewood, IL: Richard D. Irwin, Inc.

Obubuafo, J., Gillespie, J., Paudel, K., & Kim, S.-A. (2006, February). *Knowledge, application and adoption of best management practices by cattle farmers under the environmental quality incentives program – A sequential analysis*. Paper presented at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL.

Pindyck, R.S., & Rubinfeld, D.L. (1976). *Econometric models and economic forecasts*. New York: McGraw Hill, Inc.

Rahm, M.R., & Huffman, W.E. (1984). The adoption of reduced tillage: The role of human capital and other variables. *American Journal of Agricultural Economics*, *66*, 405-413.

Roberts, R.K., English, B.C., Gao, Q., & Larson, J.A. (2006, December). Simultaneous adoption of herbicide-resistant and conservation-tillage cotton technologies. *Journal of Agricultural and Applied Economics*, *38*(3), 629-643.

Sandretto, C. (1997). *Crop residue management* (Agricultural Resources and Environmental Indicators, Agricultural Handbook 712, pp. 155-174). Washington, DC: USDA ERS.

Soule, M., Tegene, A., & Wiebe, K.D. (2000, November). Land tenure and the adoption of conservation practices. *American Journal of Agricultural Economics*, *82*(4), 993-1005.

US Department of Agriculture Economic Research Service (USDA ERS). (1997). *Agricultural resources and environmental indicators* (Agricultural Handbook 712) Washington, DC: Author.

Wu, J.J., & Babcock, B.A. (1998). Tillage, rotation, and soil testing. *American Journal of Agricultural Economics*, *80*, 494-511.

Zepeda, L. (1994). Simultaneity of technology adoption and productivity. *Journal Agricultural and Resource Economics*, *19*(1), 46-57.

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