Appendix IV. A Simultaneous Adoption Model for Herbicide-Tolerant Soybeans and No-Till

This appendix presents an econometric model developed to address the question of whether the availability of herbicide-tolerant soybeans is encouraging farmers to adopt no-till practices for soybean production (Soule and Klotz-Ingram, 2000). Because the availability of herbicide-tolerant soybeans may affect the no-till decision, while at the same time, the use of no-till may impact the decision to adopt herbicide-tolerant seeds, the two decisions must be considered simultaneously. Therefore, a simultaneous, two-equation econometric model is developed, where both equations are binary, to address the simultaneous nature of the decisions. The model is used to determine which factors are most important in explaining the adoption of no-till and herbicide-tolerant soybeans. Also, the hypothesis of simultaneity is tested to determine if the two decisions are actually endogenous to each other.

Model Specification and Testing. Studies of the adoption of agricultural technologies usually motivate the binomial or multinomial variable approach using either a latent variable or random utility argument. In the latent variable case (Long, 1997), there is an unobserved latent variable (y*), such as expected profits or expected utility from each technology choice, that generates the observed binary variable of actual technology choice. The latent variable is assumed to be linearly related to the observed explanatory variables through a structural model of the form:

$$y_i^* = \delta' \boldsymbol{X_i} + e_i , \quad (i = 1, ..., N) \tag{1}$$

The latent variable is then linked to the observed binary variable through the following equation:

$$\begin{aligned} y_i &= 1 \text{ if } y_i^* > 0 , \\ y_i &= 0 \text{ if } y_i^* \leq 0 . \end{aligned} \tag{2}$$

The random utility model is based on the idea that the farmer chooses the technology (y_i=1) that maximizes the utility gained from the choice between technologies. In either case, the argument results, generally, in a model of the form:

$$Pr[y_i = 1] = F(\delta' \boldsymbol{X_i}) , \tag{3}$$

where Pr[.] is a probability function and *F(.)* is the cumulative distribution function, and $\boldsymbol{X_i}$ is a vector of variables explaining the probability of adoption. The exact distribution of *F* depends on the distribution of the random term e_i. If e_i is distributed as a normal random variable, then we have a probit statistical model.

In this study, the single-equation probit model is extended to a simultaneous model with two probit equations using a two-stage method. Following Maddala (1983, p. 246), two reduced-form probit models are first estimated:

$$\begin{aligned} y_1^* &= \delta_1' \boldsymbol{X} + e_1 \\ y_2^* &= \delta_2' \boldsymbol{X} + e_2 \end{aligned} \tag{4}$$

where $\boldsymbol{X}$ includes all exogenous variables expected to impact the probability of adoption of either technology. Next, the structural equations below, which also include predicted values of y_1^{**} and y_2^{**}, retrieved from equation (4), are estimated, where X_1 and X_2 are the explanatory variables expected to impact each technology:

$$\begin{aligned} y_1^{**} &= \Upsilon_1 \, y_2^{**} + \delta_1' \boldsymbol{X_1} + u_1 \\ y_2^{**} &= \Upsilon_2 \, y_1^{**} + \delta_2' \boldsymbol{X_2} + u_2 \end{aligned} \tag{5}$$

In the empirical analysis, the simultaneous system presented above is estimated first. Then, two standard, single-equation probit models for the probability of adopting no-till and herbicide-tolerant seeds are estimated separately to test the simultaneous adoption decision. In each equation, we include the adoption of the other technology as one of the explanatory variables. The parameters from the two models are then used to construct Wu-Hausman tests to determine the simultaneity of the two decisions. The Wu-Hausman statistic tests the null hypothesis that the standard probit model that ignores simultaneity is the correct specification. If the conservation tillage and herbicide-tolerant seed choices are indeed simultaneous, the standard probit estimates are inconsistent and the simultaneous equation model is preferred.

Data and Estimation. Data come from the 1997 ARMS survey. Explanatory variables included in both the no-till and herbicide-tolerant seed equations are regional dummy variables, operator's education and age, dummy variables for whether the operator worked off-farm for more than 200 days per year, rotated soybeans with other crops, irrigated, or kept records to track pests (appendix table 4.1). In addition, the no-till equation included the following explanatory variables: whether the operator participated in government programs, the proportion of the farm in corn and soybeans, average precipitation, whether the field is cash-rented or share-rented (vs. owned) by the operator, and whether the field has been classified as highly erodible by the National Resources Conservation Service (NRCS). Additional variables in the herbicide-tolerant seed equation are whether the farm is mainly a crop (vs. livestock) farm, the yield the farmer normally expects on the field, and whether the operator used herbicide-tolerant seeds in 1996.

Results. Farm size was positively related to the adoption of no-till, but was not related to herbicide-tolerant soybean adoption (appendix table 4.2). Farmer age and education level, the number of days the operator worked off-farm, and whether or not farmers irrigated or cultivated continuous soybeans did not significantly affect the adoption of no-till or herbicide-tolerant seed. Farmers who kept records to track weeds or other pests were more likely to use no-till practices. However, recordkeeping was not associated with the adoption of herbicide-tolerant seed.

There are several variables unique to either the no-till or the herbicide-tolerant seed model that were significant. In the no-till model, farmers who received government program payments and farmers with highly erodible land (HEL) were more likely to use no-till. This is probably because farmers need to meet conservation compliance requirements on HEL in order to receive program payments. Farmers who experienced greater precipitation levels were also more likely to use no-till practices, probably to protect soil from eroding. Furthermore, farmers having a greater proportion of their farm devoted to corn or soybeans (generally considered to be more erosive crops) had a higher probability of adopting no-till, and farmers who share-rented were less likely to use no-till than owner-operators.

In reference to the herbicide-tolerant seed model results, crop farmers were less likely to use these seeds than livestock farmers. Other positive and significant variables included expected yields (indicating that higher expected yields may increase the expected value of adopting the technology) and whether a farmer used herbicide-tolerant seed the previous year.

The most interesting result in the simultaneous model was the interactive effects of the no-till and herbicide-tolerant seed variables. Farmers using no-till were found to have a higher probability of adopting herbicide-tolerant seed, but using herbicide-tolerant seed did not significantly affect no-till adoption. The result seems to suggest that farmers already using no-till found herbicide-tolerant seeds to be an effective weed control mechanism that could be easily incorporated into their weed management systems. Alternatively, the commercialization of herbicide-tolerant soybeans did not seem to encourage the adoption of no-till, at least at the time of the survey in 1997. However, this may change as herbicide-tolerant soybeans gain greater acceptance.

Two standard models were evaluated and compared to the simultaneous model with the Wu-Hausman statistic. For the single-equation no-till model, herbicide-tolerant seed adoption was found to be a significant explanatory factor, contrary to the simultaneous model. For both the single-equation and simultaneous-equation models, no-till was a significant explanatory factor in herbicide-tolerant seed adoption. Two Wu-Hausman statistics were calculated to test the null hypotheses that two standard probit models, rather than the simultaneous equations, is the correct specification. For the no-till model, the χ^2 statistic is 12.8, meaning we reject the null hypothesis that the standard model is the correct specification. However, for the herbicide-tolerant seed model, we cannot reject the null hypothesis (χ^2 statistic of 0.6). This suggests that accounting for simultaneity is important for the no-till decision but not for the seed-use decision. This result serves to strengthen our finding that the adoption of conservation tillage, at least in 1997, was not affected by the introduction of herbicide-tolerant seeds. In addition, not incorporating the simultaneity of the decision into the modeling effort could lead researchers to erroneously conclude that availability of herbicide-tolerant soybeans is driving no-till adoption, as suggested by the standard model, when this is not the case. Variables that were significant in the simultaneous no-till model but not in the standard model include farm size and the proportion of the farm in corn and soybeans. On the other hand, no-till adoption was found to have a significant impact on herbicide-tolerant seed adoption in both the standard model and simultaneous model, so the misspecification does not lead to incorrect conclusions on the main variable of interest. For herbicide-tolerant seeds, the standard probit and the simultaneous probit results are very similar, the main difference being that off-farm work, recordkeeping, and irrigation were found to be significant in the standard model while they were not in the simultaneous equation model.

The results suggest that farmers already using no-till are more likely to adopt herbicide-tolerant seeds, but the use of herbicide-tolerant seeds is not an important factor affecting no-till adoption. However, the results should be taken with caution since the conclusion is based on 1997 data when herbicide-tolerant seeds were still a new technology, and we may start seeing an impact of herbicide-tolerant seed adoption on no-till adoption in the future.

Inconsistent estimates provided by estimating two single-equation probit models separately imply that herbicide-tolerant seed adoption is a significant factor in no-till adoption. However, the consistent estimates provided by the simultaneous equation approach suggest that this is not the case and show the importance of considering simultaneity when modeling adoption decisions that are known to be interrelated.

Appendix table 4.1—Definitions of variables–Adoption of no-till and herbicide-tolerant soybeans, 1997

Variable	Description
Lakes	1 if in MI, MN, or WI
Corn Belt	1 if in IL, IN, IO, MS, or OH
Southeast	1 if in KY, NC, or TN
Plains	1 if in KS, NE, or SD
Delta	1 if in AR, LA, or MS
Farm size	farm size in 100s of acres
Age	age of the operator, years
Education	1 if operator has some college education
Off-farm work	1 if operator works off-farm 200 days or more per year
No rotation	1 if no rotation of crop (continuous soybeans)
Irrigation	1 if the field is irrigated
Records	1 if records were kept to track pests, including weeds
Program participant	1 if operator received some Government payments in 1997
HEL	1 if field is classified as Highly Erodible by NRCS
Avg. precipitation	30-year average annual precipitation, in centimeters
Corn-soy prop.	Fraction of farm planted to corn and soybeans
Cash-rent	1 if field is cash-rented
Share-rent	1 if field is share-rented
Crop farm	1 if the farm is primarily a crop rather than a livestock operation
Expected yield	yield per acre (in bushels) that operator normally expects
Herb. tolerant seed, 1997	1 if used herbicide-tolerant soybeans in 1997
Herb. tolerant seed, 1996	1 if used herbicide-tolerant soybeans in 1996
No-till	1 if used no-till in 1997

Appendix table 4.2—Simultaneous-equation model of no-till and herbicide-tolerant soybean adoption, U.S. 1997

	No-till		Herbicide-tolerant soybeans	
Variables	parameter estimate	t-ratio	parameter estimate	t-ratio
Constant	-3.694	-4.824**	-1.053	-2.231**
Lakes	0.797	2.873**	-1.238	-3.395**
Corn Belt	1.053	4.496**	-1.198	-3.695**
Southeast	1.088	5.960**	-1.000	-3.000**
Plains	0.964	3.902**	-0.800	-3.117**
Farm size	0.015	2.256**	0.005	0.450
Age	-0.006	-1.366	0.003	0.417
Education	0.200	1.519	0.182	1.596
Off-farm work	-0.021	-0.174	0.264	1.602
No rotation	-0.234	-0.793	-0.022	-0.080
Irrigation	-0.329	-1.084	-0.338	-1.175
Records	0.449	2.606**	0.226	0.984
Program participant	0.373	2.370**		
HEL	0.578	3.689**		
Avg. precipitation	0.013	2.940**		
Corn-soy prop.	0.005	2.030*		
Cash-rent	0.195	1.662		
Share-rent	-0.300	-2.281**		
Crop farm			-0.320	-2.153**
Expected yield			0.030	3.336**
Herb. tolerant seed, 1996			3.028	3.379**
Herb. tolerant seed, 1997	-0.097	-0.604		
No-till			0.659	2.394**
% correct predictions	75		87	

** Significant at 5-percent level, cutoff is 2.145 for 14 degrees of freedom.
* Significant at 10-percent level, cutoff is 1.761 for 14 degrees of freedom.