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1. Estimating the Demand for a New Technology: Bt Cotton and Insecticide Policies in the Southeast

B. J. Hubbell, M. C. Marra and G. A. Carlson

Food Marketing Policy Center
Department of Agricultural and Resource Economics
University of Connecticut
and
Department of Resource Economics
University of Massachusetts, Amherst

Estimating the Demand for a New Technology: Bt Cotton and Insecticide Policies in the Southeast

B. J. Hubbell

M. C. Marra

G. A. Carlson

Department of Agricultural and Resource Economics
North Carolina State University

Chapter 1

Estimating the Demand for a New Technology: Bt Cotton and Insecticide Policies in the Southeast

B. J. Hubbell, M. C. Marra and G. A. Carlson[1]

Introduction

Cotton genetically engineered to express the toxin from the *Bacillus thuringiensis* (Bt) bacterium, a biological insecticide, was commercially introduced in 1996. This new biotechnology not only has the potential to increase cotton grower profits, but also to affect off-site benefits and costs.[2] The external costs associated with spills, runoff, and residues from conventional pesticide applications, as well as development of insect resistance to conventional pesticides may be reduced as conventional cotton varieties and chemical insecticide applications are replaced with Bt cotton. However, growers of other crops (including conventional cotton) in close proximity to Bt cotton may experience decreases in the effectiveness of sprayable Bt as insect resistance to the Bt toxin builds up over time. This may be particularly costly for nearby organic growers, who rely heavily on sprayable Bt.

Given the potentially large external effects (positive and negative) resulting from adoption of Bt cotton, it is desirable for policymakers to know how both adopting and non-adopting farmers perceive the benefits of Bt cotton, and the relationship between its price and its adoption and use. This information can be useful in several ways. For example, if the policy decision were to encourage adoption of the Bt technology, knowing the demand relationship would allow policymakers to calculate the subsidy cost of achieving different target levels of adoption. Alternatively, if a restriction on the use of the technology were being considered (as is currently the case in several European countries), the value placed on the technology by those who did not adopt but would have at lower prices should be included in the welfare loss calculations. Knowledge of the price-adoption-acreage demand relationship also could allow policymakers to impose an appropriate tax, if it is desirable to limit use in some areas.

A simple method to assess future demand and price elasticity obviously will be useful to the sellers of biotechnology products, as well. Biotechnology companies have little experience in pricing genetically engineered crop varieties. Price setting in the initial stages of technology introduction may not result in market clearing prices or profit maximization. This is true of the early marketing of Bt cotton. Bt cotton was sold in 1996 using a two-part pricing scheme. Bt cottonseed was priced at a slight premium over conventional varieties, and a separate $32/acre technology-licensing fee was assessed.[3] Some farmers chose not to adopt at this price. In the second year, there was a discount offered (of $10/acre for the first 50 acres per farm) for new adopters in the Carolinas.

Even so, although Bt cottonseed was available for planting 7.5 million acres in 1997, only 5.5 million acres were actually planted (Context Consulting, 1997).

Typically, adoption studies of emerging technologies treat the price of the new technology as given. However, additional information on the demand for a new technology can be gained by examining the stated preferences of non-adopters in response to hypothetical changes in the cost of the technology. Combining this stated preference (SP) information with revealed preference (RP) data on adoption at the industry-set price results in a more complete characterization of the demand potential for the new technology.

Bt cotton is already on the market and thus has a price. Farmers have chosen either to adopt Bt cotton at the market price or not to adopt. Thus, the farmers have *revealed their preferences for Bt cotton at the market price* (the $32/acre technology fee). Some of the adopters would be willing to pay more than the market price. Some of the non-adopters would adopt at lower prices. The model presented below which includes both revealed choices of adopters and revealed and stated choices of non-adopters permits estimation of willingness to pay (WTP) for either or both groups.

Contingent valuation (CV) alone has been used extensively to obtain estimates of the willingness to pay (WTP) for non-market goods. Cameron and James (1987) suggest that CV can be equally useful in pre-testing new market goods. There have been several recent studies combining stated and revealed preferences to establish WTP for various environmental amenities and public services (e.g. Cameron (1992); Cooper; Englin and Cameron; Nestor). We apply this methodology to estimate the WTP for an important, newly-introduced technology where there is little information available about price responsiveness and where that information could be very useful in formulating reasonable policy responses.

The objectives of this paper are: 1) to estimate the per-acre WTP for Bt cotton for non-adopting farmers, 2) to combine the non-adopter stated and adopter revealed preference data to estimate a demand function for Bt cotton, and 3) to demonstrate how the model results can be used to analyze proposed public policies, using as an example the calculation of subsidy levels required to reach specified reductions in chemical insecticide applications through Bt cotton adoption.

Theoretical Model

The Willingness to Adopt

A cotton grower's decision to adopt a Bt cotton variety on a given acre of cotton land is modeled using the random utility model (Cooper, Hanemann). A dichotomous choice (DC) contingent valuation approach is used to determine the WTP of non-adopters. This approach has been shown to provide respondents with a more market-like structure for responses than a simple open-ended question directly eliciting WTP. In addition, federal guidelines for conducting contingent valuation studies recommend using the DC approach (U.S. Department of Commerce).

Farmers will be willing to pay P dollars/acre and adopt the Bt technology on a given acre if utility with the new income minus the cost of the technology is at least as high as utility without the new technology. Bt cotton is evaluated against the individual farmer's previous choice, which should represent the optimal technology choice for cotton acreage given the set of technologies available prior to the introduction of Bt cotton. We further assume that rotational considerations make total cotton acreage relatively fixed. Formally, a farmer chooses the Bt technology if

$$U(1, y_1 - P; \mathbf{x}) \geq U(0, y_0; \mathbf{x}), \tag{1}$$

where 1 indicates the Bt technology and 0 indicates the non-Bt technology, y_0 and y_1 are net income (profits) without and with the Bt technology, respectively, and x is a vector of farm and farmer attributes which may affect the farmer's perceptions of the technology and WTP. Utility is only partially observable to the analyst, such that $U = V(i, y_i; \mathbf{x}) + \boldsymbol{\varepsilon}$, where $V(i, y_i; \mathbf{x})$ is the observable portion of the utility function associated with technology i and ε is a random variable with mean zero. The farmer's willingness to adopt at price P can then be expressed as

$$V(1, y_1 - P; \mathbf{x}) + \boldsymbol{\varepsilon}_1 \geq V(0, y_0; \mathbf{x}) + \boldsymbol{\varepsilon}_0 . \tag{2}$$

If we assume the typical linear specification for V, i.e.

$$V = \boldsymbol{x}' \boldsymbol{\beta}^{\boldsymbol{i}} + \alpha y_i \text{, i=0,1,} \tag{3}$$

and a is the marginal utility of income, then (2) can be rewritten as

$$\left(\boldsymbol{x}' \boldsymbol{\beta}^1 - \boldsymbol{x}' \boldsymbol{\beta}^0\right) + \boldsymbol{\alpha}(y_1 - y_0 - P) \geq \boldsymbol{\varepsilon}_0 - \boldsymbol{\varepsilon}_1 . \tag{4}$$

Estimates of the parameters of (4) can be obtained by assuming a distribution for $\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_0 - \boldsymbol{\varepsilon}_1$, and maximizing the likelihood function for (4). Assuming that ε is distributed iid N(0,1), then the probability of the grower responding yes to the hypothetical technology fee, P_h, is specified as a probit:

$$prob(WTP \geq \$P_h) = prob(\varepsilon_0 - \varepsilon_1 \leq \boldsymbol{x}' \boldsymbol{\beta} + \alpha(\Delta y - P_h)) = \Phi(\boldsymbol{x}' \boldsymbol{\beta} + \alpha(\Delta y - P_h)) \tag{5}$$

where $\boldsymbol{x}' \boldsymbol{\beta} = \boldsymbol{x}' \boldsymbol{\beta}^1 - \boldsymbol{x}' \boldsymbol{\beta}^0$, $\Delta y = y_1 - y_0$, and $\Phi(\cdot)$ denotes the standard normal distribution.

Estimation of (5) would be correct if we had information only about the respondent's answer to the hypothetical WTP question. However, since we have asked each grower if they adopted at the $32/acre technology fee, and, if not, if they would adopt at the hypothetical fee level, we can combine the revealed preference information from the actual choices with the stated preference data from the hypothetical choices. Using these combined data, we are estimating a model similar to the double-bounded dichotomous choice contingent valuation model (Hanemann, Loomis and Kanninen).[4] The upper bound on willingness-to-pay for all non-adopters is $32/acre, while the lower bound is the hypothetical fee amount, P_h. Thus the probabilities that a non-adopting grower responds yes or no to the hypothetical fee are

$$prob(yes) = prob(WTP \le \$32) - prob(WTP \le \$P_h) \tag{6}$$

and

$$prob(no) = prob(WTP \le \$P_h). \tag{7}$$

Thus, the log-likelihood function for the non-adopter RP/SP adoption model is

$$\sum_i I_i^{YES} \ln\left[\Phi\left(x'\beta + \alpha(\Delta y - 32)\right) - \Phi\left(x'\beta + \alpha(\Delta y - P_h)\right)\right] + I_i^{NO} \ln\left[\Phi\left(x'\beta + \alpha(\Delta y - P_h)\right)\right] \tag{8}$$

where I^j, j=Yes or No, are indicator variables equal to one if the farmer gave response j and no otherwise.

For the utility specification in (3), the mean WTP can be obtained using the estimated parameters from (8) and the mean levels of the explanatory variables. Following Hanemann, the formula for mean WTP is

$$\text{mean WTP} = \frac{\bar{x}'\beta + \alpha\overline{\Delta y}}{-\alpha}. \tag{9}$$

Adoption potential can be examined by plotting the predicted adoption level against the technology fee. However, this only gives the demand response from a zero price level up to $32/acre. Also, this ignores the information provided by the current adopters at the $32/acre fee level. Thus, the WTP estimate in (9) will be valid only for the sub-sample of current non-adopters.

Characterization of the Demand Curve for Bt Cotton

In order to obtain an estimate of the demand for Bt cotton, we must first develop a model to combine the RP information provided by both adopters and non-adopters with the SP information provided by the hypothetical fee question asked to non-adopters. Cooper combined RP and SP data to determine the impact of incentive payments on the adoption of water quality protection practices. He estimates a "one-way-up" model of adoption combining data on actual adoption at a subsidy amount of $0 with data on contingent adoption at a range of hypothetical subsidy amounts. In his model, the probability of adopting given a hypothetical subsidy is conditional on the respondent having not adopted at the $0 bid amount. That is, the sub-sample of contingent adopters is self-selected from the total sample of potential adopters based on their technology choice with no subsidy payments. The estimated mean probability of adoption is thus dependent on both the revealed technology choices with no subsidy and the stated technology choices with the hypothetical subsidy payments. By combining the two types of data, the information set is expanded, leading to more efficient estimation of the parameters of the farmers' underlying utility functions. In addition, by anchoring the estimation with actual market choices, some of the biases that may occur from using only stated preferences in response to hypothetical subsidies may be reduced (Cooper). We apply a slightly modified version of Cooper's econometric methodology to estimate the demand for Bt cotton.

For the demand revelation portion of our model, we take a full-sample (FS) combined RP/SP approach similar to Cooper. The observed choices of all growers at the $32/acre market price provides the revealed preference portion of the model, while the responses of the non-adopting growers to the hypothetical fee question provides the stated preference portion of the model.[5] There are three possible outcomes:

1. The grower adopts the Bt variety at the initial technology fee of $32/acre. WTP is thus greater than or equal to $32/acre. Prob(Yes) = Prob(WTP ≥ $32).
2. The grower does not adopt the Bt variety at the initial $32/acre technology fee but indicates she will adopt at the hypothetical fee of $\$P_h$. WTP is between $\$P_h$/acre and $32/acre. Prob(No/Yes) = Prob(WTP ≤ $32) – Prob(WTP ≤ $\$P_h$).
3. The grower does not adopt the Bt variety at either the initial $32/acre technology fee or the hypothetical fee of $\$P_h$. WTP is less than $\$P_h$/acre. Prob(No/No) = Prob(WTP ≤ $\$P_h$).

The log-likelihood function for this full-sample RP/SP model is:

$$(10) \qquad LLF = \sum_i I_i^Y \ln\{1-\Phi[\mathbf{x}_i'\boldsymbol{\beta} + \boldsymbol{\alpha}(\Delta y_i - 32)]\}$$

$$+ I_i^{NY} \ln\{\Phi[\mathbf{x}_i'\boldsymbol{\beta} + \alpha(\Delta y_i - 32)] - \Phi[\mathbf{x}_i'\boldsymbol{\beta} + \alpha(\Delta y_i - P_{hi})]\} + I_i^{NN} \ln\{\Phi[\mathbf{x}_i'\boldsymbol{\beta} + \alpha(\Delta y_i - P_{hi})]\}.$$

where I^Y, I^{NY}, and I^{NN} are binary indicator choice variables (yes; no, yes; or no, no) for each farmer.

In addition to the decision to adopt or not adopt Bt cotton, the farmer must also choose what proportion of cotton acres to plant to the Bt variety. Once again following Cooper's econometric approach, we model the proportion of 1996 cotton acres planted to Bt varieties as a function of the technology fee and other explanatory variables. The dependent variable will be reported as intended acres to be planted to Bt varieties for farmers not adopting in 1996 but stating they would adopt given the hypothetical technology fee and acres planted to Bt varieties for farmers adopting in 1996. The acreage proportion equation is specified as:

$$(11) \qquad BTPROP = z'\gamma_z + u$$

where BTPROP is the stated or actual proportion of 1996 acres planted in Bt varieties for non-adopters and adopters, respectively, z is a vector of explanatory variables, γ_z is a vector of parameters to be estimated, and u is a random disturbance with mean zero and variance, σ^2.

Equation (11) can be estimated with ordinary least squares (OLS). However, OLS estimation of (11) may be biased because BTPROP is only observed for those farmers who have either adopted in 1996 or answered yes to the hypothetical adoption question. There is thus non-random sample selection for the BTPROP regression equation. To correct for this potential bias, we follow Cooper and use the Heckit procedure outlined in Greene. The Heckit procedure uses the predicted probabilities of adoption from the one-way-down model to correct for non-random sampling. Because BTPROP is observed only when $I^y=1$ (for 1996 adopters) or $I^{ny}=1$ (for contingent adopters), (11) can be rewritten as:

$$(12) \qquad BTPROP = z'\gamma_z + \gamma_\lambda \lambda + v,$$

where λ is the Mills ratio calculated from the full-sample RP/SP model.[6]

As in Cooper, we estimate a tobit version of the Heckit model to account for the fact that the proportion of acres is censored at 0. There is no upper bound censoring at 1 because contingent adopters could report an increase in total cotton acres relative to their current acres. Potential heteroskedasticity between current and contingent adopters is accounted for by specifying the error term as $var(v)=\sigma^2 e^{\theta D}$, where D=1 if the farmer adopted in 1996 and 0 if the farmer did not.

The estimated full-sample RP/SP adoption model and Heckit acreage model can be used to predict the total cotton acreage (BTACRES) at each level of the technology fee (given the total cotton acreage in 1996). Given the estimated parameters α, β, and γ the estimated demand function for Bt cotton acreage is the product of a) the probability of adopting Bt cotton, b) the proportion of acreage planted to Bt cotton if it is adopted, and c) total cotton acreage:

$$(13) \qquad BTACRES=[Prob(Adopt)\,(\alpha,\beta,P) \times BTPROP\,(\alpha,\beta,\gamma,P)] \times \text{Total Cotton Acres.}$$

Data and Methods

A survey of cotton growers in North Carolina, South Carolina, Georgia and Alabama was conducted in early 1997. The random sample of 1000 growers was stratified according to the state's proportion of the four-state total cotton acreage in 1995. Two mailings were sent, along with a follow-up telephone survey to achieve a response rate of useful surveys of 38%. This resulted in 293 responses complete enough for overall analysis, with 105 growers who adopted Bt cotton in 1996 and 188 growers who did not. A check against the proportion of total acres planted to Bt cotton in the four states in 1996 indicates that our sample respondents are reasonably representative of the population. The total state-level proportions of Bt cotton-to-total cotton acres in 1996 were 0.74 in Alabama, 0.30 in Georgia, 0.06 in North Carolina, and 0.14 in South Carolina (Williams). The same proportions in our sample were 0.66 in Alabama, 0.25 in Georgia, 0.03 in North Carolina, and 0.17 in South Carolina.

Of the 188 non-adopters, 145 answered the contingent valuation question. The question was posed as a dichotomous choice question with bid levels of $0 to $25 in increments of $5 randomly assigned to the growers (See the Appendix for the relevant portion of the survey questionnaire). The non-adopters in 1996 were asked to respond using a three point scale to potential reasons for not adopting Bt cotton. As expected, the $32/acre license fee was a very important factor in over half of the non-adopters' decisions. About one-third were uncertain about the quality they could expect and about the same proportion were concerned about uncertain yields in the lower South, with about 40 percent in the upper South citing uncertainty about yields as an important reason for not adopting. Seed availability did not seem to be a problem, nor was the resistance management requirement, although about forty percent saw it as either a somewhat or very important barrier to adoption.

The change in net income from adoption of Bt cotton will vary over farmers. Since we do not have data on expected changes in net income for each grower, we proxy for the income change through a dummy variable equal to one if the farmer is in Alabama or Georgia (lower South) and zero if the farmer is in North or South Carolina (upper South). In addition, we include variables that should be correlated with the change in income, including whether the farmer had experienced insect resistance to conventional insecticides in 1995 and the level of insect damage in 1995.[7] Both of these variables indicate the effectiveness of previously available alternative technologies and should track relatively well with the heterogeneous differences in expected income across farmers.

Besides the technology fee and the income related variables, other variables hypothesized to affect adoption of new crop varieties include total enterprise size, share of income from the crop affected by the new technology, and several human capital variables, including age (capturing general experience levels and investments in current technologies), education, and experience growing cotton (Feder and O'Mara; Lin; Marra and Carlson; Rahm and Huffman). With the exception of age, we expect all of these variables to have a positive effect on the probability of adopting Bt cotton. Summary statistics for the variables included in the adoption models are presented in Table 1, grouped by outcome category. Adopters seem to have larger cotton enterprises, have a higher share of income from cotton, have more education, had more boll damage and insecticide resistance in 1995, and are located in the lower South.

TABLE 1 Summary Statistics for Adoption Model Variables				
		Outcome Group[b]		
	All Respondents	Yes (n=93)	No/Yes (n=86)	No/No (n=31)
	Mean (Std Deviation)			
Total acres planted to cotton (TACRCOT)	417.44 (439.83)	540.50 (568.96)	304.73 (228.89)	360.90 (346.27)
Share of income from cotton (%) (SHRINC)	50.55 (23.22)	54.36 (22.64)	47.79 (23.24)	46.77 (23.90)
Percent damaged bolls in 1995 (%) (DM95)	11.96 (13.42)	15.32 (16.37)	9.50 (7.83)	8.74 (13.76)
Experienced resistance problems in 1995[a] (RES95)	0.24	0.32	0.22	0.06
Operator's age (AGE)	45.31 (11.23)	46.03 (11.41)	43.73 (10.30)	47.52 (12.81)
Operator attended at least some college[a] (COLLEGE)	0.62	0.72	0.56	0.48
Operator's years growing cotton (YRSCOT)	11.45 (11.01)	13.35 (11.72)	9.20 (8.64)	12.00 (13.63)
Operator farms in lower South[a] (LSOUTH)	0.53	0.67	0.49	0.26
Operator farms in upper South[a] (USOUTH)	0.47	0.33	0.51	0.74
Hypothetical Fee (FEE)	–	–	10.87 (7.68)	17.10 (7.62)

[a] Binary variable, mean represents proportion of sample with positive value.

[b] 'Yes' indicates the growers adopted Bt cotton in 1996 at the $32/acre price, 'No/Yes' indicates the growers did not adopt in 1996 at the $32/acre price but responded "yes" to a hypothetical price, and 'No/No' indicates the growers did not adopt in 1996 and responded "no" to the hypothetical price.

Variables expected to influence the proportion of cotton acres planted to Bt varieties are largely the same as for adoption, with the exception of total cotton acres due to the normalization of the dependent variable.

Results and Discussion

Regression Results and Adoption Curves

Table 2 provides the results from the three models: the double-bounded probit non-adopter only (NA) RP/SP model, the full-sample (FS) RP/SP probit adoption model, and the continuous acreage demand model.

In the NA RP/SP model, as expected, the coefficient on the hypothetical technology fee is negative and highly significant. Other variables having a significant, positive effect on adoption at the hypothetical fee include whether the farmer experienced resistance to conventional insecticides in 1995, had some education at the college level, and was located in the lower South. This suggests that both price and the expected change in income (proxied by resistance to conventional insecticides and location) are important in determining adoption. The NA RP/SP adoption model correctly predicts 75.2 percent of potential adopters.

Using equation 9 and the estimates from the NA RP/SP adoption model, WTP for Bt cotton can be calculated for the set of current non-adopters. Table 3 shows the mean estimated WTP for the total Southeast region to be approximately $18/acre. Due to the significance of the parameters associated with the region, resistance and education dummy variables, WTP is calculated for each possible combination of region, education and resistance. WTP ranges from a low of $14 for upper South farmers with no college and no experience with resistant insects to a high of $25 for college educated, lower South farmers who had experience with resistant insects in 1995.

At this point, we still have an incomplete adoption specification for Bt cotton. We know the percent of cotton farmers adopting from a price of zero to a price of $32/acre, but we do not know how the percent adopting responds at fees greater than $32/acre. In addition, the partial adoption curve is based only on the contingent responses of non-adopters, ignoring the information provided by current adopters at the $32/acre price level. In order to characterize fully the adoption function for Bt cotton, we must make use of the results from the full-sample RP/SP model (n=210) using information from both current and potential adopters (Table 2). The full-sample model parameter estimates are used to extrapolate the adoption curve to higher fee levels.

Similar to the NA adoption model, the estimated parameter on the technology fee in the FS model is negative and highly significant, although only about half as large (-0.75). The coefficients for resistance, education, and location in the lower South all remain significant and positive, but the total cotton acreage coefficient is now also significant and positive. The full-sample RP/SP model correctly predicts 69.6 percent of current adopters and 76.1 percent of the contingent adopters, slightly better than the NA model. Also, McFadden's pseudo R^2 is much higher for the full-sample RP/SP model than for the NA RP/SP model. This provides additional evidence that combining stated and revealed choice data leads to a better model of demand for a new technology.[8]

TABLE 2 Results from Adoption Models

Variable	Non-Adopter Only RP/SP Model (n=117)			Full-sample RP/SP Model (n=210)			Acreage Proportion Model (n=170)[a]		
	Parameter	t-value	Partial Effect	Parameter	t-value	Partial Effect	Parameter	t-value	Partial Effect
Constant	3.163	3.62	–	1.250	2.72	–	0.717	6.03	0.683
FEE (P)	-0.141	-9.50	-0.056	-0.075	-10.25	-0.030	-0.007	-1.83	-0.007
RES95	0.542	2.47	0.194	0.398	1.91	0.153	0.177	2.85	0.168
DM95	-0.002	-0.19	-0.855-03	0.009	0.85	0.004	0.004	1.25	0.003
TACRCOT	-0.330-03	-0.65	-0.129-03	0.676-03	2.45	0.269-03	[b]		
SHRINC	-0.003	-0.68	-0.001	0.819-03	0.22	0.326-03	-0.002	-2.19	-0.002
LSOUTH	0.487	2.47	0.176	0.507	3.06	0.191	0.138	2.61	0.131
AGE	-0.024	-1.59	-0.009	-0.003	-0.39	-0.001	[b]		
COLLEGE	0.549	2.08	0.327	0.422	2.50	0.288	[b]		
YRSCOT	0.014	0.93	0.005	0.009	0.93	0.003	[b]		
MILLS							-0.106	-1.98	-0.101
HETERO	–			–			-0.594	-4.32	
Log-likelihood	-66.95			-184.12			-62.31		
McFadden's pseudo R^2	0.02			0.49					
% correct predictions current adopters				69.6%					
% correct predictions contingent adopters	75.2%			76.1%					

[a] Dependent variable is proportion of cotton acres planted to Bt varieties.
[b] Coefficients on demographic variables AGE, COLLEGE, and YRSCOT had absolute t-values less than one and were removed from the regression.

TABLE 3 Estimated Mean WTP by Education Level and Experience with Resistant Insects			
	Region	College Education	No College Education
		Mean (Standard Error[a])	
Non-adopter only RP/SP model	Total South	$18.02 (0.96)	
Experience with insect resistance in 1995	Upper South	$21.48 (1.92)	$17.60 (2.00)
	Lower South	$24.93 (1.33)	$21.05 (1.71)
No experience with insect resistance in 1995	Upper South	$17.65 (1.67)	$13.77 (1.62)
	Lower South	$21.10 (1.54)	$17.21 (1.75)
Full-sample RP/SP model	Total South	$30.28 (1.18)	
Experience with insect resistance in 1995	Upper South	$32.84 (2.98)	$27.19 (2.98)
	Lower South	$39.63 (2.91)	$33.98 (2.89)
No experience with insect resistance in 1995	Upper South	$27.51 (2.03)	$21.86 (2.37)
	Lower South	$34.31 (1.90)	$28.65 (2.23)

[a] Standard errors for the WTP estimates from the adoption models are estimated using the ANALYZ command in TSP. This procedure uses a procedure known as the "delta method" to calculate the covariance matrix for a set of non-linear constraints, i.e. for the function WTP(β), the covariance matrix is calculated as $V(WTP(\beta)) = (\partial WTP/\partial\beta)' V(\beta)(\partial WTP/\partial\beta)$, evaluated at the estimated β vector (Hall).

Table 3 shows that for the full sample of cotton growers, mean WTP for the Bt cotton technology is approximately $30/acre, ranging from a low of $22/acre for an upper South farmer with no college and no resistance experience to a high of $40 for a lower South, college educated farmer who experienced resistance in 1995. These adoption curves, along with the non-adopter only adoption curves are shown in Figure 1 for comparison. The full-sample adoption curves now allow for examination of the proportion of farmers adopting along the full range of technology fees.[9] For the lower South, a 75 percent adoption level can be reached by lowering the technology fee to $23/acre, while for the upper South, the technology fee would have to be reduced to $11/acre to achieve a 75 percent adoption level.

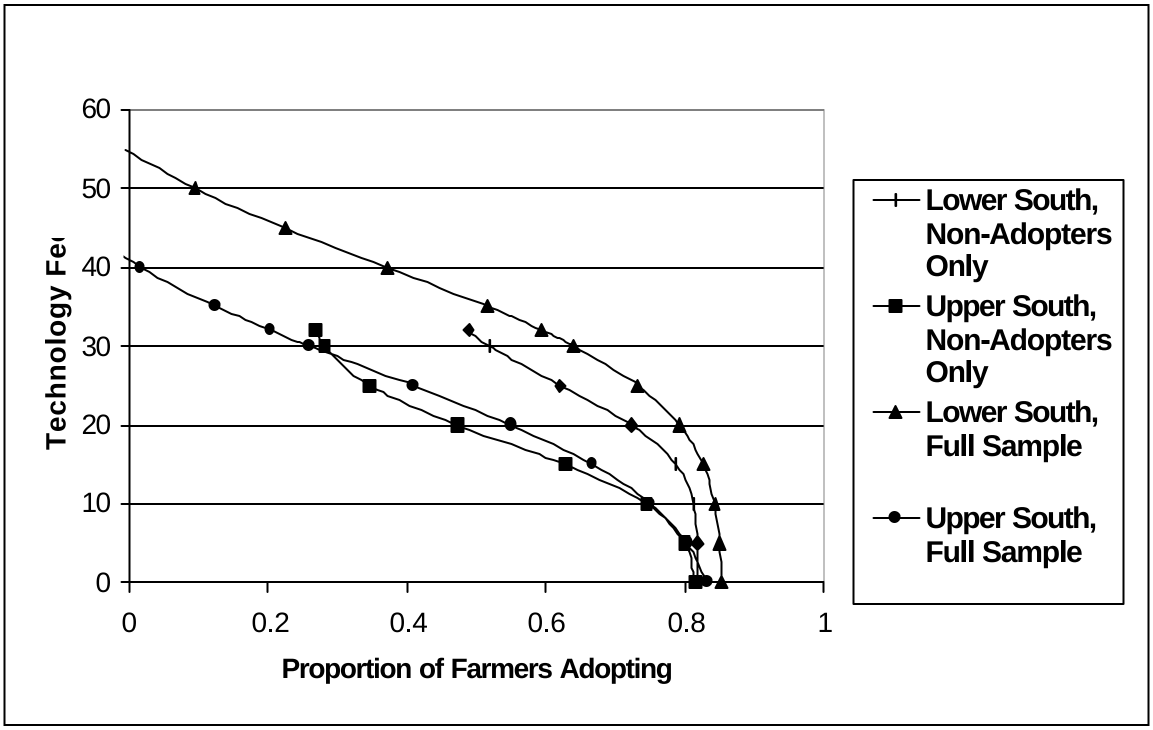

FIGURE 1 Estimated Proportion of Farmers Adopting Bt Cotton by Region and Sample Used

Comparing the response curves from the two models in Figure 1, the main difference is that the full-sample RP/SP model tends to predict higher adoption levels at any given technology fee. This points out the potential bias when using the contingent responses of non-adopters alone, not taking advantage of the additional information provided by the choices of the current adopters. Adding the current adopters to the model lends additional weight to positive responses at higher technology fee levels, thus shifting the adoption curve upward.

The adoption curve for Bt cotton based on the full sample can be summarized in terms of price elasticities of adoption. Table 4 gives point elasticities and computational details at the market price ($32/acre), above the market price ($40/acre) and below the market price ($20/acre). For the full sample, adoption is inelastic at prices below the mid-twenties, and very elastic at prices above the market price of $32/acre. However, keep in mind that extrapolations of the adoption price response curve above the $32/acre price are based on willingness to pay preferences of 1996 non-adopters only. If adopters are less price responsive to price increases than non-adopters, then the point estimates of elasticities above $32/acre will overstate the true elasticities.[10]

Results from the continuous stage regression examining the proportion of cotton acres planted to Bt varieties (Table 2) indicate that price has the expected negative impact on BTPROP. In addition, farmers having experienced resistance to conventional insecticides in 1995 were more likely to plant a greater proportion of cotton acres to Bt varieties, indicating that the expected change in income is also important in acreage decisions. The negative coefficient on SHRINC indicates that farmers with a larger proportion of their income coming from their cotton enterprise are less likely to plant a high proportion of their acreage to the new technology, possibly indicating a degree of risk-aversion given the relative uncertainty about the new technology. As expected, farmers in the lower South plant a higher proportion of their acreage to the Bt varieties, reflecting the higher expected benefits in the region.

TABLE 4 Price Elasticities for the Three Model Stages

Technology Fee	Price Elasticity of Adoption[a]	Price Elasticity of Acreage Proportion[b]	Price Elasticity of Acreage[c]
$20	-0.57	-0.35	-0.92
32	-2.11	-0.67	-2.98
40	-3.91	-0.89	-5.43

[a] Computed as: $-\Phi_P \alpha * \dfrac{P}{1-\Phi_P}$ using estimated parameters from the full-sample RP/SP model.

[b] $$\frac{\partial E(PROPBT \mid Adopt=1)}{\partial P} * \frac{P}{PROPBT} = \gamma_P - \alpha\gamma_\lambda\delta(\beta'X + \alpha P)$$

where: $\delta = \lambda^2 + \lambda * (\beta'X + \alpha P)$.

[c] $$P * \left(\text{Prob}(Adopt) * \frac{\partial PROPBT}{\partial P} + PROPBT * \frac{\partial \text{Prob}(Adopt)}{\partial P} \right) * \frac{TOTCOT}{BTACRES}\ .$$

The heteroskedasticity term is significant and negative, indicating that the estimated variance in BTPROP for 1996 adopters is less than that for non-adopters. This supports assertions that data from stated responses contain a higher degree of noise than data from revealed choices.

The coefficient on the Mills ratio is negative and significant, indicating that sample selection bias is a concern in estimating the acreage equation and validating the endogenous acreagechoice model and the two-stage approach used here. This significant selection coefficient has the effect of increasing the impact of the price and income variables on the proportion of cotton acres planted to the Bt varieties. Because the derivative of the Mills ratio with respect to price is positive, an increase in price will both directly reduce BTPROP and indirectly reduce BTPROP through the increase in the Mills ratio. Likewise, RES95 will both directly increase BTPROP and indirectly increase BTPROP through the decrease in the Mills ratio. Acreage proportion adoption curves are shown in Figure 2.

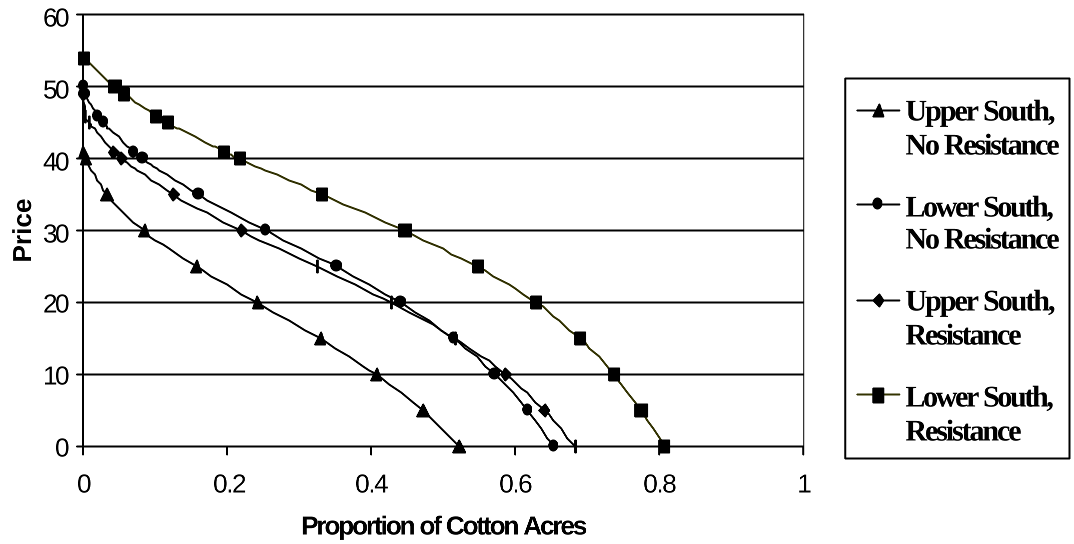

FIGURE 2 Estimated Proportion of Cotton Acreage Planted to Bt Cotton by Resistance Experience and Region

Acreage proportion price elasticities and computational details for the proportion of acreage planted to Bt varieties are presented in table 4.[11] Compared with the adoption elasticities, acreage proportion is less elastic than adoption, indicating that once the decision to adopt has been made, farmers are less sensitive to technology price when selecting how many of their cotton acres to plant to the Bt varieties. For all three price levels examined, acreage proportion is price inelastic, with point elasticities ranging from -0.35 at a price of $20 to -0.89 at a price of $40.

Development of the Bt Cotton Demand Curve for the Southeast

The estimated full-sample RP/SP adoption model and the acreage model can be used to develop a simplified demand curve for Bt cotton in the Southeast. For a given point on the demand curve, predicted demand is constructed by predicting the proportion of 1996 cotton acres that an average adopting farmer would plant to Bt cotton at the given price and multiplying the predicted acreage by the proportion of farmers who would adopt Bt cotton at the same price. This gives the adoption-adjusted proportion of total cotton acres that would be planted at the given price. Multiplying this adjusted proportion by total cotton acreage in the Southeast gives the quantity (in acres) demanded at the given price. Repeating this process for the range of prices gives the predicted demand curve for Bt cotton in the Southeast. This demand curve is shown in Figure 3. Point estimates and computational details of the price elasticity of BTACRES at three different price levels are presented in Table 4. Notice that this elasticity is larger in absolute value than that for either the adoption component or acreage component. This reflects the fact that both adoption and acreage are significantly related to price. Total Bt cotton acreage demand, which reflects both the probability of adoption and the proportion of acres on which the technology is adopted, will reflect the changes in both components due to a change in price, increasing the impact of price changes. Southeastern demand for Bt cotton is inelastic for the portion of the demand curve below prices in the lower twenties. Demand is highly elastic at the market price of $32/acre and above. However, for the same reasons mentioned above, caution should be used when interpreting point elasticities above $32/acre.

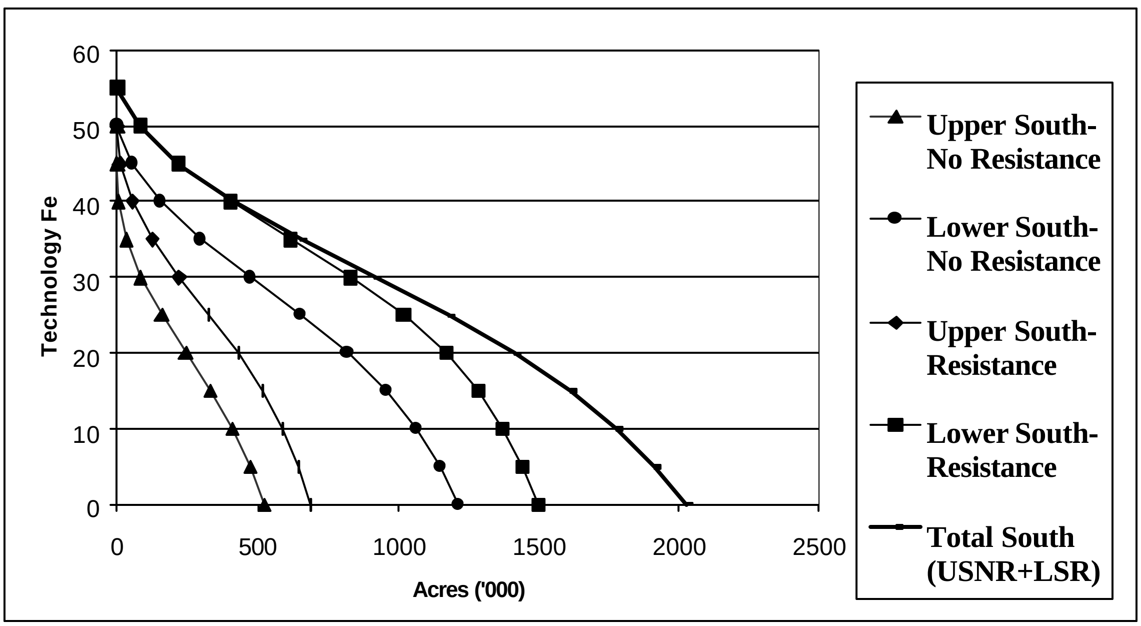

FIGURE 3 Examples of Estimated Bt Cotton Acreage Demand Functions

Policy Implications

The primary non-market benefit of Bt cotton is the substitution of the in-plant Bt protection for potentially harmful external effects of conventional insecticide sprays. Based on the sample of farmers in our survey, Bt cotton adoption resulted in a reduction of about two insecticide applications/acre (2.8 to 0.8 applications/acre). Using the average regional per-acre reductions in insecticide applications and the estimated demand curve for Bt cotton in the Southeast, the aggregate level of insecticide application reductions on cotton farms in the Southeast can be derived as a function of the technology fee. These results are depicted in Figure 4. This graph assumes a "most likely" scenario of no pyrethroid resistance in the upper South and pyrethroid resistance in the lower South.[12] From the graph, we can see that the potential aggregate reduction in insecticide applications on cotton is quite large, at around four million applications avoided. A large fraction of these reductions for the entire Southeast region occur at the $32/acre market price. However, almost all of the reductions at this price occur in the lower South. A subsidy of $12/acre or a reduction in the fee to $20/acre attains almost 70 percent of the reductions in the Southeast, including almost 80 percent of the reductions in the lower South, and close to 50 percent of the reductions in the upper South.

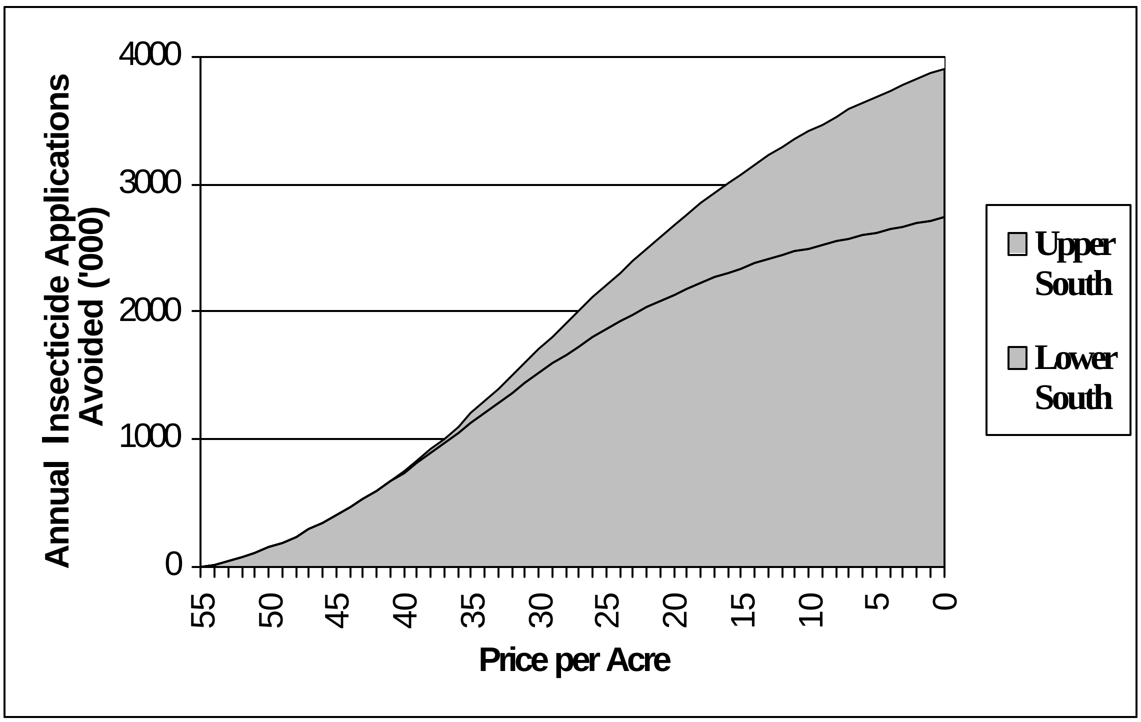

FIGURE 4 Estimated Reductions in Insecticide Applications by Region

In addition, Bt cotton may be useful in reducing the buildup of resistance to conventional insecticides. Contributions of Bt cotton to reducing resistance to other insecticides are more difficult to quantify. Resistance build-up is in general caused by heavy reliance on a single family of insecticides (Tabashnik, Croft, and Rosenheim; Carlson). Prior to the introduction of Bt cotton, cotton farmers had to rely primarily on pyrethroid insecticides for control of budworm and bollworm. Bt cotton substitutes for pyrethroid applications, thus reducing reliance on this family of insecticides. Survey data indicate that the percent of insecticide applications with pyrethroids accounted for 55 percent of total applications on Bt cotton versus 83 percent of total applications on conventional cotton (Carlson, Marra, and Hubbell, 1998). It is apparent that not only do Bt cotton adopters use less insecticides, they also use proportionately less pyrethroids. This suggests that Bt cotton may have a large impact in preserving the remaining efficacy of pyrethroid insecticides. This benefit is likely to accrue mainly to cotton farmers but could also benefit other farmers by preserving an effective tool for budworm control.

Due to the potential public benefits associated with reductions in insecticide applications and the apparent decrease in insecticide use in Bt cotton, policymakers may be interested in how effective and how costly programs using Bt cotton to achieve insecticide reductions will be. By using the estimated demand curve for Bt cotton, we can determine the costs of policies using Bt cotton to target reductions in insecticide applications. Table 5 illustrates both the per-acre subsidies needed to reach various insecticide application reduction targets on cotton and total program (subsidy) costs. If the regions are targeted separately, a 50 percent reduction can be achieved in the lower South at a cost of $30 million and a 35 percent reduction can be achieved in the upper South at a cost of $29 million. A total percentage reduction for the two regions combined of 45 percent will cost $83 million, but will cost $72 million when using a multiple subsidy strategy. It is apparent that reductions in the upper South are much more costly than those in the lower South, due to the greater WTP for Bt cotton of farmers in the lower South. Thus, whenever a reduction target greater than 25 percent is selected, it is always cheaper (political considerations aside) to target each sub-region separately than it is to target the entire region as a whole. Note that subsidy costs are non-linear in the target level. Achieving a 40 percent reduction in the lower South requires around 13 million dollars. However, reaching a 50 percent reduction target more than doubles the cost.

It is important to note that this analysis is based on a Bt cotton demand curve using only the first two years of the adoption process. If the typical sigmoidal diffusion pattern holds for Bt cotton, then we would expect that for a given price, the level of adoption will increase over time, as farmers become more familiar with the technology and expectations of changes in income from adopting the technology become more certain. In addition, the proportion of acres planted to Bt varieties at a given price may also increase over time due to the same factors. The implication of this is that the potential reductions in insecticide applications from an additional dollar of subsidy for Bt cotton adoption may increase over time, increasing the effectiveness of a Bt cotton subsidization program in reducing insecticide applications.

Conclusions

Using data from a survey of southeastern cotton growers, we have combined responses to hypothetical prices with market choices to estimate the demand for a newly introduced agricultural technology, Bt cotton. Estimated mean WTP for Bt cotton using the combined actual and contingent responses ranges from $14 for upper South growers with no college education and no experience with resistant insect populations to $40 for lower South, college-educated growers who experienced resistant insect populations in 1995. The full-sample combined RP/SP model tends to predict higher levels of adoption at any given price relative to predictions based on the sub-sample of non-adopters alone.

TABLE 5 Estimated Costs of Achieving Insecticide Reduction Targets on Cotton in the Southeast

	Per-Acre Subsidy			Total Program Costs ($ million/year)			
% Reduction	Total South	Lower South	Upper South	Total[a] South	Lower South	Upper South	Upper South + Lower South
15	$ 0	$ 0	$ 10	$ 0	$ 0	$ 10	$ 10
20	2	0	14	6	0	14	14
25	6	0	18	17	0	18	18
30	10	0	23	29	0	23	23
35	15	3	29	43	6	29	35
40	21	7	40[b]	60	13	40	53
45	29	11	51	83	20	51	72
50	35[b]	16	63	100	30	63	93
55	46	24	75	132	45	75	120
60	58	39	87	166	73	87	160

[a]Total South means that the target reduction is for the southeastern region as a whole with the same subsidy level, while upper South and lower South indicates that each region must separately meet the target reduction, each with a separate subsidy level.

[b]Subsidies greater than $32/acre imply that in addition to paying the full cost of the technology fee, the government would pay each farmer an additional amount equal to (subsidy - $32) per acre per year.

In the case of Bt cotton, demand is shown to be relatively responsive to prices in the $20 to $50 range. Achieving a 25 percent reduction in insecticide applications in the Southeast through a Bt cotton adoption subsidy program is relatively inexpensive at $17 million/year. However, achieving reduction goals of 35 percent or 45 percent would require public expenditures two and a half and five times as large, respectively.

This study has demonstrated how hypothetical valuation questions can be used to aid policy decisions in emerging markets or when demand curves are unknown. Given the existence of both positive and negative spillovers from both conventional and transgenically produced insecticides, we cannot expect individual farmer choices to maximize regional gains from these technologies. With more genetically modified crops being introduced, it is useful to have a method for assessing demand for these technologies in the early stages of adoption. Our results show that use of survey data on both stated and revealed choices is a reasonable way to provide this demand assessment.

Appendix

The Contingent Valuation Portion of the Survey Instrument

USE THIS FORM IF YOU DID NOT PLANT BT COTTON IN 1996

1996 Cotton Crop

1. How many acres did you farm in 1996? _________ acres.

   … (several questions about 1996 production practices on conventional cotton)

6. On a scale of 1 to 3, with 1=Not Important, 2=Somewhat Important, and 3=Very Important, rate the following factors in terms of importance in your decision not to plant Bt cotton varieties in 1996:

   a) ______ License fee too high
   b) ______ Seed cost too high
   c) ______ Uncertain about cotton quality
   d) ______ Uncertain about yields
   e) ______ No Bt cotton seed available from my seed supplier
   f) ______ Didn't like resistance management requirements
   g) ______ Other (explain) ____
   ____

7. If you ranked a) in question 6 as "Somewhat Important" or "Very Important," please answer the following question. If not, please skip to question 8 and continue.

   If the license fee was reduced from the current $32 per acre to $_____ per acre, would you plant Bt cotton? (Note: Dollar amounts inserted in the blank above ranged from $5 to $25 in increments of $5.)

   _______ yes. How many acres? ___________.
   _______ no.

   … (several questions about pest problems and pest management on the 1996 crop)

Endnotes

[1]Bryan J. Hubbell is Economist, Air Quality Division; USEPA, Research Triangle Park, North Carolina and Adjunct Assistant Professor, Department of Agricultural and Resource Economics, North Carolina State University, Michele C. Marra is Associate Professor, Department of Agricultural and Resource Economics, North Carolina State University and Gerald A. Carlson is Professor, Department of Agricultural and Resource Economics North Carolina State University. This research was supported in part by USDA/SRPIAP Grant No. 96-0826, the North Carolina Agricultural Research Service, and the Georgia Agricultural Experiment Station. The opinions and conclusions put forth in this paper are ours and not necessarily those of the sponsoring agencies or of EPA.

[2]Industry estimates show a 1996 national average yield increase of eight percent. Estimates from the survey used in this analysis show an 11.4 percent yield increase in the Southeast, along with a 72 percent decrease in insecticide applications which resulted in an estimated \$51 per acre increase in profit.

[3]For this analysis we are primarily interested in how the technology fee affects adoption decisions and, therefore, we ignored the small seed price premiums.

[4]While the forms of the log likelihood functions are similar between our model and that of Hanemann, Loomis, and Kanninen, the statistical efficiency gains will not be as large in our model because there is no variation in the upper bound across the sample. The upper bound in our model is fixed at the observed market price, while in their model, both upper and lower bounds are hypothetical and randomly assigned across respondents.

[5]We did not ask the preferences of the adopters in response to prices higher than \$32/acre.

[6]Note that the form of the Mills ratio will differ between current and contingent adopters. For the current adopters,

$$\lambda\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - P\right)\right)=\frac{\phi\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - 32\right)\right)}{\Phi\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - 32\right)\right)}.$$

For contingent adopters, the Mills ratio is calculated as

$$\lambda\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - P\right)\right)=\frac{\phi\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - P\right)\right)}{\Phi\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - 32\right)\right)-\Phi\left(x_i'\boldsymbol{\beta}+\alpha\left(\Delta y_i - P\right)\right)}.$$

[7]This will change the form of the utility difference specification in (5) and subsequent equations to $x'\beta+Y'\delta-\alpha P$, where Y is a vector of proxies for the change in income and δ is a vector of coefficients to be estimated. Note that (5) implies that $\delta_j=\alpha\eta_j$, where η_j is a parameter. In the estimation of the parameters of (5), we do not

impose any restrictions on the δ_j to insure that $\delta_j = \alpha\eta_j$. Restrictions were attempted, but resulted in the inability of the model to converge.

[8]The McFadden's pseudo R^2 estimates for our three models are similar in magnitude to those obtained for single and double bounded models estimated in previous studies, i.e. Hanemann, Loomis, and Kaninnen.

[9]Notice that even at a zero price, Bt cotton is not fully adopted. This is a construct of the model and the way the data were collected. The contingent adoption question was asked only to those farmers who indicated that the technology fee was an important factor in their decision not to plant Bt cotton in 1995. Those non-adopting farmers indicating that price was not an important factor were assumed not to be sensitive to price reductions in their adoption decisions. Therefore, even at a zero price, these farmers were assumed to remain non-adopters.

[10]In general, farmers in the upper South are more responsive at lower prices than are farmers in the lower South. This is reasonable given that resistance development in the lower South has left these farmers with fewer viable insect control substitutes for Bt cotton. In addition, the relatively elastic response of upper South growers supports the price discounts on Bt cotton offered by suppliers in the Carolinas in 1997.

[11]Standard errors are not presented any of the demand elasticities due to the highly non-linear nature of the functions and that due to the two-stage estimation procedure, standard errors for acreage price elasticities are a function of two separate covariance matrices. However, given that the price coefficients are significant for both the adoption and acreage proportion models, it is unlikely that the standard errors for the estimated elasticities would be large enough to call into question the significance of any of the elasticity estimates.

[12]In our sample, 33 percent of farmers in the lower South had experienced resistance to conventional insecticides, as compared with only 12 percent of farmers in the upper South.

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