Journal of Agricultural and Resource Economics 26(1):158–175
Copyright 2001 Western Agricultural Economics Association

Information Quality, Technology Depreciation, and Bt Cotton Adoption in the Southeast

Michele C. Marra, Bryan J. Hubbell, and Gerald A. Carlson

In 1996, Bt cotton became one of the first genetically engineered crops to be available commercially. This study focuses on the various sources and quality of information about Bt cotton profitability available to farmers in the Southeast and assesses the relative importance of such information in the farmers' adoption decisions. A model of the individual decision to adopt is developed to incorporate two recent theories of the role of information quality (the "effective information" hypothesis and the "popularity" hypothesis), as well as the effect of current technology depreciation. The data show some support for all three factors as determinants of adoption.

Key words: Bt cotton, information, technology adoption, transgenic crops

Introduction

Transgenic crop technology may be as important as agricultural mechanization with regard to its potential impact on worldwide agricultural productivity. Certain transgenic crops may have the potential to reduce many offsite externalities associated with chemical pest control and to increase farm profits. Some concern exists as to possible negative external effects, such as out-crossing or unintended target effects, although there is little hard evidence of this to date. The commercialization of this new technology is still in its infancy, but more and more transgene types and varieties are entering the marketplace every year. One of the first to be introduced was Bt cotton.

In 1996, enough Bt cotton seed was available to plant 1.8 million acres nationwide. The patent holder, Monsanto Corporation, charged a technology fee of $32/acre, and Bt cotton seed price was about $1.50/acre above the price of conventional cotton seed. In addition, adopters of Bt cotton had to agree to set aside some of their acreage to be used to insure against potential rapid insect resistance build-up to the strain of Bt used. They had a choice of setting aside either 3.85% of their cotton land and planting it to conventional cotton with no control of bollworms and budworms, or planting 20% to conventional cotton and controlling insects by means other than foliar Bt. Experimental results were promising and, despite these relatively high adoption costs and restrictions, interest in Bt cotton in early 1996 was widespread (Carlson, Marra, and Hubbell).

Michele Marra is professor, North Carolina State University; Bryan Hubbell is economist, Office of Air Quality Planning and Standards, USEPA, and adjunct assistant professor, North Carolina State University; and Gerald Carlson is professor, North Carolina State University. We wish to thank Jake Pasternak, Pam Kaval, and Kim Warren for help with the data, Paul Fackler and Barry Goodwin for productive conversations about the paper, the editors and two anonymous journal reviewers, and the members of SRIEG70 for helpful comments on earlier drafts. All opinions expressed are solely those of the authors and do not reflect those of the EPA or any other sponsoring agency. Any remaining errors are ours alone.

Review coordinated by J. Scott Shonkwiler and George Frisvold; publication decision made by George Frisvold.

Adoption of transgenic crop seed technology that incorporates pest control capabilities may not provide socially optimal levels of the technology's use because of both informational and biological externalities. Information from university trials, seed company marketing literature, and local reports of farmers has public good characteristics. Information may be over- or under-provided because of its public goods nature (although with the technology developer's vested interest, it might be expected to be over-provided in this case). Likewise, there may be production externalities associated with the movement of insects resistant to current insecticides. In addition, insects may develop resistance to the new Bt technologies. Understanding the public goods and externality features associated with the Bt cotton technology may help guide public and private information generation and dissemination and other resource use for this rapidly evolving industry.

The purpose of this study is to determine the factors affecting the early adoption of the new Bt cotton technology and, in the process, provide a unifying theoretical model and some empirical tests of several hypotheses recently proposed to explain patterns of adoption. An explanation of the hypotheses is provided in the next section, followed by the development of a unifying behavioral model that allows the hypotheses to be tested empirically. Next is a description of the farm-level survey data used in the empirical tests. A report of the results and a discussion of our findings comprise the final sections of the article.

Recent Theories of Technology Adoption and Diffusion

The adoption of new agricultural technologies has generally been found to be a function of farm and farmer characteristics and features of the particular technology (e.g., Just and Zilberman; Rahm and Huffman; Marra and Carlson). However, most studies have ignored the technology depreciation feature of the current technologies. In the context of technologies such as crop varieties or pesticides, this may affect the adoption process. Although the importance of declining pesticide efficacy because of increasing pest resistance has been examined in the context of the demand for replacement pesticides, there is no similar analysis for adoption of new crops (Carlson). Adoption of improved seed varieties has been widely studied, particularly in the case of developing countries,[1] but the declining yields of currently used varieties due to increasing pest or disease pressure have not been considered as a potentially important factor. Innovation cycles for a succession of technologies have been examined in the context of agricultural technology adoption (Kislev and Sechori-Bachrach). However, the cycles are hypothesized to be associated with adopter heterogeneity, not the depreciation of the current technology.

The role of information in the adoption and diffusion processes has been investigated extensively (Feder and O'Mara; Lindner, Fischer, and Pardey; and McCardle, to name a few). Foster and Rosenzweig emphasized the importance of learning from neighbors as well as learning by doing in the early stages of the use of a new innovation. Recently, the information line of inquiry has begun to focus on how the *quality* of information

---

[1] A recent example is the adoption of new wheat varieties to control the spread of wheat rust in Pakistan (Heisey et al.).

about the technology might affect the adoption process (Fischer, Arnold, and Gibbs; Ellison and Fudenberg).

Fischer, Arnold, and Gibbs argue that if pieces of information about a new technology are not independent, then the amount of "effective" information is less than the total amount of information available to a decision maker at any point in time. The authors criticize the Bayesian framework, which predicts more rapid adoption than the effective information model. They also note that technologies having different efficacies in different locations will generate data that may not be a perfect predictor of the efficacy in a particular location. Fischer, Arnold, and Gibbs call this feature of the information its "bias" and argue the degree of bias is partially a function of the "nearness" of the information to the farmer. They characterize nearness to be geographic proximity, as have others (Lindner, Fischer, and Pardey), although theoretically it could be related to some other characteristic.

A related component of information effectiveness is how much "noise" is in the information (call it the information's "precision," to borrow from standard statistical parlance). That is, if the variance around the mean outcome is large, as might be the case with information about a new technology's profitability comprised of only a few individual outcomes, then the information is less significant to the potential adopter. If, for example, a measure of the mean difference in yield between conventional and Bt cotton were made up of only a few nearby observations, then the potential adopter may not place as much weight on it compared to a mean of many observations, even if they are geographically more dispersed. Particularly in the early years of a new technology when there are relatively few observations on its use within a small geographic area (say a county), the state average result may be regarded as more "precise" because it is made up of more observations and thus is measured with greater precision.

Conversely, the information's nearness may be the more important feature to the decision maker. This is an empirical issue. Also, the *source* of information (e.g., agricultural experiment station plots, the purveyor of the technology, neighboring farmers) may affect the faith a decision maker has in its reliability.

The second recent theory of the role of information in technology adoption also is based on the results of other potential adopters' decisions, but in a slightly different way than the effective information hypothesis. Ellison and Fudenberg evaluate theoretical models of adoption in which learning is mostly based on profitability in the past year. They allow for popularity weighting of information by assuming that potential adopters take account of their neighbors' decisions in making their own. If a new technology seems to be "popular" within the decision maker's "window" of relevant potential adopters, then he/she will be more likely to adopt it. The "window" of relevant adopters is related to the notion of the information's nearness as defined above.

To date, there has been little empirical evaluation of the effective information hypothesis,[2] and no empirical test (of which we are aware) of the popularity weighting hypothesis in the context of adoption of a new technology.[3] We set out to test the hypotheses described above.

---

[2] Small tests are provided in the Fischer, Arnold, and Gibbs study, where they use a modest amount of pooled data from experimental and on-farm results across two wheat varieties, a barley variety, and a new herbicide.

[3] The notion of popularity weighting relates closely to the "bandwagon" hypothesis in consumer demand.

A Model of Information Quality and Technology Depreciation in the Adoption Decision

We now turn to the development of a behavioral model of an individual's decision to adopt, and the role technological depreciation and various aspects of information quality might play in that decision. Consider a grower faced with the decision to adopt or not to adopt a new technology. Allowing for nonneutral risk attitudes, adoption will occur if the expected utility from adopting is greater than the expected utility from not adopting. Utility is a function not only of expected profit, $E(\pi_i)$, where $i = 1$ if the technology is adopted and 0 if it is not, but also of farm and farmer characteristics, $\mathbf{x}_i$, that affect perceptions about the relative profitability of the new and old technologies as well as other product characteristics, including environmental and health effects:[4]

$$EU(\pi_1, \mathbf{x}_1) > EU(\pi_0, \mathbf{x}_0). \tag{1}$$

Assuming there is an observable (V) and an unobservable (ε) part to the decision maker's expected utility function and that the observable part can be assumed to be linear in the arguments, so that $EU_i = V_i(E(\pi_i), \mathbf{x}_i) + \varepsilon_i$ and $V_i = \mathbf{x}_i'\beta_i + \gamma E(\pi_i)$, where γ is the total effect of expected profit, then adoption occurs when:

$$\mathbf{x}_i'\beta_1 - \mathbf{x}_0'\beta_0 + \gamma\,[E(\pi_1 - \pi_0)] > (\varepsilon_0 - \varepsilon_1).^5 \tag{2}$$

The decision maker's expectation about the profit difference depends upon information about the new technology and upon information about the depreciation status of the old technology. The depreciation status may represent a longer-term view of the expected net gain from adopting than reported profit differences for any one year. There are several sources of information about how profitable the new technology will be for the individual potential adopter. These sources vary in quality in the ways described above and may be more or less discounted by the decision maker according to his/her judgment of that quality.

Assume there are z pieces of information available about $E(\pi_1 - \pi_0)$, and that w_j $(j = 1, 2, \ldots, z)$ is a quality weighting factor that is small if the information is not very useful for the decision maker and large if it is. Combining terms yields a utility difference equation that is linear in the farm and farmer characteristics and in the estimates of the difference in profitability:

$$\Delta V^* = \Delta V + \varepsilon = \mathbf{x}'\phi + \pi'\alpha > \delta, \tag{3}$$

where ΔV^* = a latent or perceived change in expected utility; $\Delta V = V_1 - V_0$; $\phi = (\beta_0 - \beta_1)$;

$$\pi = \begin{bmatrix} \widehat{(\pi_1 - \pi_0)_1} \\ \widehat{(\pi_1 - \pi_0)_2} \\ \vdots \\ \widehat{(\pi_1 - \pi_0)_z} \end{bmatrix} \text{ ($\wedge$ denotes an estimated value); } \alpha = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_z \end{bmatrix}\text{; and } \delta = (\varepsilon_1 - \varepsilon_0).$$

---

[4] Nonadoption is equivalent to using the old technology, which can have a range of efficacies in controlling insects.

[5] Note that higher moments of the distribution of $(\pi_1 - \pi_0)$ are unobservable in the early stages of a new technology, and are thus assumed to be included in the error term. Here we focus on the quality of information available about $E(\pi_1 - \pi_0)$.

Defining Y_{tk} equal to 1 if the farmer adopts (i.e., if $\Delta V^*_{tk} > 0$), and equal to 0 otherwise, then the probability that farmer k will adopt in year t is:

$$\begin{aligned}(4)\qquad \Pr(ADOPT)_{tk} &= \Pr(Y_{tk} = 1) = \Pr(\Delta V^*_{tk} > 0) = \Pr(\Delta V_{tk} + \varepsilon > 0)\\ &= \Pr(\varepsilon < \Delta V_{tk}) = \Phi(\Delta V_{tk}) = \Phi(\mathbf{x}'\phi + \pi'\alpha)_{tk}\\ &\quad \text{if } \varepsilon \sim N(0, 1).\end{aligned}$$

Equation (4) describes the farmer's propensity to adopt. All of the forms of information about expected relative profitability are contained in π, including direct estimates from external sources and own-farm estimates of revenue and cost differences, as well as indirect estimates such as the technology's popularity with others and farmer-assessed pest resistance, which is a measure of the degree of depreciation of the old technology.

Each piece of information about $E(\pi_1 - \pi_0)$ has an absolute effect on ΔV, equal to w_j. We define the *relative* contribution of each piece of information as $W_j = w_j/\Sigma_z w_j$, where $\Sigma_z w_j = \gamma$ from equation (2). Using this specification, we can determine both the total impact of all information about $E(\pi_1 - \pi_0)$ on the propensity to adopt relative to other factors and the individual contribution of each piece of information to that total impact.

In the early years of the technology's availability, the relative quality of information from different sources may change from year to year. For example, in the first year of availability, own-farm experiential information about profit differences between the old and new technologies is not available. The adoption decision will depend more heavily on farm and farmer characteristics, including own-farm experience with pest resistance and whatever data are available from commercial or university trials. However, in subsequent years, farmers may place more weight on their own experience (if they have adopted), and/or on external information including the experience of those adopting farmers "near" to them (if they have not adopted).

The Survey Data

A survey of cotton growers in North Carolina, South Carolina, Georgia, and Alabama was conducted during the winter of 1996, following the first crop year Bt cotton was commercially available. The random sample of 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 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. Comparison of the sample and population proportions of adopters in each state indicates that the sample responses can be considered representative of the population.[6]

Growers were asked two questions regarding their adoption of Bt cotton. The first question asked if the grower planted any Bt cotton in 1996. The second question asked if the grower planned to plant any Bt cotton in 1997.[7] Together with their adoption decisions in 1996 and their plans for 1997, the growers were asked questions about their

---

[6] The sample (population) proportions of adopters by state in 1996 were: Alabama = 0.74 (0.66), Georgia = 0.30 (0.25), North Carolina = 0.06 (0.03), and South Carolina = 0.14 (0.17). Population statistics are taken from Williams.

[7] The survey was executed during February and March of 1997. It is likely that most respondents had already made their planting decisions for the year, so that responses to the 1997 adoption question should be representative of actual planting decisions.

Table 1. Descriptive Statistics of Selected Farm and Farmer Characteristics in the Survey Data Set, by 1996 and 1997 Adoption Decisions

	Adopted in 1996		Did Not Adopt in 1996	
Plan to adopt in 1997?	Yes	No	Yes	No
No. of respondents in category	[N = 84]	[N = 18]	[N = 47]	[N = 116]
Variable Name	Mean[a] (Std. Dev.)	Mean[a] (Std. Dev.)	Mean[a] (Std. Dev.)	Mean[a] (Std. Dev.)
Farm Characteristics:				
Total Farm Acreage	1,039.88	1,025.06	745.19	566.47***
	(1,047.52)	(813.59)	(605.18)	(468.39)
Total Cotton Acreage	564.81	505.11	376.98	257.32***
	(617.89)	(351.53)	(277.75)	(241.07)
Proportion of Bolls Damaged in 1995	0.19	0.09**	0.10	0.09
	(0.22)	(0.08)	(0.07)	(0.13)
Proportion Reporting Pest Resistance in 1995	0.33	0.23	0.28	0.15*
	(0.47)	(0.44)	(0.46)	(0.36)
Share of Income from Cotton[a]	0.56	0.44**	0.53	0.44**
	(0.23)	(0.24)	(0.20)	(0.25)
Farmer Characteristics:				
Operator's Age	47.20	43.33	45.04	46.45
	(11.33)	(14.68)	(12.04)	(12.84)
Operator's Years of Schooling	14.51	14.50	13.81	13.64
	(1.73)	(1.71)	(1.89)	(1.70)
Operator's Years Growing Cotton	12.94	11.11	9.75	9.59
	(11.78)	(11.75)	(10.33)	(11.12)
Total Household Income ($)[b]	79,623	78,088	79,714	85,184
	(48,599)	(57,121)	(51,548)	(48,727)

[a] Statistical comparisons are within 1996 adoption categories (*, **, and *** denote mean difference is significant at the 10%, 5%, and 1% levels, respectively).

[b] The original categorical variable was set to the midpoint of each category range. The highest household income category (>$100,000) was set to $150,000. This may bias down the effect of larger farm sizes on the means in this category.

human capital and farm-specific characteristics, as well as reasons for adopting or not adopting Bt cotton in 1996. They also were asked detailed questions about the pest control regimes they practiced on both their conventional and Bt cotton acres (if applicable), including amounts and types of insecticides applied.

Table 1 reports descriptive statistics and *t*-test results for respondents, separated by their 1996 adoption decision and by whether or not they planned to plant Bt cotton in 1997. There is little statistical difference in the means of the two categories associated with 1996 adopters, although continued adopters reported significantly higher boll damage in 1995 than those who disadopted between 1996 and 1997. Of the 18 adopters in 1996 who did not plan to plant Bt cotton in 1997, only four made the "wrong" decision in that their Bt cotton yield and spray cost savings in 1996 favored Bt cotton over conventional cotton [using profits calculated from applying equation (5) below]. The rest found Bt cotton to be unprofitable for them, and thus made the "correct" decision to disadopt it.

There are several statistically significant differences in the means in the two categories associated with nonadoption in 1996. Those respondents who did not plant Bt cotton

Table 2. Yield and Spray Number Differences of 1996 Adopters, by Their 1997 Adoption Plans

		MEAN DIFFERENCE (Bt acres minus non-Bt acres):	
Region	Description	Adopters Who Planned to Plant Bt Cotton in 1997	Adopters Who Did Not Plan to Plant Bt Cotton in 1997
Lower South	Yield (lbs./acre)	118.47*** (4.90) [n = 55]	-95.71* (-2.35) [n = 7]
	Pesticide Sprays (lbs./acre/season)	-2.02*** (-6.49) [n = 51]	-0.33 (-0.47) [n = 6]
Upper South	Yield (lbs./acre)	99.15* (2.09) [n = 20]	-14.50 (-0.53) [n = 10]
	Pesticide Sprays (lbs./acre/season)	-2.57*** (-7.14) [n = 19]	-2.37*** (-6.53) [n = 8]
Combined	Yield (lbs./acre)	113.32*** (5.24) [n = 75]	-47.94* (-1.95) [n = 17]
	Pesticide Sprays (lbs./acre/season)	-2.17*** (-8.77) [n = 70]	-1.50*** (-3.30) [n = 14]

Notes: * and *** denote significance at the 10% and 1% levels, respectively. Numbers in parentheses are *t*-values; numbers in brackets denote number of respondents in that category.

in both 1996 and 1997 were those with the smallest farms, the least cotton acreage, lower pest resistance in 1995, and a smaller share of total income from cotton. This implies that the expected gains from adoption for these individuals probably were small relative to the adopters, both in terms of per acre gains (because of less pest resistance than that experienced by the nonadopters to current insecticides) and total gains (because of smaller cotton acreage).

We also tested differences between groups according to their 1996 adoption decision only. In general, the 1996 adopters had significantly larger farms, more cotton acreage, more experience growing cotton, and more education than did the nonadopters. They also reported more boll damage and pest resistance than their nonadopter counterparts. Of the characteristics tested, the only insignificant differences between these two groups were their age and total income.

Table 2 depicts the average differences in the within-farm yield and spray numbers on Bt acres versus conventional acres for the 1996 adopters, according to their Bt cotton planting intentions for 1997. For the most part, those farmers who chose to continue planting Bt cotton were the ones with the more favorable results in 1996. They experienced yield gains and saved pesticide sprays (except in Alabama) compared to conventionally planted cotton acres on their farms. Those who did not plan to plant Bt cotton again in 1997 generally had a bad experience with it in 1996. Overall, the 1996 yield gain experienced by continued adopters on their Bt cotton acres compared to their conventional cotton acres was about 113 pounds/acre, while those adopters who did not plan to plant Bt cotton in 1997 experienced an average yield *loss* in 1996 of about 48 pounds/acre.

We also asked nonadopters in 1996 to give their ranking in importance (very important, somewhat important, not important) of several reasons for not adopting Bt cotton. As expected, the $32/acre license fee had a significant impact, with over half of the nonadopters ranking it as very important. Approximately one-third were uncertain about the quality they could expect, and approximately the same proportion were concerned about uncertain yields in the lower South (Alabama and Georgia), with about 40% of nonadopters in the upper South (South Carolina and North Carolina) citing this as an important reason. Seed availability did not appear to be a problem, nor was the resistance management requirement, although about 40% of the respondents saw it as at least somewhat of a barrier to adoption.

Information About Expected Profit Change, $E(\pi_1 - \pi_0)$

There are several potential sources of information about $E(\pi_1 - \pi_0)$ available to the grower. Own-farm information about insect damage in previous years and insect resistance to existing insecticides provides indirect information about the potential difference in profit between the old and new technologies. Also, there may be information on recent field trials of the technology from universities or from the technology developer. In our empirical analysis, we used average regional (upper South and lower South) yield differences between Bt cotton and conventional cotton varieties reported by Monsanto at the Beltwide Cotton Conferences for 1994 and 1995 as representative of the experimental information available at the time of initial adoption (Kerby et al.; Jones et al.).

Some sources of information may not be available in the first year of introduction including observed profit changes on surrounding farms and state-level average profit changes, as well as the number of adopters in the area. These sources of information are available in subsequent years, although the quality of the information from these sources may change over time—i.e., as more growers in a region adopt, the number of surrounding farms available for profit comparison will increase, giving growers a more precise measure of the distribution of profit changes in their region.

Using the survey responses, we constructed the average change in profit for each farm that adopted Bt cotton in 1996. This is calculated as:

$$P_c(Y_{bt} - Y_{nbt}) - P_s(S_{bt} - S_{nbt}) - 33.50,^{8} \tag{5}$$

where P_c = the 1996 state-level season average cotton price per pound; $Y_{bt} - Y_{nbt}$ = the reported average yield difference per acre on the acres planted to Bt cotton compared to acres planted to conventional cotton on the farm in 1996; P_s = the 1996 average cost per acre of treating with a conventional cotton insecticide, including application and

---

[8] Note that there were two choices of refugia to aid in the delay of resistance buildup to the Bt strain, one of which was required to plant Bt cotton. The choices were to leave 3.85% of the cotton land planted to conventional cotton varieties with no pest control allowed, or to leave 20% of the cotton land planted to conventional cotton varieties with conventional pest control allowed. In this early adoption stage with our sample of farmers, rarely were the refugia requirements a binding constraint, so we left the implicit cost out of our expected per acre profit calculations.

materials cost (taken from cotton enterprise budgets for each state); $S_{bt} - S_{nbt}$ = the reported difference in the number of sprays needed on the Bt cotton acres compared to the conventional cotton acres on the farm in 1996; and 33.50 = the technology fee per acre plus the average southeastern Bt cotton seed premium.

Further, we computed state-level and county-level average changes in profit from the survey data (both yield differences and spray cost differences) and used them as explanatory variables as well, to test the trade-off between the "bias" and the "precision" of the measures in the respondents' judgment of how "effective" the profit information was. Also, the more popular the technology becomes in the area, the greater the likelihood it will be profitable for any individual grower.[9] We obtained from Monsanto the actual proportion of total cotton acres planted to Bt cotton in 1996 by county and state. These proportions were used to test the popularity hypothesis and, nested within, the trade-off between bias and precision of this type of information.

The Empirical Evidence

We examined both the 1996 and 1997 adoption decisions of the survey respondents using the logistic regression routine with a normally distributed error option in SAS (SAS Institute, Inc.). Because the information available to a particular grower for the 1997 adoption decision depended on his/her 1996 adoption decision, we modeled the 1997 adoption decisions of the two groups (1996 adopters and 1996 nonadopters) separately. We take account of potential simultaneous equation bias by estimating the 1997 adoption decision of the 1996 adopters with two-stage least squares. In addition, since not all of the forms of information are in the same units, we redefine their relative contributions in elasticity terms in the tables that follow.[10]

1996 Adoption

Table 3 provides parameter estimates for various versions of the standard adoption model [equation (5) above] for 1996. For the most part, these results conform to those of previous studies in that both farm characteristics and human capital variables were significant and had the expected signs (Just and Zilberman; Rahm and Huffman; Marra and Carlson). Resistance to conventional pesticides had mixed results (as seen by the statistical significance for only one of the two models), although the coefficients were both large and positive. Farm size was important, whether measured as cotton acres or total crop acres. Regional yield information reported by Monsanto had a small, but significant and positive effect on the propensity to adopt. The operator's education level, measuring increased expected profit change from higher allocative skills, greater information-gathering and learning skills, or greater awareness of health problems with conventional pesticides, was positively related to the propensity to adopt, while cotton-growing experience did not seem to matter.

---

[9] We assume no product or input price effect in the early years of commercialization.

[10] Elasticities were calculated using first quartiles for the 1997 adoption models for the 1996 adopters because the probabilities are close to one when evaluated at the means. This means that the elasticities evaluated at the means will be close to zero. Evaluating at the first quartiles for this group yields a more useful comparison metric among the models.

Table 3. Probit Results for the 1996 Propensity to Adopt

[Dependent Variable = $P(ADOPT)$]	Adoption Models	
	Model 3A	Model 3B
Explanatory Variable	Parameter Estimate (Elasticity)	Parameter Estimate (Elasticity)
Intercept Term	-3.922**	-3.618***
Profit:		
Resistance to Conventional Pesticides in 1995? [yes or no]	0.342 (40.263)	0.384* (45.190)
Regional Yield, 1994–1995	0.006*** (0.783)	0.005*** (0.827)
Farm Characteristics:		
Cotton Share of Income	0.573 (0.243)	0.176 (0.095)
Total Cotton Acres	—	0.001*** (0.423)
Total Crop Acres	5.0E-4*** (0.398)	—
Farmer Characteristics:		
Operator's Years of Education	0.130** (1.587)	0.134*** (2.073)
Operator's Years Growing Cotton	0.008 (0.077)	0.007 (0.084)
McFadden's R^2	0.162	0.154

Notes: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Elasticities for continuous variables are evaluated at variable means. Elasticities for discrete variables are calculated as follows:

$$[P(Y|X=1) - P(Y|X=0)]/P(Y|X=0).$$

Note that although measures of goodness of fit are about 0.15 here (not uncommon for a cross-sectional analysis), they improve to about 0.56 for the 1997 adoption decision for 1996 adopters, but remain comparable to the fit of the 1996 adoption equations for the nonadopters' 1997 adoption decision (tables 3–5). This difference in fit is probably due to the on-farm profit information (the "highest quality" information available) which was available only to the 1996 adopters.

Continued Adoption by 1996 Adopters

Table 4 provides two-stage least squares (2SLS) probit model results of the 1997 adoption propensities for the 1996 Bt cotton adopters. The various models tested differ by type and levels of aggregation of the information variables. The profitability differences realized in 1996 are a function of the management skill of the operator, which is also a determinant of the initial adoption decision (whether to adopt and the degree of adoption as measured by the proportion of acres planted to the new technology). Although both types of variables are obvious candidates for explaining the 1997 adoption decision for the 1996 adopters, including them both in the continued adoption decision could lead

Table 4. 2SLS Probit Results for 1996 Adopters: 1997 Propensity to Adopt

[Dependent Variable = *P*(*ADOPT*)]	ADOPTION MODELS		
	Model 4A	Model 4B	Model 4C
Explanatory Variable	Param. Est. (Elasticity)	Param. Est. (Elasticity)	Param. Est. (Elasticity)
Intercept Term	-9.700***	-9.528***	-10.594***
PROFIT:			
Yield Difference	0.036***	0.037*	0.037**
	(0.000)	(0.000)	(0.000)
Spray Cost Difference	-0.123**	-0.121**	-0.136**
	(1.121)	(0.865)	(1.968)
Resistance to Conventional Pesticides in 1995? [yes or no]	4.678*	4.918**	4.854**
	(14.399)	(10.421)	(27.782)
POPULARITY:			
% State Bt Acres	—	-1.328	—
		(-0.035)	
% County Bt Acres	—	—	-2.226
			(-0.104)
FARM CHARACTERISTICS:			
Cotton Share of Income	4.647	4.572	4.841
	(0.412)	(0.318)	(0.682
Total Crop Acres	0.001	0.001	0.002
	(0.086)	(0.067)	(0.272)
Predicted Probability of Adoption in 1996	11.286	12.095	10.920
	(0.948)	(0.797)	(1.457)
McFadden's R^2	0.561	0.563	0.567

Notes: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Elasticities for continuous variables are evaluated at first quartiles of variables. Elasticities for discrete variables are calculated as follows: $[P(Y|X=1) - P(Y|X=0)]/P(Y|X=0)$.

to simultaneity problems. Therefore, rather than using the actual proportion of acres planted to Bt cotton in 1996 as an explanatory variable in the 1997 adoption models, we chose to use the predicted probability of adoption from the 1996 equation as an instrumental variable. The 1996 adoption model was estimated and a predicted probability for each observation was generated. We then used the predicted probability as one of the explanatory variables in the 1997 adoption models for this group.

The covariance matrix generated by the estimation routine is incorrect, because the instrument we chose is a prediction with error. Maddala gives the form of the covariance matrix in the case of simultaneous equations with binary dependent variables in a probit framework. Our model is similar, but the potential problem is in only one of the two equations, because they are sequential and not truly simultaneous. Derivation of the correct covariance matrix for this model is "complicated" (Maddala, p. 246), and we did not attempt it here. Therefore, in general, some caution is called for in making inferences for this group. However, the strength of the significance of the own-farm information variables implies that their significance probably would not be affected by a standard error adjustment.

Own-farm experiential information played a major role in the 1997 adoption decision for this group of farmers. The estimated coefficients on own-farm measures of the yield

Table 5. Probit Results for 1996 Nonadopters: 1997 Propensity to Adopt

[Dependent Variable = *P*(*ADOPT*)]	ADOPTION MODELS			
	Model 5A	Model 5B	Model 5C	Model 5D
Explanatory Variable	Param. Est. (Elasticity)	Param. Est. (Elasticity)	Param. Est. (Elasticity)	Param. Est. (Elasticity)
Intercept Term	-1.931***	-1.971***	-2.278***	-1.786
PROFIT:				
▸ **Own-Farm**				
Resistance to Conventional Pesticides in 1996? [yes or no]	0.869*** (52.954)	0.965*** (65.522)	0.946*** (61.165)	1.012*** (62.638)
▸ **State Level**				
Yield Difference	—	—	0.006* (0.660)	0.007 (0.767)
Spray Cost Difference	—	—	-0.056** (-0.948)	-0.020 (0.337)
▸ **County Level**				
Yield Difference	0.001* (0.052)	0.001* (0.065)	—	—
Spray Cost Difference	-0.012** (-0.231)	-0.012* (-0.291)	—	—
POPULARITY:				
% State Bt Acres	—	1.160* (0.287)	—	-1.430 (-0.326)
% County Bt Acres	1.479** (0.311)	—	0.082 (0.020)	—
FARM CHARACTERISTICS:				
Cotton Share of Income	1.130** (0.598)	1.250** (0.831)	0.649 (0.396)	0.913* (0.554)
Total Crop Acres	6.2E-4** (0.437)	0.7E-4*** (0.062)	0.5E-5** (0.004)	4.6E-5** (0.037)
McFadden's R^2	0.208	0.202	0.155	0.143

Notes: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Elasticities for continuous variables are evaluated at variable means. Elasticities for discrete variables are calculated as follows: $[P(Y|X=1) - P(Y|X=0)]/P(Y|X=0)$.

difference (Bt cotton yield less conventional cotton yield on the same farm) and spray cost differences (Bt cotton insecticide spray costs less conventional cotton spray costs on the same farm) are mostly highly significant and have the correct sign.

The popularity hypothesis (using either county- or state-level percentage of acres planted to Bt cotton) is rejected for these farmers. This is understandable, since they had direct own-farm profitability information available to them.

1997 Adoption by 1996 Nonadopters

The 1996 nonadopters had no own-farm profitability information and so had to rely on indirect measures. Table 5 reports the results of several models of this group's adoption decision, varying by information measures included. Where they were included, state-level profit measures had the correct sign and were significant in one of the two regressions. County-level profit measures all had the correct sign and significant coefficients.

This supports the nearness (bias) hypothesis in that information close to the farm is important even if it is made up of a small number of outcomes, although the greater precision of the state-level information seems to have some influence as well. Where county-level profit information is included, the popularity variable (either state level or county level) had a significant coefficient with the correct sign. This result may lend some support to the notion that the county-level profit information was confirmed and enhanced by the popularity information, whereas the state profit information was sufficient on its own.

Including state-level profit and popularity information in the same model resulted in insignificant coefficients for those variables. The coefficient on the popularity measure even has the wrong sign (model 5D). The state-level profit and popularity variables contain similar information, which may have resulted in some collinearity problems with these variables. Almost all measures of farm characteristics were significant and had the correct sign. As with the 1996 adopter group, none of the farmer characteristics were ever significant, and thus they were left out of the final models. Those who adopted Bt cotton in 1996 were not swayed very much with additional information beyond their own experience, while those who decided not to adopt in 1996 regarded several types of secondary information as important in their 1997 adoption decision.

Technology Depreciation: Resistance Development

The farmer's last non-Bt cotton crop year's experience with resistance development was a major determinant of the 1997 adoption decisions for both adopters and nonadopters. The coefficient on reported experience with resistance development (tables 4 and 5) is likely capturing the present value of the flow of expected future net gains from adoption of the new technology, although this relative advantage may erode over time.

Relative Contribution of the Individual Pieces of Information

It is difficult to compare the relative importance of a marginal change in a continuous variable and a discrete change in a binary variable using standard metrics such as point elasticities. As a result, we calculate two metrics that are arguably more comparable for use in examining the relative importance of the profit information variables. The first of these metrics is the change in the probability of adoption given a 100% increase (in absolute value) of each variable, holding all other variables at mean values for the 1996 adoption model and the 1997 adoption model for the 1996 nonadopters, and at the first-quartile values for the 1996 adopter models.[11] This provides a comparable nonmarginal change for comparison with the nonmarginal change in the binary variables.

Table 6 provides the estimated total change in the probability of adoption given a 100% change in all variables and a state shift from 0 to 1 in the binary variables, and the relative contribution of profit information-related variables to that total change. Both the total change in the probability of adoption and the percentage of that total

---

[11] We attempted to estimate a simultaneous self-selection model, which would provide more efficient parameter estimates in theory, but given the low number of observations in the "disadopters" category and the nonlinear estimation routine required, the model would not converge.

Table 6. Relative Importance of Expected Profit Information on Farmers' Adoption Decisions

Adoption Model / Version	Total Change in $P(ADOPT)^a$	% of Total Due to Expected Profit Variables
1996 *P*(*ADOPT*) [evaluated at means]:		
3A	416.208	35.40
3B	380.692	35.29
1997 *P*(*ADOPT*) for 1996 Adopters [evaluated at 1st quartiles]:		
4A	64.243	44.83
4B	50.678	48.80
4C	141.257	47.42
1997 *P*(*ADOPT*) for 1996 Nonadopters [evaluated at means]:		
5A	228.323	50.56
5B	212.994	63.37
5C	237.645	81.44
5D	164.923	59.44

[a] Denotes estimated total change in the probability of adoption given a 100% change in all variables and a state shift from 0 to 1 in the binary variables.

contributed by the profit information variables are presented in table 6 for all of the models of the 1996 and 1997 adoption decisions we are still considering at this point. For the 1996 adoption models, around 35% of the total change in the probability of adoption is due to the information variables (experience with resistance and experimental yield information). The results are quite different for the 1997 adoption models. For those farmers adopting in 1996, the information variables account for between 45% and 48% of the total change.[12] For those not adopting in 1996, the information variables account for over 50% of the total change for all model specifications. It is clear that information about the technology's profitability is very important to both groups.

The relative weights, $W_j = w_j/\gamma$, of the individual pieces of information about profitability are presented in table 7. To construct weights that would be independent of both the scale of the individual variables and the level of the variables, we chose first to convert the coefficients into semi-standardized coefficients by multiplying each coefficient by the sample standard deviation, S, for the associated explanatory variable (Kaufman). The semi-standardized coefficients are now in units of standard deviations for each variable. This provides a clearer comparison of the importance of each variable, as long as the relative variability of each variable is comparable.[13] The weights are thus calculated empirically as:

---

[12] These numbers are somewhat misleading, because the 100% change metric is evaluated from a starting point of the first quartile of each variable. The own-farm yield difference is equal to zero at the first quartile, so the own-farm yield information contributes zero when a 100% increase is applied.

[13] We examined the coefficient of variation for each of the profit-related variables included in the models. For most of the variables, the coefficient of variation was similar (between 0.7 and 0.9). However, for the own-farm and county-level yield difference variable, the coefficient of variation was over 2, suggesting a much greater degree of variability in yield changes.

Table 7. Relative Importance of the Information Variables

Adoption Model / Version	Experienced Resistance to Conventional Pesticides	Own-Farm Yield Difference	Own-Farm Spray Cost Difference	County Average Yield Difference	County Average Spray Cost Difference	State Average Yield Difference	State Average Spray Cost Difference	Proportion of County Cotton Acres in Bt	Proportion of State Cotton Acres in Bt	1994–1995 Regional Experimental Yields
	PROFIT INFORMATION SOURCES (EXPLANATORY VARIABLES):									
	<—— Proportion of Expected Profit Effect on $P(ADOPT)$ ——>									
1996 $P(ADOPT)$:										
3A	0.312	—	—	—	—	—	—	—	—	0.688
3B	0.374	—	—	—	—	—	—	—	—	0.626
1997 $P(ADOPT)$ for 1996 Adopters:										
4A	0.185	0.588	0.227	—	—	—	—	—	—	—
4B	0.188	0.575	0.215	—	—	—	—	—	0.023	—
4C	0.173	0.553	0.228	—	—	—	—	0.045	—	—
1997 $P(ADOPT)$ for 1996 Nonadopters:										
5A	0.353	—	—	0.148	0.202	—	—	0.297	—	—
5B	0.418	—	—	0.158	0.216	—	—	—	0.208	—
5C	0.346	—	—	—	—	0.376	0.263	0.015	—	—
5D	0.331	—	—	—	—	0.391	0.084	0.015	0.194	—

Note: The weights of the information variables are calculated as follows, where S is the sample standard deviation of the associated explanatory variable:

$$W_j = \frac{\hat{\beta}_j S_j}{\sum_j \hat{\beta}_j S_j}.$$

$$W_j = \frac{\hat{\beta}_j S_j}{\sum_j \hat{\beta}_j S_j}.$$

From table 7, we can see that the source and form of the information make a difference. The resistance experience dummy variable makes up 31% to 37% of the total impact in the 1996 adoption models. The lion's share of the impact is from the reported yield gains from Monsanto (63% to 69%). Resistance experience for the 1996 nonadopter group in the 1997 adoption models also makes up a significant portion of the total impact (33% to 42%). The resistance experience variable is less important in the 1997 adoption decision of the 1996 adopters (17% to 19%). In the 1997 adoption models, for the 1996 adopters, own-farm information on yield differences has by far the largest relative impact (55% to 59%), followed by own-farm information on spray-cost differences (21% to 23%). There are very mixed results from the popularity variables, and they depend on the other variables present in the models.

Conclusions and Future Work

Information on the profitability of new technologies is available in a variety of forms and in varying levels of quality. Arguably, own-farm information from early adoption is the most precise and unbiased information available to an individual farmer. Our results suggest that, when it is available, own-farm information carries the most weight in the decision to adopt (or to continue to adopt). In all cases, we find that profit information, whether own-farm or from another source, accounts for over 35% of the estimated impact of all modeled variables on adoption. However, when direct (own-farm or broader average) information is not available (as in the first year of introduction), the importance of profit information is reduced relative to information on farm and farmer attributes.

To predict where adoption of the new technology will take place first, one should look not only where field experiments suggest the greatest improvements in yield will occur, but also where the current technology is becoming less effective (indicated in our model by reported experience with insecticide-resistant pests). Our results show that in both the first and second years, experience with resistant insects is a consistent predictor of adoption. This supports the technology depreciation hypothesis and reminds researchers to partially focus on past technologies when evaluating the potential of new technologies.

It is clear from our results that when own-farm information on yield and spray cost differences (direct evidence of current profitability) is available, it is weighted most heavily relative to other profit information. When own-farm information is not available, farmers appear to more equally weight a variety of information sources, including technology depreciation (measured by resistance to conventional insecticides), county or state average levels of yield and spray cost differences, and popularity of the new technology.

It is interesting to note that relative to popularity, geographic nearness (relative unbiasedness) seems to be outweighed by the relative precision of the more aggregated information in the off-farm profit estimates. When the state-level estimates of yield and spray cost differences are included in the model, popularity measures are assigned less weight than when county-level estimates are included. Also, state-level yield difference information seems to have the largest weight, suggesting that farmers may value precise information about yields more than information about spray cost differences. Or, this may suggest that farmers consider state-level yield difference averages to be more in line with their own expectations, while state-level spray cost differences are seen as less reliable. This may have implications for how extension educators assemble information about a new technology to present to farmers.

Our measures of Bt cotton's popularity made some (but not much) difference in the adoption decisions of this group of farmers. Popularity made very little difference to those farmers who adopted in 1996; however, in some model specifications for the 1996 nonadopters, popularity was weighted as much or more than either the yield or spray cost difference information (although not as much as the combined weight of both pieces of information). Popularity may be weighted more heavily in future years than would be suggested by our model. This can arise if farmers are slow to respond to what others are doing during the beginning years of commercial availability of a new technology until a "critical mass" of off-farm popularity information is reached.

The results of this study have implications for the off-farm information generators and reporters of profit potential of a new agricultural technology similar to the one considered here. A summary of information from around the state or region may be more effective (and more appreciated by farmers) than the results of one small field trial conducted close by. This would seem to indicate that information gathered and averaged from scattered research plots (perhaps even from several research institutions) might be more influential than county demonstration projects for this type of adoption decision.

Many transgenic crop technologies are now being introduced every year. Future application of this model to more of these crops and in other regions may prove fruitful. It would also be interesting to explore the nearness-precision trade-off in other contexts, such as industrial technology adoption decisions.

[*Received July 1999; final revision received October 2000.*]

References

Carlson, G. A. "The Long-Run Productivity of Insecticides." *Amer. J. Agr. Econ.* 59(1977):543–48.

Carlson, G. A., M. C. Marra, and B. J. Hubbell. "Yield, Insecticide Use, and Profit Changes from Adoption of Bt Cotton in the Southeast." *Proceedings of the Beltwide Cotton Conferences* 29(1998):973–74. National Cotton Council, Memphis TN.

Ellison, G., and D. Fudenberg. "Rules of Thumb for Social Learning." *J. Polit. Econ.* 101(1993):612–43.

Feder, G., and G. T. O'Mara. "Farm Size and the Diffusion of Green Revolution Technology." *Econ. Develop. and Cultural Change* 30(1981):59–70.

Fischer, A. J., A. J. Arnold, and M. Gibbs. "Information and Speed of Innovation Adoption." *Amer. J. Agr. Econ.* 78(1996):1073–81.

Foster, A. D., and M. R. Rosenzweig. "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture." *J. Polit. Econ.* 103(1995):1176–1209.

Heisey, P. W., M. Smale, D. Byerlee, and E. Souza. "Wheat Rusts and the Costs of Genetic Diversity in the Punjab of Pakistan." *Amer. J. Agr. Econ.* 79(1997):726–37.

Jones, K., T. Kerby, H. Collins, T. Wofford, M. Bates, J. Presley, J. Burgess, B. Buchler, and R. Deaton. "Performance of NuCotn Bollgard™." *Proceedings of the Beltwide Cotton Conferences* 27(1996):46–47. National Cotton Council, Memphis TN.

Just, R. E., and D. Zilberman. "Stochastic Structure, Farm Size, and Technology Adoption in Developing Countries." *Oxford Econ. Pap.* 35(1983):307–28.

Kaufman, R. L. "Comparing Effects in Dichotomous Logistic Regression: A Variety of Standardized Coefficients." *Social Sci. Quart.* 77(1996):90–109.

Kerby, T., T. Wofford, J. Presley, J. Thomas, M. Bates, and J. Burgess. "Field Performance of Transgenic Bt Cotton in Multiple Locations Across the Belt." *Proceedings of the Beltwide Cotton Conferences* 26(1995):574–76. National Cotton Council, Memphis TN.

Kislev, Y., and N. Sechori-Bachrach. "The Process of an Innovation Cycle." *Amer. J. Agr. Econ.* 55(1973): 28–37.

Lindner, R. K., A. J. Fischer, and P. G. Pardey. "The Time to Adoption." *Econ. Letters* 2(1979):187–90.

Maddala, G. S. *Limited Dependent and Qualitative Variables in Econometrics.* Econometric Society Monograph No. 3. Cambridge, England: Cambridge University Press, 1987.

Marra, M. C., and G. A. Carlson. "The Role of Farm Size and Resource Constraints in the Choice Between Risky Technologies." *West. J. Agr. Econ.* 12(1987):109–18.

McCardle, K. F. "Information Acquisition and the Adoption of New Technology." *Manage. Sci.* 31(1985): 1372–89.

Rahm, M. R., and W. E. Huffman. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *Amer. J. Agr. Econ.* 66(1984):405–13.

SAS Institute, Inc. *SAS Statistical Analysis System, Version 7.* Cary NC: SAS Institute, Inc., 1998.

Williams, M. R. "Cotton Insect Losses, 1996." *Proceedings of the Beltwide Cotton Conferences* 28(1997): 834–53. National Cotton Council, Memphis TN.