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4. Farm-Level Effects of Adopting Genetically Engineered Crops in the U.S.A.

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Chapter 4

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Introduction

Genetically engineered crops with enhanced input traits for pest management carry genes that confer herbicide tolerance and insect control. Use of these crops has risen dramatically in only a few years since commercial approval (Table 1). By 1998, around 40 percent of the cotton acres,

TABLE 1 Adoption of Genetically Engineered (GE) Crops in Major Producing States

Field Crop	Year of First Introduction	Estimated Planted Acreage 1996	1997	1998[a]
		Percent of planted acreage		
Cotton				
Bt cotton	1995	14.6	15.0	16.8
Herbicide-resistant cotton	1996	id	10.5	26.2
Corn				
Bt corn	1996	1.4	7.6	19.1
Herbicide-resistant corn[b]	1996	3.0	4.3	18.4
Soybean				
Herbicide-resistant soybean	1996	7.4	17.0	44.2

[a]Includes stacked varieties (with Bt and herbicide-tolerant genes).

[b]Includes seeds obtained by traditional breeding but developed using of biotechnology techniques that helped to identify the herbicide-tolerant genes.

id = Insufficient data for a reliable estimate.

Source: Calculated from USDA s ARMS data for 1996, 1997, and 1998.

a third of the corn acres, and more than 40 percent of the soybean acres were planted to genetically engineered varieties. Adoption is expected to increase in 1999 as seed companies continue to offer new seed varieties with herbicide-tolerant and insect-resistant traits, including "stacked" varieties containing more than one trait. Now that these crops are in the field, researchers are examining the effect of these crops on pesticide use, yields, farmers' profits, and the use of other cropping practices.

It has been claimed that the use of genetically engineered crops with enhanced input traits can increase land productivity, thus allowing an increase in the production of food and fiber, while reducing chemical pesticide use, but few farm-level empirical studies have reported the effect of those crops on yields, profits, and pesticide use. This paper summarizes the potential benefits, costs, and possible environmental implications from using genetically engineered crops with enhanced input traits. In addition, the paper presents the results of an empirical study on the effect of adopting herbicide-tolerant crops such as soybean and cotton, as well as an insect resistant crop (Bt cotton), on yields, profits, and pesticide use.

Promises and Fears

Modern plant biotechnology methods, such as cell culture and genetic engineering, have led to the development of novel plant varieties that would not have been possible using traditional breeding methods. The genetic modification of organisms by recombinant DNA techniques can range from either enhancing or suppressing the performance of existing genes to the transfer of genetic information from one organism into a host organism. Genetic engineering reduces the time required to identify desirable traits and allows a more precise alteration of a plant's traits. Seed developers are able to target a single plant trait which can decrease the number of unintended characteristics that may occur with traditional breeding methods.

Most of the genetically modified crops that are commercially available have been developed to carry herbicide-tolerant or insect-resistant genes. Crops carrying herbicide-tolerant genes were developed to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds, and allow farmers to use them as postemergent herbicides, providing a broader variety of herbicides to control weeds. The most common herbicide-tolerant crops are Roundup Ready (RR) crops resistant to glyphosate, an herbicide effective on many species of grasses, broadleaf weeds, and sedges. Glyphosate tolerance has been incorporated into cotton, corn, soybeans, and canola. Other genetically modified herbicide-tolerant crops include Liberty Link (LL) corn resistant to glufosinate-ammonium, and BXN cotton resistant to bromoxynil. There are also traditionally bred herbicide-tolerant crops, such as corn resistant to imidazolinone (IMI) and sethoxydim (SR), and soybeans resistant to sulfonylurea (STS).[2]

Bt crops containing the gene from a soil bacterium, *Bacillus thuringiensis*, are the only insect-resistant crops commercially available. The bacteria produces a protein that is toxic when ingested by certain Lepidopteran insects. Crops containing the Bt gene are able to produce this toxin, thereby providing protection throughout the entire plant. Bt has been built into many crops, such as corn and cotton, and is effective in controlling Lepidopteran insects. For example, Bt cotton is primarily effective in controlling the tobacco budworm, the bollworm, and the pink bollworm. Similarly, Bt corn provides protection against the European corn borer (ECB), and, to a lesser extent, protects against the corn earworm, the southwestern corn borer and the lesser cornstalk borer.

Proponents claim that the use of herbicide-tolerant and insect-resistant crops may benefit the environment by reducing the use of potentially harmful synthetic pesticides that could be transported into waterways or lead to residues in/on the food. There are significant benefits to U.S. farmers from using pesticides, as evidenced by the willingness of these farmers to spend $8 billion on pesticides in 1996 (USDA, 1997). However, the potential hazard of these chemicals to human health and the environment has caused increased concern. Agricultural chemical firms have invested increasingly in plant biotechnology, partly in response to tougher health and environmental regulations that have raised the costs of developing chemical pesticides that are both harmless to crops and sufficiently toxic to kill target pests. As a result, a chemical pesticide takes an average of 11 years at a cost of $50-70 million to develop, whereas the development of a genetically engineered plant takes about 6 years and costs about $10 million (Ollinger and Fernandez-Cornejo, 1995).

Although there may be some environmental benefits from using crops with herbicide-tolerant or insect-resistant traits, there are some concerns about extensive use of these crops. One concern is that herbicide-tolerant crops would foster farmers' reliance on herbicides. However, these crops may require lower application rates or fewer herbicide applications. And, in some cases, these crops could allow farmers to substitute the use of more benign herbicides for more harmful ones and allow farmers to use them as postemergent herbicides. For example, glyphosate is considered to be environmentally benign (Culpepper and York, 1998; Roberts et al., 1998).

Another concern is that extensive use of these crops could lead to the development of insect and weed resistance. Genetically modified organisms (GMOs), in general, have the potential to reproduce, mutate, and migrate. Since GMOs interact with the environment, concerns have been raised about risks associated with the release of GMOs. One potential risk is that herbicide-tolerant crops may pass their genes to weedy relatives, thereby making those weeds resistant to herbicides. Another risk is that Bt crops would promote insect resistance to Bt.[3] Resistant insects could make crops more vulnerable. This problem exists with chemical pesticides as well, but Bt genetically engineered into a plant will persist in the environment longer than foliar Bt, thus shortening the time for targeted insect pests to become resistant to foliar Bt. Some agricultural producers, such as organic growers, rely on Bt for insect control, and if insects become resistant these growers could lose the option of using these products. However, the Environmental Protection Agency (EPA) requires resistance management plans to control insect resistance to Bt to ensure that enough susceptible moths survive to mate with resistant ones. The two resistance management alternatives mandated by EPA are: 1) planting a refuge of 20 percent of crop acres which can be treated only with foliar conventional insecticides without the use of Bt products, or 2) planting a refuge of 4 percent of crop acres that is left entirely untreated for Lepidopteran insects (Cotton Insect Control Guide, 1997).

Despite environmental concerns, herbicide-tolerant and insect-resistant varieties may offer farmers many benefits, including decreased pest management costs, increased yields, and greater cropping practice flexibility. The expected benefits and performance of these crops will vary greatly by region, mostly depending on infestation levels, the development of popular regional varieties containing these genes to ensure yield advantages, and seed and technology costs. For many farmers, expected benefits appear to have outweighed expected costs, translating into rapid adoption of these crop varieties.

Potential Effects of Using Genetically Engineered Crops with Pest Management Traits

Herbicide-tolerant and insect-resistant crops may help reduce chemical pesticide use in agriculture. For example, it has been claimed that Bt corn would reduce the need for conventional chemical pesticides by about 10 million pounds per year (*Pesticide & Toxic Chemical News*, Salquist). Similarly, genetically engineered plant varieties resistant to particular herbicides may reduce herbicide use. It was claimed that by converting 30 percent of cotton acreage to cotton varieties tolerant to bromoxynil, which is effective at lower rates than traditional herbicides, herbicide use could be reduced by 10 million pounds and farmers would have annual savings of $40 million (Salquist).[4] Also, a report by James (1998) indicated that the use of herbicide-tolerant soybeans led to 10 to 40 percent less herbicide requirements.

Savings in herbicide costs may be achieved with the use of herbicide-tolerant crops by decreased herbicide application rates through the ability to use more effective postemergence herbicides. Similarly, farmers using Bt crops may be able save in insecticide costs by being able to discontinue the use of Bt foliar sprays and possibly decrease applications of other insecticides, such as pyrethroids in cotton. Farmers planting Bt crops may also benefit from decreased dependence on variable weather conditions. They would not have to worry about timing insecticide applications because the Bt toxin remains active in the plant throughout the crop year.

Farmers may also benefit from increased planting flexibility. For example, herbicide-tolerant crops may alleviate any problems arising from the carryover of herbicides. Farmers may be able to practice strippcropping (a practice where corn and soybeans are grown in alternating rows). Also, farmers that use production practices such as notill may benefit if the adoption of herbicide-tolerant crops allow them to use a more effective herbicide treatment system.

Herbicide-tolerant and insect-resistant crops are expected to offer more effective options for controlling pests, resulting in higher crop yields. A yield lag, however, has made adoption of these crops in some regions slower than others. Adoption is expected to increase as preferred, high-yielding, regional cultivars are developed to contain herbicide-tolerant or insect-resistant genes. Additionally, crop revenues could be affected by crop prices. These prices may depend on crop quality and whether exports are restricted by countries that do not commercially approve genetically engineered crops.

Although farmers may experience decreased pest management costs and higher revenues attributed to herbicide-tolerant and insect-resistant crops, there is a cost. Seed costs are greater than traditional seed. Not only is there a seed price premium, but farmers are also required to pay a technology fee. Seed developers not only determine seed prices to recoup research and development expenses, but also to encourage adoption. Falck-Zepeda and Traxler (1998) found that U.S. cotton farmers shared the surplus with Bt cottonseed development companies. They each received about 49 percent of the surplus. The study showed, however, that consumers did not benefit that much. Only about 2 percent of the surplus went to consumers in the U.S. and the rest of the world combined. Regional benefits will vary because of differences in pest infestation, seed prices, and technology fees.

Previous Empirical Studies

There have been several field test and enterprise studies that have analyzed the agronomic, environmental and budget effects of adopting genetically modified crops (Culpepper and York, 1998; Roberts et al., 1998). However, there have been few studies that have investigated the actual yield, pesticide use, and profit effect from farm-level adoption (Stark, 1997; Marra et al., 1998; Fernandez-Cornejo and Klotz-Ingram, 1998). Some of the findings of these studies are summarized below.

Herbicide-Tolerant Crops

Weed control is critical in the production of many crops, especially cotton. Crops usually require several types and applications of herbicides to control weeds. Some of the studies on herbicide-tolerant crops (Culpepper and York , 1998; Marra et al., 1998; Fernandez-Cornejo and Klotz-Ingram, 1998) found that the adoption of these varieties did not necessarily translate into yield gains. However, Roberts et al. (1998) concluded that herbicide treatments that included glyphosate on RR soybeans led to lower treatment costs combined with a higher yield "resulting in a positive impact on net farm income."

The greatest advantage of planting herbicide-tolerant varieties was the reduced herbicide use. Herbicide treatments that included glyphosate were as effective, if not more effective, than traditional herbicide treatment systems on RR cotton and soybean varieties (Culpepper and York, 1998; and Roberts et al., 1998). Herbicide treatment systems with glyphosate on RR cotton required fewer herbicide treatments and less total herbicide to produce equivalent yields and net returns (Culpepper and York, 1998). The study on RR soybeans by Roberts et al. (1998) also found that total herbicide costs were lower for herbicide treatment systems that included glyphosate.

Fernandez-Cornejo and Klotz-Ingram (1998) estimated the effects of herbicide-tolerant corn adoption on yields, profits and herbicide use. The analysis used field-level survey data on herbicide-tolerant (mainly IMI) corn adoption in 1996. They concluded that the adoption of these corn varieties was negatively and significantly related to herbicide use, especially for the acetamide herbicide family. The effect of adoption of those corn varieties on yields was small and on profits was not statistically significant. Other studies determined that farmers had greater net returns from RR crop varieties. Marra et al. (1998) estimated that the net gains from using RR soybeans was about $6.00 per acre. The lower herbicide costs alone were enough to outweigh the higher seed costs.

Bt Crops

Insect pests can cause considerable damage to crops. In cotton, bollworms and budworms combined accounted for about $186 million in cotton losses and treatment expenses in 1998 (Williams,1999). In 1998, about 9 million cotton acres were infested with bollworms and budworms. The European corn borer is among the major pests in corn production and its annual damage have been estimated at about $1 billion (James, 1998).

Many of the studies found that Bt varieties had a yield advantage and lower insecticide costs. Marra et al. (1998) conducted a Bt cotton survey to determine the effects of adoption on yields, net revenues and pesticide use. Surveys were returned by 300 farmers in North and South Carolina, Georgia and Alabama. They found that yields were significantly greater for farmers planting Bt in the lower southern states and for the entire sample. This was not true for the upper southern states. They also found that farmers growing Bt cotton had fewer insecticide applications, especially for pyrethroid insecticides. The rate of return was less in the upper South than the lower South. The additional crop revenues and insecticide savings outweighed the higher seed and technology costs in the lower south. For Bt corn, Marra et al. (1998) determined that better control of ECB boosted yields by 4 to 8 percent depending on location and year. Alternatively, Bt corn use only resulted in modest savings from reduced insecticide applications. However, returns from increased corn yields were greater than the seed premiums and technology fees. This translated into net gains of about $3-$16 per acre (Marra et al., 1998).

Falck-Zepeda and Traxler (1998) estimated the distribution of benefits from the adoption of Bt cotton. The net surplus for farmers adopting Bt cotton ranged from -$13 per acre to $65 per acre. Some farmers faced a 300-percent seed price premium. They found higher adoption rates in the Southeast, although it varied by state. Insect loss expectations are generally higher in the Southeast.

For farmers to obtain economic benefits from adopting herbicide-tolerant and insect-resistant crops, it would take a certain infestation level to break-even. The expected benefits from adopting these varieties greatly depend on infestation levels and the associated yield advantages and pesticide use. Therefore, farmers in regions that have an increased probability of pest infestations would benefit from reduced pesticide applications and higher expected yields. Their willingness to pay for Bt seed would be higher.

Empirical Results

This section presents the empirical evaluation of the effect of adopting genetically engineered soybean and cotton with pest management traits on yields, variable farm profits, and pesticide use using nationwide field- and farm-level survey data.[5] After briefly showing survey results on the reasons, stated by farmers, for adopting these crops, we present the methodology used and the econometric model developed to examine the impact of adoption.[6] The method is then used to conduct separate analyses for herbicide-tolerant soybeans, herbicide-tolerant cotton, and insect-resistant cotton (Bt cotton).

Reasons for Adoption According to Farmers

The majority of farmers surveyed (ranging from 54 to 76 percent of adopters, Table 2) have indicated that the main reason they adopted genetically engineered crops with pest management traits was to "increase yields through improved pest control." The second top reason, stated by 19-42 percent of adopters, was "to decrease pesticide costs." All other reasons combined ranged between 3 and 15 percent of adopters.

These results confirm other adoption studies pioneered by Griliches who showed that expected profitability positively influences the adoption of agricultural innovations. Hence, factors expected to increase profitability by increasing revenues per acre (price of the crop times yield) or reducing costs are generally expected to positively influence adoption. Given that an objective of pest management in agriculture is to reduce crop yield losses, there is a high incentive for innovations that reduce these losses. However, yields also depend on locational factors, such as soil fertility, rainfall, and temperature. The physical environment of the farm (e.g., weather, soil type) may affect profitability directly through increased fertility, and indirectly through its influence on pests. For these reasons, empirical studies often include dummy variables for states or regions as locational proxies, or separate analyses are conducted for some regions.[7]

TABLE 2 Main Stated Reason to Adopt Herbicide-Tolerant Soybeans/Cotton and Bt Cotton by U.S. Farmers, 1997

Stated Reason to Adopt	Percent of Acreage among Adopters: Herbicide-tolerant soybeans	Herbicide-tolerant cotton	Bt Cotton
1. Increase yields through improved pest control	65.2	76.3	54.4
2. Decrease pesticide input costs	19.6	18.9	42.2
3. Increased planting flexibility[a]	6.4	1.8	2.2
4. Adopt more environmentally friendly practices	2.0	0.9	0.0
5. For some other reason(s).	6.8	2.3	1.2

[a]For example, easier to rotate crops, reduce carryover, use reduced tillage or notill systems, etc.

The Model to Measure the Impacts of Adoption

The model takes into consideration that farmers' adoption and pesticide use decisions may be simultaneous, due to unmeasured variables correlated with both adoption and pesticide demand, such as the size of the pest population, pest resistance, farm location, and grower perceptions about pest control methods (Burrows). In addition, the model corrects for self-selectivity to prevent biasing the results (Greene). Self-selection arises because farmers are not assigned randomly to the two groups (adopters and nonadopters), but they make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different and these differences may manifest themselves in farm performance and could be confounded with differences due purely to adoption. Finally, the model ensures that the pesticide demand functions are consistent with farmers' optimization behavior, since the demand for pesticidal inputs is a derived demand.

The adoption of a new technology is essentially a choice between two alternatives, the traditional technology and the new one. As such, choice models developed in consumer theory have been used to motivate adoption decision models. In this context, growers are assumed to make their decisions by choosing the alternative that maximizes their perceived utility. Assuming that the stochastic disturbances are independently and identically distributed with a normal distribution, a probit transformation can be used to model the farmer's decision to adopt (Fernandez-Cornejo, 1996, 1998). Thus, the adoption probability equation is $P(I_k=1) = F(\tilde{a}_k'\mathbf{Z}_k)$ where I_k denotes the adoption of genetically engineered crops (k=1) and (to control for in the second stage) weed (insect) management practices that might also affect the use of herbicide (insecticides) (k=2). F indicates the cumulative normal distribution and **Z** is the vector of explanatory variables (factors or attributes), including farm size, farmer's education and experience, crop price, weed infestation levels/target pests, sources of pest information, use of irrigation, use of conventional tillage, seed price, and contractual arrangements for the production/marketing of the product. In addition, following Fernandez-Cornejo et al., **Z** also includes a proxy for risk (debt to assets ratio).

To account for simultaneity and self-selectivity we expand a method developed by Fernandez-Cornejo (1996, 1998) who adapted Heckman's (1976) two-step procedure. First, we estimate the parameters $\tilde{\mathbf{a}}_{\mathbf{k}}$ of the adoption decision equations, i.e., the probit equations for the adoption of a genetically engineered crop as well as other pest management practices that might affect the use of pesticides on that crop (Greene). We also estimate the inverse Mills ratio ë$_k$ for each observation. Moreover, to account for simultaneity, as I_k is endogenous, the predicted probabilities (from the probit model) are used as instrumental variables for I_k in the second stage.

To examine the impact of using herbicide-tolerant and insect-resistant crops on yields, farm profits, and pesticide use, we conduct separate analyses for two herbicide-tolerant crops (soybean, and cotton) and an insect-resistant crop (Bt cotton). For each case, we specify three herbicide (insecticide) demand functions considering the main herbicide (insecticide) "families," together with the supply function and the variable profit function as a simultaneous system.[8] Using a normalized quadratic restricted profit function (Diewert and Ostensoe; Fernandez-Cornejo, 1996, 1998), considering land as a fixed input and a single output (the crop being studied, soybean or cotton), using the price of labor as the numeraire, appending the inverse Mills ratio terms as additional regressors to the supply, demand, and profit equations, and appending disturbance terms, the per acre supply function (Y), the three per-acre herbicide (insecticide) demand functions, vector **X** with components for the main herbicide (insecticide) families considered, and the per acre profit function (π) become:

(1) $$\pi = A_0 + A_y P + S_j A_j W_j + S_k C_k R_k + 0.5\, G_{yy} P^2 + S_j G_{yi} P W_j + S_k F_{yk} P R_k$$

$$+ 0.5\, S_j\, Si\, G_{ij} W_i W_j + S_k S_j E_{jk} W_j R_k + 0.5\, S j\, C_{ik} R_i R_k + \theta_{01}\lambda_1 + \theta_{02}\lambda_2 + \varepsilon_\pi$$

(2) $$Y = A_y + G_{yy} P + S_j G_{yj} W_j + S_k E_{yk} R_k + \theta_{y1}\lambda_1 + \theta_{y2}\lambda_2 + \varepsilon_y$$

(3) $$X_1 = A_1 + G_{y1} P + S_j G_{1j} W_j + S_k E_{1k} R_k + \theta_{11}\lambda_1 + \theta_{12}\lambda_2 + \varepsilon_1$$

(4) $$X_2 = A_2 + G_{y2} P + S_j G_{2j} W_j + S_k E_{2k} R_k + \theta_{21}\lambda_1 + \theta_{22}\lambda_2 + \varepsilon_2$$

(5) $$X_3 = A_3 + G_{y3} P + S_j G_{3j} W_j + S_k E_{3k} R_k + \theta_{31}\lambda_1 + \theta_{32}\lambda_2 + \varepsilon_3$$

where P and W are the output and input prices, A, C, E, F and G are parameters. The vector **R** includes pest infestation levels, and the predicted probabilities of adoption, obtained from the probit equation system for the adoption of genetically engineered crops as well as for the adoption of pest management practices that might affect the use of herbicides (insecticides).

Data and Estimation

The model is estimated using data obtained from the nationwide Agricultural Resource Management Study (ARMS) surveys developed by the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) of USDA and conducted in 1996-97. The ARMS surveys were designed to link the resources used in agricultural production to technologies and farm financial/economic conditions for selected field crops. In particular, the ARMS survey data can be used to link the adoption of genetically engineered crops with yields, other management techniques, chemical use, and profits.

The data were obtained using a three-phase process (screening, obtaining production practices and cost data, and obtaining financial information) (Kott and Fetter). The 1997 soybean survey covered 19 states, which account for 93 percent of the U.S. soybean production. The third phase included 17 states, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Mississippi, Michigan, Minnesota, Missouri, Nebraska, North Carolina, Ohio, South Dakota, Tennessee, and Wisconsin. After excluding observations with missing values, 1444 observations from 17 states were available for analysis.

The 1997 cotton data include cotton-producing farms from 12 states accounting for 96 percent of the U.S. upland cotton production. The states included are Alabama, Arizona, Arkansas, California, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Texas. After excluding observations with missing values, 696 observations were available for analysis

For the empirical evaluation, the probit equations are estimated together as a bivariate probit model (Greene) because the errors of the estimating equations are likely to be correlated. Moreover, the disturbances of the equations for the second stage (equations 1-5) are also likely to be correlated. Thus, to gain estimation efficiency, the per acre supply and the three demand equations are estimated together with the per acre profit function in an iterated seemingly unrelated regression (ITSUR) framework (Zellner).

The impact of adoption of genetically engineered crops on pesticide use is calculated from equations (3)-(5). For example, for the case of Bt cotton, from equation (4) the impact of using Bt cotton on pyrethroid insecticide use is: $X_2/ \quad R_4 = E_{24}$. The elasticity of pyrethroid insecticide use with respect to the probability of adoption of Bt cotton is $E_{24}*(R_4/X_2)$.

Because of the complexity of the survey design (the sample is not a simple random sample) a weighted least squares (WLS) technique is used to estimate the parameters. A delete-a-group jackknife method is used to calculate variances and standard errors. The method consists of partitioning the sample data into r groups of observations (r=15 in this survey); thus forming 15 replicates and deleting one group of observations in each replicate. A set of sampling weights is calculated by the National Agricultural Statistics Service (NASS) of the USDA for each replicate.

Results for Herbicide-Tolerant Soybean

Soybean production in the U.S. uses a large amount of herbicides, and 97 percent of the 66.2 million acres devoted to soybean production in the 19 major states were treated with more than 78 million pounds of herbicides in 1997 (USDA, 1998). As shown in Table 3, pendimethalin was the top herbicide, as farmers applied more than 17 million pounds of this chemical in 1997. Glyphosate, whose use grew substantially compared with 1996, was second (15 million pounds), followed by trifuralin (12 million pounds) and metolachlor (9 million pounds).

TABLE 3 Major Herbicides Used on Soybeans, 1997[a]

Herbicide active ingredient	Area applied	Appli-ations	Rate per crop year	Total applied
	Percent	Number	Lbs/acre	Million lbs
Acetamides				
Metolachlor	7	1.1	1.87	8.91
Alachlor	3	1.0	2.36	4.50
Glyphosate	28	1.3	0.81	14.92
Other herbicides				
Pendimethalin	25	1.1	0.95	17.53
Trifuralin	21	1.0	0.88	12.27
Bentazon	11	1.0	0.65	4.74
Clomazone	5	1.0	0.71	2.32
2, 4-D	8	1.0	0.39	2.11
Acifluorfen	12	1.0	0.21	1.69
Metribuzin	10	1.0	0.25	1.69
Imazethapyr	38	1.0	0.05	1.24
Sethoxydim	7	1.0	0.21	1.03

[a]Planted acres was 66.2 million acres for the 19 states surveyed.

Source: USDA, 1998.

The results of the adoption- impact model estimated using the ITSUR are shown in Table 4 in elasticity form. The use of other herbicides (which are applied in larger amounts than any other herbicide "family," Table 3) is negatively and significantly related to the adoption of herbicide-tolerant soybeans. The elasticity of demand of other herbicides with respect to the probability of adoption of herbicide-tolerant soybeans (calculated at the mean) is -0.14. On the other hand, use of glyphosate is positively and significantly related to the adoption of herbicide-tolerant soybeans. The elasticity of demand of glyphosate with respect to the probability of adoption of herbicide-tolerant soybeans is 0.43. While the elasticity for glyphosate is comparatively high, the effect is not very large as glyphosate starts from a low base. As expected, the use of acetamide herbicides is also negatively related to the probability of adoption of herbicide-tolerant soybean, but the results are not significant.

TABLE 4 The Impact of Adoption of Herbicide-Tolerant and Insect-Resistant Crops

	Elasticity with respect to probability of adoption of		
Elasticity of	Herbicide-tolerant soybean, 1997	Herbicide-tolerant cotton, 1997	Bt cotton, 1997 (Southeast)
Yields	+0.03	+0.17	+0.21
Profits	0[a]	+0.18	+0.22
Pesticide use			
Herbicides			
Acetamide herbicides	0[a]		
Triazine herbicides		0[a]	
Other synthetic herbicides	-0.14	0[a]	
Glyphosate	+0.43	0[a]	
Insecticides			
Organophosphate insecticides			0[a]
Pyrethroid insecticides			0[a]
Other insecticides		-0.21	

[a]Insignificant underlying coefficients.

Table 4 also shows that the effect of adoption of herbicide-tolerant soybeans on yields is positive and significant, but small. The elasticity of yields with respect to the probability of adoption of herbicide-tolerant soybeans is 0.03. Regarding variable farm profits, the adoption of herbicide-tolerant soybeans does not have a statistically significant effect on variable profits.[9]

Results for Herbicide-Tolerant Cotton

Cotton production relies heavily upon herbicides to control weeds, often requiring applications of two or more herbicides at planting and postemergence herbicides later in the season

(Culpepper and York, 1998). Close to 28 million pounds of herbicides were applied to 97 percent of the 13 million acres devoted to upland cotton production in the 12 major states in 1997 (USDA, 1998). As shown in table 5, trifuralin was the top herbicide applied in 1997 (5.5 million pounds) followed closely by MSMA (4.9 million pounds) and fluometuron (4.9 million pounds).

TABLE 5 Major Herbicides Used on Cotton, 1997[a]

Herbicide active ingredient	Area Applied	Appli-cations	Rate per crop year	Total applied
	Percent	Number	Lbs/acre	Million lbs
Acetamides				
Metolachlor	5	1.1	1.17	0.74
Triazines				
Cyanazine	18	1.3	0.95	2.20
Prometryn	19	1.2	0.66	1.67
Glyphosate	14	1.3	0.81	1.54
Other herbicides				
Trifuralin	55	1.1	0.76	5.46
MSMA	29	1.4	1.30	4.90
Fluometuron	44	1.3	0.84	4.85
Pendimethalin	28	1.1	0.69	2.49
Norflurazon	13	1.0	0.63	1.04
Diuron	12	1.1	0.55	0.88

[a]Planted acres was 13.1 million acres for the 12 states surveyed.

Source: USDA, 1998.

The results of the adoption impact model using the ITSUR estimation framework are summarized in elasticity form in Table 4. The effect of adoption of herbicide-tolerant cotton on yields is positive and significant. The elasticity of yields with respect to the probability of adoption of herbicide-tolerant cotton (calculated at the mean) is +0.17. The adoption of herbicide tolerant cotton also has a positive and statistically significant effect on variable farm profits. The elasticity of variable profits with respect to the probability of adoption of herbicide-tolerant cotton is +0.18. However, herbicide use is not significantly related to the adoption of herbicide-tolerant cotton.

Results for Bt Cotton

Cotton production in the U.S. uses a large amount of insecticides and seventy-seven percent of the 13 million acres devoted to upland cotton production in the 12 major states were treated with 18 million pounds of insecticides in 1997 (USDA, 1998). As shown in Table 6, malathion was the top insecticide, as farmers applied more than 7 million pounds of this chemical in 1997. Aldicarb was second (2.4 million pounds), followed by methyl parathion (2 million pounds), and acephate (0.9 million pounds).

TABLE 6 Major Insecticides Used on Cotton, 1997[a]

Insecticide active ingredient	Area applied	Appli-cations	Rate per crop year	Total applied
	Percent	Number	Lbs/acre	1,000 Lbs
Organophosphates				
Malathion	11	5.9	4.97	7,246
Methyl parathion	13	2.7	1.22	1,996
Acephate	10	1.7	0.72	898
Phorate	7	1.0	0.73	667
Profenofos	4	1.6	0.98	558
Dicrotophos	8	1.7	0.35	377
Synthetic pyrethroid compounds				
Cypermethrin	8	1.7	0.14	137
Cyfluthrin	13	1.7	0.05	92
Other insecticides				
Aldicarb	27	1.0	0.68	2,428
Chlorpyrifos	4	1.9	1.45	805
Oxamyl	15	1.6	0.33	648
Endosulfan	2	2.3	0.88	267
Dicofol	2	1.0	1.13	255

[a]Planted acres was 13.1 million acres for 12 states surveyed.

Source: USDA, 1998.

The results of the adoption impact model using the ITSUR estimation framework are summarized in elasticity form in table 4. We focus on the Southeast region because states in the

Southeast show much higher rates of adoption of Bt cotton than other regions (Falck-Zepeda and Traxler) and infestation levels of pests nontargeted by Bt appear to be more important than Bt target pests in the rest of the cotton-producing states.

For the Southeast region, the effect of adoption of Bt cotton on yields is positive and significant. The elasticity of yields with respect to the probability of adoption of Bt cotton (calculated at the mean) is +0.21. In addition, the adoption of Bt cotton has a positive and statistically significant effect on variable farm profits. The elasticity of variable profits with respect to the probability of adoption of Bt cotton is +0.22. Use of other insecticides is significant and negatively related to the adoption of Bt cotton. The elasticity of demand of other insecticides with respect to the probability of adoption of Bt cotton is -0.21. The use of organophosphate and pyrethroid insecticides are not significantly associated with the adoption of Bt cotton.

Concluding Comments

This paper summarizes previous work and presents new empirical results on the impact of adopting genetically engineered crops with input traits for pest management. In particular, it provides recent estimates on the effect of adopting herbicide-tolerant crops (soybean, and cotton), as well as an insect-resistant crop (Bt cotton) on yields, farm profits, and pesticide use, using an econometric model that corrects for self-selection and simultaneity, and using nationwide survey data for 1997. The results presented should be regarded as preliminary, as the research is ongoing.

Preliminary econometric results controlling for factors other than adoption of genetically engineered seeds show that impacts of adoption on yields, profits, and pesticide use vary with the crop and technology examined. Increases in adoption of herbicide-tolerant cotton were associated with significant increases in yields and variable profits, but were not associated with significant changes in herbicide use. On the other hand, increases in adoption of herbicide-tolerant soybeans were associated with small increases in yields and variable profits, and significant decreases in herbicide use. Increases in adoption of Bt cotton resistant to insects in the Southeast was associated with significant increases in yields and profits and a significant decrease insecticide use.

Endnotes

[1]The authors are economists with the Economic Research Service, U.S. Department of Agriculture. 1800 M Street, NW. Washington, DC 20036-5831. The views expressed are those of the authors and do not necessarily correspond to the views or policies of the U.S. Department of Agriculture.

[2]Imidazolinone (IMI) tolerant corn was first introduced in 1992. Over 85 seed companies offer 225 corn hybrids containing the imidazolinone resistant gene patented by American Cyanamid

IMI corn allows the use of imidazolinone herbicides, which are used for post-emergence control of grasses and broadleaf weeds (American Cyanamid, Zinkand).

[3]There could also be risks to nontarget insect species if Bt crops deplete populations of prey species, but this is also a problem with many traditional pest management systems. Overall, the extent of environmental risks to Bt is still not completely known.

[4]However, in January 1998, the EPA announced that it could not grant a request to extend tolerances for bromoxynil to continue its use in cotton crops. The EPA could not ensure that there was a reasonable certainty of no harm under the FQPA due to concerns about developmental risks to infants and children and studies showing that bromoxynil caused cancer in laboratory animals.

[5]In this paper we define variable profits as revenues minus the costs that are likely to vary with the adoption decision, including pesticide costs, seed costs, and the technology fee.

[6]Additional information of the survey results is presented in McBride and Brooks.

[7]Adoption may also vary among crops and regions because of differences in the availability (or cost) of the innovation.

[8]The herbicide "families"considered are: (i) acetamides (acetochlor, alachlor, metolachlor, and propachlor); (ii) Glyphosate; (iii) triazines (atrazine, cyanazine, metribuzin, prometryn), and (iv) other synthetic herbicides (such as 2,4-D, acifluorfen, bentazon, clomazone, pendimethalin, and trifuralin). The insecticide families included are: organophosphates (e.g., malathion, methyl parathion, acephate, phorate); (ii) synthetic pyrethroids (e.g., cypermethrin, cyfluthrin); and (iii) other synthetic insecticides (such as aldicarb, chloropyrifos, oxamyl, and endosulfan).

[9]For the case of corn, reported in Fernandez-Cornejo and Klotz-Ingram, the elasticity of herbicide demand with respect to the probability of adoption herbicide-tolerant hybrids (calculated at the mean) is -0.13 for the case of acetamide herbicides, which are applied in larger amounts than any other herbicide "family". The effect of adoption of herbicide-tolerant corn on yield is small and the effect on profits is not statistically significant.

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