THE DIFFUSION OF BT COTTON AND ITS IMPACT ON THE USE OF CONVENTIONAL PESTICIDES IN COTTON PRODUCTION

by

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STATEMENT BY AUTHOR

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ABSTRACT

This study examines diffusion of Bt cotton in 27 U.S. cotton-producing regions from 1996 to1999. First, a dynamic logistic diffusion function is estimated to explain regional differences in both the rate and extent of Bt cotton adoption. The function's flexible specification allows for accelerated adoption as well as de-adoption. Second, a pesticide use equation is estimated to test whether or not Bt cotton has reduced traditional pesticide use. The two equations are estimated independently and then as part of a simultaneous system to account for potential endogeneity of Bt adoption in the pesticide use equation.

Results suggest that demand-side factors, such as pest damage, input costs, output price and government policy significantly influence diffusion, as do supply-side constraints on Bt seed variety availability. The hypothesis that use of Bt cotton does not reduce the use of traditional pesticides is solidly rejected in all of the econometric specifications tested. Results concerning farmers' overall costs, however, are more ambiguous. Estimates suggest that, in many regions, overall costs have not decreased and in several regions, may have increased. Cost-savings alone may not explain the widespread adoption of Bt cotton. Future research on the impacts of Bt cotton on yields would be useful.

CHAPTER ONE: INTRODUCTION

This study has two objectives. The first is to estimate the diffusion of Bt cotton utilizing a wide set of explanatory variables to explain the initial level of adoption of Bt cotton as well as the rate of diffusion. The second is to evaluate the aggregate impact of U.S. farmers' use of Bt cotton on the use of manually applied insecticides.

1.1 What is Bt Cotton?

Bt cotton is a genetically modified cotton plant that is capable of producing the naturally occurring soil bacterium known as Bt, or Bacillus thuringiensis. Bacillus thuringiensis produces proteins that are indigestible to certain insects of the Lepidopteran (caterpillar) class, including three of the most damaging cotton predators: tobacco budworms, cotton bollworms, and pink bollworms (Klotz-Ingram et al. 2001). The naturally produced insecticide has been widely used by organic and conventional farmers in an aerial spray form since the 1950s (Edge et al. 2001).

The seed, produced by Monsanto in partnership with seed conglomerate Delta and Pine Land, was commercially released in 1996 and has reportedly been adopted by farmers faster than any other genetically modified crop on the market (International Cotton Advisory Committee 2000). This rapid acceptance is likely due to the often vain struggle many farmers experienced while attempting to control these pests prior to the introduction of the insecticide-producing cotton. Evidence of this struggle is clearly evident in the 1995 volume of the Mississippi State University Cotton Insect Loss data base. The database reveals that, in 1995, the year before Bt cotton's introduction, U.S.

farmers lost an average of four percent of their crop, worth approximately $315 million given cotton price of $0.765 per pound [1], to budworms and bollworms despite applying an average 2.4 insecticide treatments, costing approximately 23.23 per farmer, to infested cotton acreage (Williams 1995). Moreover, Alabama's cotton crop was decimated in that year due to the unexpected development of insect resistance to the commonly used pyrethroid insecticides (Frisvold, Tronstad, and Mortenson 2000). The state lost an astonishing 29 percent of its cotton crop (approximately $95 million) despite making an average 6.7 insecticide applications (approximately $65 per farmer) per acre (Williams 1995).

1.2 What Can Bt Cotton Do?

Monsanto (2001) claims that the Bt producing plants are capable of reducing farmers' needs for applied pesticides, a claim that has been substantiated by various farm- and plot-level studies (see Table 1.1). Bt cotton therefore purportedly offers farmers a cost- and risk-saving alternative to manually applied insecticides such as Bt sprays, synthetic pyrethroids, or the more highly toxic organophosphates, and as a result offers the earth and its inhabitants less exposure to these toxins as well.

1.3 Cotton Production and the Use Of Insecticides

Cotton is the fifth largest crop in the U.S. in terms of acreage in production (Carpenter and Gianessi 2001). It is also the largest consumer of insecticides of the major

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[1] Average U.S. cotton price in 1995 was $0.765 according to the PEDB of the USDA

U.S. crops. In 1995, insecticides used on cotton accounted for fifty-five percent of all insecticides used on major commercial crops (Natural Resources and Environment Division 1997)[2]. The top six cotton producing states in that year, which included Arizona, Texas, California, Arkansas, Louisiana, and Mississippi, harvested just over eleven million acres of cotton, producing more than six trillion pounds of cotton (Carpenter and Gianessi 2001). Of the 11 million acres of cotton harvested in 1995, nearly 80 percent, or 8,760,000 acres, were treated with more than 20,600,000 pounds of insecticides (USDA 1996). Of the cotton pests treated with insecticides in the previous year, bollworms accounted for 32 percent of all insecticide acre treatments made to cotton, making these pests the primary target species in 1994 (Paggit et al. 2000).

The major insecticides used in the treatment of bollworms, budworms, and pink bollworms are synthetic pyrethroids, organophosphates, and Bt. Before the introduction of Bt cotton, however, the latter chemicals were often preferred to the conventional spray form of Bt, for several reasons. For one, Bt is toxic to its targeted pests only while in their larval stage of development. Secondly, Bt sprays decompose within 72 hours after being released into the environment, and consequently quickly lose their ability to destroy the pests. Thus, farmers who use Bt sprays have to employ intensive pest scouting measures to pinpoint the narrow window of opportunity when they successfully destroy the pests. The alternative synthetic chemicals, on the other hand, retain their toxicity for much longer period and are toxic to the pests at a later stage in their lifecycles, giving farmers much more flexibility in their treatment regimen.

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[2]Major commercial crops include soybeans, corn, Upland cotton Fall potatoes and Spring, Durum and Winter wheat.

The advent of the Bt cotton greatly reduced Bt, however. Because the genetically modified cotton produces Bt throughout its lifetime and in all parts of the plant, susceptible larvae are continuously exposed to the chemical, and thus the need for intensive scouting by the farmer is greatly diminished. This flexibility gives farmers a large incentive to switch from pyrethroid and organophosphate insecticides to Bt, and it is therefore likely that use of Bt cotton does in fact significantly reduce the use of alternative applied pesticides.

There is a cost to this increased flexibility however, and that is the fact that organisms continuously exposed to any toxin over a number of generations are increasingly likely to become resistant to its effects, thus rendering the toxin harmless. An increased probability of insect resistance to the Bt toxin is a massive concern to everyone involved in the development of Bt cotton. In response, legislation that requires farmers to set aside a portion of their cotton acreage to be planted with only conventional cotton has been instituted in hopes of creating pools of non-resistant pests that will breed with the more resistant ones, therefore delaying or preventing total insect resistance. While this scheme may be successful, there is a chance that it will not, and that any benefits reaped by farmers from the use of Bt cotton will be sadly short-lived.

1.4 Study Objective: Does Bt Cotton Reduce the Need for Applied Pesticides?

While field- and plot- level studies provide evidence that Bt cotton can result in reduced conventional applications, many of these studies are based on very small samples. Consequently, they lack the statistical power to determine whether differences in application rates on Bt versus non-Bt fields are statistically significant (see Table 1.1). To determine whether Bt cotton has in fact reduced pesticide use across the United States, I have developed a simultaneous econometric model depicting the diffusion of Bt cotton and its overall impact on pesticide use in all cotton producing regions. The structure of this analysis is similar to the two-stage model used in the Fernandez-Cornejo and McBride (2000) field-level study.[3] They use a probit model to predict farmers' adoption of Bt cotton in the first stage, then the adoption estimates are used as instruments in the second stage to examine the technology's impact on pesticide use and yields. Unlike comparison-of-mean studies, the multivariate model used in this study makes it possible to statistically control for changes in pesticide use that are unrelated to the use of Bt cotton, such as changes in the price of cotton or pesticides. Also, the model corrects for possible simultaneity in farmers' decisions concerning whether or not to adopt Bt cotton and how much pesticide to use. Moreover, the diffusion model that I have developed uses data on pest pressure, pest control costs, and pest-induced yield losses, among other things, to explain the initial adoption level of Bt cotton as well as the rate of diffusion. Few previous diffusion studies, if any, have attempted to estimate these parameters as a function of such a large number of explanatory variables.

1.5 Organization of Thesis

There are seven remaining chapters in this thesis. Chapter two surveys the existing literature on diffusion and impact studies. Chapter 3 presents actual diffusion

[3] Fernandez-Cornejo and McBride found a statistically significant decrease in the use of "other pesticides" not including

data from the regions examined in this study. It then discusses the functional forms available to model diffusion and the theoretical debates surrounding them. Lastly, it discusses the empirical function chosen to model diffusion in this study. Chapter four presents the empirical function used to model Bt cotton's impact on pesticide use and the econometric theory and framework of the simultaneous equation model. Chapter five examines the data used in this study. Chapters 6 and 7 present the empirical results from the diffusion and simultaneous system estimations, respectively.

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organophosphates or pyrethroids and a statistically significant increase in yields as a result of farmers' use of Bt cotton.

Table 1.1 Comparison of Mean Studies

Researchers	Crop Year	Region	# Obs.	Unit of Analysis	Difference in # Pesticide Applications		Difference in Pest control Costs		Report Stat. Sig.?
					Bt	Conventional	Bt	Conventional	
Benson and Hendrix III (1999)	1999	South	31	Field Experiment	NA	NA	$16.55	$24.19	No
Bryant and Robertson and Lorenz III (1997, 1998, 1999)	(1) 1996 (2) 1997 (3) 1998	AK	12 16 14	Field Experiment	NA	NA	(1) Bt average cost savings over conventional = $24.03 (2) Bt average cost savings over conventional = $12.87 (3) Bt average cost savings over conventional = $10.22		No
Carlson and Marra and Hubbell (1998)	1996	AL, GA, SC, NC	300	Survey	0.78	2.81	Bt average cost savings over conventional = $33.37		Yes
Gibson IV et al. (1997)	1995	MS	33	Field Experiment	6.74	11.66	$61.48	$68.15	No
Layton, Williams, Long (2000+, 2001+)	(1) 1999 (2) 2000	MS	93 55	Field Experiment	0.44 0.27	2.47 2.44	NA NA	NA	Yes Yes
Layton et al. (1998)	1997	MS	106	Field Experiment	0.33	3.05	NA	NA	Yes
Layton et al. (1999)	1998	MS	133	Field Experiment	1.46	5.24	NA	NA	Yes
Oppenhuizen, Mullins, Mills (2001)	2000	South	54	Field Experiment	1.2	4.2	$8.75	$40.18	No
Stark (1997)	1997	GA	28	Field Experiment	1.1	3.6	Bt average cost savings over conventional = $27.50		No
Stewart et al. (1998)	3 Year Avg. (1995-1997)	MS	5	Field Experiment	1.46	5.24	NA	NA	Yes

Sources: See citations for researches listed above in the references at end of thesis.

CHAPTER TWO: LITERATURE REVIEW

As stated in the first chapter of this thesis, the final goal of this study is to examine the impact of adoption of Bt cotton on use of applied pesticides. However, another focus of the study the diffusion function that explains the aggregate adoption of Bt cotton. Estimation of this function is important because it allows us to examine what factors influence the spread of this technology. It is also important as part of the system of equations that is used to estimate the impact of Bt cotton on the use of applied pesticides because it enables us to control for simultaneity of Bt adoption and pesticide use decisions. Therefore, this review concentrates on adoption and diffusion literature.

2.1 Adoption versus Diffusion Studies

There exist two types of technology adoption studies: those that examine adoption of new technologies at the farm- or micro-level, and those that examine technology adoption at the aggregate level. Formally, the term adoption is used exclusively to refer to studies that examine the decision of an individual producer or consumer concerning whether or not to use a new technology (Day and Klotz-Ingram 1997). The term diffusion is used exclusively to refer to studies that examine aggregate adoption by a population or within a specific region, or the rate and extent of adoption of a new technology over time by a population (Feder, Just and Zilberman 1985). However, today many authors use these terms interchangeably. In this review I will retain the formal definition and use of the two terms.

This study examines diffusion of Bt cotton at the aggregate level, and thus the majority of this review will consist of discussion of diffusion literature. However, because it is important to understand the difference between these two types of analysis, I will first provide a more in-depth description of adoption studies and give several examples in order to clarify how these studies differ in methodology from the aggregate-level diffusion studies.

2.1.1 Adoption Studies

Studies of adoption behavior emphasize factors that affect if and when a particular individual will begin using an innovation (Sunding and Zilberman 2000). While adoption studies may use either a discrete choice model or a continuous variable model to depict the extent of adoption (Sunding and Zilberman 2000), most authors restrict the definition of adoption to refer only to a producer's or consumer's choice to adopt or not adopt a certain technology. Most adoption studies therefore employ discrete choice models, such as the probit or logit functions, to estimate the adoption decision.

The data used in adoption studies often originates from cross-sectional surveys of individual farmers throughout a country or in specific regions. The Agricultural Resource Management Study (ARMS), a set of national surveys developed by the Economic Research Service and the National Agricultural Statistics Service of the USDA, is the main source of nation-wide farm-level information concerning the financial conditions of production agriculture. Fernandez-Cornejo and McBride (2000) utilize data taken from the ARMS survey to estimate probit models of farmers' adoption of several genetically modified crops, including herbicide tolerant soybeans and cotton, and Bt cotton. To explain adoption they considered farm size, operator education and experience, target pests for insecticide use, seed price, debt-to-assets ratios, use of marketing or production contracts, irrigation practices, crop price, use of consultants, and pest pressure. They do not include a discussion of the statistical significance of these variables included in the adoption decision portion of their model.

Another large-scale study of technology adoption at the farm level is the Area Studies Project, also sponsored by the USDA Economic Research Service (Caswell et al. 2001). This study was undertaken to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that effect adoption of these practices. Data used in this study consists of responses to questionnaires designed by the National Agricultural Statistics Service concerning farm operators' use of cropping systems, agricultural production technologies, and chemicals at both the field and whole-farm level in twelve US watershed areas from the years 1991-1993.

The authors of this study identified a core set of variables that they claim are most often cited in the literature as important determinants of the adoption decision. This core set of variables includes: (1) human capital variables, such as the farmer's education level and years of experience (used as proxies for a farmer's ability to acquire and effectively use information about new agricultural production technologies); (2) production characteristics, including farm size, crop(s) grown, and the cropping practices used; (3) agricultural policies, such as commodity subsidy programs and conservation compliance programs or other government-imposed environmental restrictions; (4)natural resource characteristics, such as soil quality and climate; and finally, (5) area dummies in multi-region models to capture inter-regional differences not accounted for in other variables.

Although the human capital category of variables does not have an analogous counterpart at the aggregate level, the remaining sets often do, and tend to play a large role in diffusion analysis as well as adoption analysis.

2.2 Diffusion of Technologies

Whereas adoption studies describe factors that influence an individual's behavior and choice to adopt a new technology, usually at a single point in time, diffusion studies attempt to show the path taken through time by an innovation as it penetrates its potential market (Griliches 1960). Therefore, diffusion studies must examine factors that determine adoption of new technologies by different groups of potential adopters rather than by individuals.

Social scientists in different fields explain the diffusion of technologies in different ways. Sociologists, for example, focus on interactions between people and how different communication channels develop and influence decisions (Rogers 1995), while economists focus largely on how the relative profitability of new technologies and the location characteristics of different groups relative to the point of origin of new technologies influence their adoption (Schimmelpfennig et al. 1994; Feder, Just, and Zilberman 1985).

2.2.1 History of Diffusion Research

The diffusion of new technologies has been examined in various social science disciplines since the beginning of the twentieth century. Gabriel Tarde, a French lawyer and judge at the turn of the century, is credited as the first person to thoroughly study diffusion and today he is viewed by many as a forefather of modern sociology and social psychology. He found the changes occurring in human society fascinating. To Tarde, the diffusion of innovations was the basic and fundamental explanation of human behavior change (Rogers 1995). To investigate this phenomenon he began to analyze the trends occurring in the French society via the legal cases that were presented in his court.
In his 1903 book entitled, The Laws of Imitation, Tarde identifies several generalizations about the diffusion of innovations, which he coined the "laws of diffusion" (Rogers 1995). Among these generalizations is the idea that the adoption or rejection of innovations is a crucial outcome variable in diffusion research. Moreover, although the present quantitative methods employed in the analysis of diffusion were decades from being developed at his time, Tarde was astute enough a data collector for his judiciary bench to recognize that the rate of adoption of a new technology typically follows an S-shaped curve.

This observation of the time path of diffusion behavior remains the basis of the mathematical functions used to describe diffusion today. However, the first extensive empirical study of diffusion did not appear until four decades after Gabriel Tarde's groundbreaking observations were printed. In this 1943 study sociologists Bryce Ryan and Neal Gross (1943) examine the diffusion of hybrid corn in two regions of Iowa. A substantial portion of the study focuses on the social interactions underlying the observed diffusion pattern, but the authors also conduct a thorough statistical analysis of the shape of the data. This examination leads the researchers to conclude that the cumulative frequency curve of acceptance of hybrid corn appears similar to the S-shaped curve used by students to explain other growth phenomena. However, upon closer inspection they conclude that the observed data vary significantly from the normal frequency distribution, which had been postulated in a previous general study by Earl Pemberton (1936) to be the path followed in the diffusion of several non-technological innovations. In the end, Neal and Gross (1943) suggest that a logistic curve may in fact fit the data well, but they then wholly reject the idea that the "sociological phenomena" of diffusion could perhaps follow the same pattern as what they perceive as the purely biological phenomena of population growth. They contend that "if there is indeed an expected diffuison curve, its contours must be derived from comparative inductive research (1943, p.23)."

Despite Ryan and Gross's considerable doubts concerning the merit of the logistic distribution to describe the process of human adaptation through diffusion, subsequent diffusion researchers, including economists, adopted the curve as a tool in diffusion analysis with little question of its appropriateness. Econometric practitioners relentlessly preach the importance of a solid understanding of the economic theory underlying models of human decision. Yet, many early studies openly admit that the choice to use the logistic function to model the diffusion process is arbitrary, used solely to summarize observed information and not to explain it.

2.2.2 Diffusion Studies

The seminal economic diffusion study, written by Zvi Griliches in 1957 and entitled, "Hybrid Corn: An Exploration in the Economics of Technological Change," was also the first attempt to show that the process of innovation, adaptation, and distribution is amenable to economic analysis. In this study, Griliches examines the diffusion of hybrid corn at the aggregate-level throughout the United States over the years 1935 to 1950.

Like the sociology-based diffusion studies before his, Griliches chooses to describe his data with a logistic trend function, which, because of its ease of computation and compatibility with the observed S-shape of technology diffusion data, is the most common trend function used in aggregate-level adoption studies. However, whereas the previous sociological studies attributed the diffusion of innovations solely to the communication process between marketers, adopters and non-adopters, Griliches attributes the farmers' differential adoption rates and levels to the relative profitability of the hybrid corn.

His logistic curve is defined as:

(1) $P = K / 1 + e^{-(a+bt)}$,

where P is the percentage of acreage planted with hybrid seed, K is the ceiling, or long-run equilibrium value of hybrid corn acreage in each region, t is the time variable, b the rate of growth coefficient, and a is a constant that describes the "date of origin," or date at which the individual regions began to adopt hybrid corn. Griliches chose to define a as the date by which a region had planted 10 percent of its total corn acres with hybrid seed.

Griliches' utilized hybrid corn acreage data from states and crop reporting districts. He first fits this data to the logistic function and derives the best fitting slope and intercept parameter estimates. To do this, Griliches linearly transformed the logistic diffusion model so that is was re-expressed as:

$$(2)\ \ln\left(\frac{P}{K-P}\right) = a + \beta t + \ell,$$

where ℓ is a stochastic error term. He was then able to estimate the model parameters directly by least squares as long as the ceiling values, (K), used in the model were assumed known. These values were, of course, not known, so Griliches calculated his ceiling values "crudely" by plotting the percentage planted to hybrid seed on logistic graph paper and varying *K* until the resulting graph approximated a straight line. He stated in a later article (1980) that he was not able to estimate his ceiling values because the econometric methods available to him did not allow him to do so.

He then estimates above equation, with the date at which each region had planted ten percent of its total acreage to hybrid corn identified by:

(3) *date of origin* $(t) = \frac{-2.2 - a}{\beta}$, where *date of origin* indicates the date at which the function passed through the ten percent value (Griliches 1957).[4]

He obtained coefficient of determination (R^2) values between .90 and .99 at the state level and .95 and .99 at the District level.

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[4]Time (t) is measured from 1940 and the date of origin is defined as the date at which the function, $\ln\left(\frac{P}{K-P}\right) = a + \beta t$, passed through its ten percent value. Substituting 0.10 in the left-hand term and solving for t yields: t= [ln (0.10) --a]/b. Note: ln (0.10) ≈ 2.2.

Griliches then tests various hypotheses about what factors influence these parameter values by linearly regressing other variables on the slope and rate of diffusion estimates. His test variables are derived from data on average total corn acreage per region and total land in farms, average corn acreage per farm, and seed-pedigree characteristics. These data were used in various transformations to create proxies that describe the relative profitability of hybrid corn for both seed producers and farmers. His hypotheses are explained below.

Griliches asserts that the initial date of acceptance, *a,* of the hybrid corn technology was determined by supply-side factors, while the rate of acceptance, *b,* of the hybrid corn technology was determined by demand-side factors. He therefore breaks his analysis into two distinct phases. First, he analyzes the cause of the different dates of availability of hybrid seed to farmers in different regions, which he calls the "availability problem." Second, he examines the different rates of acceptance by farmers of hybrid corn in different regions, which he calls the "acceptance problem."

The availability problem arose, says Griliches, because seed producers did not supply farmers in all regions with viable hybrid varieties at a single point in time. Rather, he shows that the availability of hybrid seeds spread from the heart of the Corn Belt outward. He postulates that innovators among seed producers first entered those areas where the expected profits from the commercial production of hybrid corn seed were the largest. He asserts that the farmers' ability to adopt hybrid seed in different areas depended on the seed producers' production of appropriate seed varieties in each area. As an example he points out that the delayed adoption of hybrid varieties in the southern regions of the United States was not the fault of southern farmers, but rather the result of a lack of seed varieties compatible with the growing conditions in those regions.

The seed-producers' expected profits, states Griliches, depended on the size of the market for corn seed in each region, marketing costs, and the cost of innovating for (or entry into) each region. Griliches uses the 1949 density of corn acreage per farm as a proxy for market size. He uses two proxies for the cost of entry. First, he reasons that regions that were most similar to the Corn Belt benefited from the high adaptability of the original Corn Belt hybrid lines, making the cost of entry into the areas directly east and west of the Corn Belt significantly lower than the cost of entry into regions to the north or south of the Corn Belt. He therefore includes a variable that describes each region's "Corn Beltliness," defined as the percentage of imbred lines initially developed for use in the Corn Belt. Second, he argues that other cost factors in areas that are close together are likely to be similar, and so includes the earliest date of entry into any neighboring area of a potential market as a second proxy for cost of entry.

The acceptance problem arose, on the other hand, because farmers failed to plant the new varieties at a single point in time once the hybrid seed technology was made available in each region. Griliches asserts that these differential rates of acceptance among farmers were attributable to differences in the magnitude of profits to be realized from the change. He postulates that the farmers' expected profits were dependent on the pre-hybrid yield in each region (because regions where the pre-hybrid yield was lowest had less to gain by adopting the new varieties), as well as the per acre increase in yield (in bushels) caused by a shift to hybrid corn. These two variables were used as a proxy for profitability per acre. Also, average corn acres per farm was included as a measure of profitability per farm.

Griliches tests his relative profitability hypotheses for both the supply-motivated date of origin parameter and the demand-motivated rate of diffusion parameter by linearly regressing the profitability variables on the intercept and rate of diffusion parameter estimates. His results reveal that the majority of his profitability variables are in fact significant.

Although he was forced to incorporate a constant ceiling value into his model, Griliches did succeed in making a major contribution to diffusion analysis in economics by incorporating the exponential growth function so common in biology and other social sciences. This compact model enabled him to utilize a complex set of variables in his estimation and explain their impact on diffusion in a simple and succinct manner.

This method does have a serious drawback however, namely the existence of serial correlation in the independent variables. Griliches attempts to circumvent this problem by analyzing the simple correlation coefficients between the independent variables and between the dependent and independent variables, a technique that is not likely to show the true degree of association between them (Kennedy 1998). In spite of this difficulty, Griliches concludes that his results do clearly reveal that profitability did play an important role in the diffusion of hybrid corn. However, all of his "profitability" variables are indirect measures of the price signals that seed producers or farmers may have received in the market. His championing of the influence of profitability based on such subjectively defined data has led other diffusion researchers to question his conclusions.

In 1980 Robert Dixon wrote "Hybrid Corn Revisited," a critical examination of Griliches' hybrid corn study in which Dixon criticizes Griliches' choice of the logistic functional form as well as the static specification of his ceiling parameter. Dixon, noting that US farmers had almost completely converted from open-pollinated to hybrid seed varieties by 1960, questions Griliches's conclusion that the differences apparent in the ceiling values for different states in 1957 were due to "the expectation of profits to be realized from the change" (Griliches 1960, p.280).

In the study, Dixon re-estimates Griliches's (1957) diffusion model after incorporating additional data and changing the original ceiling values used by Griliches to the ultimate ceiling value of 1.00 achieved in all regions. Dixon also corrects for heteroskedacticity in the OLS residuals by appropriately weighting each observation. In addition, Dixon analyzes the cumulative frequency distribution of the data and concludes that data from twenty-one of the thirty-one total states analyzed by Griliches deviates from the symmetry consistent with the true logistic curve. He suggests that the logistic functional form is therefore an inappropriate model of diffusion in these states. He thus re-estimates the diffusion parameters using the Gompertz function.

Furthermore, Dixon is intensely skeptical of Griliches's use of pre-hybrid corn yield per acre and corn acres per farm measurements as proxies for profitability (per acre and per farm, respectively), and of Griliches's and other's acceptance of relative profitability as a reliable sole-predictor of adoption behavior to the exclusion of other sociological factors. Dixon argues that the adoption of hybrids in slowly adapting areas such as the south was accompanied by changes in production techniques, and that such alterations in technology renders Griliches's proxies ineffectual. However, Dixon tests Griliches's hypothesis that pre-hybrid yield per acre and average corn acres per farm are linearly related to the rate of acceptance of hybrid corn varieties, and his results prove to be highly supportive of Griliches's claim.

Griliches (1980) responded to Dixon's evaluation in a brief comment entitled, "Hybrid Corn Revisited, A Reply." In it, Griliches reminds the reader that the static ceiling parameter he employed is only capable of modeling behavior when prices and technologies are held constant, and he acknowledges that his model did not provide adequate estimation capabilities once the second wave of hybrid seeds entered the market.

Secondly, he defends his choice of the logistic function form as a good choice for an economic model when evaluating tractability, interpretation and fit--the usual criteria when choosing a function with which to imitate observed patterns of behavior--and in further defense, he attributes the observed asymmetry of the extended data set to lags in the availability of well-adapted hybrid corn varieties in various regions.

He agrees that an endogenous and shifting ceiling parameter would have yielded a more appropriate model, but concedes that the econometric technology available to him at the time of his original analysis did not allow him to pursue the more dynamic model.

The next major diffusion study to be published was Edwin Mansfield's 1961 article entitled, "Technical Change and the Rate of Imitation." While both Griliches

(1957) and Mansfield (1961) examine the diffusion of process innovations among producers, Mansfield's study differs greatly from Griliches's work in many aspects. As the title suggests, Mansfield's study focuses on producers' response to competitors' adoption of a new technology, a factor that Griliches does not consider. The study also takes a much wider look at technology diffusion, examining the spread of twelve different innovations within four industries. Also, whereas Griliches examines a scale-neutral technology that requires no additional fixed-investment by producers, eleven of the twelve innovations examined by Mansfield are "lumpy" technologies that require adopting firms to significantly increase their fixed-costs of production. Thus, while Griliches' investigation focuses on the impact of product and market characteristics when determining the relative profitability of an innovation, Mansfield's inquiry is based on the hypothesis that the relative profitability of a new technology increases as an increasing number of producers adopt it. Also, while Mansfield purports to explain the rate of diffusion of innovations throughout different industries, he examines only a portion of all firms in each industry and utilizes firm-level data in his analysis, rendering a perhaps borderline adoption diffusion study.

Mansfield examines the actions of four industries regarding the diffusion of three process innovations in each industry, all of which were introduced between 1894 and 1951. The industries studied include (relevant innovations listed in parentheses): the bituminous coal industry (shuttle car, trackless mobile loader, continuous loading machine), the iron and steel industry (continuous wide strip mill, by-product coke oven, continuous annealing procedure), the brewing industry (tin container, high-speed bottlefiller, pallet-loading machine) and the railroad industry (diesel locomotive, centralized traffic control, car retarders). Because of the limited amount of published information available, his data consists largely of subjective estimates, taken from questionnaires and personal interviews, of the initial date of installation of the new technology, the innovations' relative profitability, and the size of the investments made to install the new technology. Also, Mansfield restricts the firms representing each industry to those meeting certain arbitrary size criteria because of the smaller firms' lack of responses to the questionnaires and inability to use certain technologies. All four industries examined therefore reach 100 percent adoption levels for each innovation.

Mansfield first plots the data and concludes that the rate of imitation varies widely among the various innovations.—He calculates that the number of years elapsing before half of all firms in each industry introduce an individual innovation range from 0.9 to 15, with the average number of years being 7.8.

To model the rate of imitation by producers Mansfield utilizes a logistic model defined by:

$$m_{ij}(t) = \frac{n_{ij}}{1 + e^{-(l_{ij}+\phi_{ij}t)}},$$

where $m_{ij}(t)$ is the number of firms having introduced the innovation at time t, n_{ij} is the total number of firms included in the study, l_{ij} is a constant term, and ϕ_{ij} is the slope coefficient that determines the rate of imitation. This slope coefficient is specified as a linear function of the relative profitability of the innovation (defined as the ratio of the industry-reported average pay-out period necessary to justify investment in the new technology and the actual average pay-out period of the investment) and the size of investment necessary to install the innovation.

To estimate the rate of imitation Mansfield linearly transforms the logistic model, and uses the adoption data to obtain the best fitting slope and intercept parameter estimates. As a second step in his analysis, he regresses the slope variable on a linear combination of the profitability and investment variables to determine whether this specification is proper. He obtains a high overall correlation coefficient, and concludes that there in fact exists a linear relationship between these variables. He also finds significant inter-industry differences in the rate of imitation given constant relative profitability and investment.

Mansfield acknowledges several shortcomings of his study, including a non-representative sample of American industries, imprecise data, and bias in regards to the exclusion of small firms from his data.

The last major diffusion study to be examined in this review is Lovell Jarvis's 1980 article entitled, "Predicting the Diffusion of Improved Pastures in Uruguay." Sponsored by the Uruguayan government, this study estimates cumulative growth of improved pastureland between 1961 to 1978 to predict the extent of farmers' future investments in the government-backed technology. Jarvis's examination differs from the previous studies discussed because he examines diffusion of a process innovation before the diffusion process has ceased and he therefore must estimate the rate of diffusion and ceiling parameters simultaneously. By incorporating beef prices directly into his model, Jarvis is also the first person to define the diffusion rate of a single innovation as a function of output prices.

Jarvis (1980) initially follows Griliches's (1957) and Mansfield's (1961) approach and assumes that diffusion follows a standard sigmoid path. He thus defines the diffusion process by a logistic function. After using this model to predict cumulative growth of improved pastureland by estimating both the number of adopters and the total area planted, he questions the assumption of constant profitability that is built into the simple logistic form. Because the diffusion of improved pastureland follows a twenty-year time path, Jarvis argues, one cannot presume that changes in prices, technology and learning would not seriously impact the diffusion process and distort its profile away from the logistic growth pattern. He postulates that farmer experimentation and adaptation slow the rate of diffusion in the early years of adoption. To implement this hypothesis, he forces diffusion to follow a linear path in the years prior to 1965 and then tests this model with different zero-restrictions on the intercept, ceiling, and rate of diffusion parameters. He finds the linear intercept term to be significant at the five-percent level in all cases when estimating the diffusion rate of planted hectares, but only once when estimating the diffusion rate of adopting ranchers.

His initial model is defined by $Z_t = \frac{K}{1 + e^{-(c+\phi_t)}}$, where Z_t is cumulative individual adopters or cumulative acres of improved pastureland, K is the ceiling, ϕ_t is the rate at which diffusion occurs, and c is a constant term. He linearly transforms this function to estimate cumulative growth, and then chooses K by varying the parameter from 10 to 100 percent of potential adopters and selects the conditional ceiling and diffusion rate values for which the R^2 is maximized. For the number of adopting ranchers he finds that a ceiling value of 0.56 maximizes the coefficient of determination and thus concludes that a majority of potential adopters have invested in improved pastures.

Jarvis also determines that, at the time of the study, the entry of new adopters is small and declining. However, he asserts that a model which estimates only the number of adopters cannot reveal the entire picture of pasture diffusion because such a model says nothing about the intensity at which adopting farmers are planting improved land. He points out that, even while the number of adopters is falling, the number of improved pastures could possibly continue to expand as adopters begin to increase the proportion of improved pastures on their land. Jarvis notes, however, that deterioration of improved pastureland is more rapid in Uruguay than in the project's native country of New Zealand, and proposes that low beef prices may be the cause of this lack of upkeep as well as a disincentive to expansion. He tests this hypothesis by estimating the number of cumulative net hectares, employing the same logistic model used in his previous estimation. He maximizes the R^2 at a value of 18 percent of land suitable for improvement.

He then includes lagged beef prices in the model to test whether such market information can improve his estimation results. In the simple logistic model he specifies only the rate of diffusion as a function of the beef price. He obtains a better fit in both the linear and non-linear cases, although he is unable to conclude whether serial correlation is present because of indeterminate Durbin Watson statistics.

Jarvis then uses an iterative nonlinear least-squares approach to directly estimate both the rate of diffusion and the ceiling parameters. He also incorporates the linearly modified logistic function, discussed above, to allow for a slower adoption rate in the initial years of the project. The Durbin Watson statistic is lower in this modified version than in the simple logistic model when the linear intercept term is found to be significant (in one case for adopting ranchers and in all cases for planted hectares).

The sign and significance of the price parameter is extremely inconsistent in the modified nonlinear model, however. When only the rate of diffusion is specified as a function of the beef price the price coefficient is positive but not significant for either the adopting rancher estimates or the planted hectare estimates. When only the ceiling parameter is specified as a function of the beef price the price coefficient is positive and significant in both cases. When both the rate of diffusion and the ceiling parameters are made a function of the beef price, however, Jarvis obtains unsatisfactory results. He finds that neither coefficient is significant for the adopting rancher estimates, while for the planted hectare estimates both are significant. Moreover, while the rate of diffusion coefficients are significant, the sign changes from positive to negative depending on the restrictions set.

Jarvis also examines the price elasticity of the ceiling parameter and determines it to be rather small, suggesting that the farmers' decisions to invest in improved pasture are only slightly influenced by changes in the price of beef. He suggests that this low responsiveness may be a result of the extreme price cycles that occurred in the beef market during the two decades of the study. In addition, he collects farmer-level data to determine the underlying causes of the low levels of adoption which are evident in both his analysis and through direct observation. His findings are enlightening.—The farmers report that they limit adoption because, (1) the impact of the improved pastures varies by season and by the type of animal, (2) management becomes too complex when the improved pasture area grows to large, and, (3) the animals cannot consume the extra forage generated once improved areas reach twenty to twenty-five percent of total pasture area. These findings seem impressively consistent with the estimates Jarvis obtains in his study.

2.3. General Trends and Shortcomings of the Literature

Economists' attempts at modeling the diffusion of technologies have basically summarized the data but have not attempted to explain the factors that influence diffusion. Moreover, both Griliches (1957) and Mansfield (1961), the most widely cited authors of economic diffusion studies, use a technique that by today's standards would be considered inherently biased.[5] Jarvis's (1980) specification is an improvement over these two studies because he incorporates the price of output directly into his model, but he

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[5] Both Griliches and Mansfield find estimates of the intercept and slope parameters, a and b, of the logistic function,

(1) $P = K/1 + e^{-a-bt}$, by estimating its linear transformation, defined by:

(2) $\ln(\frac{P}{K-P}) = a + \beta t + e_t$,

And then use the estimates $\hat{a}$ and $\hat{b}$ as dependent variables in linear models such as the following:

(3) $\hat{a} = a_0 + a_1 X_a + e_a$, and

(4) $\hat{b} = b_0 + b_1 X_b + e_b$

where X_a and X_b contain a set of explanatory variables.

If the parameters a and b are in fact functions of X_a and X_b so that $a=a(X_a)$ and $b=b(X_b)$, then the initial estimates , $\hat{a}$ and $\hat{b}$, are biased and the OLS properties of the estimators a_1 and b_1 in the above equations (in terms of biasedness and consistancy) are questionable does not examine any other economic factors that affect initial adoption or the rate of diffusion.

Unlike these previous studies, this study utilizes extensive economic data on yield losses inflicted by bollworms and budworms, pesticide costs, seed parent varieties, and bollweevil eradication costs, all of which enter into the diffusion function as variables. The outcome of this estimation will therefore help to determine what economic variables influence the initial level of adoption as well as the rate of diffusion.

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unless restrictions are placed on the error terms and explanatory variables (see any basic econometrics text for further discussion of the consequences of omitting relevant explanatory variables.

CHAPTER 3: THE DIFFUSION MODEL

This chapter presents the empirical specification of a model of the diffusion of Bt cotton in the United States.

3.1 Observed Diffusion Patterns

To give the reader an overview of the patterns observed in the adoption of Bt cotton throughout the U.S., the levels of Bt cotton adoption in each region from 1996-98 are shown below in Table 3.1, followed by a discussion of the factors that may influence them.

As the information in Table 3.1 reveals, adoption of Bt cotton has not followed a smooth, predictable pattern throughout all regions. A variety of patterns in adoption behavior can be identified in various regions. Adoption rates over the four year period have: (1) fallen, (2) risen steadily, (3) increased overall but experienced a substantial drop during one of the four years, (4) remained basically flat, (5) remained flat or have risen slightly for the first three years and then jumped in the fourth, or, (6) been seemingly random.

Initial adoption of Bt varieties was highest throughout the state of Alabama where it reached 91.7 percent of total acreage in 1996, but since then adoption rates there have fallen steadily. Adoption has risen steadily throughout the four years in the states of Mississippi, Oklahoma, Arizona, and Virginia and the Coastal Bend region of Texas, although total adoption in Virginia remained very low in 1999, comprising only 7 percent of total cotton acreage. Adoption levels in 1999 in Northeast Arkansas, Georgia, Louisiana, Missouri, New Mexico, North Carolina, Texas North Central, and the Texas

Table 3.1 Bt Cotton Adoption Patterns

Region	Bt Cotton as a percentage of total cotton acreage				Percent of total Bt Cotton Acres 1999	Percent of Total Cotton Acres 1999
	1996	*1997*	*1998*	*1999*		
Central AL	91.7	85	72.5	70	1.5	0.7
N. AL	85	78	75.1	82	4.7	1.8
S. AL	63	58.5	86.7	55	2.6	1.5
AZ	23.2	60.8	71.2	70.3	4	1.8
N.E. AR	1.1	0.4	1.2	4.2	0.6	4.8
S.E. AR	37.8	31.2	44.2	40	3	2.4
San Joaquin Valley-CA	0	0	0	1.5	0.3	6.1
FL	43	60	53.8	60	1.4	0.7
GA	29.7	38.3	30.8	58.6	20.1	10.7
LA	14.9	38.1	24	62	8.9	4.5
MS Delta	30	31.5	44	60.5	10.9	5.6
MS Hills	55.1	63.7	82	82.9	8.2	3.1
MO	0.1	1	0.1	2.1	0.2	2.8
NM	0.6	6.4	35.3	28.6	0.4	0.4
NC	6	3	6.2	20	4.1	6.3
OK	6.2	8.7	13.3	30.1	1.2	1.2
SC	13.8	31	14.3	85	6.3	2.3
TN	1.1	2.9	1.3	65	9.2	4.4
TX Coastal Bend	6.1	8.4	5.6	18.7	2.4	4
TX N. Central	6.7	17.1	2.5	20	0.5	0.8
TX N. Rolling Plains	0	0.2	0.1	5.4	0.5	3.1
TX High Plains	0	0	0	5.2	3.5	21.3
TX S. Rolling Plains	8.1	17.1	14.7	32.2	3.3	3.2
TX Lower Rio Grande	5	5.6	4.7	0	0	1.9
TX Far West	3.5	16.5	3.6	18.8	1.8	3
TX S. Central (S. Blacklands)	21.4	77.6	41.4	0.8	0	0.9
VA	0	0.2	3	7	0.2	0.8

Southern Rolling Plains have increased over their 1996 levels, although in all of these regions, adoption rates fell substantially during one of the four years. Adoption rates in South East Arkansas have been flat, remaining close to their 1996 level throughout the four years, as they have in Florida since 1997 after a 17 percent increase over the 1997 levels. In Tennessee and South Carolina adoption rates doubled from 1996 to 1997, returned to their initial levels by 1998, and then jumped by 63 and 70 percent, respectively, in 1999. Rates also increased substantially in the regions of Texas Northern Rolling Plains and High Plains in 1999, jumping from close to zero to over five percent. Lastly, adoption in the regions of Far West and South Central Texas has been seemingly random, and in South Central Texas, fell from over 41 percent in 1998 to near zero in 1999.Overall adoption levels in 1999 vary widely throughout all regions as well. Alabama, Mississippi and Arizona, all with over 70 percent of total cotton acreage planted to Bt varieties, have experienced the highest levels of adoption. Northeast Arkansas, Missouri, Virginia, California, and the North Rolling Plains and High Plains of Texas, all with 7 percent or less of total cotton acreage planted to Bt varieties, have adopted the least amount of Bt cotton.

What has caused these differences in the rates and levels of diffusion of Bt cotton throughout the U.S? By implementing a logistic diffusion function to describe them, I hope to examine the factors that influence these various patterns. Now that the observed rates of diffusion have been examined, I will discuss how I intend to model them.

3.2 Choice of Functional Forms

Traditional diffusion literature has included debates concerning the most appropriate functional form to use when estimating the diffusion of different technologies (Dixon 1980, Griliches 1980, Knudson 1991). Due to the econometric limitations faced by authors of the early diffusion studies, including Griliches (1957), Mansfield (1961), and Dixon (1980), and these authors were unable to employ a dynamic function that would allow the diffusion path to change over time. The aggregate rate of adoption was specified solely as a function of time, while the ceiling parameter was forced to remain constant, forcing the change in adoption over time to follow a fixed path. They were therefore left to debate which fixed diffuison path was appropriate for a given technology, and each questioned the merits of symmetric curves (such as the logistic) versus asymmetric curves (such as the Gompertz). Today's econometric programs allow us to specify aggregate adoption as a function of multiple variables, not just time, so that the diffusion path can vary across regions and change with fluctuating economic and agronomic conditions. The original debate concerning symmetric or non-symmetric curves has therefore become far less relevant today, although authors continue to debate the appropriateness of static versus dynamic curves (perhaps due to the lack of economic theory behind the a priori S-shaped specification). Nevertheless, there exists little doubt concerning the inability of the static functional form to capture observed and theoretical diffusion scenarios (Knudson 1991).

The logistic curve used in this study has greater flexibility than the earlier specifications employed by Griliches and Mansfield. First, its general specification allows the adoption ceiling parameter, which characterizes the total potential rate of adoption, to vary by region according to differences in latitude and the availability of locally adapted seed varieties. Second, the parameter that characterizes initial adoption is a function of variables affecting expected returns to Bt cotton adoption (demand-side variables) as well as the availability of locally adapted seed varieties (supply-side variables). Third, the speed of adoption is a function of market conditions (relative input and output prices), farm policy (price support payments), and pre-existing pest control policies (participation in boll weevil eradication programs).

3.3 Empirical Logistic Diffusion Function

The logistic diffusion function is a symmetric exponential growth function of the following form:

$$(3.1) \quad y_{it} = \frac{\overline{\mathbf{K}}_i}{1 + e^{-\mathbf{a}_i - \mathbf{b}_{it} t - \mu_{it}}},$$

where y_{it} is the proportion of cotton acreage planted to Bt cotton in region i at time t, the ceiling parameter $\overline{\mathbf{K}}_i$ is the total proportion of acres on which Bt cotton may potentially be adopted in region i, the parameter $\mathbf{a}_i$ characterizes initial adoption of Bt cotton, and μ_{it} is a random error term. The term $\mathbf{b}_{it}$ measures the rate of diffusion of Bt cotton varieties.

The rate of diffusion depends on the ratio of non-adopters to potential adopters at time t. This relationship can be verified by taking the derivative of equation (3.1) with respect to t, which yields,

$$(3.2) \quad \frac{dy}{dt} \cdot \frac{1}{y} = \mathbf{b}_{it} \cdot \frac{e^{-a_i - b_{it} t}}{1 + e^{-a_i - b_{it} t}}.$$

Solving for $\overline{\mathbf{K}}_i$ in equation (3.1) and simplifying, it can then be shown that

$$(3.3)\qquad \frac{dy}{dt}\cdot\frac{1}{y_{it}} = \mathbf{b}_{it}\cdot\frac{\overline{K}_i - y_{it}}{\overline{K}_i}.$$

Equation (3.3) shows that the rate of adoption slows as aggregate adoption approaches the adoption ceiling, $\overline{\mathbf{K}}_i$.

In sum, $\mathbf{a}_i$ characterizes the initial rate of Bt cotton adoption in region *i* in the first year it is available, $\overline{\mathbf{K}}_i$ characterizes the total proportion of acreage that will ultimately adopt Bt cotton in region *i*, while $\mathbf{b}_{it}$ determines how quickly the rate of adoption moves from the initial adoption rate to the adoption ceiling.

In this study $\overline{\mathbf{K}}_i$, $\mathbf{a}_i$, and $\mathbf{b}_{it}$ are themselves functions of economic and agronomic variables: The adoption ceiling for each region is defined as:

$$(3.4)\qquad \overline{\mathbf{K}}_i = K_0 k + K_1 lat1 + K_2 lat2 + K_3 strip\text{, where } k = 0.96.$$

The twenty-seven regions examined in this study were divided into three latitude groups in order to analyze the effect of latitude on Bt cotton adoption and pest pressure. The variable *lat1* is a dummy variable representing the regions in the northern-most latitude. Regions in the northern latitude group include Northeast Arkansas, San Joaquin Valley California, Missouri, North Carolina, Tennessee, and Virginia. The variable *lat2* is a dummy variable representing regions in the middle latitude. Regions included in this latitude group include Central Alabama, Northern Alabama, Arizona, Southeast Arkansas, Mississippi Hills, New Mexico, Oklahoma, South Carolina, Texas North Central, Texas North Rolling Plains, Texas South Rolling Plains, Texas Lower Rio Grande, Texas Far West, and Texas South Central.

The variable *strip* is a dummy variable representing the regions that produce stripper cotton. This variable is included because Bt producing seeds were not available in stripper cotton varieties until 2001.

The initial adoption intensity parameter, $\mathbf{a}_i$, is specified as a function of demand-side factors affecting expected initial gains to Bt cotton adoption, as well as the availability of Bt seed varieties that are adapted to local growing conditions. It is defined as follows:

(3.5) $\mathbf{a}_i = A_0 + A_1 \ln lossval_i + A_2 \ln p\cos t_i + A_3 parent_i$, where

$lnlossval_i$ = The natural log of the 1991-1995 average real dollar value of yield losses per infested acre.

$lnpcost_i$ = The natural log of the 1991-1995 average real pesticide cost per treated acre.

$parent_i$ = The percentage of total acreage in a region in 1994 that was planted with a seed variety used to create the initial strains of Bt cotton seed. This variable is included because it is hypothesized that farmers already familiar with the non-Bt parent of Bt varieties will be more likely to adopt the Bt versions of those seeds.

The slope parameter, $\mathbf{b}_{it}$, is a function of the expected price of cotton, relative input costs, and the costs faced by those regions participating in boll weevil eradication programs. It is defined as follows:

(3.6) $\mathbf{b}_{it} = \beta_0 + \beta_1 \text{lnlagrev}_{it} + \beta_2 \text{lnCratio}_{it} + \beta_3 \text{bwerad}_{it}$, where

lnlagrev = The natural log of the variable lagrev, which is the effective price of cotton (the sum of the real price of cotton and the loan deficiency payments).

lnCratio = The natural log of the variable *Cratio*, which is the ratio of the real cost of Bt cotton per acre and the real cost per application of pesticide.

bwerad = The weighted real boll weevil eradication cost per acre.

3.3.1 Choice and Placement of Variables

Each variable included in the ceiling, initial adoption, and rate of diffusion parameters were chosen to describe observed regional differences or government mandates or to test an economic, behavioral, or entomological hypothesis. Following Griliches, the variables can be viewed as either supply-side or demand-side factors, where supply-side factors impact the farmers' ability to obtain region-appropriate Bt seed varieties, and demand side factors determine when and how quickly the farmers' adopt the seed once it becomes available. In this study, supply-side factors are accounted for by the parent-variety and stripper region variables, and demand-side factors are accounted for by the pest-control cost and pesticide application variables.

The ceiling parameter, $\overline{\mathbf{K}_i}$, varies among regions but is constant through time. The parameter is defined as a function of the constant *k,* plus dummy variables to account for differences across different latitude groups and between stripper and picker cotton regions. The constant *k* is included to incorporate the government mandated refuge requirement described above. The latitude dummy variables were included to account for differences in agro-climatic conditions across different latitudes, while the stripper cotton dummy variable, *strip*, was included to account for the shortage of transgenic Bt varieties in stripper cotton. The parameter, $\mathbf{a}_i$, describes adoption of Bt cotton in year zero, or 1995.

Although adoption can not occur in year zero, one can interpret this parameter as describing the conditions that are likely to influence the initial adoption decision in 1996. The parameter is a function of historical averages of cost variables, including the cost of yield losses and pest control, as well as a variable describing the original Bt cotton varieties' relationship to existing parent varieties. The historical cost variables are included to test the hypothesis that the decision to adopt Bt cotton in the first year of availability depends on farmers' past experience of significant crop damage or pest control expense. The variable $parent_i$ is included to test the hypothesis that those regions where traditional parent varieties were easily adaptable to the genetic transformations necessary to create Bt cotton would be the first to have access to the plant, and would therefore adopt it sooner than other regions.

The slope parameter, $\mathbf{b}_{it}$, describes the rate of diffusion of Bt cotton through time. It is a function of lagged revenue, current year costs of pesticide and Bt cotton, and the cost incurred from state-level participation in boll weevil eradication programs. The latter variable is included to test the entomological hypothesis that eradication of one pest is likely to cause an increase in the occurrence of other pests.

The natural log of the cost variables is used because linear regressions of the cost variables on the observed values of the proportion of Bt cotton acreage in each region revealed a linear-log relationship between these variables.

CHAPTER 4: MODEL SPECIFICATION OF THE EFFECT OF BT COTTON ADOPTION ON THE USE OF CONVENTIONAL INSECTICIDES

Chapter 3 specified an econometric model to explain diffusion of Bt cotton varieties across different regions over time. Chapter four focuses on specifying an econometric model of the impact of the diffusion of Bt cotton varieties on the use of conventional insecticides.

4.1 Pesticide Use Model

The model used to describe pesticide use is defined as follows:

(4.1) $deltapest = \mathbf{gx}_{it} + \theta btacres_{it} + v_{it}$.

The dependent variable, $deltapest_{it}$, is the difference in the number of pesticide applications used to control bollworms and budworms in region i during year t, and the average number of bollworm and budworm targeted applications between 1991 and 1995. In short, the dependent variable describes the change in the number of pesticide applications in each region during 1996 to 1999 from that region's historic (1991-1995) average.

The term **x** is a vector of exogenous variables and **g** is the vector of parameters to be estimated. The variable $btacres_{it}$ is the proportion of cotton acres planted to Bt cotton in region i in year t, and v_{it} is a stochastic error term. A key parameter of interest is θ, which measures the impact of Bt cotton adoption on the change in the number of insecticide applications.

Equation (4.1) attempts to control for factors that may account for changes in insecticide use over time other than the adoption of Bt cotton. The exogenous variables in **x** are defined as follows:

$\mathbf{x} = (1, t1, t2, t3, lagprice, appcost, bwerad, lat1, lat2, strip)$, where

t1, t2, t3 = dummy variables for each year (1999 is omitted as the default comparison year).

lagprice = the effective price of cotton, lagged one year. The effective price is the market price of cotton per pound plus the government price support payment made per pound of cotton. The effective price of cotton varies by state and year.

appcost = the per acre cost of insecticide applications to control budworms and bollworms in region *i* at time *t*.

bwerad = the weighted real boll weevil eradication cost per acre. Including this variable allows one to test the hypothesis that boll weevil eradication programs reduce the demand for boll worm and bud worm targeted applications. Alternatively, eliminating one pest may allow other pests to take over and cause more damage (therefore increasing the need for boll and bud worm insectide treatments .

lat1, *lat2* = are dummy variables for the different latitude groups, and

strip = the dummy variable for regions growing stripper cotton varieties.

4.2 Simultaneous System of Equations

One could, in principle, simply estimate equation (4.1) as a single equation using ordinary (or generalized) least squares. However, this procedure may lead to biased and inconsistent parameter estimates. To elaborate, equations (3.1) and (4.1) are shown together below.

$$(3.1)\quad btacres_{it} = \frac{\overline{K_i}}{1+e^{-a_i-b_{it}t-u_{it}}}$$

$$(4.1)\quad deltapest = \mathbf{gx}_{it} + \theta btacres_{it} + v_{it}$$

The first equation estimates regional choice of seed technology. The second estimates the number of insecticide applications in each regions given its prior choices concerning seed technology.

Because the dependent variable of the first equation, the proportion of total cotton acreage planted to Bt cotton, enters the second as a regressor, these two models form a recursive system of equations.

Econometric theory states that equation (3.1) can be estimated via OLS without fear of bias or inefficiency because the dependent variable in the first equation, *btacres*, is purely a function of exogenous variables that are by assumption uncorrelated with the error term, *u*. If the error terms across equations were uncorrelated, so that

$\text{cov}(u,v)=0$,

then the second equation could also be estimated by OLS without fear of bias or inefficiency because the predicted value of *bt acres* would be, in effect, a predetermined variable that would not be correlated with the error term.

However, because Bt cotton is itself a pesticide product and thus a substitute for applied pesticides, it cannot be assumed that adoption of Bt cotton would not impact pesticide use, or consequently, that within an econometric model of the two functions, underestimated (overestimated) error terms in equation (3.1) would not lead to overestimated (underestimated) error terms in equation (4.1). Further, if the error terms u and v represent the impact of omitted explanatory variables from the two equations describing the regions' pest control decisions, it would be reasonable to assume that these omitted variables affect both u and v.

It is therefore assumed that the error terms in each equation corresponding to a single time period are correlated, so that

$$\text{cov}(u,v) = \sigma_{ij} \neq 0.$$

To account for this expected correlation among the error terms in the above system of recursive equations, a simultaneous equation method, such as three-stage least squares or full information maximum likelihood, must be implemented. A short description of these estimators follows:

4.2.1 Three-Stage Least Squares Estimation

The three-stage least squares estimator accounts for endogeneity of the regressor bt*acres* in the second equation as well as correlation among error terms u and v by combining the two-stage- and generalized- least squares estimators[6]. To do this, it first computes the reduced form parameter estimates for each endogenous variable by multiplying each equation by the matrix of exogenous variables or instruments, X. It then calculates the reduced form residuals, $\bar{u}_i$ and $\bar{v}_i$, and uses them to compute the estimated general covariance matrix, *W**, where

$$\hat{W}* = \begin{bmatrix} \hat{\sigma}_{11}X'X & \hat{\sigma}_{12}X'X \\ \hat{\sigma}_{21}X'X & \hat{\sigma}_{22}X'X \end{bmatrix}, \text{ where } \sigma_{12} \neq \sigma_{21}$$

Lastly, it uses this generalized coviarance matrix to compute the generalized least squares estimates of the parameters and sampling errors.

4.2.2 Iterated Three-Stage Least Squares

Whereas the 3SLS estimator uses the ordinary-least squares estimate of the variance-covariance matrix to calculate its generalized least-squares estimate of the error terms, the Iterated Three-Stage Least Squares estimator continuously updates the error term matrix, using the generalized least squares estimate of the independent variable parameter matrix calculated in the previous iteration to calculate the new error term matrix. The iteration process ends when changing the independent variable parameter matrix fails to improve the objective function. Various econometricians have proven that achieving convergence with this method will yield the same result as the Full Information Maximum Likelihood estimator, described below (Amemiya 1983).

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[6] Refer to any upper-level econometrics text for further explanation of these methods. Contents of this paragraph are adapted from

4.2.3 Full-Information Maximum Likelihood Estimation

The full-information maximum likelihood estimator is the simultaneous equation counterpart to maximum likelihood. To estimate a system of M equations simultaneously using FIML the system must be complete, containing as many endogenous variables as there exist equations. All variables, endogenous and exogenous, must be assigned a parameter so that the system is of the form[7]:

$$\Gamma y_t + B_o x_t = e_t$$

The system is then solved in terms of the endogenous variable, y_t:

$$y_t = -\Gamma^{-1} B x_t + \Gamma^{-1} e_t .$$

The reduced form parameters are then defined as:

$$\Pi' \equiv \Gamma^{-1} B, \text{ and}$$
$$v_t \equiv \Gamma^{-1} e_t$$

It is assumed that the endogenous variable, y_t and the reduced form error term v_t are distributed multivariate normal conditional on x_t:

$$v_t | x_t \sim N(0, [\Gamma^{-1}\Sigma(\Gamma^{-1})]')$$
$$y_t | x_t \sim N(\Gamma^{-1} B x_t, \Gamma^{-1}\Sigma(\Gamma^{-1})]')$$

The conditional log likelihood function for T observations is then:

$$\ln f(y_t | x_t; \delta, B) = -\frac{TM}{2}\ln(2\pi) - \frac{T}{2}\ln(|\Gamma^{-1}\Sigma(\Gamma^{-1})'|) - (\frac{T}{2})[y_t + \Gamma^{-1} B x_t]'[\Gamma^{-1}\Sigma(\Gamma^{-1})]'[y_t + \Gamma^{-1} B x_t].$$

Griffiths, Hill, and Judge (1993) p.631.

[7] Discussion of Full Information Maximum Likelihood estimation is taken from *Econometrics* by Hayashi, Fumio.

CHAPTER 5: DATA

The main sources for data used in this study are the *Cotton and Insect Loss* (CIL) database, compiled by the Mississippi State University Cooperative Extension Service (Williams 1995-99), and the *Published Estimates Database* (PEDB), compiled by the National Agricultural Statistics Service of the United States Department of Agriculture (NASS 1995-99). A total of 108 observations were collected and consist of data for twenty-seven regions from the years 1996 to 1999. The twenty-seven regional divisions used represent distinct cotton producing areas within fifteen U.S. states as designated in the *Cotton and Insect Loss* database with the exception of the Imperial and Sacramento Valleys of California, which have been omitted in this study due to missing observations. Included in the observations for each region are data on total cotton acreage and Bt-cotton acreage, cost of Bt-cotton technology, acreage allotments in boll-weevil-eradication programs, historic cotton yields, historic pest infestation levels, historic pesticide costs, cotton prices, and federal Loan Deficiency Program payments.

Data on total cotton acreage and Bt cotton acreage, cost of Bt cotton technology, acreage allotments in boll weevil eradication programs, cotton yields, pest infestation levels, and pesticide costs were collected from the CIL database. Data on abandonment rates, cotton prices, parent varieties and Loan Deficiency Program Payments were taken from various USDA sources. These data categories are described individually below. All data used for estimation in this study are included in Appendix A of this thesis.

5.1 Description of Data and Calculations

Cost of Bt cotton technology: The cost incurred by farmers in each state to purchase and use Bt cotton seed was calculated by summing the technology fee per acre charged to farmers for using the seed, found in the *Bt Cotton Cost by State* table of the CIL database (Williams 1996-99) under the heading, "Bt cost per acre", and the per-bag seed premium incurred by farmers, found in the same table under the heading, "Seed Premium Costs".

Bt Cotton Acreage: The proportion of total cotton acreage planted to Bt cotton in each region was calculated by dividing the average cost per acre of planting Bt cotton, found under the heading, "Bt use license fees" in the individual region summaries within the CIL database, by the state-level cost of using the Bt cotton technology, explained above.

Historic Acres Harvested: The number of harvested acres from the years 1991 to 1995 is found under the heading "Acreage Harvested" in the regional summaries of the CIL database The five-year average was then calculated by summing each year's total and dividing by five.

Historic Acres Treated: The number of acres treated for bollworm and budworm infestations from the years 1991 to 1995 was found under the heading "Above Treat Thresholds" in the regional summaries of the CIL database.

Eradication Acreage: The percentage of total cotton acreage involved in boll weevil eradication programs in each region during the years 1996 to 1999 was calculated by dividing the number of acres under eradication control, found in the *Eradication Costs* tables of the CIL database under the heading "Number of Acres", by the total number of acres produced in each region, found in the regional summaries within the CIL database under the heading, "Total Acres".

Real Price of Cotton: The real price of cotton received by farmers in each state for years 1996 to 1999 was calculated by dividing the price per pound of cotton, found in the PEDB in *the US and State* tables under the heading, "Price Per Unit", by the implicit price deflator of the Gross Domestic Product as published by the Bureau of Economic Analysis in the *National Income and Product Account* Tables. Because the BEA updates these deflators monthly, the deflator used in this study is included with the data in Appendix B of this thesis.

Lagged Real Price of Cotton: The lagged real price of cotton for the years 1996 to 1999 is the real price of cotton, as described above, for the previous year (t- 1).

Loan Deficiency Program (LDP) Payments: The LDP payments received by farmers in each state were calculated by summing the total Loan Deficiency and Market Gain payments made for upland cotton, as quoted by the Farm Service Agency of the USDA in *the PSL-82r Cumulative Report* tables. For each type of payment, the quantity eligible for program payments, found under the headings, "Total Quantity" and, "Market Gain Quantity" for LDP and Loan Activity, respectively, was multiplied by the average payment made, found under the headings, "Average Payment" and, "Average Market Gain". These totals were then summed to arrive at the total LDP payment. Because the FSA updates these program payment numbers weekly, the total LDP payments as calculated are included with the data in Appendix A of this thesis.[8]

Lagged LDP Payments: The lagged LDP payment received by farmers for the years 1996 to 1999 are the LDP payments, as calculated above, for the previous year (t-l).

Historic Yield Per Acre: The 1995 average yield per acre, in bales, for each region was obtained from the CIL regional summaries under the heading, "Yield Per Acre". The regional yields were then converted to pound per acre measurements by multiplying the bale estimates by 480 pounds per bale.

Historic Infestation Rate: The 1995 infestation level, in number of acres, of bud worms, boll worms, and pink boll worms was obtained from the CIL regional summaries under the heading, "Acres infested". Infested acreage as a percentage of total acreage was then calculated by dividing the number of infested acres by total acres planted, as found in the

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[8] The total LDP payments for the years 1996 to 1998 were furnished directly from Dr. George Frisvold. The quantities and average payments used to calculate LDP payments form 1996 to 98 were not available. Therefore, these numbers are not listed in the appendix.

CIL database in the regional summaries under the heading, "Total Acres" and multiplying this ratio by 100.

Historic Pesticide Costs per Acre: The 1995 Costs per acre for the treatment of boll worm, bud worm, and pink boll worm in each region were calculated by multiplying the number of acres treated, found under the heading, "Acres Treated" in the regional summaries of the CIL database, and the number of pesticide applications, found in the same tables under the heading, " # Insect Applicat."

Historic Yield Loss: The percentage of total acreage lost to bollworms, budworms and pink bollworms in each region in 1995 was obtained from the CIL regional summaries under the heading, "%Yield Reduction".

CHAPTER 6: ESTIMATION AND RESULTS OF THE DIFFUSION MODEL

Estimation of the simultaneous equation model described in chapter four was completed with SAS ETS software. Estimation of the final model involved several intermediate estimations. First, the diffusion model was estimated using non-linear least squares. Once a satisfactory specification of this function was found, the pesticide use equation was added to complete system. Chapter six will present the results of the non-linear least squares estimation of the diffusion equation. Discussion of the pesticide use model and simultaneous system results will follow in chapter seven.

6.1 Estimation Procedures

6.1.1 Estimation of the Logistic Diffusion Function

Estimation of a non-linear model in SAS requires the use of appropriate parameter starting values to better enable the program to locate the function maximum and achieve convergence. Starting values were obtained for the non-linear diffusion model by first estimating the linear transformation of the function via OLS. The OLS coefficients were then utilized as start values in the non-linear model. As a reminder, the logistic diffusion function is defined as follows:

$$(6.1) \quad y_{it} = \frac{\overline{\mathbf{K}_i}}{1 + e^{-\mathbf{a}_i - \mathbf{b}_{it} t - v_{it}}}$$

The linear transformation of this function is easily obtained by isolating the exponential term on the left-hand side of the equation and then taking the natural log of both sides. The transformed equation takes the following form:

(6.2) $\ln y_{it} = -a_i - b_{it}t - u_{it}$, where

(6.3) $y_{it} = \dfrac{\overline{K}_i - btacres_{it}}{btacres_{it}}$

(6.4) $\mathbf{a}_i = A_0 + A_1\text{lnlossval}_i + A_2\text{lnpcost}_i + A_3\text{parent}_i$

(6.5) $\mathbf{b}_{it} = \beta_0 + \beta_1\text{lnlagrev}_{it} + \beta_2\text{lnCratio}_{it} + \beta_3\text{bwerad}_{it}$

The OLS estimates from this model provided satisfactory starting values for the non-linear function. Convergence of the non-linear least-squares estimation via the Gauss-Newton iteration method was obtained using the SAS procedure PROC MODEL.

The model was estimated both with and without the boll weevil eradication variable (i.e with and without $B_3 = 0$). For each version of the model three variations of the ceiling parameter were estimated. In the first case, the ceiling was set equal to 0.96 for all regions. The maximum ceiling value of Bt cotton acreage is restricted to this level because Environmental Protection Agency regulations require a minimum non-Bt cotton refuge of at least four percent. In the second case, the ceiling parameter was estimated directly along with other model parameters via non-linear least squares. In this case, the ceiling parameter can differ from 0.96 but is restricted to remain equal across all regions. In case 3, the ceiling parameter was made a function of dummy variables:

(6.6) $K_i = K_0k + K_1lat1_i + K_2lat2_i + K_3strip_i$

to allow its value to vary across regions. The non-linear OLS models and parameter estimates are presented below in Table 6.1.

As seen in Table 6.1, the descriptive power of both versions of the model (with and without the boll weevil eradication variable) improve, in terms of their adjusted R^2

values, as the ceiling function becomes increasingly flexible. Of the two models in which the ceiling value is defined as function of the three dummy variables, the model that includes the boll weevil eradication variable appears, based on its higher adjusted R^2 value, to be the stronger of the two.

Table 6.1 Nonlinear LS estimation without BW eradication variable (Cases 1 and 2)

Case 1: Ceiling value set exogenously K_0 restricted to = 1 K_1, K_2, and K_3 set = 0				Case 2: K_0 estimated directly but set equal across all regions. K_1, K_2, and K_3 restricted to = 0.		
Parameter/ Variable	Parameter Estimate	Standard Error	t value	Parameter Estimate	Standard Error	t value
K_0	--	--	--	0.8565	0.1008	8.50
lat1	--	--	--	--	--	--
lat2	--	--	--	--	--	--
strip	--	--	--	--	--	--
A_0	-8.7	1.3323	-6.53	-10.26	1.9888	-5.16
lnlossval	1.11	0.2351	4.73	1.37	0.3632	3.77
lnpcost	0.998	0.3067	3.25	1.21	0.3632	3.77
parent	0.034	0.00632	5.44		0.00937	2.89
B_0	0.945	0.2847	3.32	0.04	0.4059	4.23
lnlagrev	1.29	0.5772	2.23	1.63	0.7882	2.07
Cratio	-0.11	0.2143	-0.5	-0.099	0.2528	-0.39
R^2	0.6791			R^2	0.6838	
Adjusted R^2	0.6600			Adjusted R^2	0.6617	

Table 6.1- *Continued* (Case 3)

Case 3: K varies across regions			
$K_i = K_0k + K_1lat1_i + K_2lat2_i + K_3strip_i$			
Parameter	parameter estimate	Standard error	t value
K_0	0.70	0.0704	9.95
lat1	-0.44262	0.0894	-4.95
lat2	0.157	0.0584	2.70
strip	-0.420	0.0868	-4.84
A_0	-11.81	2.43	-4.87
lnlossval	2.83	0.7149	3.96
lnpcost	0.69	0.3539	1.95
Aparent	0.0362	0.0092	3.96
B_0	1.80	0.5528	3.25
lnlagrev	1.129	0.9292	1.22
Cratio	-0.94	0.3913	-2.40
R^2	0.7891		
Adjusted R^2	0.7674		

Table 6.2 Nonlinear LS estimation with BW eradication variable (Case 1 and 2)

Case 1: Ceiling value set exogenously K_0 restricted to = 1 K_1, K_2, and K_3 set to = 0				Case 2: K_0 estimated directly but set equal across all regions. K_1, K_2, and K_3 set to = 0		
Parameter	Parameter estimate	Standard error	t value	Parameter estimate	standard error	t value
K_0	--	--	--	0.840	0.0998	8.42
lat1	--	--	--	--	--	--
lat2	--	--	--	--	--	--
strip	--	--	--	--	--	--
A_0	-8.138	1.14	-7.12	-10.45	2.60	-4.02
lnlossval	1.0647	0.2290	4.65	1.27	.3689	3.43
lnpcost	0.874	0.2699	3.24	1.35	.4794	2.82
Aparent	0.037	0.0060	6.18	0.0411	0.00942	4.37
B_0	0.514	0.2731	1.89	0.813	0.2929	2.78
lnlagrev	1.158	0.5173	2.24	1.77	0.6430	2.75
Cratio	0.107	0.2188	0.49	0.126	0.1749	0.72
bwerad	0.025	0.00581	4.31	0.036	0.0138	2.60
R^2	0.7340			R^2	0.7393	
Adjusted R^2	0.7154			Adjusted R^2	0.7182	

Table 6.2- *Continued* (Case 3)

Case 3: K varies across regions			
$K_i = K_0k + K_1lat1_i + K_2lat2_i + K_3strip_i$			
Parameter	Parameter estimate	Standard error	t value
K_0	0.676	0.0627	10.79
lat1	-0.404	0.0879	-4.6
lat2	0.169	0.0549	3.09
strip	-0.245	0.0873	-2.81
A_0	-15.75	3.9942	-3.94
lnlossval	2.97	0.7657	3.87
lnpcost	1.47	0.6147	2.39
Aparent	0.043	0.0109	3.94
B_0	1.753	0.7145	2.45
lnlagrev	2.27	1.33	1.71
Cratio	-.358	0.4558	-0.79
bwerad	0.047	0.0214	2.22
R^2	0.8060		
Adjusted R^2	0.7838		

The parameter estimates listed in these tables correspond to the following ceiling values:

Table 6.3 Ceiling values for nonlinear model without BW eradication variable

Ceiling function	Region	Ceiling Value
Case 1:	All regions	0.96
Case 2:	All regions	0.82
Case 3:	Latitude 1	0.23
	Latitude 2	0.83
	Latitude 2 (stripper regions)	0.41
	Latitude 3 (default region)	0.67
	Latitude 3 (stripper regions)[9]	0.25

[9] All Stripper Regions are included in the Latitude 2 group, with exception of the TX Coastal Bend Region, which is part of the Latitude 3 group.

Table 6.4 Ceiling values for nonlinear model with BW eradication variable

Ceiling function	Region	Ceiling Value
Case 1:	All regions	0.96
Case 2:	All regions	0.81
Case 3:	Latitude 1	0.25
	Latitude 2	0.79
	Latitude 2 (stripper regions)	0.55
	Latitude 3 (default region)	0.63
	Latitude 3 (stripper regions)	0.24

These models were compared via a formal Wald hypothesis test to determine whether the above results are significantly different from one another. First, the three cases were compared within each version of the model, and then case 3 was compared across models. The results are shown below in Tables 6.5 to 6.7:

Table 6.5 Wald Hypotheses Tests for model without BW eradication variable

Comparison	Wald statistic	Chi square distribution	Pr > Chi Square
Case 1 vs. Case 2	0.98	χ^2 (1)	<0.3320
Case 2 vs. Case 3	73.30	χ^2 (3)	< 0.0001
Case 1 vs. Case 3	471.60	χ^2 (4)	< 0.0001

Table 6.6 Wald Hypotheses Tests for model with BW eradication variable

Comparison	Wald statistic	Chi square distribution	Pr > Chi Square
Case 1 vs. Case 2	2.57	χ^2 (1)	< 0.1090
Case 2 vs. Case 3	118.35	χ^2 (3)	< 0.0001
Case 1 vs. Case 3	318.69	χ^2 (4)	< 0.0001

Table 6.7 Comparing Case 3 of both models using Wald Hypothesis Test

	Wald statistic	Chi square distribution	Pr > Chi Square
Case 3 without *bwerad* vs. Case 3 with *bwerad*	4.91	χ^2 (1)	< 0.0267

As seen in these results, although the OLS parameter estimate in case 2 is much lower than the federally mandated value of 0.96 to which the ceiling value is restricted in case 1, there is no significant difference between case 1 and case 2 in either version of the model. This result is likely due to the fact that the OLS estimate in case 2 is still forced to apply to all regions. The Wald test reveals that the regional dummy variables included in the ceiling function in case 3 do have a significant impact on the model.

Comparison of the model with the boll weevil eradication variable to that without it reveals that the variable does have a significant impact on the parameter estimates. Given this result and the evidence in support of significant differences across regions with respect to Bt cotton adoption ceiling values, case 3 of the model with the boll weevil eradication variable was selected for use in the simultaneous equation estimation. Interpretation of the meaning of the parameter estimates of the variables that comprise the intercept and rate of diffusion parameters is difficult because of the non-linear specification of the model. However, it is possible to infer from the results that the statistically significant parameters do in fact influence initial adoption levels and the rate of diffusion. As the results in Table 6.2 reveal, the historic dollar value of yield losses, pesticide costs per acre and adaptability of regional parent varieties to initial Bt cotton strains all significantly influence the initial level of adoption of Bt cotton. As for the rate of diffusion, the results in Table 6.2 reveal that the time variable and the cost of boll weevil eradication variable both exert significant influence on the rate of diffusion of Bt cotton.

All parameter estimates in the final specification have the expected sign.

CHAPTER 7: ESTIMATION AND RESULTS OF THE PESTICIDE USE EQUATION AND SYSTEM OF EQUATIONS

7.1 Estimation of the Pesticide Use equation

As stated in chapter 4, the pesticide use equation is defined as:

$$(4.1) \quad deltapest_{it} = \mathbf{g}\mathbf{x}_{it} + \theta btacres_{it} + \mathbf{v}_{it}.$$

The dependent variable $deltapest_{it}$ is the difference in the number of pesticide applications used to control bollworms and budworms in region *i* during year *t,* and the average number of bollworm and budworm targeted applications between 1991 and 1995. The vector $\mathbf{x}_{it}$ is a vector of exogenous variables, other than the amount of Bt cotton planted, that may impact the regions' use of conventional pesticides, and **g** and θ are parameters to be estimated. The term v_{it} is a stochastic error. Once again, the vector $\mathbf{x}_{it}$ contains the following variables, which were explained in depth in chapter 4:

$$\mathbf{x} = (1,\ t1, t2, t3,\ lagprice,\ appcost,\ bwerad,\ lat1, lat2, strip).$$

As also explained in chapter 4, the error term in the above equation (v) is assumed to be correlated with the error term in the diffusion function (u [as described in chapter 3]) so that

$$\text{cov}(u,v) = \sigma_{ij} \neq 0,$$

and thus use of a simultaneous estimator, such as FIML or 3SLS is required to ensure unbiased and efficient estimates.

Before estimating the two equations as a system, however, the change in pesticide use function was first estimated via OLS in order to establish base estimates to use as comparisons against those obtained with the simultaneous estimators. The OLS estimates are shown below in Table 7.1:

Table 7.1 OLS Estimates of Change in Pesticide Use

Parameter	Estimate	Standard Error	t value
Intercept	-1.66196	1.78	-0.93
t1	0.249546	0.3692	0.68
t2	0.292533	0.2785	1.05
t3	0.471779	0.2955	1.6
Btacres*	-3.34513	0.516	-6.48
Appcost**	0.145268	0.0435	3.34
Lagrev	-1.46418	2.646	-0.55
Bwerad	-0.02179	0.0184	-1.18
lat1*	0.960796	0.3626	2.65
lat2*	0.49223	0.2503	1.97
Strip*	0.630986	0.2861	2.21
R^2	0.6787		
Adjusted R^2	0.6456		

*significant at 95% confidence level
** significant at 95% confidence level but has incorrect sign

As seen in Table 7.1, the coefficients of the parameters $btacres_{it}$, $appcost_{it}$, *lat1, lat2* and *strip* are significant at the ninety-five percent confidence-level.

The significance of the intercept dummy coefficients *lat1, lat2* and *strip* imply that the average drop in the number of pesticide applications in these areas was less (by the amount of the coefficient value) than in the default latitude group (latitude group 3). The coefficient of the parameter $btacres_{it}$ implies that for every percent increase in Bt cotton acreage (e.g. the regional adoption rate increases from 29 percent to 30 percent) the number of pesticide applications will fall by an average of 0.0344 applications per acre. If a region experienced a 10 percent point increase in Bt cotton adoption (e.g. Bt cotton acreage rose from 10 to 20 percent or 20 to 30 percent of total cotton acreage), regional pesticide applications would fall from 0.6 to 0.3 applications per acre. Or, if adoption rates increased from 0 to 50 percent, then regional pesticide applications would fall by 0.5 X 3.44 = 1.67 applications per acre[10]. The parameter $appcost_{it}$, which is the per acre cost of insecticide applications used to control budworms and bollworms in region *i* at time *t*, is significant but has the wrong sign, as one would expect an increase in the cost/acre of pesticide applications to cause a decrease in the number of pesticide applications made.

The parameter estimates shown in Table 7.1 may be important in their own right if it is determined that no correlation exists between error terms in the two equations. Formal testing of such correlation can be completed with the Hausman Test of simultaneity once the simultaneous model has been estimated. As discussed in Greene (2000), employing the Hausman Test to a simultaneous system of equations to test the exogeniety a certain variable is not straightforward, and requires the arbitrary choice of an equation that does not contain the variable in question[11]. Due to this complexity the test was not attempted in this study. However, given the nature of the product and impact in question in this study, it is assumed that a simultaneous relationship does exist between the two equations (see econometric discussion in chapter 4 for further explanation).

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[10] The data used to arrive at these estimates is aggregated over all cotton acres, and thus does not apply exclusively to acres of Bt cotton. Therefore, the estimates of the reduction in the number of pesticide applications do not correspond to the number of pesticide applications made to Bt cotton only, but to pesticide applications per total cotton acres, whether planted to conventional or Bt varieties. The pesticide reductions experienced by farmers using Bt cotton are therefore larger than what is implied by these estimates.

[11] See Greene (2000), pages 701-702 for further details.

Equation (4.1) can be estimated as part of a simultaneous system of equations that contains both the diffusion and pesticide use equation using the SAS procedure PROC MODEL. To do so, one must specify the endogenous variables and parameters within the system, state the equations to be estimated, and then supply starting values for the parameters and specify which simultaneous method, such as two- or three- stage least squares or full-information maximum likelihood, is to be used. If an instrumental variable method is specified, appropriate instrumental variables must be supplied as well.

As a reminder, the two equations that define the full system of equations are defined by:

$$(3.1) \quad btacres_{it} = \frac{\overline{\mathbf{K}_i}}{1 + e^{-\mathbf{a}_i - \mathbf{b}_{it} t - u_{it}}}$$

$$(4.1) \quad deltapest_{it} = \mathbf{g}\mathbf{x}_{it} + \theta btacres_{it} + v_{it}$$

The coefficient values obtained from the linearly transformed version of the diffusion function (see equation 6.2) were used as starting values for the parameters in equation (3.1). To obtain appropriate starting values for the parameters in the change in pesticide use equation (equation 4.1), the function was initially solved via OLS using the predicted values of the *btacres* parameter coefficient obtained from the non-linear least squares estimation of the diffusion function. These instrumental variable estimates are shown below in Table 7.2.

Table 7.2 Instrumental variable estimates of pesticide use equation (Btacres endogenous)

Parameter	Parameter estimate	Standard error	t value
Intercept	-3.56394	1.62619	-2.19
Btacres	-5.27117	0.60189	-8.76
Lagrev	3.2971	2.52538	1.31
Appcost	0.09126	0.04016	2.27
Bwerad	0.00204	0.01714	0.12
Strip	-0.05625	0.28869	-0.19
t1	-0.34534	0.34985	-0.99
t2	-0.00426	0.25395	-0.02
t3	0.62714	0.26468	2.37
lat1	0.28822	0.35157	0.82
lat2	0.54169	0.22408	2.42
R^2	0.7428		
Adjusted R^2	0.7163		

7.2 Estimation of the system of equations

Estimation of the simultaneous system of equations was completed using the SAS ETS procedure PROC MODEL. The system of equations given by equations (3.1) and (4.1) above contains as many equations as endogenous variables, and thus the system is fully defined. It can therefore be estimated by either the instrumental variable method of three-stage lease squares (or iterated 3SLS) or by FIML. Earlier studies avoided FIML because it is computationally expensive. However, the FIML estimator can now be employed and solved easily using econometric software such as the SAS procedure PROC MODEL. Therefore, in this study the system was solved using both methods in order to compare results generated by the different estimators. If the system of equations is well defined this comparison can be very useful because the iterated 3SLS and FIML estimators should yield the same maximum point solution.

Unfortunately, the two procedures yielded significantly different results for the system of equations defined above. Thankfully, however, among the OLS, IT3SLS and FIML estimators, OLS yielded the most conservative estimate of the change in conventional pesticide use attributable to Bt cotton. As I was not able to determine the cause of the divergent estimates yielded by the other two methods, this study will present the non-linear OLS estimates of the second equation, with the acknowledgement that these estimates are potentially biased and inefficient (but conservative, none-the-less).

As seen in Table 7.3, the coefficient of the term *btacres* is highly significant regardless of the estimation method used, and non-linear OLS does in fact yield the smallest change in pesticide use of the three techniques.

Table 7.3 Range of Estimates of Parameter *btacres*

Estimator	Parameter Estimate	Standard Error	t-value
OLS	-3.34513	0.516	-6.48
IV	-5.27117	0.60189	-8.76
IT3SLS	-5.57848	0.967	-5.77
FIML	-6.03952	0.7713	-7.83

7.3 Implications of the Estimation Results

The above coefficient of the variable *btacres* represents Bt cotton's contribution to the decrease in the number of pesticide applications used as experienced in 1996 to 1999 over each region's historic (1991-1995) average. This term can be used to estimate Bt cotton's impact on pesticide costs. First, the drop in the number of pesticide applications in each region and time period must be calculated by multiplying the *btacres* coefficient value by the proportion of Bt cotton acreage planted in each region each year.

This estimate can then be multiplied by the regional average cost per pesticide application to arrive at the average cost savings per year resulting from the decreased use of conventional pesticides. Net savings can then be calculated by subtracting out the cost of using the Bt seed technology. This method was used to compute estimates of the cost-savings experienced by cotton producers due to the use of Bt cotton.

These calculations are summarized two ways in the tables below. Tables 7.4 and 7.5 show the savings experienced each year by all regions, and Tables 7.6 and 7.7 show the 1996-1999 average savings experienced by each region individually. In order to give the reader an overview of the range of estimates obtained, these calculations were made using both the OLS (low-range) and FIML (high-range) estimates.

Table 7.4 OLS Estimates of Average Net Savings Each Year (All Regions)

Year	Average Net Savings (Upper Bound) [12,13]	Average Net Savings (Actual Estimate)	Average Net Savings (Lower Bound)
1996	$47,667,139.50	-$7,642,730.53	-$62,952,600.56
1997	$72,931,360.18	-$1,208,636.19	-$75,348,632.56
1998	$86,865,969.45	$13,829,637.23	-$59,206,695.00
1999	$191,964,575.11	$42,040,605.63	-$107,883,363.84

[12] Net savings is the amount saved per acre due to reduced use of traditional pesticides, minus the per acre technology fees and seed costs incurred to use Bt cotton (negative value implies increased expense).

[13] Upper bound and lower bound estimates are based on the 95 percent confidence interval of the btacres estimate found in Table 7.10.

Table 7.5 FIML Estimates of Average Net Savings Each Year (All Regions)

Year	Average Net Savings (Upper Bound)	Average Net Savings (Actual Estimate)	Average Net Savings (Lower Bound)
1996	$136,826,266.89	$36,926,833.76	-$62,972,599.37
1997	$192,444,520.79	$58,534,540.43	-$75,375,439.92
1998	$204,600,031.11	$72,683,463.90	-$59,233,103.30
1999	$433,640,975.45	$162,851,701.23	-$107,937,573.00

Table 7.6 OLS Estimates of Pesticide Cost Savings as a Result of Bt Cotton Use (1996-1999)

REGION	Net Savings (upper bound)	Net Savings (actual estimate)	Net Savings (lower bound)
Central AL	$7,819,450.18	-$40,900.35	-$7,901,250.88
N. AL	$14,510,134.01	-$1,739,102.93	-$17,988,339.86
S. AL	$16,371,254.00	-$453,398.08	-$17,278,050.15
AZ	$31,728,921.14	$5,203,516.17	-$21,321,888.80
N.E. AR	$1,405,912.74	$80,730.11	-$1,244,452.52
S.E. AR	$21,794,893.79	$1,902,775.17	-$17,989,343.44
San Joaquin Valley-CA	$1,454,081.46	$534,157.36	-$385,766.75
FL	$6,492,177.73	-$227,462.66	-$6,947,103.04
GA	$78,179,257.04	$8,018,723.29	-$62,141,810.46
LA	$41,030,237.34	$7,051,058.51	-$26,928,120.32
MS Delta	$49,745,644.10	$8,409,996.15	-$32,925,651.80
MS Hills	$40,003,519.81	$4,340,348.30	-$31,322,823.20
MO	$320,964.53	-$543.20	-$322,050.93
NM	$1,012,491.64	$177,542.81	-$657,406.02
NC	$7,670,430.31	$597,005.95	-$6,476,418.42
OK	$6,130,396.87	$1,840,514.33	-$2,449,368.21
SC	$15,894,350.56	$2,310,184.40	-$11,273,981.76
TN	$21,381,502.50	$5,823,293.33	-$9,734,915.83
TX Coastal Bend	$6,129,082.17	$751,865.85	-$4,625,350.48
TX N. Central	$1,158,380.70	-$612,563.52	-$2,383,507.73
TX N. Rolling Plains	$1,131,161.71	$285,093.96	-$560,973.79
TX High Plains	$5,072,840.15	-$124,581.01	-$5,322,002.18
TX S. Rolling Plains	$11,534,347.90	$1,993,912.26	-$7,546,523.39
TX Lower Rio Grande	$1,043,991.52	$107,970.59	-$828,050.34
TX Far West	$6,504,129.94	$1,325,415.70	-$3,853,298.54
TX S. Central	$3,373,483.27	-$696,839.32	-$4,767,161.90
VA	$ 536,007.13	$ 160,162.96	-$215,681.21
US TOTAL	**$ 798,858,088.48**	**$ 94,037,752.29**	**-$610,782,583.90**

Table 7.7 FIML Estimates of Pesticide Cost Savings as a Result of Bt Cotton Use (1996-1999)

REGION	Net Savings (upper bound)	Net Savings (actual estimate)	Net Savings -(lower bound)
Central AL	$20,490,280.78	$6,293,093.89	-$7,904,093.01
N. AL	$40,703,791.40	$11,354,788.09	-$17,994,215.23
S. AL	$43,492,476.60	$13,104,171.52	-$17,284,133.57
AZ	$74,487,690.22	$26,578,105.21	-$21,331,479.79
N.E. AR	$3,542,097.96	$1,148,583.14	-$1,244,931.67
S.E. AR	$53,860,851.21	$17,932,157.61	-$17,996,535.99
San Joaquin Valley-CA	$2,936,992.75	$1,275,446.69	-$386,099.38
FL	$17,324,191.49	$5,187,329.38	-$6,949,532.72
GA	$191,277,551.48	$64,555,186.27	-$62,167,178.94
LA	$95,804,438.26	$34,432,015.91	-$26,940,406.43
MS Delta	$116,378,422.28	$41,718,912.22	-$32,940,597.84
MS Hills	$97,492,305.26	$33,078,293.53	-$31,335,718.21
MO	$839,232.76	$258,532.79	-$322,167.18
NM	$2,358,423.38	$850,357.73	-$657,707.92
NC	$19,072,741.40	$6,296,882.69	-$6,478,976.01
OK	$13,045,657.82	$5,297,369.24	-$2,450,919.34
SC	$37,791,932.32	$13,256,519.41	-$11,278,893.49
TN	$46,461,227.91	$18,360,343.29	-$9,740,541.33
TX Coastal Bend	$14,797,117.65	$5,084,911.44	-$4,627,294.76
TX N. Central	$2,699,648.54	$388,714.68	-$1,922,219.18
TX N. Rolling Plains	$2,495,017.06	$966,868.68	-$561,279.71
TX High Plains	$13,451,047.07	$4,063,582.81	-$5,323,881.45
TX S. Rolling Plains	$26,913,464.08	$9,681,745.54	-$7,549,973.00
TX Lower Rio Grande	$2,552,850.78	$862,231.00	-$828,388.79
TX Far West	$14,852,181.43	$5,498,505.19	-$3,855,171.05
TX S. Central	$9,934,815.09	$2,583,090.72	-$4,768,633.64
VA	$1,141,865.32	$463,024.11	-$215,817.11
US TOTAL	**$1,933,710,106.53**	**$661,567,302.11**	**-$610,575,502.31**

7.4 Conclusions

As seen in the above tables, these estimates imply that Bt cotton adoption has unequivocally reduced the use of traditional pesticides. In all of the specifications estimated the negative effect of Bt adoption on traditional insecticide use was large and statistically significant.

With respect to input cost savings, however, the results are more ambiguous. The estimates imply that the cost impact of using Bt cotton over the four year period from 1996 to 1999 could range from a possible savings worth nearly two-billion dollars to losses worth over six-hundred million dollars.

This wide range of estimates is attributable to the shift in input costs that many farmers have experienced because of Bt cotton. While the costs of traditional insecticide applications have certainly declined for growers as a result of Bt cotton adoption, their seed costs have increased due to the significantly higher price of Bt seed. Consequently, although several econometric specifications examined in this study yield results suggesting that Bt cotton has significantly reduced overall costs, others suggest that the cost reductions have been quite modest, or have, in fact, increased. The upper-bound and actual estimates shown in Tables 7.4 - 7.7 reveal that the cost-savings resulting from the use of Bt cotton have increased each year, a result likely due to the improvement of Bt varieties and greater usage of them. The estimates from the lower-bound of the 95 percent confidence interval, on the other hand, imply a minute decrease in the number of pesticide applications in comparison to the additional seed cost incurred, and thus an increase in overall costs.

These "lower bound" results suggest that Bt cotton may not be profitable to many growers based on cost-savings alone. Yet adoption of Bt cotton and stacked Bt cotton varieties has increased over time. There must therefore exist additional advantages to using Bt cotton. It seems sensible that in addition to it's cost-saving potential, one must consider the plant's ability to reduce pest damage and increase yields to truly understand Bt cotton's success.

The fact that farmers remain pleased with Bt cotton's performance in both pest-damage prevention and yield in spite of its lackluster cost performance points to Bt cotton's multiple advantages. Although the benefits of higher yields were not examined in this study, this topic would be a useful line of future research.

APPENDIX A: DATA USED IN REGRESSIONS

REGION	Obs	Year	REGION	(1)*[1] Acres harvested (91-95 Avg)	(2)* Acres infested (91-95 Avg)	(3)* Acres treated (91-95 Avg)	(4)*[2] Real Pest. Cost/acre (91-95 Avg)	(5)* Real $ value yield losses $/acre (91-95 Avg.)	(6)* Real cost/appl. Of pesticide
C. Alabama	1	1996	1.00	94000.00	100000.00	100000.00	50.64	123.26	8.50
N. Alabama	2	1996	2.00	232220.00	234580.00	219360.00	23.85	38.05	7.70
S. Alabama	3	1996	3.00	144000.00	150000.00	147000.00	37.34	28.73	7.50
Arizona	4	1996	4.00	389600.00	368680.00	227760.00	20.20	11.28	12.00
NE Arkansas	5	1996	5.00	523000.00	510500.00	388000.00	16.76	8.75	8.64
SE Arkansas	6	1996	6.00	459500.00	459500.00	459500.00	71.13	15.76	9.37
San Joaquin	7	1996	7.00	1149468.00	13260.00	1720.00	0.00	0.00	0.00
Florida	8	1996	8.00	64800.00	65000.00	64800.00	42.23	14.14	7.20
Georgia	9	1996	9.00	769000.00	763000.00	1752500.00	25.49	21.88	9.00
Louisiana	10	1996	10.00	893181.80	885955.00	850975.40	44.19	18.62	11.35
MS Delta	11	1996	11.00	838590.80	817536.60	787876.60	44.66	16.73	9.84
MS Hills	12	1996	12.00	488803.40	480201.40	441037.40	34.86	24.80	7.23
Missouri	13	1996	13.00	333600.00	224336.00	189165.60	6.89	5.09	12.00
New Mexico	14	1996	14.00	66120.00	42710.00	18460.00	3.59	8.28	11.00
North Carolina	15	1996	15.00	497400.00	504600.00	496160.00	27.67	26.50	9.40
Oklahoma	16	1996	16.00	357000.00	367000.00	208000.00	15.49	5.21	11.50
South Carolina	17	1996	17.00	229400.00	226600.00	218000.00	33.54	14.78	8.00
Tennessee	18	1996	18.00	596000.00	396000.00	232000.00	11.90	14.87	10.53
TX Coastal Bend	19	1996	19.00	490543.33	455352.67	203045.33	6.85	4.65	9.82
TX North Central	20	1996	20.00	165500.00	127833.33	103500.00	11.69	16.81	6.00

[1] All data in columns marked with one (1) asterisk were obtained from the Mississippi State University *Cotton and Insect Loss Database.* Http: http://www.msstate.edu/Entomology/Cotton.html. Accessed: 3/2000.

[2] All prices and costs were deflated to 1996 dollar (real) values using the implicit price deflator listed in Appendix B.

REGION	Obs	Year	REGION	(13) * Real Erad. Wt. Cost/acre	(14) [p] Avg. farm size	(15) * # Pesticide Applications/ total acres (current year)	(16) * Average # Pesticide App. (91-95)
Central Alabama	82	1999	1.00	4.77	3571	0.389	5.920
N. Alabama	83	1999	2.00	4.77	302	0.205	3.420
S. Alabama	84	1999	3.00	4.77	302	0.675	5.240
Arizona	85	1999	4.00	1.70	312	0.336	1.900
NE Arkansas	86	1999	5.00	0.00	231	0.300	1.950
SE Arkansas	87	1999	6.00	14.32	224	0.875	5.875
San Joaquin Valley-CA	88	1999	7.00	0.10	272	0.000	0.000
Florida	89	1999	8.00	5.73	265	0.450	5.260
Georgia	90	1999	9.00	2.39	265	0.552	3.740
Louisiana	91	1999	10.00	11.93	274	1.203	4.700
Mississippi Delta	92	1999	11.00	21.00	2884	1.342	4.440
Mississippi Hills	93	1999	12.00	21.00	160	1.143	3.840
Missouri	94	1999	13.00	0.00	405	0.913	0.720
New Mexico	95	1999	14.00	7.59	194	1.100	0.340
N. Carolina	96	1999	15.00	3.25	131	1.923	2.960
Oklahoma	97	1999	16.00	11.69	575	0.667	1.440
South Carolina	98	1999	17.00	5.25	575	1.111	4.180
Tennessee	99	1999	18.00	1.23	575	0.598	1.180
Texas Coastal Bend	100	1999	19.00	14.31	575	0.296	0.726
Texas N. Central	101	1999	20.00	0.00	575	0.027	1.677
Texas N. Rolling Plains	102	1999	21.00	12.15	575	0.082	0.467
Texas High Plains	103	1999	22.00	4.06	575	0.034	0.233
Texas S. Rolling Plains	104	1999	23.00	12.28	575	0.049	0.767
Texas Lower Rio Grande Valley	105	1999	24.00	0.00	575	0.235	1.200
Texas Far West	106	1999	25.00	4.68	575	0.057	0.600
Texas S. Central	107	1999	26.00	0.00	575	0.800	3.700
Virginia	108	1999	27.00	3.10	178	1.818	1.300

REGION	Obs	Year	REGION	(7) ^{p} Real Price Cotton	(8) ^{p} Lagged Real Price Cotton	(9) ^{f} Real LDP payments	(10) ^{f} Real Lagged LDP payments	(11) * Proportion total acreage planted to Bt	(12) * Real cost Bt technology
Central Alabama	82	1999	1.00	0.503	0.609	0.18	0.083	0.7000	26.73
N. Alabama	83	1999	2.00	0.503	0.609	0.18	0.083	0.8200	24.82
S. Alabama	84	1999	3.00	0.503	0.609	0.18	0.083	0.5500	26.73
Arizona	85	1999	4.00	0.479	0.632	0.18	0.084	0.7029	30.54
NE Arkansas	86	1999	5.00	0.506	0.632	0.19	0.077	0.0418	25.77
SE Arkansas	87	1999	6.00	0.506	0.632	0.19	0.077	0.4000	25.77
San Joaquin Valley-CA	88	1999	7.00	0.602	0.721	0.17	0.081	0.0150	30.54
Florida	89	1999	8.00	0.445	0.525	0.20	0.082	0.6000	23.86
Georgia	90	1999	9.00	0.475	0.653	0.19	0.087	0.5862	24.82
Louisiana	91	1999	10.00	0.467	0.575	0.17	0.073	0.6197	28.41
Mississippi Delta	92	1999	11.00	0.492	0.614	0.19	0.081	0.6053	27.68
Mississippi Hills	93	1999	12.00	0.492	0.614	0.19	0.081	0.8286	27.39
Missouri	94	1999	13.00	0.460	0.684	0.18	0.059	0.0205	21.00
New Mexico	95	1999	14.00	0.493	0.674	0.19	0.089	0.2857	30.54
N. Carolina	96	1999	15.00	0.481	0.666	0.19	0.072	0.1998	18.13
Oklahoma	97	1999	16.00	0.399	0.596	0.18	0.082	0.3009	19.09
South Carolina	98	1999	17.00	0.474	0.660	0.18	0.060	0.8500	21.95
Tennessee	99	1999	18.00	0.459	0.616	0.17	0.084	0.6500	22.91
Texas Coastal Bend	100	1999	19.00	0.493	0.563	0.18	0.077	0.1874	20.04
Texas N. Central	101	1999	20.00	0.493	0.563	0.18	0.077	0.2000	21.00
Texas N. Rolling Plains	102	1999	21.00	0.493	0.563	0.18	0.077	0.0538	23.58
Texas High Plains	103	1999	22.00	0.493	0.563	0.18	0.077	0.0517	35.17
Texas S. Rolling Plains	104	1999	23.00	0.493	0.563	0.18	0.077	0.3218	26.73
Texas Lower Rio Grande	105	1999	24.00	0.493	0.563	0.18	0.077	0.0000	0.00
Texas Far West	106	1999	25.00	0.493	0.563	0.18	0.077	0.1877	21.04
Texas S. Central	107	1999	26.00	0.493	0.563	0.18	0.077	0.0080	23.53
Virginia	108	1999	27.00	0.493	0.563	0.19	0.068	0.0700	17.18

REGION	Obs	Year	REGION	(1)* Acres harvested (91-95 Avg)	(2)* Acres infested (91-95 Avg)	(3)* Acres treated (91-95 Avg)	(4)* Real Pest. Cost/acre (91-95 Avg)	(5)* Real $ value yield losses $/acre (91-95 Avg.)	(6)* Real cost/appl. Of pesticide
Central Alabama	82	1999	1.00	94000.00	100000.00	100000.00	117.43	123.26	9.07
N. Alabama	83	1999	2.00	232220.00	234580.00	219360.00	61.19	38.05	7.87
S. Alabama	84	1999	3.00	144000.00	150000.00	147000.00	58.64	28.73	9.07
Arizona	85	1999	4.00	389600.00	368680.00	227760.00	0.00	11.28	11.45
NE Arkansas	86	1999	5.00	523000.00	510500.00	388000.00	27.73	8.75	9.54
SE Arkansas	87	1999	6.00	459500.00	459500.00	459500.00	70.34	15.76	10.50
San Joaquin Valley-CA	88	1999	7.00	1149468.00	13260.00	1720.00	0.00	0.00	0.00
Florida	89	1999	8.00	64800.00	65000.00	64800.00	59.27	14.14	8.59
Georgia	90	1999	9.00	769000.00	763000.00	1752500.00	28.87	21.88	9.54
Louisiana	91	1999	10.00	893181.80	885955.00	850975.40	49.20	18.62	12.91
Mississippi Delta	92	1999	11.00	838590.80	817536.60	787876.60	47.84	16.73	12.60
Mississippi Hills	93	1999	12.00	488803.40	480201.40	441037.40	86.76	24.80	12.60
Missouri	94	1999	13.00	333600.00	224336.00	189165.60	13.91	5.09	7.87
New Mexico	95	1999	14.00	66120.00	42710.00	18460.00	3.12	8.28	11.45
N. Carolina	96	1999	15.00	497400.00	504600.00	496160.00	24.38	26.50	7.16
Oklahoma	97	1999	16.00	357000.00	367000.00	208000.00	21.56	5.21	12.41
South Carolina	98	1999	17.00	229400.00	226600.00	218000.00	33.54	14.78	9.31
Tennessee	99	1999	18.00	596000.00	396000.00	232000.00	35.47	14.87	11.19
Texas Coastal Bend	100	1999	19.00	490543.33	455352.67	203045.33	5.99	4.65	8.35
Texas N. Central	101	1999	20.00	165500.00	127833.33	103500.00	3.98	16.81	6.68
Texas N. Rolling Plains	102	1999	21.00	493333.33	435000.00	115333.33	11.21	7.40	10.79
Texas High Plains	103	1999	22.00	3138333.33	1814333.33	536000.00	2.06	3.40	10.26
Texas S. Rolling Plains	104	1999	23.00	198333.33	231666.67	131666.67	11.21	12.64	11.93
Texas Lower Rio Grande	105	1999	24.00	233000.00	303333.33	133333.33	1.83	2.84	6.60
Texas Far West	106	1999	25.00	393391.33	403026.00	210000.00	4.08	8.42	9.54
Texas S. Central	107	1999	26.00	59865.00	55865.00	54198.33	23.85	43.86	9.07
Virginia	108	1999	27.00	42465.60	42500.00	38780.00	15.29	5.74	10.50

REGION	Obs	Year	REGION	(13) * Real Erad. Wt. Cost/acre	(14) P Avg. farm size	(15) * # Pesticide Applications/ total acres (current year)	(16) * Average # Pesticide App. (91-95)
San Joaquin Valley-CA	61	1998	7.00	4.07	226	0.006	0.000
Florida	62	1998	8.00	5.81	273	2.000	5.260
Georgia	63	1998	9.00	4.36	276	1.538	3.740
Louisiana	64	1998	10.00	3.21	276	3.484	4.700
Mississippi Delta	65	1998	11.00	4.77	274	3.130	4.440
Mississippi Hills	66	1998	12.00	22.48	2831	1.547	3.840
Missouri	67	1998	13.00	0.00	162	1.574	0.720
New Mexico	68	1998	14.00	4.78	410	1.900	0.340
N. Carolina	69	1998	15.00	3.49	196	3.045	2.960
Oklahoma	70	1998	16.00	11.87	131	1.500	1.440
S. Carolina	71	1998	17.00	5.57	582	3.438	4.180
Tennessee	72	1998	18.00	3.27	582	2.713	1.180
Texas Coastal Bend	73	1998	19.00	15.02	582	0.220	0.726
Texas N. Central	74	1998	20.00	0.00	582	0.013	1.677
Texas N. Rolling Plains	75	1998	21.00	0.61	582	0.433	0.467
Texas High Plains	76	1998	22.00	0.00	582	0.789	0.233
Texas S. Rolling Plains	77	1998	23.00	30.31	582	0.062	0.767
Texas Lower Rio Grande Valley	78	1998	24.00	0.00	582	0.419	1.200
Texas Far West	79	1998	25.00	0.00	2831	0.340	0.600
Texas S. Central (S. Blacklands)	80	1998	26.00	0.00	192	0.643	3.700
Virginia	81	1998	27.00	3.63	192	2.162	1.300

REGION	Obs	Year	REGION	(7) [p] Real Price Cotton	(8) [p] Lagged Real Price Cotton	(9) [r] Real LDP payments	(10) [r] Real Lagged LDP payments	(11) * Proportion total acreage planted to Bt	(12) * Real cost Bt technology
San Joaquin Valley-CA	61	1998	7.00	0.768	0.718	0.08	0.004	0.0000	31.00
Florida	62	1998	8.00	0.559	0.641	0.08	0.001	0.5375	38.85
Georgia	63	1998	9.00	0.696	0.664	0.09	0.001	0.3077	25.19
Louisiana	64	1998	10.00	0.612	0.637	0.07	0.003	0.2396	31.94
Mississippi Delta	65	1998	11.00	0.654	0.637	0.08	0.005	0.4400	28.10
Mississippi Hills	66	1998	12.00	0.654	0.637	0.08	0.005	0.8200	28.10
Missouri	67	1998	13.00	0.729	0.674	0.06	0.004	0.0006	36.81
New Mexico	68	1998	14.00	0.718	0.566	0.09	0.005	0.0075	31.00
N. Carolina	69	1998	15.00	0.709	0.646	0.07	0.002	0.0619	28.58
Oklahoma	70	1998	16.00	0.635	0.568	0.08	0.003	0.1333	25.19
S. Carolina	71	1998	17.00	0.703	0.688	0.06	0.001	0.1429	24.22
Tennessee	72	1998	18.00	0.656	0.641	0.09	0.008	0.0131	19.38
Texas Coastal Bend	73	1998	19.00	0.600	0.590	0.08	0.002	0.0564	20.59
Texas N. Central	74	1998	20.00	0.600	0.590	0.08	0.002	0.0250	26.93
Texas N. Rolling Plains	75	1998	21.00	0.600	0.590	0.08	0.002	0.0006	19.38
Texas High Plains	76	1998	22.00	0.600	0.590	0.08	0.002	0.0001	22.77
Texas S. Rolling Plains	77	1998	23.00	0.600	0.590	0.08	0.002	0.1471	29.06
Texas Lower Rio Grande Valley	78	1998	24.00	0.600	0.590	0.08	0.002	0.0465	19.38
Texas Far West	79	1998	25.00	0.600	0.590	0.08	0.002	0.0359	22.77
Texas S. Central (S. Blacklands)	80	1998	26.00	0.600	0.590	0.08	0.002	0.4143	19.38
Virginia	81	1998	27.00	0.600	0.662	0.07	0.001	0.0300	27.61

REGION	Obs	Year	REGION	(1)* Acres harvested (91-95 Avg)	(2)* Acres infested (91-95 Avg)	(3)* Acres treated (91-95 Avg)	(4)* Real Pest. Cost/acre (91-95 Avg)	(5)* Real $ value yield losses $/acre (91-95 Avg.)	(6)* Real cost/appl. Of pesticide
San Joaquin Valley-CA	61	1998	7.00	1149468.00	13260.00	1720.00	0.00	0.00	10.66
Florida	62	1998	8.00	64800.00	65000.00	64800.00	59.27	14.14	12.84
Georgia	63	1998	9.00	769000.00	763000.00	1752500.00	28.87	21.88	9.69
Louisiana	64	1998	10.00	893181.80	885955.00	850975.40	49.20	18.62	10.95
Mississippi Delta	65	1998	11.00	838590.80	817536.60	787876.60	47.84	16.73	10.66
Mississippi Hills	66	1998	12.00	488803.40	480201.40	441037.40	86.76	24.80	9.98
Missouri	67	1998	13.00	333600.00	224336.00	189165.60	13.91	5.09	10.41
New Mexico	68	1998	14.00	66120.00	42710.00	18460.00	3.12	8.28	13.08
N. Carolina	69	1998	15.00	497400.00	504600.00	496160.00	24.38	26.50	6.97
Oklahoma	70	1998	16.00	357000.00	367000.00	208000.00	21.56	5.21	18.41
S. Carolina	71	1998	17.00	229400.00	226600.00	218000.00	33.54	14.78	9.20
Tennessee	72	1998	18.00	596000.00	396000.00	232000.00	35.47	14.87	11.99
Texas Coastal Bend	73	1998	19.00	490543.33	455352.67	203045.33	5.99	4.65	8.33
Texas N. Central	74	1998	20.00	165500.00	127833.33	103500.00	3.98	16.81	6.78
Texas N. Rolling Plains	75	1998	21.00	493333.33	435000.00	115333.33	11.21	7.40	10.85
Texas High Plains	76	1998	22.00	3138333.33	1814333.33	536000.00	2.06	3.40	10.41
Texas S. Rolling Plains	77	1998	23.00	198333.33	231666.67	131666.67	11.21	12.64	12.11
Texas Lower Rio Grande Valley	78	1998	24.00	233000.00	303333.33	133333.33	1.83	2.84	10.17
Texas Far West	79	1998	25.00	393391.33	403026.00	210000.00	4.08	8.42	8.19
Texas S. Central (S. Blacklands)	80	1998	26.00	59865.00	55865.00	54198.33	23.85	43.86	6.78
Virginia	81	1998	27.00	42465.60	42500.00	38780.00	15.29	5.74	10.66

REGION	Obs	Year	REGION	(13) * Real Erad. Wt. Cost/acre	(14) p* Avg. farm size	(15) * # Pesticide Applications/ total acres (current year)	(16) * Average # Pesticide App. (91-95)
New Mexico	41	1997	14.00	0.97	161	0.667	0.340
N. Carolina	42	1997	15.00	3.53	410	1.980	2.960
Oklahoma	43	1997	16.00	0.00	200	1.946	1.440
S. Carolina	44	1997	17.00	5.39	132	3.319	4.180
Tennessee	45	1997	18.00	0.29	584	0.346	1.180
Texas Coastal Bend	46	1997	19.00	11.11	584	1.100	0.726
Texas N. Central	47	1997	20.00	0.00	584	0.038	1.677
Texas N. Rolling Plains	48	1997	21.00	3.39	584	0.579	0.467
Texas High Plains	49	1997	22.00	0.00	584	0.494	0.233
Texas S. Rolling Plains	50	1997	23.00	11.08	584	0.722	0.767
Texas Lower Rio Grande Valley	51	1997	24.00	0.00	584	1.250	1.200
Texas Far West	52	1997	25.00	0.00	584	0.110	0.600
Texas S. Central (S. Blacklands)	53	1997	26.00	0.00	180	1.690	3.700
Virginia	54	1997	27.00	3.29	194	1.176	1.300
Central Alabama	55	1998	1.00	6.78	194	1.181	5.920
N. Alabama	56	1998	2.00	7.27	3603	0.519	3.420
S. Alabama	57	1998	3.00	4.84	298	2.320	5.240
Arizona	58	1998	4.00	2.22	298	0.375	1.900
NE Arkansas	59	1998	5.00	0.00	320	2.550	1.950
SE Arkansas	60	1998	6.00	0.00	236	3.977	5.875

REGION	Obs	Year	REGION	(7) [p] Real Price Cotton	(8) [p] Lagged Real Price Cotton	(9) [r] Real LDP payments	(10) [r] Real Lagged LDP payments	(11) * Proportion total acreage planted to Bt	(12) * Real cost Bt technology
New Mexico	41	1997	14.00	0.588	0.743	0.00	0.000	0.0636	33.51
N. Carolina	42	1997	15.00	0.672	0.719	0.00	0.000	0.0303	32.96
Oklahoma	43	1997	16.00	0.590	0.617	0.00	0.000	0.0865	32.37
S. Carolina	44	1997	17.00	0.715	0.617	0.00	0.000	0.3103	32.37
Tennessee	45	1997	18.00	0.666	0.671	0.01	0.000	0.0294	32.86
Texas Coastal Bend	46	1997	19.00	0.613	0.656	0.00	0.000	0.0839	34.97
Texas N. Central	47	1997	20.00	0.613	0.656	0.00	0.000	0.1714	34.97
Texas N. Rolling Plains	48	1997	21.00	0.613	0.656	0.00	0.000	0.0017	34.97
Texas High Plains	49	1997	22.00	0.613	0.656	0.00	0.000	0.0003	34.97
Texas S. Rolling Plains	50	1997	23.00	0.613	0.656	0.00	0.000	0.1714	34.97
Texas Lower Rio Grande Valley	51	1997	24.00	0.613	0.656	0.00	0.000	0.0561	34.97
Texas Far West	52	1997	25.00	0.613	0.656	0.00	0.000	0.1649	34.97
Texas S. Central (S. Blacklands)	53	1997	26.00	0.613	0.656	0.00	0.000	0.7756	34.97
Virginia	54	1997	27.00	0.688	0.710	0.00	0.000	0.0020	39.23
Central Alabama	55	1998	1.00	0.649	0.660	0.08	0.085	0.7250	30.03
N. Alabama	56	1998	2.00	0.649	0.660	0.08	0.085	0.7514	30.03
S. Alabama	57	1998	3.00	0.649	0.660	0.08	0.085	0.8667	25.19
Arizona	58	1998	4.00	0.673	0.635	0.09	0.006	0.7120	39.72
NE Arkansas	59	1998	5.00	0.673	0.644	0.08	0.004	0.0117	32.94
SE Arkansas	60	1998	6.00	0.673	0.644	0.08	0.004	0.4415	32.94

REGION	Obs	Year	REGION	(1)* Acres harvested (91-95 Avg)	(2)* Acres infested (91-95 Avg)	(3)* Acres treated (91-95 Avg)	(4)* Real Pest. Cost/acre (91-95 Avg)	(5)* Real $ value yield losses $/acre (91-95 Avg.)	(6)* Real cost/appl. Of pesticide
New Mexico	41	1997	14.00	66120.00	42710.00	18460.00	3.12	8.28	13.24
N. Carolina	42	1997	15.00	497400.00	504600.00	496160.00	24.38	26.50	8.58
Oklahoma	43	1997	16.00	357000.00	367000.00	208000.00	21.56	5.21	11.77
S. Carolina	44	1997	17.00	229400.00	226600.00	218000.00	33.54	14.78	9.81
Tennessee	45	1997	18.00	596000.00	396000.00	232000.00	35.47	14.87	10.50
Texas Coastal Bend	46	1997	19.00	490543.33	455352.67	203045.33	5.99	4.65	8.61
Texas N. Central	47	1997	20.00	165500.00	127833.33	103500.00	3.98	16.81	6.87
Texas N. Rolling Plains	48	1997	21.00	493333.33	435000.00	115333.33	11.21	7.40	10.79
Texas High Plains	49	1997	22.00	3138333.33	1814333.33	536000.00	2.06	3.40	10.54
Texas S. Rolling Plains	50	1997	23.00	198333.33	231666.67	131666.67	11.21	12.64	9.81
Texas Lower Rio Grande Valley	51	1997	24.00	233000.00	303333.33	133333.33	1.83	2.84	9.81
Texas Far West	52	1997	25.00	393391.33	403026.00	210000.00	4.08	8.42	13.24
Texas S. Central (S. Blacklands)	53	1997	26.00	59865.00	55865.00	54198.33	23.85	43.86	6.38
Virginia	54	1997	27.00	42465.60	42500.00	38780.00	15.29	5.74	11.77
Central Alabama	55	1998	1.00	94000.00	100000.00	100000.00	117.43	123.26	10.66
N. Alabama	56	1998	2.00	232220.00	234580.00	219360.00	61.19	38.05	8.23
S. Alabama	57	1998	3.00	144000.00	150000.00	147000.00	58.64	28.73	9.69
Arizona	58	1998	4.00	389600.00	368680.00	227760.00	0.00	11.28	15.42
NE Arkansas	59	1998	5.00	523000.00	510500.00	388000.00	27.73	8.75	10.17
SE Arkansas	60	1998	6.00	459500.00	459500.00	459500.00	70.34	15.76	13.49

REGION	Obs	Year	REGION	(13) * Real Erad. Wt. Cost/acre	(14) [P] Avg. farm size	(15) * # Pesticide Applications/ total acres (current year)	(16) * Average # Pesticide App. (91-95)
TX Rolling Plains	21	1996	21.00	0.00	589	0.458	0.467
TX High Plains	22	1996	22.00	4.62	589	0.584	0.233
TX S. Rolling Plains	23	1996	23.00	8.00	589	0.645	0.767
TX Lower Rio Grande Valley	24	1996	24.00	0.00	589	0.050	1.200
TX Far West	25	1996	25.00	0.00	589	0.603	0.600
TX S. Central (S. Blacklands)	26	1996	26.00	0.00	589	2.328	3.700
Virginia	27	1996	27.00	3.80	180	1.000	1.300
Central Alabama	28	1997	1.00	18.88	196	0.156	5.920
N. Alabama	29	1997	2.00	10.10	196	0.560	3.420
S. Alabama	30	1997	3.00	4.90	3582	1.000	5.240
Arizona	31	1997	4.00	1.76	302	0.912	1.900
NE Arkansas	32	1997	5.00	0.03	302	0.845	1.950
SE Arkansas	33	1997	6.00	0.03	330	2.836	5.875
San Joaquin Valley-CA	34	1997	7.00	0.33	236	0.000	0.000
Florida	35	1997	8.00	4.90	231	0.952	5.260
Georgia	36	1997	9.00	4.90	273	2.530	3.740
Louisiana	37	1997	10.00	1.14	279	3.225	4.700
Mississippi Delta	38	1997	11.00	8.16	279	3.206	4.440
Mississippi Hills	39	1997	12.00	8.16	274	1.333	3.840
Missouri	40	1997	13.00	0.00	2923	0.708	0.720

REGION	Obs	Year	REGION	(7) [p*] Real Price Cotton	(8) [p*] Lagged Real Price Cotton	(9) [f*] Real LDP payments	(10) [f*] Real Lagged LDP payments	(11) * Proportion total acreage planted to Bt	(12) * Real cost Bt technology
TX Rolling Plains	21	1996	21.00	0.656	0.760	0.00	0.000	0.0002	36.00
TX High Plains	22	1996	22.00	0.656	0.760	0.00	0.000	0.0001	40.00
TX S. Rolling Plains	23	1996	23.00	0.656	0.760	0.00	0.000	0.0806	37.00
TX Lower Rio Grande Valley	24	1996	24.00	0.656	0.760	0.00	0.000	0.0500	32.00
TX Far West	25	1996	25.00	0.656	0.760	0.00	0.000	0.0348	40.00
TX S. Central (S. Blacklands)	26	1996	26.00	0.656	0.760	0.00	0.000	0.2143	32.00
Virginia	27	1996	27.00	0.710	0.744	0.00	0.000	0.0000	32.00
Central Alabama	28	1997	1.00	0.686	0.709	0.09	0.000	0.8501	32.86
N. Alabama	29	1997	2.00	0.686	0.709	0.09	0.000	0.7800	32.86
S. Alabama	30	1997	3.00	0.686	0.709	0.09	0.000	0.5854	32.86
Arizona	31	1997	4.00	0.660	0.697	0.01	0.000	0.6078	33.04
NE Arkansas	32	1997	5.00	0.670	0.707	0.00	0.000	0.0042	32.56
SE Arkansas	33	1997	6.00	0.670	0.707	0.00	0.000	0.3123	32.56
San Joaquin Valley-CA	34	1997	7.00	0.746	0.765	0.00	0.000	0.0000	0.00
Florida	35	1997	8.00	0.667	0.686	0.00	0.000	0.6000	41.20
Georgia	36	1997	9.00	0.690	0.705	0.00	0.000	0.3833	32.37
Louisiana	37	1997	10.00	0.662	0.655	0.00	0.000	0.3814	32.74
Mississippi Delta	38	1997	11.00	0.662	0.680	0.00	0.000	0.3149	32.86
Mississippi Hills	39	1997	12.00	0.662	0.680	0.00	0.000	0.6370	32.86
Missouri	40	1997	13.00	0.700	0.685	0.00	0.000	0.0100	39.23

REGION	Obs	Year	REGION	(1)* Acres harvested (91-95 Avg)	(2)* Acres infested (91-95 Avg)	(3)* Acres treated (91-95 Avg)	(4)* Real Pest. Cost/acre (91-95 Avg)	(5)* Real $ value yield losses $/acre (91-95 Avg.)	(6)* Real cost/appl. Of pesticide
TX Rolling Plains	21	1996	21.00	493333.33	435000.00	115333.33	5.05	7.40	11.02
TX High Plains	22	1996	22.00	3138333.33	1814333.33	536000.00	2.32	3.40	11.50
TX S. Rolling Plains	23	1996	23.00	198333.33	231666.67	131666.67	6.80	12.64	11.00
TX Lower Rio Grande Valley	24	1996	24.00	233000.00	303333.33	133333.33	13.12	2.84	9.00
TX Far West	25	1996	25.00	393391.33	403026.00	210000.00	6.03	8.42	10.00
TX S. Central (S. Blacklands)	26	1996	26.00	59865.00	55865.00	54198.33	35.90	43.86	8.50
Virginia	27	1996	27.00	42465.60	42500.00	38780.00	14.37	5.74	11.00
Central Alabama	28	1997	1.00	94000.00	100000.00	100000.00	117.43	123.26	8.83
N. Alabama	29	1997	2.00	232220.00	234580.00	219360.00	61.19	38.05	8.83
S. Alabama	30	1997	3.00	144000.00	150000.00	147000.00	58.64	28.73	8.83
Arizona	31	1997	4.00	389600.00	368680.00	227760.00	0.00	11.28	11.82
NE Arkansas	32	1997	5.00	523000.00	510500.00	388000.00	27.73	8.75	8.19
SE Arkansas	33	1997	6.00	459500.00	459500.00	459500.00	70.34	15.76	10.12
San Joaquin Valley-CA	34	1997	7.00	1149468.00	13260.00	1720.00	0.00	0.00	0.00
Florida	35	1997	8.00	64800.00	65000.00	64800.00	59.27	14.14	10.54
Georgia	36	1997	9.00	769000.00	763000.00	1752500.00	28.87	21.88	9.81
Louisiana	37	1997	10.00	893181.80	885955.00	850975.40	49.20	18.62	10.07
Mississippi Delta	38	1997	11.00	838590.80	817536.60	787876.60	47.84	16.73	9.66
Mississippi Hills	39	1997	12.00	488803.40	480201.40	441037.40	86.76	24.80	8.85
Missouri	40	1997	13.00	333600.00	224336.00	189165.60	13.91	5.09	8.36

REGION	Obs	Year	REGION	(13) * Real Erad. Wt. Cost/acre	(14) [p] Avg. farm size	(15) * # Pesticide Applications/ total acres (current year)	(16) * Average # Pesticide App. (91-95)
C. Alabama	1	1996	1.00	27.50	198	0.021	5.920
N. Alabama	2	1996	2.00	0.00	198	0.179	3.420
S. Alabama	3	1996	3.00	8.00	198	0.128	5.240
Arizona	4	1996	4.00	1.79	3582	1.728	1.900
NE Arkansas	5	1996	5.00	0.00	301	1.495	1.950
SE Arkansas	6	1996	6.00	0.00	301	3.500	5.875
San Joaquin Valley-CA	7	1996	7.00	0.00	337	0.000	0.000
Florida	8	1996	8.00	5.00	238	1.080	5.260
Georgia	9	1996	9.00	5.50	238	1.673	3.740
Louisiana	10	1996	10.00	0.00	277	3.854	4.700
Mississippi Delta	11	1996	11.00	0.00	283	2.504	4.440
Mississippi Hills	12	1996	12.00	0.00	283	1.511	3.840
Missouri	13	1996	13.00	0.00	274	0.140	0.720
New Mexico	14	1996	14.00	0.00	2910	0.334	0.340
North Carolina	15	1996	15.00	3.85	161	3.070	2.960
Oklahoma	16	1996	16.00	0.00	415	1.731	1.440
South Carolina	17	1996	17.00	4.50	200	4.190	4.180
Tennessee	18	1996	18.00	0.00	132	0.215	1.180
Texas Coastal Bend	19	1996	19.00	0.00	589	0.400	0.726
Texas North Central	20	1996	20.00	0.00	589	1.417	1.677

REGION	Obs	Year	REGION	(7) p* 3 Real Price Cotton	(8) p* Lagged Real Price Cotton	(9) f* 4 Real LDP payments	(10) f* Real Lagged LDP payments	(11) * Proportion total acreage planted to Bt	(12) * Real cost Bt technology
C. Alabama	1	1996	1.00	0.709	0.743	0.00	0.000	0.9168	34.00
N. Alabama	2	1996	2.00	0.709	0.743	0.00	0.000	0.8500	34.00
S. Alabama	3	1996	3.00	0.709	0.743	0.00	0.000	0.6300	34.00
Arizona	4	1996	4.00	0.697	0.743	0.00	0.000	0.2315	33.68
NE Arkansas	5	1996	5.00	0.707	0.748	0.00	0.000	0.0108	41.36
SE Arkansas	6	1996	6.00	0.707	0.748	0.00	0.000	0.3775	39.82
San Joaquin Valley	7	1996	7.00	0.765	0.837	0.00	0.000	0.0000	32.00
Florida	8	1996	8.00	0.686	0.815	0.00	0.000	0.4300	32.00
Georgia	9	1996	9.00	0.705	0.781	0.00	0.000	0.2974	33.00
Louisiana	10	1996	10.00	0.655	0.746	0.00	0.000	0.1491	33.00
Mississippi Delta	11	1996	11.00	0.680	0.748	0.00	0.000	0.3000	33.00
Mississippi Hills	12	1996	12.00	0.680	0.748	0.00	0.000	0.5509	33.00
Missouri	13	1996	13.00	0.685	0.715	0.00	0.000	0.0005	38.00
New Mexico	14	1996	14.00	0.743	0.833	0.00	0.000	0.0061	32.00
North Carolina	15	1996	15.00	0.719	0.798	0.00	0.000	0.0601	33.45
Oklahoma	16	1996	16.00	0.617	0.749	0.00	0.000	0.0615	36.40
South Carolina	17	1996	17.00	0.617	0.812	0.00	0.000	0.1379	38.00
Tennessee	18	1996	18.00	0.671	0.765	0.00	0.000	0.0110	34.00
Texas Coastal Bend	19	1996	19.00	0.656	0.760	0.00	0.000	0.0612	33.20
Texas North Central	20	1996	20.00	0.656	0.760	0.00	0.000	0.0667	33.75

[3] All data in columns marked with a lowercase p and one (1) asterisk were obtained from the Published Estimates Database of the USDA National Agricultural Statistics Service.
HTTP: http://www.nass.usda.gov:81/ipedb, downloaded 2/2001.

[4] All data in columns marked with a lowercase f and one (1) asterisk were obtained from *the LDP / Loan / Market Gain Activity Tables* of the Price Supports Division of the USDA Farm Service Agency.
HTTP: http://www.fsa.usda.gov/dafp/psd/reports.htm,downloaded 2/2001.

APPENDIX B: DATA USED IN CALCULATIONS

Implicit price deflator	
1991	89.66
1992	91.84
1993	94.05
1994	96.01
1995	98.1
1996	100
1997	101.95
1998	103.22
1999	104.77
2000	106.92

Source: U.S. Department of Commerce Bureau of Economic Analysis
"Table 7.1. Quantity and Price Indexes for Gross Domestic Product."
Available:www.bea.doc.gov/bea/dn/nipaweb/TableViewFixed.asp?SelectedTable=144&FirstYear=1995&LastYear=2000 &Freq=Annual
Accessed 4/2001

Pre-1995 Texas Districts and Corresponding post-1995 CIL Regions	
District #	Cotton Crop Loss Region
9,11	Texas, Coastal Bend
6	Texas, Far West
1,2	Texas, High Plains
12	Texas, Lower Rio Grande
4,5,8	Texas, North Central

Source: Eddleman, et al. (1995)

REFERENCES

Amemiya, Takeshi. "Non Linear Regression Models." *Handbook of Econometrics, Volume 1.* Intrilligator, Michael D. and Zvi Grilliches, eds. 1983.

Benson, M.A.W.H. Hendrix III. "Economics of Tracer/Karate Z Conventional Cotton Program vs. Bt Cotton." *Proceedings of the Beltwide Cotton Conference*, vol. 2:1143-1145 (1999).

Bryant, Kelly J., William C. Robertson, and Gus M. Lorenz III. "Economic Evaluation of Bollguard Cotton in Arkansas, " *Proceedings of the Beltwide Cotton Conference, vol.*1:349-350 (1999).

____________. "Economic Evaluation of Bollguard Cotton in Arkansas: 1997." *Proceedings of the Beltwide Cotton Conference,* vol.1: 388-389(1998).

___________. "Economic Evaluation of Bollguard Cotton in Arkansas: 1996." *Proceedings of the Beltwide Cotton Conference*, vol.1: 358-359(1997).

Carlson, G.A, Michelle C. Marra and Bryan J. Hubbell. "Yield, Insecticide Use, and Profit Changes from Adoption of Bt Cotton in the Southeast." Proceedings of the Beltwide Cotton Conference, vol. 2:973-974 (1998).

Carpenter, Janet E., and Leonard P. Gianessi. "Agricultural Biotechnology: Updated Benefit estimates." National Center for Food and Agricultural Policy, January 2001. Available: www.ncfap.org. Accessed 2/01.

Caswell, Margaret, Keith Fuglie, Cassandra Ingram, Sharon Jans, and Catherine Kascak. "Adoption of Agricultural Production Practices: Lessons Learned from the U.S. Department of Agriculture Area Studies Project." ERS Agricultural Economic Report No. 792. January 2001.

Day, Kelly and Cassandra Klotz-Ingram. "Agricultural Technology Development." *Agricultural Resources and Environmental Indicators, 1996-1997.* Margot Anderson and Richard Magleby, eds. U.S. Department of Agriculture Economic Research Service Agricultural Handbook No.712 July 1997. Available: http://www.ers.usda.gov/publications/ah712/AH7125-1.PDF.

Dixon, Robert. "Hybrid Corn Revisited." *Econometrica* 48(September 1980):1451-61.

Eddleman, B.R., D. Dearmont, Q. He, and Bruce A. McCarl. "Potential Economic Benefits to Society From Bt Cotton." Cotton Economics and Marketing Conference.1995 Beltwide Cotton Conferences.

Edge, Julie M., John H Benedict, John P.Carroll, and H. Keith Reding. "Bollgard Cotton: An Assessment of Global Economic, Environmental and Social Benefits." *Journal of Cotton Science* 5(2001):121-136.

Farm Service Agency Price Support Division. *Up to Date Summary Reports (unofficial) National LDP / Loan / Market Gain Activity* (1999). Available http://www.fsa.usda.gov/dafp/psd/reports.htm. Accessed 2/2001.

Feder, Gershon, Richard E. Just, and David Zilberman. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change* 33(January 1985):255-98.

Fernandez-Cornejo, Jorge and William D. McBride. *Genetically Engineered Crops for Pest Management in U.S. Agriculture Farm-Level Effects.* Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economics Report No. 786, April 2000.

Frisvold, George, Russell Tronstad, and Jorgen Mortenson. "Economics of Bt Cotton." 2000. Available: http://ag.arizona.edu/arec/ext/btcotton/display.html.

Gibson IV, Joe W., David Laughlin, Randy G Luttrell, Don Parker, Jack Reed, and Aubrey Harris. "Comparison of Costs and Returns Associated with Heliothis Resistant Bt Cotton to Non-Resistant Varieties." *Proceedings of the Beltwide Cotton Conference*, vol 1:244-247(1997).

Greene, William H. *Econometric Analysis.* 4th Edition, Upper Saddle River, N.J.: Prentice Hall, 2000.

Griffiths, William E., R. Carter Hill, and George G. Judge. *Learning and Practicing Econometrics*. New York+: John Wiley & Sons. 1993.

Griliches, Zvi. "Hybrid Corn and the Economics of Innovation." *Science, New Series* 132 (July 29, 1960): 275-280.

___________. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25 (October 1957):501-22.

___________. "Hybrid Corn Revisited, A Reply." *Econometrica* 48(September 1980): 1463-65.

Gruber, Harald and Frank Verboven. "The Diffusion of Mobile Telecommunications Services in the European Union." *European Economic Review* 45(2001):577-588.

Hayashi, Fumio. *Econometrics*, Princeton and Oxford: Princeton University Press, 2000.

International Cotton Advisory Committee. *Report of an Expert Panel on Biotechnology in Cotton*. November, 2000. Available: http://www.icac.org/icac/meetings/plenary/59cairns/documents/e_biotech.pdf. Accessed 2/2001.

Jarvis, Lovell S. "Predicting the Diffusion of Improved Pastures in Uruguay." *American Journal of Agricultural Economics* 63(August 1981):495-502.

Kennedy, Peter. *A Guide to Econometrics* 4th Edition. Cambridge, Massachusetts: MIT Press, 1998.

Klotz-Ingram, C., Sharon Jans, Jorge Fernandez-Cornejo, and W. McBride. "Farm-Level Production Effects Related to the Adoption of Genetically Modified Cotton for Pest Management." *AgBioForum* 2(2):73-84. Available: http://www.agbioforum.missouri.edu. Accessed 3/01.

Knudson, Mary. "Incorporating Technological Change in Diffusion Models." *American Journal of Agricultural Economics* 73(August 1991):724-733.

Layton, M.B., M.R Williams, J.L. Long. "Performance of Bt Cotton In Mississippi, 2000." *Proceedings of the Beltwide Cotton Conference*, vol 2:847-849 (2001).

__________. "Performance of Bt Cotton In Mississippi,1999." *Proceedings of the Beltwide Cotton Conference*, vol. 2:1037-1039 (2000).

Layton, M.B., S.D. Stewart, M.R Williams, J.L. Long. "Performance of Bt Cotton In Mississippi, 1998." *Proceedings of the Beltwide Cotton Conference*, vol 2: 942-945x-x (1999).

Layton, M.B, S.D. Stewart, M.R Williams, and J.T. Reed. "Performance of Bt Cotton In Mississippi, 1997." *Proceedings of the Beltwide Cotton Conference*, vol. 2:970-973 (1998).

Lesser, W., John Bernard, and Kaafee Billah. "Methodologies for Ex Ante Projections of Adoption rates for Agbiotech Products: Lessons learned from rBST." *Agribusiness* 15(2):149-152.

Mansfield, Edwin. "Technical Change and the Rate of Imitation." *Econometrica* 29(October 1961):741-766.

Monsanto. *Environmental Benefits of Crops Developed through Biotechnology.* Available:http://www.monsanto.com/monsanto/biotechnology/background_information/00mar22bt.html. Accessed 3/01.

Nelson, Jeannie, Sukant K. Misra, and Alan Breshears. "Economics and Marketing Costs Associated with Alternative Cotton Stripper-Harvesting Systems in Texas." Journal of Cotton Science 4:70-78 (2000).

Oppenhuizen, Mark J., J. Walt Mullins, and Jane M. Mills. "Six Years of Economic Comparisons of Bollgard Cotton." *Proceedings of the Beltwide Cotton Conference*, vol.2:862-865 (2001).

Padgitt, Merritt, Doris Newton, Renata Penn, and Carmen Sandretto. *Production Practices for Major Crops in U.S. Agriculture, 1990-97*. Statistical Bulletin No. 969 U.S. Department of Agriculture Economic Research Service, Washington DC., September 2000.

Pemberton, Earl H. "The Curve of Cultural Diffusion Rate." *American Sociological Review* 1(August 1936):547-556.

Rogers, Everett M. *Diffusion of Innovations*. 4th Edition, New York : Free Press, 1995.

Ryan, Bruce and Neal C. Gross. "The Diffusion of Hybrid Seed Corn In Two Iowa Communities." *Rural Sociology* 8(1943):15-24.

Schimmelpfennig, David., Jan Lewandrowski, John Reilly, Marinos Tsigas, Ian Parry, Roy Darwin, Zhuang Li , Robert Mendelsohn, and Tim Mount. "Agricultural Biotechnology: An Economic Perspective", U.S. Department of Agriculture, ERS Agricultural Economics Report no. 687, May 1994.

Stark, Robert C. "Economics of Transgenic Cotton: Some Indicators Based on Georgia Producers." *Proceedings of the Beltwide Cotton Conference*, vol.1:251-253 (1997).

Stewart, Scott, Jack Reed, Randall Lutrell, and F. Aubrey Harris. "Cotton Insect Control Strategy Project: Comparing Bt and Conventional Cotton Management and Plant bug Control Strategies at Five Locations in Mississippi, 1995-1997." *Proceedings of the Beltwide Cotton Conference*, vol 2:1199-1203 (1998).

Sunding, David, and David Zilberman. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." Handbook of Agricultural Economics. Bruce L. Gardner and Gordon C. Rausser, eds. Forthcoming. Available:http://www.are.berkeley.edu/~zilber/innovationchptr.pdf. Accessed 2001.

U.S. Department of Agriculture National Agricultural Statistics Service. *Published Estimates Database*. Available http://www.nass.usda.gov:81/ipedb/. 1995-1999. Available: http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/agch0396.txt. Accessed 3/01.

U.S. Department of Agriculture National Agricultural Statistics Service. *Agricultural Chemical Usage, Field Crop Summary 1995*. Issued March 25(1996).

U.S. Department of Agriculture Economic Research Service Natural Resources and Environment Division. *Pest Management on Major Field Crops.* Updates on Agricultural Resources and Environmental Indicators. Feburary 1997. Available http://www.ers.usda.gov/publications/arei/97upd/upd97-1.pdf. Accessed 3/01.

Williams, Michael.R., Cotton Insect Losses (1995-1999). Mississippi State University, Available http://www.msstate.edu/Entomology/Cotton.html. Accessed 8/00.