COMPLEMENTARY TECHNOLOGIES: HERBICIDE TOLERANT COTTON AND CONSERVATION TILLAGE

by

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ABSTRACT

When considered together, conservation tillage and herbicide-tolerant (HT) cotton seem to increase potential environmental benefits while decreasing certain costs to producers. This study tests the hypotheses that the diffusion of conservation tillage positively influences the diffusion of HT cotton and vice versa.

To test the hypotheses, state-level data HT cotton diffusion and conservation tillage diffusion were estimated using both ordinary least squares, two-stage least squares and simultaneous equation estimation techniques. To determine the quantitative effects of one technology's diffusion on the other, elasticities of the diffusion of HT cotton with respect to conservation tillage and vice versa were calculated.

Based, on results from a three-stage least squares model, the null hypothesis that diffusion of each technology is independent of diffusion of the other can be rejected. Adoption of one technology appears to have a significant, positive effect on the adoption of the other technology. The calculated mean elasticities indicate that a one-percent increase in the diffusion of HT cotton increases conservation tillage diffusion by 0.48 percent. Similarly, a one-percent increase in the adoption of conservation tillage increases adoption of HT cotton by 0.16 percent.

CHAPTER 1: INTRODUCTION

The objective of this study is to examine the diffusion of two agricultural technologies, conservation tillage and herbicide-tolerant (HT) cotton, among sixteen cotton-producing states and to determine the extent to which each technology's diffusion influences the other. This introduction provides definitions and discusses the relevance of conservation tillage and HT cotton.

1.1 What is Conservation Tillage?

Farmers employ conventional tillage as a means of controlling weeds and preparing soil for future plantings. Conventional tillage involves plowing or intensive tillage of the soil before planting that leaves less than fifteen percent of the surface residue from the previous season's crop on the soil surface. Conventional tillage was standard operating procedure before farmers had access to effective weed and pest control strategies (EPA, 2005). Concerns over soil erosion led to the development of crop management practices that left soil residues on the soil surface. Soil erosion decreases soil structure and fertility. Water and air quality are also affected by the degradation of the topsoil. The United States Department of Agriculture's National Resources Conservation Service (NRCS) reports that the national state average of erosion is 3.1 tons of cropland per acre per year (NRCS, 2000). Of the sixteen cotton-producing states included in this study, eight of those are above the national average: Alabama, Arkansas, Georgia, Mississippi, Missouri, North Carolina, Tennessee, and Virginia. The other eight states below the national average are: Arizona, California, Florida, Louisiana, New Mexico, Oklahoma, South Carolina, and Texas (NCRS, 2000). Developed to combat this problem, conservation tillage is any planting or tillage system leaving more than thirty percent of crop residue on the soil surface before planting.

Three different types of conservation tillage exist: no till, ridge till, and mulch till (Fawcett and Towery, 2002). Reduced till is a soil conservation technique leaving between fifteen to thirty percent of the soil residue on the surface; however, it is not classified as conservation tillage. No-till involves no cultivation of the soil from planting to harvest except for seed and nutrient injection. Weed control is achieved primarily by herbicides. The actual planting and injection of nutrients is accomplished in narrow seedbeds by row cleaners, coulters, disk openers, in-row chisels, or rotary chisels. Similar to no till, the ridge till method does not disturb the soil surface from planting to harvest. Planting occurs in seedbeds that are planted on ridges created by row cleaners, sweeps, disk openers, or coulters. Weeds are controlled with herbicides, mechanical cultivation, or both. With mulch till, the soil is disturbed prior to planting. Mulch till uses tillage tools including chisels, blades, sweeps, disks, and blades. Herbicides and/or mechanical cultivation control weeds.

1.2 What are the potential environmental benefits/tradeoffs of conservation tillage?

One of the environmental benefits of implementing conservation tillage is a reduction in soil erosion (CTIC, 2002). Leaving crop residue on the soil surface protects the topsoil against wind and water erosion. Soil erosion worsens soil structure and water quality. The EPA found in 1998 that sediments from agriculture rank as the leading water pollutants in rivers and streams and the third highest pollutants in lakes, ponds, and reservoirs (EPA, 1998). Leaving crop residue on the soil surface increases water infiltration of the fields, reducing the amount of runoff and decreasing flooding potential. This prevents sediments from running into waterways and harming aquatic habitat and species.

Crop residues provide habitat for organisms like spiders, beetles, and earthworms, and a food source for birds and other mammals. Spiders and beetles act as beneficial predators for crops while earthworms improve the soil quality by aerating soil, contributing organic residues to the soil, and improving water infiltration.

Other environmental benefits of conservation tillage accrue from the reduced hours of machine time spent on the fields. The decreased machinery usage means fewer air pollutants like exhaust, dust, and debris released into the air and less fuel consumption. For every gallon of diesel fuel saved, 3.72 lbs. of CO_2 are not released (Fawcett and Towery, 2002). Tillage also increases soil compaction and the amount of oxygen available in the soil. Oxygen speeds the decomposition process that releases carbon dioxide, a gas that contributes to global warming, into the air.

One of the environmental drawbacks to implementing conservation tillage is the possibility of increased use of herbicides and insecticides. Herbicides and insecticides harm vegetation surrounding the crops and other organisms if the chemicals drift from their initial point of application.

Whether herbicide or pesticide usage increases depends on tillage system, crop type, and climate, among other factors. A study by the USDA’s Economic Research

Service examined the herbicide and insecticide use of a conventional tillage system compared to a conservation tillage system (ERS, 2001). The results show herbicide use increased with the conservation tillage system, but insecticide use decreased. The study also found that ridge till used less herbicide than conventional tillage.

1.3 What are the economic benefits/tradeoffs of conservation tillage?

The economic benefits of employing conservation tillage are savings due to decreased use of machinery, fuel, and labor to cultivate fields. These savings range from $20 to $40 per acre (ERS, 2001). No-till reduces fuel consumption 3.5 to 5.7 gallons/acre. The amount reduced depends on the number of tillage trips over field, clay, moisture content of soil, and the type of tillage operations eliminated (Fawcett and Towery, 2002). Operators no longer have to invest time in the spring and fall tilling the soil; they move directly to planting. The decreased number of passes on the field translates into direct labor cost or time savings. The time can be spent expanding the farm operation by adding more acres, adding other farming operations, or earning off-farm income (ERS, 2001). Also, farmers benefit because smaller tractors are needed to pull the conservation tillage machinery when compared to conventional plows. The smaller machinery wears less on tractors decreasing machinery expense.

Producers must make a substantial investment in new machinery to practice conservation tillage. The cost of new machinery is not trivial. The Pennsylvania Five Acre Corn Club published a study comparing the fixed machinery costs of conventional and no-till tillage per acre from 1990 to 1994. The fixed cost for conventional machinery per acre was calculated as $43.99 per acre and no-till was $23.89 (Harper, 1996). The cost of no-till machinery is added to that of conventional tillage machinery unless the farmer converts entirely to no-till tillage. Conservation tillage also requires more intensive farm management to combat problems with weed, insects, and diseases that large-acreage farmers may find too costly when deciding to either stray from the uniform planting systems or to adopt the new technology (CTIC, 2002).

The soil may need time to regain improved structure and infiltration when the switch from conventional to conservation tillage is made. Depending on soil and weather conditions, this period could require substantial or little investment. Yield losses are associated with this transition period and provide a barrier to adoption (CTIC, 2002). Crop yields increase or remain the same depending on site-specific soil characteristics such as climate, cropping patterns, and management skill (ERS, 2001). Conservation tillage also retains more moisture in the topsoil that creates problems at planting time if the soil is too wet or cold. Planting in an untimely manner can decrease yields; planting in wet soil can cause soil compaction that may take time and ripping of the soil to correct.

1.4 What is herbicide-tolerant cotton?

Introduced in 1997, herbicide-tolerant (HT) cotton has been engineered to resist the herbicide glyphosate, commercially known as Roundup®, which kills many types and sizes of weeds. Normally, glyphosate would damage the cotton crop along with the weeds, but a gene that provides herbicide tolerance prevents the cotton plant from being harmed.

The expected benefits of adopting HT Cotton are increased yields, lower production costs and decreased risk. Better weed management may result in greater yields as crops are undamaged. Less labor and machinery inputs may be needed as a result of fewer pesticide applications translating to decreased costs. The less expensive glyphosate can be substituted for more expensive types of herbicides resulting in lower production costs. HT cotton may require a reduced number of sprays as well. Other herbicides require precise application timing, but using glyphosate widens the spraying window because it controls weeds of all sizes. The expanded spraying time frame reduces risk if spraying is not possible at precise times due to inclement weather or wet fields. (Kalaitzandonakes and Suntornpithug, 2003).

1.5 Study Objective: Did the introduction of HT cotton increase conservation tillage diffusion?

When considered together, conservation tillage and HT cotton seem to increase potential environmental benefits while decreasing certain costs to producers. Conservation tillage reduces soil erosion and air pollution, both of which are serious environmental concerns. But, it also requires heavy to entire reliance on herbicides to control weeds. HT cotton facilitates weed control as it relies solely on glyphosate. HT cotton requires fewer herbicide applications than other cotton seed. One study found that U.S. cotton producers decreased the herbicide active ingredient used from 2.1 lbs/acre in 1997 to 1.8 lbs/acre in 2000 due to genetically modified cotton seed (Carpenter et al., 2002). This is an important aspect when considering herbicide applications potentially increase with conservation tillage.

Past studies have suggested that complementary technologies will be adopted as bundles rather than separately. The Conservation Technology Information Center (CTIC) published a paper based on a survey of producers suggesting that the introduction of herbicide-tolerant crops increases adoption of conservation tillage from the results of surveying producers (Fawcett and Towery, 2002). CTIC is a non-profit organization that receives public and private funds to promote soil and water quality while providing agricultural producers with affordable strategies to accomplish this goal. Kalaitzandonakes and Suntornpithug (2003) also used survey data and estimated the simultaneous adoption of genetically engineered crops and minimum tillage using simultaneous equations. The variables are based on producers' perceptions of the technologies' profitability.

This study will test the hypotheses that the diffusion of conservation tillage positively influences the diffusion of HT cotton and vice versa. If this is indeed the case, I will be able to determine if the diffusion of HT cotton increases the diffusion rate for conservation tillage. To do so, I will use a simultaneous equation model to estimate the diffusion of conservation tillage and HT cotton. The calculated marginal effects will measure the actual extent to which the diffusion of one technology influences the other. This study departs from the existing literature as I will model the diffusion of these technologies as functions of state-specific explanatory variables like input and output prices and climate and land conditions, among others that contribute to the decision making of cotton producers.

Understanding the diffusion relationship between these technologies enables agricultural economists and farm-policy makers to improve social welfare. Government agencies spend money on farm program payments, educational programs and publications. These activities are designed to promote conservation tillage to improve the environment yet they contribute to social costs. When used together, the two technologies seem to increase social benefits through environmental quality improvement. A government agency must understand the rate and determinants of the diffusion of conservation tillage in order to increase the use of these technologies and to create efficient programs. If it can be determined that HT cotton leads to quicker diffusion of conservation tillage, farm and educational programs can be tailored accordingly.

Agricultural research firms can also apply knowledge of the rate and determinants of diffusion of both technologies towards marketing them more efficiently. The information can motivate future research and development of new technologies for cotton.

The environmental drawback to conservation tillage is increased dependency on herbicides. Is controlling soil erosion more important than controlling the levels of herbicides used? Establishing a positive relationship between conservation tillage and HT cotton would suggest that controlling soil erosion and herbicide usage are both important aspects of cotton production.

1.6 Organization of Thesis

The five remaining chapters of this thesis are organized in the following way. Chapter 2 presents the existing literature of agricultural technologies diffusion studies and microeconomic adoption of conservation tillage and HT cotton studies. Chapter 3 presents the observed diffusion patterns for conservation tillage and HT cotton and defines the diffusion model and the different types. Chapter 4 describes the econometric modeling employed in the study. Chapter 5 defines the data and variable calculations. Chapter 6 presents the estimation of the models and discusses results and conclusions of the study.

CHAPTER 2: LITERATURE REVIEW

As stated in the first chapter, the objective of this study is to model the diffusion of conservation tillage and HT cotton as functions of economic variables. At the outset, this chapter introduces the literature on diffusion studies of agricultural technologies. The review examines Zvi Griliches' seminal diffusion study of agricultural technology. I present other diffusion studies that progressively expand on Griliches' initial work and discuss the contribution of each study.

The literature review then focuses on microeconomic factors that lead to the adoption of conservation tillage and HT cotton. The results of these studies motivate inclusion of certain variables in this study which employs aggregate-level data. I will focus, therefore, on variables that significantly drove individual adoption of conservation tillage to determine if those variables drive state-level adoption as well.

2.1 Diffusion Studies

Zvi Griliches (1957) introduced agricultural technology diffusion studies to the field of economics. Griliches borrowed from previous sociological studies on the diffusion of new technologies and applied these ideas to the economic field. In this article, Griliches explains diffusion of hybrid corn in the United States using economic theory.

Rather than viewing the diffusion data as points of equilibrium, Griliches describes the data as points on an adjustment path moving toward a new equilibrium position. Examination of diffusion should consist of three parts, the beginning of the technology diffusion, the rate, and the destination. He fits a trend function to the observed S-shaped diffusion path. Among the several S-shaped functional forms available to fit the data, Griliches chose the logistic function because of its ease in calculating and interpreting. Thus, he fits the following logistic, S-shaped function to the data to explain diffusion of hybrid corn:

$$P = \frac{K}{1 + e^{-(a+bt)}} \tag{2.1.1}$$

P is the percent adoption of new technology or practice, and $0 \leq P \leq 1$. K is complete adoption of the technology or practice, or complete number of adopters. In this case, K is the long-run equilibrium percentages of the corn acreage planted to hybrid seed, $P \leq K$. The variable t stands for time; a is a parameter measuring aggregate adoption in the first year while b measures the speed of the diffusion of the technology.

Rearranging the diffusion equation, taking the natural logarithms of both sides, and appending a stochastic error term provide the log-linear regression equation yields:

$$\ln\left[P_{it} / \left(K_i - P_{it}\right)\right] = a_i + b_i t + u_i \tag{2.1.2}$$

where i = state or crop reporting district and t = time. The rate of adoption is comprised of three variables: the origin (a), slope (b), and adoption ceiling (K). Griliches uses Equation (2.1.2) to estimate the parameters for 31 states and 132 crop reporting districts starting in the year 1940. Equation (2.1.2) is estimated at the date in which the region planted ten percent of its corn acreage to hybrid corn. High R^2 estimates, ranging from

0.90 to 0.99 at the state level, and 0.95 to 0.99 for the crop reporting district, indicated excellent fits.

Griliches aggregated the observations for all regions of different explanatory variables into respective groups: origin or slope, and computes an estimate for *K*. To estimate *K*, a non-linear model must be employed. Griliches substituted his derivation of *K* into the equation to provide a linear model that can be estimated with ordinary least squares (OLS). His derivation of *K* involved plotting the percentage planted to hybrid seed on logistic graph paper and varying *K* until the resulting graph approximated a straight line. This procedure, though crude, was the best alternative in the absence of better econometric methods available at the time.

Griliches identified variations in origin, *a*, with supply side factors whereas he described variations in *b*, the speed of technology diffusion, with demand side factors. He broke the analysis into two groups labeled the "availability problems" and "acceptance problems," which are the lag in the supply and demand for the technology, respectively. He analyzed the determinants to different dates of availability and the different rates of acceptance by farmers of hybrid corn in different regions.

The availability problem results from the fact that hybrid corn was bred for specific locations, mainly the Corn Belt. The technology was not available everywhere at a single point in time. Griliches defined the origin as the date that farmers were planting more than ten percent of their ceiling acreage to hybrid seed. At this level, adoption of the hybrid had grown from the experimental stage to being commercially available. He hypothesized that the origin depended on availability and that agricultural experimental stations and private seed companies determined availability of hybrid seed to farmers. Experiment stations provided free research results and foundation stocks of seed to the region. The experiment stations' activities reduced the cost of innovation for the seed companies. However, the seed companies solely decided to enter a region based on their view of the profitability in a region.

The seed companies' viewpoints were influenced by eventual market size, marketing cost, innovation cost for the area, and the expected rate of acceptance. Griliches showed that the heart of the Corn Belt, for example had greater availability based on those factors than outside areas.

To estimate market size, Griliches used the average corn acreage from 1937-1946 (depending on data availability) adjusted for differences in *K*. To make them more commensurate with different regions, he then divided corn acreage by total farm acreage in 1945 to get a proxy for market size.

To estimate market cost, Griliches divided average corn acres by the number of corn farms in 1939 or 1945. Griliches hypothesized that another factor affecting market cost was the amount of innovation that had occurred in specific geographic areas. Early innovation took place in the Corn Belt, and those hybrid lines had been developed and were adapted to this region. Costs will be smaller for regions similar to the Corn Belt if Corn Belt inbred lines are adaptable. Griliches compared the differences of non-Corn Belt regions to Corn Belt regions by differences with the variable "Corn Beltiness," defined as the number of Corn Belt inbred lines in the pedigrees of the recommended hybrids for that area divided by the total number of lines. Griliches assumed that neighboring regions would have similar costs. To test this assumption he used the earliest date of entry into a neighboring area of a potential market the region as another variable.

Griliches defined the estimated slope coefficient, *b*, as the expected rate of acceptance in different areas. He stated that the differences in *b* should be interpreted as the differences in the rate of adjustment of demand to the new equilibrium. He hypothesized that this rate of adjustment is a function of both per acre and total profitability of the technology. He stated that the increase in yield is the only difference that determines the superiority of hybrid to open-pollinated seed. Differences in the price of corn, the seeding rate, and the price of seed were not significant. To measure profitability, Griliches used average increase of hybrid corn yield in bushels per acre corn and the long run average pre-hybrid yield of corn. Average corn acres were also used to measure the total profit impacts on the farm.

The main limitation to Griliches' model is he did not account for differences of supply-side geographic variables among the state and crop districts. After taking the simple correlation coefficients of the independent variables for the state and crop district level that explain the origin, he finds that the variables are highly correlated. Upon calculating the regression equation for each state and crop district in his study, he found significant differences among the parameter estimates. But he reduced the differences among regions to differences in the values of a few parameters. He notes that with the demand side variables, rates of adoption may depend on differences in geographic location, but he does not account for these geographic differences either. Despite the difficulty in determining the geographic effects, he argues that the diffusion of hybrid corn was influenced by profitability and farmers in better areas adopted first. Despite these limitations, Griliches' influential work motivated future diffusion studies, including this study.

Robert Dixon (1980) re-examined Griliches' article. His objectives were, firstly, to use the additional amount of information to re-estimate the original diffusion of hybrid equations estimated by Griliches. The second objective was to obtain parameter estimates using a non-linear least squares method and skewed growth curve in addition to the log-linear transform of the logistic.

Dixon used the same log-linear transformation of the basic logistic equation:

$$\ln\left[P_{it}/\left(K_i - P_{it}\right)\right] = a_i + b_i t + u_i \tag{2.1.4}$$

Dixon re-estimated equation (2.1.4) by changing the ceilings from Griliches' estimates to 1.0, obtaining new slope parameter estimates. As in Griliches' article, *i* = state and *t* = year. The data were collected for the years 1940 through 1960. Upon observing heteroskedasticity of the residuals from the OLS logits from each state, he re-estimated with observations weighted to correct for this. Although Dixon's results indicate that weighting observations did remove heteroskedasticity, it did not drastically affect the parameter estimates or their standard errors. The majority of the revised estimates were, however, smaller due to the higher ceiling imposed on the model.

Dixon then estimated the parameters of the logistic curve for each state by a full iterative nonlinear least squares applied directly to the time series data with the new ceiling of 1.00 for each state. After testing detected autocorrelation, he re-estimated the equations to include a first-order autoregressive scheme.

Dixon stated that a symmetric growth curve might not be appropriate to explain diffusion in every state as diffusion curves tend to be skewed with long tails. After inspecting the residuals from the fitted logistic curves, he found that a skewed growth curve might be more appropriate for many states. Dixon used the Gompertz function, which is consistent with a skewed diffusion curve.

The equation of the Gompertz function can be written as the following:

$$P_{it} = K_i \alpha_i^{\beta_i t} \qquad (2.1.5)$$

where K_i is the ceiling value (=1.00), α_i and β_i are parameters. Dixon estimated the slope of the Gompertz curve for each state estimating equation (2.1.5) directly on the data using iterative nonlinear least squares. He found a close similarity in the relative magnitudes of the Gompertz and logistic slope parameters. He performed hypothesis testing to determine symmetry of the cumulative distribution function. The skewed curve appeared to be a better fit for twenty-one of the thirty-one states, contradicting the validity of Griliches' approach of applying the logistic to every state.

Griliches' argued that diffusion of hybrid corn depended on the superior yields of hybrid corn and the average corn acres per farm. Griliches' asserted that the superiority of yields can be approximated by the average pre-hybrid yields, because the percentage difference in those yields did not vary between areas. Dixon ran regressions with the updated data set and improved estimating techniques to test Griliches' argument. His results supported Griliches claim that the diffusion rate does vary according to pre-hybrid yield and acres per farm.

Lovell Jarvis (1981) contributed a diffusion study to the literature focusing on improved pastures in Uruguay. He found the cumulative growth in both the number of ranchers who have adopted the improved pastures and the number of acres planted to improved pastures by fitting diffusion data to logistic curves. He tested two hypotheses, whether the rate, *b*, and ceiling, *K*, of technology diffusion can be predicted with information collected during the beginning years of diffusion, and whether *b* and *K* are positively related to changes in the technology's profitability. Griliches used economic variables to explain differences of the parameters in the diffusion model among states and crop reporting districts. Griliches estimated separate values for *b* for each state and crop reporting district, then examined the correlation of the *b* parameter estimates with economic variables. Jarvis modified Griliches' approach by estimating *b* and *K* directly as functions of the price of beef. Jarvis stated that diffusion generally takes twenty years, and diffusion of technology would not occur at a constant rate during that time due to factors like changing prices, technology, and learning. Jarvis used the logistic as a starting point, but then estimated the rate of diffusion and the ceiling simultaneously. Previous studies only estimated the rate of diffusion.

Jarvis rearranged the following logistic curve equation:

$$(2.1.6) \qquad P_t = \frac{K}{1 + e^{-(a+bt)}}$$

Where P_t is the cumulative number of adopters or cumulative acres by time *t; K* is the ceiling, or the number of total ranchers adopting by the time diffusion ceases; b is the rate of diffusion; and *a* is a constant term. After rearranging the logistic equation, Jarvis obtained:

(2.1.7) $$\frac{P_t}{[K - P_t]} = e^{-(a+bt)}$$

Since *K* is not known, Jarvis estimated the previous equation with *K* varying parametrically from ten to one hundred percent of total adopters considered potential adopters. The equation yielding the highest R^2 was considered as the best conditional estimates of b and *K.*

Jarvis found the R^2 maximized at 0.996; the associated ceiling estimate is 0.56. The parameter estimates of this equation most closely follow the logistic distribution. This implies that fifty-six percent of Uruguayan ranchers had adopted the technology, while ninety and ninety-nine percent will have adopted in 1975 and 1979, respectively. From these results, Jarvis inferred that a majority of potential adopters have invested in improved pastures, meaning information on the use and profitability of improved pastures was widespread, while the amount of new adopters was small and declining. Despite the minimal amount of new adopters, the current adopters had the potential to increase the amount of their acreage planted to improved pasture. Jarvis stated that the shift from the traditional extensive Uruguayan ranching practices, however, impeded productive improved pastures. He added that low beef prices prevented ranchers from obtaining the means to improve farm intensification. These factors lead to pasture deterioration due to overgrazing and reduced refertilization. He investigated this by fitting the cumulative net hectares of improved pasture to a logistic equation similarly to that for individual adopting ranchers. R^2 is maximized at a ceiling value of 18 percent of the area assumed suitable for improved pastures.

Just as Griliches hypothesized that increased profits would encourage diffusion of hybrid corn, so Jarvis believed that a beef price increase would encourage adoption of improved pastures. Beef prices fluctuated greatly between 1960 and 1978, but recovered to normal in 1975-76 from their previous lows. Jarvis anticipated increased adoption of improved pastures as a direct result of increased beef prices. He estimated the direct effect of beef prices on improved pasture adoption.

First, Jarvis estimated only the rate of diffusion as a function of price. He then estimated the ceiling using an iterative non-linear least squares method. In this case, both K (p_b) and b $((p_b)$ are estimated as functions of beef price, p_b. He changed the specification to assume a non-logistic distribution until 1961 then assumes a logistic distribution for the subsequent years.

When only the rate of diffusion b is a function of beef price, Jarvis found the price coefficient to be positive but insignificant. When only K is a function of beef price, he found that the price coefficient is positive and significant at the one-percent significance level for both adopting ranchers and planted hectares. He concluded that price impacts adoption ceiling, but has little impact on the rate of diffusion. Estimating both $K(p_b)$ and $b\ (p_b)$ as functions of beef price caused problems in that the functional form chosen could not fully characterize the price effect.

Jarvis found the ceilings estimated with both the log-linear and nonlinear methods for the two diffusion processes. The R^2 for adopting ranchers using both methods was about 0.56. He obtained one significant estimate for planted hectares, 0.115, which was slightly lower than the log-linear estimate. His estimated diffusion rate for planted hectares by the nonlinear method was significantly higher that that estimated by the log-linear method. His estimated diffusion rates for adopting ranchers from both methods were similar.

Fernandez-Cornejo, Alexander, and Goodhue (2002) contributed a study exploring the determinants of the diffusion of crop biotechnology. Their objectives were to study the diffusion paths of genetically engineered corn, soybeans and cotton, to predict the diffusion of the crops for the next two years, and to explore the determinants of diffusion.

The authors departed from the model employed by Griliches and model both the origin and slope of the diffusion curve as functions of economic variables. They used a dynamic diffusion model rather than a static diffusion model. A static diffusion path only allows for adoption to increase until it converges to the maximum. Also, static models only allow the percent of adopters to change as a function of time. Dynamic modeling allows the parameters of diffusion that determine the diffusion path to change over time. It allows for disadoption and changes in the rate of adoption. This facilitates identifying exact variables significant to the adoption of the technology.

The authors described the two types of dynamic modeling which are variable-ceiling and variable-slope models. In a variable ceiling model, *K* is a function of exogenous variables, while in a variable slope model *b* is a function of exogenous variables. They avoided using the variable-ceiling because the ceiling estimate may not stay at theoretically justifiable levels, such as a value exceeding 100 percent, and that extremely non-linear data may not converge. As a result, the variable slope coefficient is used. The benefits of using a model in which the slope varies as a function of exogenous variables are that the rate of acceptance can vary and even be negative, direct outside influences can be used, and the ceiling can be set at justifiable levels.

The authors specified the slope parameter *b* as a function of two sets of variables that operate on the demand side. The first set attempted to capture consumer preferences, concerns about genetically engineered genetically engineered products, or both. An index of agricultural biotech firms' stock prices served as a proxy attempting to capture these preferences or concerns. They labeled this vector as *R*. The second set of variables measured farmers' marginal costs, which depend on insect resistance or herbicide tolerance. The average insecticide price and the price ratio of glyphosate to other herbicides served as explanatory variables for the diffusion of Bt crops and herbicide-tolerant crops, respectively. They labeled this vector as *S*. The authors considered the following diffusion curve:

$$P_{it} = \frac{K_i}{1 + e^{-(a + b_0 t + b_1 ' R t + b_2 ' S t)}} \qquad (2.1.8)$$

Equation 2.1.8 included the origin as a vector of regional dummy variables *D* and the slope as a function of *R* and *S*. Transforming this equation and taking the natural logarithm provides Equation 2.1.9.

$$\text{(2.1.9)} \qquad \ln\left[P_{it}/\left(K_i - P_{it}\right)\right] = a_i + b_0 t + b_1{}'Rt + b_2{}'St + \gamma' D + u_i$$

A decrease in the agricultural biotech stock index, indicating consumer concern over products of biotechnology, is expected to decrease demand for genetically engineered crops. An increase in average insecticide price will increase demand for Bt crops, whereas an increase in the price of glyphosate relative to the price of other herbicides is expected lead to a decrease in the demand for herbicide-tolerant crops.

The ceilings, K_i, in their study are specified for different scenarios. First a base case ceiling was calculated for each crop, and then the authors calculate alternative scenarios. The base case for Bt crops was calculated by considering infestation levels and refugia requirements. The ceilings for HT soybeans were computed from potential demand restrictions in the export market, and the ceiling for HT cotton is set at 90 percent. The authors did not expect that consumer concerns in the export market would affect HT cotton. Therefore, they followed previous literature that set the diffusion ceiling to 90 percent. The authors used maximum-likelihood methods and weighted least squares techniques to estimate each of the regressions and correct for heteroskedasticity due to aggregate-level data, respectively.

The results indicated that exogenous variables other than time are statistically significant which suggests that dynamic modeling was warranted in this case. Both Bt crops were positively and significantly related to the biotech stock index. The rate of diffusion for the crops is positively related to the price of chemical insecticides, but only significant in the case of Bt cotton. These results suggest that the biotech stock index does capture consumer reaction to biotech products, and that prices of insecticides contribute to farmers' decisions to adopt biotech products.

Unexpectedly, the adoption of HT crops was positively and significantly related to the price ratio of glyphosate to other herbicides. The advantages to adopting herbicide-tolerant crops outweigh the cost of glyphosate. The biotech stock index was not significantly related to diffusion of herbicide-tolerant crops.

2.2 Determinants of Adoption of Agricultural Technologies

Kalaitzandonakes and Suntornpithug (2003) econometrically estimated the adoption of three agrobiotechnologies in U.S. cotton production. Their focus was whether a producer adopts or does not adopt and to what extent adoption takes place. They stated that adoption of these technologies has been studied individually in the past. Their hypothesis was that producers consider these technologies as bundles and accordingly make adoption decisions.

Bollgard (BT) cotton, Roundup Ready (RR), herbicide tolerant cotton, and Stacked Bollgard/Roundup Ready (ST) Cotton are three biotech varieties of cotton seed that offer insect resistance, herbicide, or both. These technologies may be adopted to reduce costs or exploit potential synergies with other agricultural technologies. The adoption of new technologies, however, presents the farmer with other uncertainties and the added costs of adopting the technology. The authors consider adoption to be a gradual process as producers learn. In addition to learning, they include technological interdependencies to be part of the adoption process.

They modeled the adoption of these biotech seeds together with reduced tillage practices as a system of equations. The dynamic learning effects were modeled with the inclusion of lagged dependent variables; these are intended to capture the iterative nature of the technology learning process. Three factors captured the impacts of perceived economic advantages of the new technologies on the producers' adoption decision: producer perceptions of pest control, cost savings, and risk reductions. Computer ownership was a variable included as a proxy of the producers' stage of technology adoption. Two dummy variables were included to account for regional differences in availability of seed and difference levels of infestation. All cotton producing states were included in the study except Arizona and California as these states have low conservation tillage adoption percentages.

The four equations were estimated using Generalized Method of Moments (GMM), three-stage least squares (3SLS), and full information maximum likelihood (FIML). The authors found that the three methods yield similar results. The results of the GMM estimation were then presented. The results of the estimated equations with RR cotton and reduced tillage showed that both technologies positively and significantly influence the adoption of the other.

Soule, Tegene, and Wiebe explored the effects of land tenure on the adoption of conservation tillage (Soule et al., 2000). The authors claim that research on this subject has been inconclusive because two key elements had not been addressed. Firstly, tenure's impact may depend on the timing and magnitude of the costs and returns generated by the conservation practices. Secondly, different lease arrangements may influence renters' conservation decisions. They tested two hypotheses in this study. The first was that share-renters and owner-operators were equally likely to adopt conservation tillage, while cash renters were less likely than owner-operators to adopt conservation tillage. The second hypothesis was that cash-renters are less likely than owner-operators to adopt medium-term conservation practices are, while the effect of share leasing on adoption of medium-term conservation practices was ambiguous.

To test these hypotheses, the authors employed a binary choice model where the latent variable *y** generates the observed value *y*. The variable *y* represents a farmer's decision to adopt or not. The latent variable is equal to the following equation:

$$(2.3.1) \qquad y_j^* = \delta' X_j + e_j \qquad (j = 1,\ldots,N)$$

where X_j is a vector of farm, farmer, field, and regional characteristics, δ is a coefficient vector, and e_j is a random disturbance. When *y** is positive, the conservation practice is adopted. Otherwise, the conservation practice is not adopted and $y=0$. The following relationship can be modeled by the following:

$$y_j = 1 \text{ if } y_j^* > 0$$
$$\text{and} \quad y_j = 0 \text{ if } y_j^* \leq 0$$

The probability that farmer *j* adopts the conversation practice if $y_j^* > 0$, or similarly if y_j is:

$$\text{(2.3.2)} \qquad \begin{aligned} \Pr[y_j = 1] &= \Pr[y_j^* > 0] \\ &= \Pr[\delta' X_j + e_j > 0] \\ &= 1 - F(-\delta' X_j) \\ &= F(\delta' X_j) \end{aligned}$$

where Pr[.] is a probability function and F(.) is the cumulative distribution function. The distribution of *F* depends on the distribution of e_j.

To determine the variables affecting land tenure, the authors chose the effects of farmers, farm, field, and regional attributes. Variables describing the farmer included operator's age, education, government program participation, and farmer type. Younger and more educated farmers were expected to adopt, as well as farmers farming highly erodible land (HEL). To farm HEL and receive certain government program payments and therefore higher profits, farmers must have an approved conservation plan (Soule et al, 2000). Limited resources, retired, or part-time farmers were not expected to adopt due to decreased profits from lack of time and/or resources to devote to the technology.

Farm attributes studied included farm size, the percentage of farm planted to corn and soybeans, and proximity to urban areas. The larger the farm size, the better able a farmer can spread out the cost of innovation over the revenue from the crops. The authors believe that proximity to urban areas could impede adoption as farmland may be converted to urban use in the near future.

Variables pertaining to field attributes included HEL designation, improved drainage, and tenure. Conservation programs are expected to be in place on HEL areas with or without government program supports to maintain productivity. Improved drainage could indicate wetter soils that will be less compatible with conservation tillage. Regional attributes are captured by average annual precipitation and annual temperature and by four regional dummy variables: Plains, North Central, Corn Belt, and East.

The authors then ran several logit regression models testing the explanatory variables on the adoption of owners, cash-renters, and share-renters. Some key inferences can be gained from their estimation. First, cash-renters tended to adopt conservation tillage less than owners and share-renters. Share-renters appear to behave more like owners. Cash-renters and share-renters were both less likely to adopt conservation practices that had delayed benefits than were owners. The HEL classification influenced adoption of medium-term practices by all tenure types and the adoption of conservation tillage by cash-renters.

Gould, Saupe, and Klemme (1989) contribute to the literature by modeling the adoption of conservation tillage as a series of two stages. The first stage involves recognizing soil erosion as a major problem; the second stage is adopting conservation tillage. The explanatory variables used to explain the adoption of conservation tillage in both stages can be grouped into three categories of variables: farm, financial, and operator characteristics. The data represent a random sample of 12,240 farm operators in eight counties in southwestern Wisconsin. The authors gathered information in 1983 about farm and operator characteristics, and again in 1987, this time gathering information about land usage.

To explain perception of soil erosion in the first stage within the farm characteristic category, the authors use the number of acres of total cropland and soils with a slope greater than seven percent. The variables in the operator characteristic category are education, experience as farm manager, participation in formal training through any agricultural education program, contact with Soil Conservation Service personnel, and time until retirement. The first three variables are expected to have a positive relationship with soil erosion recognition. A dummy variable was set equal to 1 if the farm operator had contact with Soil Conservation Service personnel. A dummy variable is set equal to 1 if the farm operator had the objective of being a full-time farmer for the next five years. If a farm operator is set to retire in the short term the incentive to obtain more information about soil erosion will be smaller.

For the second stage, the adoption of conservation tillage, the authors employ the predicted value of the dependent variable soil erosion perception from the first stage. They include number of planted acres, farm type, proportion of crops planted to a slope less than three percent, proportion of row crops and small grains, proportion of first year seedling of hayland, a precipitation measure, and a dummy measuring the amount of heating days in the category of farm characteristics. To gauge farm type, a dummy is set equal to 1 if mainly a dairy operation. The expected relationship between farm type and adoption of conservation tillage is expected to be positive. The proportion of crops planted to a slope less than three percent is expected to have a negative relationship with adoption of conservation tillage. The proportion of row crops and small grain crops are highly erosive and expected to have a positive relationship with adoption. First year seedling of hayland is less erosive and, therefore, expected to have a negative relationship with adoption. A thirty-year average of rainfall was collected for the eight counties. A dummy variable was set to 1 for four of those counties whose average rainfall was below thirty-one inches. Conservation tillage adoption is expected to increase in areas receiving less precipitation as the soil residue retains moisture. A dummy is set to 1 for two out of the eight counties that have the highest thirty-year average of heating days.

Variables in the financial characteristic category are the amount of debts to assets and household income. Debts to assets is a dummy variable set to 1 if the ratio is greater than 0.5. The household income includes net farm income, off-farm wage income, non-farm self-employment income, investment income, and other passive income and transfers.

Farm operator characteristic variables include education, age, and income earned off the farm, as well as an interaction term between age and income earned off the farm, and a dummy variable equal to 1 if the farm operator intends to transfer the farm to future generations in the next five years.

The results indicate that farmers recognize a soil erosion problem when they have steeply sloped fields and have used the Soil Conservation Service. The results also display a negative significant relationship between adoption and age. One interesting result is that there is a positive relationship between perception of soil erosion and experience as a farm operator. These results suggest that while younger farmers may be more likely to adopt conservation tillage, they may not be able to identify soil erosion on their farms. This implies that educational programs that focus on identifying soil erosion should be geared towards younger operators.

Similarly, the small farm operator was more likely to recognize a soil erosion problem, but the large farm operator is more likely to adopt conservation tillage. Producer perception of the need for soil conservation was also found to be a significant factor in adopting conservation tillage. The results indicate a negative relationship between farm operators earning more income off the farm and the adoption of conservation tillage. The farm operators may not view conservation tillage as a means of reducing farm work time commitments, and also those that obtain less income from the farm may not view investments in conservation tillage as worthwhile.

In the study conducted by several authors of the United States Department of Agriculture's Economic Research Service, they study the determinants of the decision to adopt conservation tillage among farmers producing in areas with thirty percent or more highly erodible cropland (Caswell et al, 2001). To identify the determinants of conservation tillage adoption, the authors estimate a multinomial logit for three regions, Susquehanna River, White River, and Illinois/Iowan Basins in the U.S. They estimate a combined model as well as three separate models. They categorize conservation tillage into no-till, mulch- or ridge-till, and conventional tillage.

The authors employed the following variables, producer characteristics including college education, farm production experience, and amount of work done off the farm. They also include farm characteristics such as land tenure, size, farm location relative to bodies of water, and type of crops grown. Management strategies including participating in farm program payments, volunteering a conservation plan, owning crop insurance, and using animal manure are hypothesized to also influence the adoption decision. Soil characteristics were also included like the soil leaching potential, soil productivity index, and the soil erodibility potential. Lastly, the average monthly precipitation and temperature were included in the model.

When considering farmer characteristics, a college education positively influenced the adoption of no-till in two of the three regions. The number of days worked off the farm increased the probability of adoption in no-till adoption in the Illinois/Iowa Basin, and mulch- or ridge-till in the Susquehanna River Basin. Farmers who owned their land were more likely to use conventional tillage and less likely to use mulch- or ridge-till when the regions are estimated together and White River Basin. Farmers with experience in operating were more likely to employ mulch- or ride-till in the combined regions and White River Basin.

The size of the farm in reference to the number of acres positively and significantly influenced the adoption of conservation tillage practices except in White River Basin. The greater amount of acres the producer manages the more likely the producer will employ conservation tillage practices. Whether or not the type of cropping practice influenced the decision to adopt conservation tillage varied across the regions. In the Illinois/Iowa Basin and the combined regions the probability of farmer’s use of no-till increased if the farmer used crop rotation for crop and/or pest management. Applying manure had differing effects on adoption, whereas irrigation generally did not encourage adoption.

Farmers subject to farm payments positively influenced adoption of no-till as well as farmers with a conservation plan except in the Susquehanna River Basin. The location of a body of water and potential soil leaching of chemicals only affected adoption in the White River Basin. Higher average monthly temperatures and rainfall encouraged adoption in the combined model; the Illinois/Iowa River Basin was the only single region model that showed climate influencing the use of no-till.

2.3 Contributions to the Literature

The first section of this chapter shows the progression of diffusion studies. Griliches (1957) sought to determine how technological change occurs and spreads in U.S. agriculture. Griliches estimates a static diffusion model to obtain estimates for the components of diffusion *a*, *b*, and *K*. He uses economic variables to explain hybrid corn diffusion differences of *a*, *b*, and *K* among states and crop-reporting districts. Jarvis (1981) expands on Griliches' model by directly estimating the *b* and *K* as functions of beef prices to explain diffusion of improved pastures in Uruguay. He finds that beef prices positively, albeit insignificantly, influence the diffusion of improved pastures. Similarly, Fernandez-Cornejo et al. (2002) estimate the diffusion of HT crops by defining *a* and *b* as functions of economic variables. The origin is a function of dummy variables for different regions. They define slope as the functions of consumer preferences/concerns and farmers' cost decisions. Their results show that an index of the price of Roundup® to other herbicides positively and significantly influences the diffusion of HT crops. HT crop diffusion is not affected by consumer preferences/concerns measured with an agricultural biotech stock price index.

To contribute to the diffusion literature, I will define *a* and *b* of the HT cotton diffusion model as functions of state-level economic variables. The slope of the conservation tillage diffusion model will also be a function of economic variables. I will estimate the diffusion models using a system of simultaneous equation model.

CHAPTER 3: DIFFUSION PATTERNS OF HT COTTON AND CONSERVATION TILLAGE

This chapter presents the observed diffusion patterns of conservation tillage and HT cotton in sixteen cotton-producing states. It then discusses the diffusion model in addition to presenting static and dynamic diffusion models.

3.1 Observed Conservation Tillage Diffusion Patterns

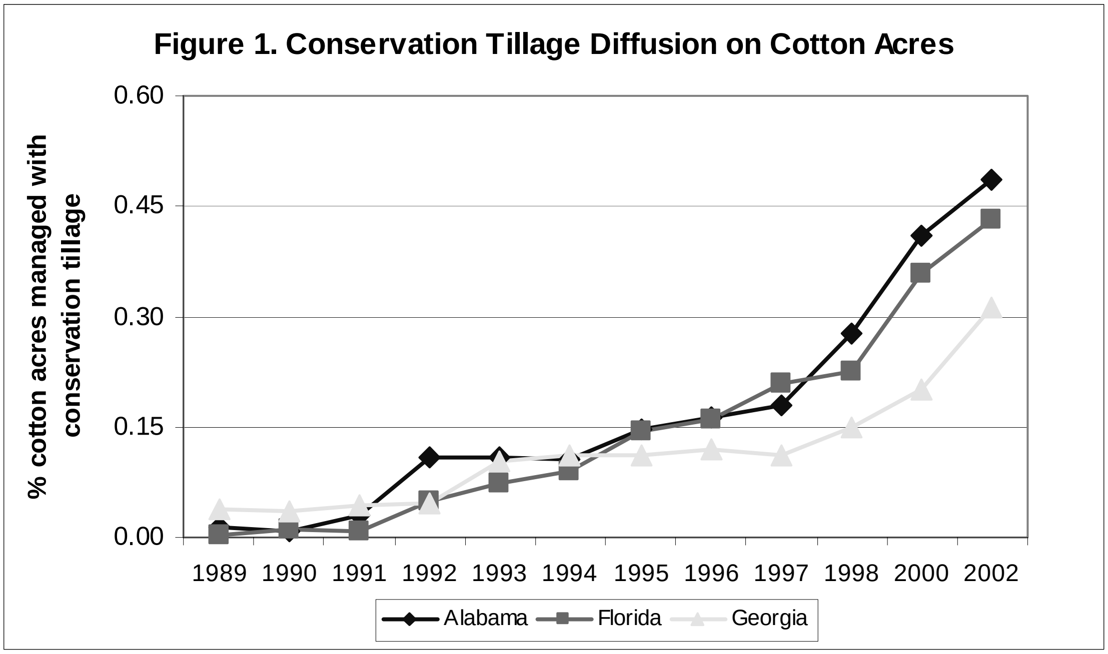
This section will outline the patterns of diffusion of conservation tillage for the selected cotton-producing states in the study from 1989 to 2002 minus the years 1999 and 2001 as no data were collected for those years. The actual adoption percentages are presented in Table 3.1. The cotton acres planted to conservation tillage are presented in Table 3.2.

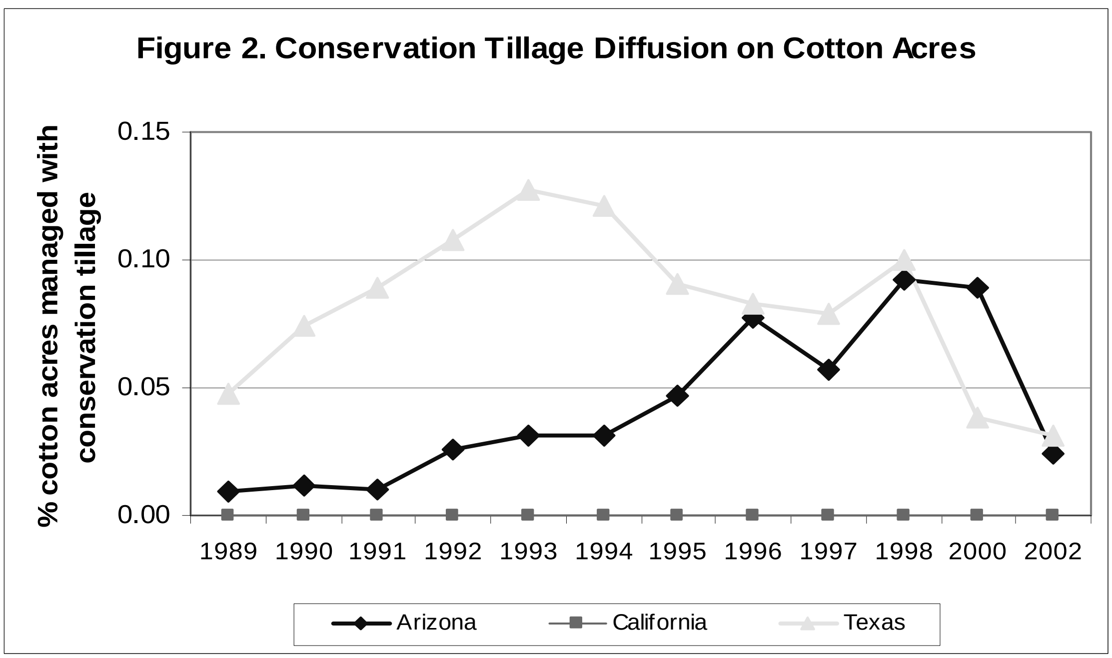
Table 3.1 Conservation Tillage Diffusion Percentages

State	Cotton acres managed with conservation tillage as a percentage of total cotton acres											
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	2000	2002
AL	1.3	0.8	3.0	10.8	10.8	10.7	14.6	16.4	18.0	27.8	40.9	48.7
AZ	1.1	1.4	1.4	1.6	1.3	1.6	1.7	1.9	2.5	2.9	2.5	2.5
AR	0.9	1.2	1.0	2.6	3.1	3.1	4.7	7.7	5.7	9.2	8.9	18.1
CA	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
FL	0.4	1.1	0.7	5.0	7.3	9.0	14.3	16.0	20.9	22.5	35.8	43.1
GA	3.8	3.4	4.3	4.5	10.2	11.0	11.0	11.9	11.0	15.0	20.0	31.3
LA	1.0	5.9	7.4	8.3	9.6	15.0	17.4	24.5	25.6	26.3	22.7	36.4
MS	5.4	3.0	7.2	8.2	11.1	11.3	11.8	12.0	9.1	10.8	11.6	26.4
MO	0.1	0.5	1.8	2.8	5.8	3.9	4.1	9.3	15.1	20.4	30.9	51.0
NM	10.2	11.8	1.3	2.7	4.3	5.5	6.7	11.6	15.7	18.0	19.3	19.4
NC	0.2	0.5	1.4	4.5	6.0	6.0	9.1	9.1	10.8	19.0	30.1	39.9
OK	2.8	5.5	5.7	4.6	8.2	8.4	8.7	6.4	7.9	6.0	12.2	14.3
SC	0.6	0.9	1.7	2.4	2.9	12.0	4.3	4.4	6.2	10.2	12.7	32.6
TN	1.5	3.0	7.3	18.8	27.3	42.0	36.2	34.1	29.2	29.1	45.8	50.2
TX	4.8	7.4	8.9	10.8	12.7	12.1	9.1	8.3	7.9	10.0	3.8	3.1
VA	13.8	0.1	0.1	0.1	0.7	1.1	8.0	14.1	16.3	17.8	20.2	53.3

Source: Conservation Technology Information Center, available:
http://www.ctic.purdue.edu/CTIC/CTIC.html

The information from Table 3.1 shows most states experience a diffusion pattern similar to the S-shaped diffusion curve described by Griliches resulting in a steady increase in the percentage of cotton acres planted to conservation tillage between 1989 and 2002. The exceptions are Arizona, California, Oklahoma, and Texas. Arizona and Texas experienced a decline in the percentage of acres. California has virtually no acres planted to conservation tillage. The following graphs show the typical S-shaped diffusion curves of the lower southeastern states and states with decreasing or zero adoption, respectively.





Initial adoption of conservation tillage was highest in Virginia and New Mexico. Virginia's adoption fell to almost zero after the initial adoption, but in 1995 the adoption started to increase. In 2002, Virginia had the highest adoption rate of 53 percent in the selected group. New Mexico's adoption fell to 1.3 percent in 1991 and climbed steadily to 19.3 percent.

Alabama, Florida, Georgia, and North Carolina have had steady increases in adoption since 1989. Arkansas, Kansas, Louisiana, Mississippi, Missouri, Oklahoma, South Carolina, and Tennessee have steadily increasing adoption until the adoption drops off in mid-1990. After this dip, adoption increases again in these states.

Table 3.2 shows the number of cotton acres planted to conservation tillage per state. The five states that show the biggest jump in the number of planted acres from 1989 to 2002 are Florida, Mississippi, Missouri, South Carolina, and Virginia. Mississippi and Missouri rank as the top two states with increases of about 195,000 and 257,000 in cotton acres planted to conservation tillage. Virginia has the highest diffusion percentage that increased conservation tillage on cotton acreage by 51,000 acres. States with increased cotton acreage ranging from 20,000 to 40,000 include Alabama, Georgia, New Mexico, North Carolina, Oklahoma, and Tennessee.

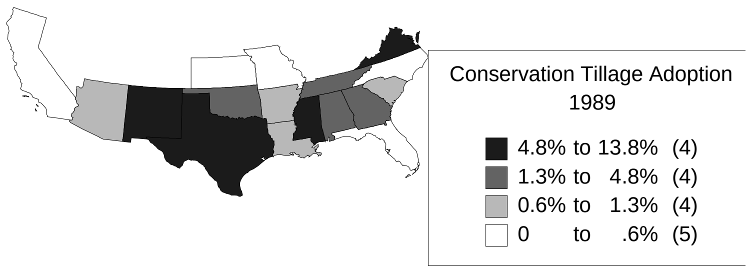
The rates of conservation tillage diffusion for Arizona, California, and Texas decrease from 1989 to 2002. Arizona has a small increase and eventual decrease that resulted in additional 500 acres planted to conservation tillage from 1989 to 2002. California's adoption remains constant over the time period and decreased a few hundred acres from 1989 to 2002. Texas has a declining rate of conservation tillage as well, but still has a significant amount of acres planted to conservation tillage at 176,000 in 2002. Louisiana has a modest increase in the time period of 12,000 acres.

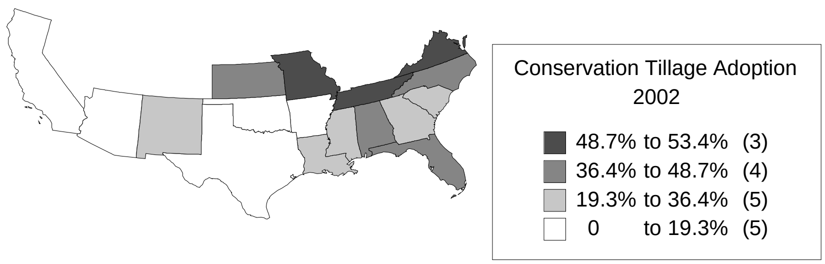
Table 3.2 Conservation Tillage Diffusion on Cotton Acres

	Cotton acres managed with conservation tillage											
State	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	2000	2002
AL	4772	3169	12495	45418	49618	50968	73150	90903	98486	136051	238737	290174
AZ	6431	8731	11878	15190	12595	15472	16809	18989	23952	26658	26335	6902
AR	4300	5733	4778	11486	11212	11012	17233	32612	21330	29659	24804	168852
CA	1396	1046	1119	1090	1192	1237	1250	1330	1231	1122	1122	1122
FL	107	402	330	2411	3804	5854	15803	17079	22186	22740	45226	57145
GA	11446	11485	18528	19621	55237	88734	162238	162456	160942	212611	290434	459160
LA	6442	43878	59378	70785	86462	132519	180335	215538	166650	144694	153935	185232
MS	57569	35175	85030	106807	144301	144743	162496	136295	91788	101473	235444	314523
MO	204	1084	4617	8249	18664	12091	15439	34536	55343	75829	121886	195113
NM	10083	10094	1119	2217	3322	4113	5403	9718	12855	15378	32502	32580
NC	200	976	6359	17037	23324	28745	71027	64410	72937	132068	274631	379151
OK	11428	21150	23458	18566	30665	29032	33303	23149	21155	10437	27268	30547
SC	773	1366	3504	4749	5874	9043	14295	12686	17803	29454	38363	96094
TN	7308	16217	43309	119622	176906	259135	244237	192220	150672	138206	244100	272326
TX	243610	419046	570912	460122	730539	678590	571480	455351	461773	556457	263799	176161
VA	350	5	18	16	168	461	8487	14471	16769	16599	18537	54761

Source: Conservation Technology Information Center, available:
http://www.ctic.purdue.edu/CTIC/CTIC.html

The following maps show the percent diffusion of conservation tillage in cotton producing states from 1989 to 2002:





3.2 Observed HT Cotton Diffusion Patterns

This section will outline the percent diffusion of cotton acres planted to HT cotton seed and the number of acres planted to HT cotton seed for the sixteen states from the introduction of HT cotton in 1997 until 2002. Table 3.3 shows the percent diffusion of HT cotton for each state.

Table 3.3 Percent Diffusion of HT Cotton

State	Percent Cotton Acres Planted to HT Cotton			
	1997	1998	2000	2002
Alabama	0.01	0.13	0.60	0.96
Arkansas	0.02	0.11	0.56	0.59
Arizona	0.05	0.03	0.42	0.83
California	0.00	0.00	0.21	0.40
Florida	0.00	0.07	0.83	0.99
Georgia	0.02	0.35	0.66	0.86
Louisiana	0.01	0.03	0.54	0.77
Mississippi	0.11	0.10	0.53	0.86
Missouri	0.00	0.02	0.22	0.62
New Mexico	0.01	0.02	0.04	0.31
North Carolina	0.10	0.32	0.65	0.89
Oklahoma	0.02	0.22	0.68	0.87
South Carolina	0.04	0.45	0.76	0.96
Tennessee	0.11	0.18	0.81	0.95
Texas	0.02	0.27	0.55	0.58
Virginia	0.03	0.19	0.49	0.91

Source: National Center for Food and Agricultural Policy (Carpenter et al 2002) and The California Cotton Review (Vargas & Wright 1998).

As can be seen in Table 3.3, the percent diffusion of HT cotton in every state increases from 1997 to 2002. Mississippi and Tennessee have the highest initial adoption of 11 percent in 1997; North Carolina also has one of the highest initial diffusion rates of 10 percent. Arizona has the next highest diffusion rate of 5 percent.

California has zero percent rate of diffusion in 1997 and 1998. This is due to California legislation that prohibited planting seed varieties other than Acala seed variety in those two years (Frisvold, 2004). This will be explained in more detail in the following chapter.

Alabama, Florida, South Carolina, Tennessee, and Virginia have the five highest diffusion percentages, all of which exceed 90 percent, in 2002. Figure 3 shows the diffusion rates of these five states. Notice that the five states with high HT cotton diffusion rates also have high conservation tillage diffusion rates. New Mexico has the lowest percent diffusion of 31 percent, followed by California at 40 percent in 2002. Texas and Arkansas have low percentages of diffusion at 58 and 59 percent, respectively. Missouri also has a relatively low diffusion rate of 62 percent. The rest of the states have diffusion percentage rates between 77 and 89 percent: Arizona, Georgia, Louisiana, Mississippi, Oklahoma, and North Carolina.

Figure 3. Percent HT Cotton Diffusion

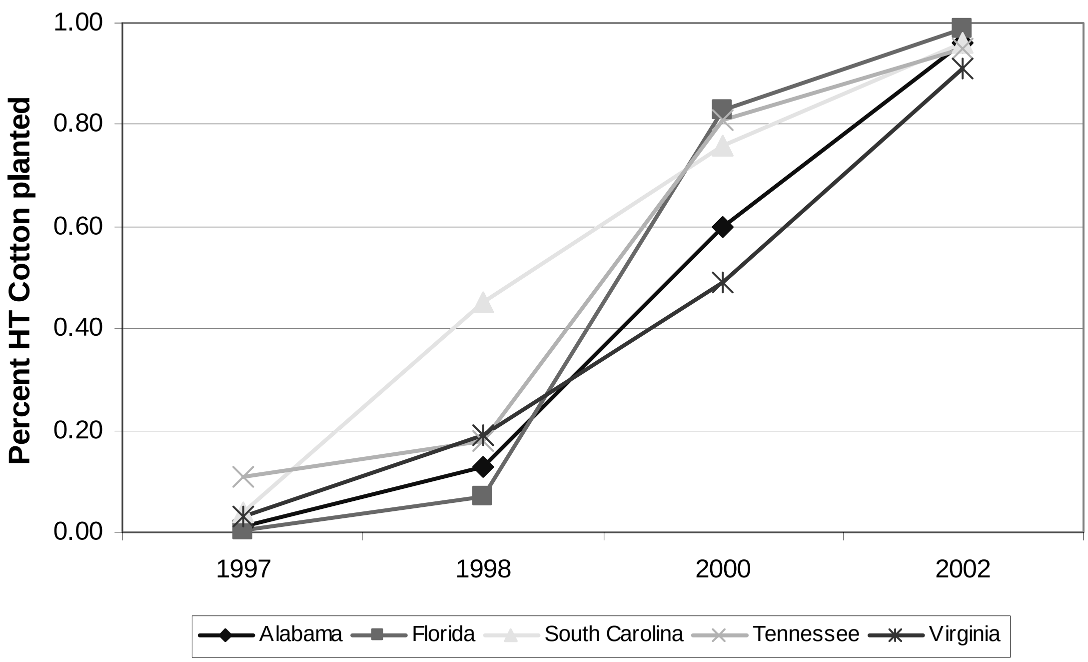


Table 3.4 presents the number of cotton acres planted to HT cotton seed. As can be seen from the table, Georgia and Mississippi have over 1,000,000 acres planted to HT

cotton seed, whereas Texas has over 3,000,000 acres planted. HT cotton diffusion in Texas from 1997 to 2002 grew enormously by over three million acres planted. Georgia's increase in diffusion from 1997 to 2002 is nearly 1,000,000 acres; Mississippi increases diffusion by 900,000 acres planted.

Florida and Virginia have a high percentage of acres planted to HT cotton, but have a relatively small amount of over 130,000 and 93,000 acres planted. Arkansas and New Mexico have low percentages of diffusion as well as a small number of acres planted to HT cotton with nearly 147,000 and 52,000 acres planted, respectively.

Table 3.4 HT Cotton Diffusion on Cotton Acres

	Planted HT Cotton Acres			
State	1997	1998	2000	2002
Alabama	5471	63621	350226	572504
Arkansas	19161	101118	589914	165908
Arizona	18711	9671	117054	774656
California	1	2	235667	448890
Florida	318	7075	104855	131130
Georgia	29262	496093	958433	1261514
Louisiana	6510	16505	366190	392283
Mississippi	110953	93956	1075736	1023326
Missouri	147	7434	86779	237177
New Mexico	819	1709	6736	52206
North Carolina	67535	222430	593057	845468
Oklahoma	5356	38271	151986	185661
South Carolina	11486	129946	229573	283394
Tennessee	56760	85488	431705	515243
Texas	116905	1502434	3818150	3289866
Virginia	3086	17718	44965	93457

Source: National Center for Food and Agricultural Policy (Carpenter et al 2002) and The California Cotton Review (Vargas & Wright 1998).

Louisiana, Missouri, Oklahoma, and South Carolina have a relatively low number of acres planted to HT cotton compared to the other states in the study. Of the four, Oklahoma has the fewest number of acres planted at about 180,000. Missouri and South Carolina have around 237,000 and 270,000 acres planted. Louisiana has 380,000 acres planted.

Alabama, Arizona, North Carolina, and Tennessee have a higher number of acres planted than the previous four states. Tennessee has 458,000 and Alabama has 55,000. Arizona and North Carolina have about the same number of acres planted at 756,000 and 782,000 acres. California has 448,890 acres planted to HT cotton after its initial lag of almost no acres planted in 1997 and 1998.

3.3 The Diffusion Model

The diffusion process contains four components: the innovation of technology, the social structure in which the innovation is introduced, the channels of communication, and time (Knudson, 1991). The innovation's characteristics will determine its adoptability. The social structure includes individuals, organizations, and agencies adopting the technology. Information about the innovations is received through the channels of communications from the adopters, and time is the period over which the social structure adopts the technology (Knudson, 1991). The empirical diffusion model will be discussed later in the chapter.

Six basic assumptions underlie the diffusion process. Firstly, the decision to adopt is binary, one either adopts or does not adopt. A fixed, finite ceiling exists for the technology as well as a fixed rate of diffusion coefficient. The innovation is not modified once introduced, and diffusion is independent of other inventions. Lastly, the geographic boundaries of the social structure remain constant (Knudson, 1991).

3.4 Static vs. Dynamic Functional Forms

Today, the diffusion process can be modeled with a static or dynamic model. When the diffusion process follows the six assumptions of the basic diffusion model, a static model performs the best. Static models explain diffusion as a function of time only. They have a pre-determined point of maximum adoption, or ceiling, and the rate of adoption increases until the maximum is reached. Once the initial information is plugged into the function the course of diffusion is set because the rate coefficient is fixed. Early economists were then left to decide which fixed functional form was the most appropriate depending on factors such as the type of technology diffusion, geographic region, etc. Early economists like Griliches' had limited econometric means to conduct research and thus static models remained the only option when modeling diffusion. Their decisions were which fixed functional form to select. Griliches used a symmetric logistic curve, whereas Dixon modeled diffusion using the Gompertz asymmetric curve.

With the advent of econometric software packages, we are now able to estimate dynamic diffusion models. The dynamic model relaxes the assumptions that the diffusion rate and ceiling values are fixed. Dynamic models have the ability to capture the effects of determinants of diffusion other than time as the rate and ceiling become functions of variables. Static models present the best predictions when the basic assumptions are satisfied; dynamic models predict better when one or more of those assumptions are violated.

This study employs dynamic modeling. The dynamic model used in this study is similar to the one used by Fernandez-Cornejo et al (2002). The diffusion path can fluctuate according to market or economic conditions represented by these variables. It is modified so that the ceiling, or maximum number of adopters of conservation tillage on cotton acres for each cotton-producing state, is set to 1 or 100 percent. The origin, or availability measure, is the intercept of my model. Lastly, the variables that explain the speed of adoption are a function of expected returns or demand-side variables. Market functions or relative input or output prices also affect the speed of adoption.

CHAPTER 4: THE EMPIRICAL DIFFUSION MODELS AND ECONOMETRIC ESTIMATION OF HT COTTON AND CONSERVATION TILLAGE

This chapter presents the econometric specification used to estimate factors affecting the diffusion paths of HT cotton and of conservation tillage in cotton.

4.1 Conservation Tillage Diffusion Model

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

$$Y_{it} = \frac{K}{1+e^{-(a_0+b_0+b_{it}t+u_{it})}} \qquad (4.1)$$

where Y_{it} is the percent of cotton acres where conservation tillage is adopted in *i* state in *t* year. I will label this percent as *CT_percent*. *K* is the estimated maximum number of adopting acres of conservation tillage. The variable a_0 is the origin term of the model; b_{it} represents the speed of adoption of the technology in state *i* in time *t*; u_{it} is a random error term.

In Equation 4.1, K_i, a_0, and b_{it} are functions of supply-side and demand-side economic variables. Dixon found that Griliches underestimated the ceiling for hybrid corn. Fernandez-Cornejo et al also set the ceiling to 90 percent for HT cotton diffusion, but by 2002 HT cotton diffusion in several states is close to 100 percent. To avoid the problem of underestimating the ceiling, I set the ceiling to 100 percent for both conservation tillage and HT cotton diffusion.

The rate of diffusion or b_{it} is a function of variables that measure market functions and expected returns of technology adoption. It is defined by:

(4.2) $$b_{it} = b_1 \text{year}_t + b_2 \text{tHT\_percent}_{it} + b_3 \text{tprecipitation}_i + b_4 \text{tprice}_{it} + b_5 \text{turban}_{it} + \text{b}_6 \text{tHEL}_i$$

year =	This variable represents the years 1997, 1998, 2000, and 2002.
tHT_percent =	The annual number of cotton acres planted to HT cotton as a percent of total cotton acres for each state. The log of the percent is interacted with *year*.
tprecipitation =	Average precipitation over the period 1950-1994 for each state interacted with *year*.
tprice =	The annual upland cotton price in dollars/bushel per state. The price in constant 2000 dollars, lagged, and interacted with *year*.
turban =	The yearly average cropland value per acre per state is then interacted with *year*
tHEL =	Percent highly erodible land in a state interacted with *year*

The variables other than year are interacted with year to show the diffusion differences per state over time.

Rearranging the terms of Equation (4.1), taking the natural log of the equation, and appending an error term provide the following log-linear regression:

(4.3)

$$Y_{it_{c.tillage}} =$$

$$a_0 + b_1\text{year}_\text{t} + b_2\text{tHT\_percent}_\text{it} + b_3\text{tprecipitation}_\text{i} + b_4\text{tprice}_\text{it} + b_5\text{turban}_\text{it} + b_6\text{tHEL}_\text{i} + u_\text{i}$$

where

(4.4) $$Y_{it_{\text{c. tillage}}} = \ln\left[\frac{CT\_percent_{it}}{(1-\ CT\_percent_{it})}\right]$$

4.2 Discussion of Variable Placement

The variables used to explain the speed of diffusion were chosen based on state differences, or economic hypotheses about expected returns and the response to certain market functions. These variables are demand-side variables that characterize how quickly farmers will accept the new technology.

The origin or regional supply-side determinants will not vary substantially for conservation tillage, therefore the intercept of the models serve as the origin. The placement of slope variables requires more explanation. Diffusion is expected to increase over time; therefore, *year* should have a positive coefficient. *tHEL, tprecipitation,* and *turban* are functions of geographic or state differences. It is hypothesized that states with highly erodible land measured directly with *tHEL* and indirectly with *tprecipitation* will adopt conservation tillage quicker. States with higher rates of urbanization measured the urbanization proxy *turban* will not invest in conservation tillage. Operators' planning horizons are shorter if the land will be converted to urban use.

In addition to geographic differences, the slope may be affected by *tPrice*, a measure of output price. *tPrice* represents annual cotton prices per region. Price is a profitability measure per state indicating the amount of funds available for technology investment. *tHT_percent* is expected to positively influence the diffusion of conservation tillage. The technologies work well when used together. Conservation tillage relies mainly on herbicides to control weeds; HT cotton facilitates weed control as it only relies on Roundup.

4.3 HT Cotton Diffusion Model

The diffusion of HT cotton can be modeled by a diffusion function in the same manner as the diffusion of conservation tillage. Recall Equation 4.1 from Section 4.1.

$$(4.1) \qquad Y_{it} = \frac{K}{1+e^{-(a_0+b_0+b_{it}t+u_{it})}}$$

The dependent variable Y_{it} in Equation (4.1) for the HT cotton adoption model is planted acres of HT cotton as a percentage of total planted cotton acres in *i* state in *t* year. I will also label this variable as *HT_percent*. By 2002, several cotton-producing states had adopted close to 100 percent HT cotton seed. Therefore, 100 percent is the chosen ceiling value to estimate the linear adoption model

The origin is a function of economic variables that explain the availability and institutional restrictions of the adoption of HT cotton seed. The following two variables explain regional adoption differences that affect availability:

$$(4.5) \qquad a_0 + a_1\text{parent} + a_2\text{CA78}$$

The variable *parent* represents the adoption of recurrent parent seed varieties planted as a percent of total cotton seed varieties in 1996. The variable *CA78* is a dummy equal to 1 for California for the years 1997 and 1998 and 0 otherwise.

The variables *parent* and *CA78* represent the supply-side economic factors that lead to the adoption of HT cotton seed. The HT trait was initially bred into a smaller subset of cotton varieties. Except for the HT trait recurrent parents were the same as the first HT cotton varieties. More widespread adoption of recurrent parent lines implies that these lines are well adapted to local growing conditions. *parent* is meant to capture the extent to which the new HT cotton varieties, first available in 1997, were adapted to local conditions.

Adopting a recurrent parent minimized the risk of adopting new technology as every other aspect of the seed remained the same. Producers familiar with the technology could then transition more easily to HT cotton seed once they were sold commercially. Recurrent parents were not omnipresent contributing to differences in diffusion patterns by geographic areas. The decision to adopt the parent seed could also affect the transition time into the initial adoption the HT cotton seed.

The other variable *CA78* is a dummy placed in the model to measure the effects of the One-Variety Law implemented in 1925 by California legislators. This law allowed only the Acala variety of cotton seed to be planted in the San Joaquin Valley in an attempt to better market California cotton. This law, however, was repealed in 1999. This law presented a supply-side restraint on the availability of HT cotton for California growers (Frisvold, 2004).

The rate of diffusion, b_{it}, is a function of variables that explain the rate of diffusion. The slope is defined by the following equation:

$$(4.6) \quad b_{it} = b_1 \text{year}_{\text{t}} + b_2 \text{tCT\_percent}_{\text{it}} + b_3 \text{tprice}_{\text{it}} + b_4 \text{tRoundup}_{\text{it}} + b_5 \text{tharvest}_{\text{i}}$$

year =	This variable represents the years 1997, 1998, 2000, and 2002.
tCT_percent =	The annual number of cotton acres managed with conservation tillage as a percent of total cotton acres for each state. The log of the percent is interacted with *year*.
tprice =	The annual upland cotton price in dollars/bushel per state. The price is inflated to 2000 dollars, lagged, and interacted with *year.*
tRoundup =	The log of the ratio of the price of glyphosate to the USDA herbicide price index is lagged one year, and then it is interacted with *year*.
tharvest =	This variable is the historic average from 1985 to 1995 of total harvested cotton acres as a percentage of total planted acres. This variable is then interacted with *year*.

Similar to the conservation tillage diffusion model, each slope variable is interacted with *year* to show diffusion differences over time and per state. The variables *tprice*, *tRoundup*, and *tharvest* are demand-side variables that determine how quickly HT cotton technology will diffuse. Cotton prices and the proportion of acres harvested determine profitability. Increased profitability could encourage investment in a new technology. When producers purchase HT cotton seed they must pay an up-front technology fee. This fee ranges from $7.48 to $19.02 depending on the region (Carpenter et al., 2002). Decreased profits could prohibit the adoption of HT cotton seed. States that have a low ratio of the price of glyphosate to an herbicide price index are expected to increase their adoption of HT cotton. Similar to the discussion of *tHT_percent* previously in this chapter, *tCT_percent* is expected to increase adoption of HT cotton as the two technologies work together.

Rearranging the terms of Equation (4.1), taking the natural log of the equation, and appending an error term provide the following log-linear regression:

(4.7)

$$Y_{it_{\text{HT\_cotton}}} =$$

$$a_0 + a_1 \text{parent}_{\text{i}} + a_2 \text{CA78}_{\text{i}} + b_1 \text{year}_{\text{t}} + b_2 \text{tCT\_percent}_{\text{it}} + b_3 \text{tprice}_{\text{it}} + b_4 \text{tRoundup}_{\text{it}} + b_5 \text{tharvest}_{\text{i}} + u_{\text{i}}$$

where

(4.8) $$Y_{it_{\text{HT\_cotton}}} = \ln \left[\frac{HT\_percent_{it}}{(1- HT\_percent_{it})} \right]$$

4.4 Simultaneous Systems of Equations

The diffusion of conservation tillage and HT cotton could be estimated separately, however, this may present estimation problems if the adoption decision is simultaneous. If the regression equation of the diffusion of conservation tillage can be explained in part by the diffusion of HT cotton, then HT cotton as an exogenous variable must be independent of the residuals of the model. If the exogenous variable and residuals are correlated then a basic assumption of the classic linear regression model assumptions are violated[1]. It is expected that the assumptions will be violated because the decision factors to adopt conservation tillage that are not explicitly accounted for in this model are likely to be the same factors as those concerning the decision to adopt HT cotton. The use of OLS in this case would provide biased and inefficient estimators.

To solve this problem, I consider Equation (4.3) and (4.7) as a system of diffusion equations:

(4.3)

$$Y_{it_{c.tillage}} =$$

$$a_0 + b_1 \text{year}_t + b_2 \text{tHT\_percent}_{it} + b_3 \text{tprecipitation}_i + b_4 \text{tprice}_{it} + b_5 \text{turban}_{it} + b_6 \text{tHEL}_i + u_i$$

[1] Discussion of Simultaneous Systems of Equations, Two-Stage Least Squares, and Three- Stage Least Squares are adapted and modified from Kennedy (1979) Chapter 9, and Maddala (1977) Chapter 11.

(4.7)

$$Y_{it_{\text{HT\_cotton}}} =$$

$$a_0 + a_1\text{parent}_{\text{i}} + a_2\text{CA78}_{\text{i}} + b_1\text{year}_{\text{t}} + b_2\text{tCT\_percent}_{\text{it}} + b_3\text{tprice}_{\text{it}} + b_4\text{tRoundup}_{\text{it}} + b_5\text{tharvest}_{\text{i}} + u_{\text{i}}$$

Recall, Equation (4.3) estimates the annual number of cotton acres managed with conservation tillage as a percentage of total cotton acres planted; Equation (4.7) estimates the total number of cotton acres planted to HT cotton seed as a percentage of total planted cotton acres. As the endogenous variables of each equation are also explanatory variables in the other equation, this violates the assumption that all independent variables are fixed in repeated samplings. The endogenous variables are determined simultaneously and correlated with the disturbance terms of the other equation; a change in the disturbance in one equation will result in a change in all the endogenous variables. Also, since the error term represents explanatory information that is not included in the model that affects producers' decision to adopt the technology, it is reasonable to assume that the disturbances from both equations, *u* and *v*, would be correlated.

4.4.1 Two-stage least squares

The two-stage least squares (2SLS) method is a commonly used method to address potential simultaneity bias. This procedure accounts for the endogeneity of *tCT_percent* and *tHT_percent*. 2SLS is referred to as a single-equation method because each equation in the system, i.e. Equation 3.4 and Equation 4.4, is analyzed separately. A special case of the instrumental variable technique, 2SLS employs the "best" instrumental variable, one that is highly correlated with the regressor for which is it acting as an instrument.

The 2SLS procedure involves regressing each of the endogenous variables, *tCT_percent* and *tHT_percent*, on all the exogenous variables in the system and obtaining the predicted values. The predicted values from the reduced-form equations replace the exogenous variable, and the updated model is estimated using OLS regression. The linear combinations of exogenous variables substitute for the endogenous variable. The estimates derived will be consistent as the variables will be independent of the residuals.

4.4.2 Three-stage least squares

The counterpart to 2SLS is the three-stage least squares (3SLS) estimation technique defined as a full-information method. The full information method estimates the equations simultaneously and incorporates knowledge of all the restrictions in the system when estimating the parameters. 3SLS method was employed because it accounts for the correlation of the error terms *u* and *v*, and it can provide more efficient estimates than 2SLS. If the disturbances are uncorrelated, 3SLS reduces to 2SLS.

The 3SLS estimator is obtained by, firstly, calculating the 2SLS estimates. These errors are then used to estimate the covariance matrix of the system of equations' errors. The last step involves using this covariance matrix to apply generalized least squares to the system of equations.

CHAPTER 5: DATA DESCRIPTIONS, ESTIMATION AND RESULTS OF THE SIMULTANEOUS SYSTEM OF EQUATIONS

Chapter 5 provides description of the data and variable calculations. This chapter also presents the Hausman hypothesis test and the estimation procedures for the OLS, 2SLS, and 3SLS methods. The chapter concludes with a discussion of the results and their implications.

5.1 Data Sources

The data on the percent of cotton acreage managed with conservation tillage were collected from the Conservation Technology Information Center's (CTIC's), *National Crop Residue Management Survey: Conservation Tillage Data*. A total of 64 observations for sixteen cotton-producing states were collected for each year from 1997 to 2002 except for the years 1999 and 2001 as CTIC did not conduct surveys for these years. The sixteen states represent those that grow a significant amount of cotton.

Data on the yearly percent of total cotton acres planted to HT Cotton from 1997 to 2002 for each state in this study were collected from the National Center for Food and Agricultural Policy (Carpenter et al. 2002) and from the *California Cotton Review* (Vargas & Wright, 1998). The total number of cotton acres planted yearly from 1997 to 2002 and the yearly upland cotton prices per state were obtained from the website of the National Agricultural Statistical Service (NASS) of the United States Department of Agriculture (USDA) under the heading *State Level Data for Field Crops: Oilseeds and Cotton.* The price in dollars per pound for each state was collected from 1996 through 2001.

Data on monthly precipitation by harvested cropland acreage were collected from the *Weather Data* set compiled by the Economic Research Service (ERS) of the USDA (ERS, 1950-1994).

The erodibility index for cropland by state for the year 1997 on nonfederal land was obtained from the USDA's Natural Resource Conservation Service. The index assigns a number from 1 to 15 according to the erodibility of the soil. Highly Erodible Land (HEL) includes cropland with the number 8 and above and is the category of interest. This data is measured in eroded tons of cultivated cropland per acre per year.

The average cropland value per acre for the years 1997 to 2002 are published in NASS's *Agricultural Land Values*. The USDA herbicide price index and price of glyphosate in dollars per gallon were collected from the NASS publication *Agricultural Prices.*

The data for planted and harvested cotton acreage for each state in the study were gathered from the NASS website under the heading *Crops by State* (NASS, 2004). The data on the adoption of a recurrent parent cotton seed were collected from *Cotton Varieties Planted* published by the USDA's Agricultural Marketing Service (AMS).

5.2 Description of Data Characteristics and Variable Calculations

Table 5.1 shows the descriptive statistics of the data used to calculate the variables in this study. These values represent the base value of the variable prior to any transformations.

Table 5.1 Descriptive Statistics of Base Case Variables

Variable	Mean	Std Dev	Minimum	Maximum
year	3.25	1.94	1.00	6.00
HT_percent	0.37	0.34	0.00	0.99
CT_percent	0.19	0.14	0.00	0.53
precipitation	3.44	1.26	0.84	4.79
price	0.55	0.18	0.26	0.82
HEL	0.29	0.26	0.03	0.89
urban	1954.39	1425.01	548.00	6167.62
CA78	0.03	0.18	0.00	1.00
parent	22.59	21.46	1.08	54.66
harvest	0.96	0.04	0.86	1.00
Roundup	43.93	4.15	39.73	48.46

Table 5.2 presents the descriptive statistics of the variables that were transformed by interacting *precipitation, HEL, urban,* and *harvest* and the natural logarithm of *HT_percent*, *CT_percent*, *price* and *Roundup* with time. The variables *year*, *parent*, and *CA78* did not undergo transformations and are not included in Table 5.2. The rest of this section describes the variables calculations.

Table 5.2 Descriptive Statistic of Transformed Variables

Variable	Mean	Std Dev	Minimum	Maximum
tHT_percent	-3.85	3.93	-26.24	-0.06
tCT_percent	-6.55	6.70	-41.45	-1.23
tprecipitation	11.17	8.18	0.84	28.72
tprice	-2.86	2.83	-8.08	-0.20
tHEL	0.94	1.13	0.03	5.34
turban	6641.68	7297.07	579.58	37005.73
tharvest	3.11	1.86	0.86	5.97
tRoundup	12.12	7.01	3.86	22.09

CT_percent: Total cotton acres managed with conservation tillage as a percent of total planted cotton acres was obtained from CTIC. The data was collected from 1997 to 2002 for each cotton-producing state in the study. The years 1999 and 2001 are missing as CTIC did not collect data for those years.

tCT_percent: This variable is calculated by taking the log of *CT_percent* for each state and interacting that value with *year*.

HT_percent: The total yearly cotton acres planted to HT cotton out of total planted cotton acres for each state in the study was obtained from the National Center for Food and Agricultural Policy and the California Cotton Review. The percent was collected for 1997, 1998, 2000, and 2002.

tHT_percent: This variable is calculated by taking the log of *HT_percent* for each state and interacting that value with *year*.

year: The time trend variable is assigned to show the effect of time on the diffusion of conservation tillage. 1 is assigned to 1997, the first year that HT cotton was introduced; 2 is assigned to 1998; 4 is assigned to 2000; and 6 is assigned to 2002.

tprecipitation: The long-run average precipitation on harvested crop land for each state was calculated by summing the states' monthly average precipitation in inches from 1950 to 1994 found in the ERS's *Weather in Agriculture,* and dividing that number by twelve. The average was then interacted with *year*.

tprice: The annual price of upland cotton per pound for each state from 1996 to 2001 minus the years 1998 and 2000 was obtained from the NASS database *State Level Data for Oilseeds and Cotton*. This price is then divided by the implicit price deflator of the Gross Domestic Product published by the Bureau of Economic Analysis in the *National Income and Product Account* Tables. The price deflator used in this study is included in the appendix. The log of the prices were then lagged one year and interacted with *year*.

tHEL: The variable was calculated from the USDA's Natural Resource Conservation Services' Erodibility Index of the year 1997. The Erodibility Index ranges from 1 to 15 and lists the number of cropland acres in each category per state. Cropland is classified as Highly Erodible Land (HEL) if the erodibility index is greater than 8. The number of acres assigned a value greater than 8 are summed and divided by total cropland acres. This percent is then interacted with *year*.

turban: This urbanization proxy variable was derived using the average annual cropland value per acre per state collected the NASS website. The value is divided by the same implicit price deflator used to calculate *price*. The value is then interacted with *year*.

CA78: This variable is a dummy equal to 1 for California for the years 1997 and 1998 and 0 otherwise. As discussed in Chapter 4, *CA78* measures the effects of the One-

Variety Law implemented in 1997, which allowed only the Acala variety of cotton seed to be planted in California's San Joaquin Valley. This law was then repealed in 1999.

parent: Using the USDA's data from *Cotton Varieties Planted,* the variable is calculated as the adoption of recurrent parent variety cotton seed planted in 1996 as a percentage of total cotton seed for each state.

tharvest: Data on the annual percentage of total harvested cotton acreage to total planted acreage from 1985 to 1995 per state were gathered from the NASS website. The yearly percentages were summed and divided by ten for each state. This variable is then interacted with *year*.

tRoundup: The data on the price of glyphosate in dollars per gallon and the USDA herbicide price index were obtained from *Agricultural Prices*. The price of glyphosate is divided by the herbicide price index based on the 1990-1992 dollar value of herbicide. The log of the ratio is lagged one year, and then it is interacted with *year*.

5.3 Hypothesis testing

Before an appropriate econometric model can be chosen, hypothesis testing must be used to determine if *tHT_percent* and *tCT_percent* are endogenous. If the test determines that there is an endogeneity problem as I hypothesize, then using simultaneous equations will provide more efficient estimators than OLS.

The Hausman test of misspecification is used to determine if the estimators from different models are statistically different from one another. Under the null hypothesis, two estimators from different econometric models are both consistent. Put differently, the null hypothesis is that the difference between two estimators is equal to zero.

Of the testing procedures, the approach followed involves using the *F* statistic to determine the joint significance of the elements of γ in the regression[2]:

$$(5.1) \qquad y = X\beta + \hat{X}^{*}\gamma + \varepsilon^{*}$$

where $\hat{X}^{*}$ are the residuals in regressions of the variables in X^{*} on the instrumental variables in the system. If the residuals from the first regression are significant in Equation 6.1 then an endogeneity problem is present. The Hausman statistic was computed for variables, *tHT_percent* and *tCT_percent* using the PROC REG procedure in SAS. *tHT_percent* and *tCT_percent* are regressed on the independent variables in the system of equations. The residuals from those regressions are inserted into new equations as an independent variable. An F test determines if one can reject the null hypothesis that the residuals are equal to zero, or if the variable is exogenous.

The results presented in Table 5.3 show that the null hypothesis of exogeneity is rejected at the 99 percent confidence level for *tHT_percent*. *tHT_percent* is endogenous and thus OLS estimates will be biased and inconsistent. Therefore using 2SLS modeling technique is required to correct for the endogeneity of *tHT_percent*.

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[2] Discussion of the Hausman Specification Test is taken from Greene (2003) Chapter 5.5, p. 80-83.

I cannot reject the null hypothesis for exogeneity for *tCT_percent*. Therefore, OLS estimates will be unbiased and more efficient than another model. Neither 2SLS nor OLS will correct if there is correlation between the error terms of the equations. 3SLS will provide the most efficient estimates if this correlation exists.

Table 5.3 Hausman Hypothesis Test Results

Endogenous variable tested	F Statistic	P-value
tHT_percent	14.94	0.0003
tCT_percent	2.12	0.15

5.4 Estimation Procedures

The results of the Hausman specification test determine that estimating HT cotton diffusion using OLS provide the best estimates for the diffusion model. OLS will not provide the best estimates for the conservation tillage diffusion model. 2SLS will correct for the endogeneity of *tHT_percent* in the conservation tillage diffusion equation. 3SLS is a modeling procedure performed here to also correct for the correlation of error terms of the two diffusion equations. The following sections describe the estimation results of the OLS, 2SLS and 3SLS models.

5.4.1 Estimation of 2SLS

Estimation of the 2SLS model was accomplished in SAS using the PROC SYSLIM procedure. This procedure requires identification of the equations in the system and endogenous variables of that system. One must instruct the procedure to perform 2SLS estimation as it can estimate several types of models. As a reminder, the following equations are estimated in the system:

(5.2)

$$Y_{it_{c.tillage}} =$$

$$a_0 + b_1 \text{year}_\text{t} + b_2 \text{tHT\_percent}_\text{it} + b_3 \text{tprecipitation}_\text{i} + b_4 \text{tprice}_\text{it} + b_5 \text{turban}_\text{it} + b_6 \text{tHEL}_\text{i} + u_\text{i}$$

(5.3)

$$Y_{it_{\text{HT\_cotton}}} =$$

$$a_0 + a_1 \text{parent}_\text{i} + a_2 \text{CA78}_\text{i} + b_1 \text{year}_\text{t} + b_2 \text{tCT\_percent}_\text{it} + b_3 \text{tprice}_\text{it} + b_4 \text{tRoundup}_\text{it} + b_5 \text{tharvest}_\text{i} + u_\text{i}$$

Table 5.4 presents the results of the parameter estimates of the 2SLS model of conservation tillage diffusion. This model's R^2 is 0.77.

Table 5.4 2SLS Estimates of the Conservation Tillage Diffusion Model

Variable	Parameter Estimate	Standard Error	t Value
Intercept	-1.54	0.38	-4.03
year	-0.86	0.28	-3.07
tHT_percent	0.19	0.04	5.10
tprice	0.08	0.16	0.53
tprecipitation	0.25	0.04	6.87
turban	-0.0001	0.00002	-3.00
tHEL	1.03	0.15	6.65

As shown in Table 5.4, all the parameter estimates except *tprice* are significant at the 95 percent confidence level. The variables *tHT_percent*, *tprecipitation*, *tprice,* and *tHEL* have the expected positive coefficient. The extent to which HT cotton affects conservation tillage will be discussed later in this chapter.

The variable *turban* has the expected negative sign and is also significant at the 95 percent confidence level. The variable *year* is not significantly different from zero and has a negative sign.

5.4.2 Estimation of OLS

The Hausman test revealed *tCT_percent* is exogenous in the HT cotton diffusion model. OLS provides unbiased and efficient estimates. I estimated the HT cotton diffusion model using the PROC REG procedure in SAS. Table 5.5 presents the results of the estimated OLS model on HT cotton diffusion. The R^2 of this model is 0.90.

Table 5.5 OLS Estimates of the HT Cotton Diffusion Model

Variable	Parameter Estimate	Standard Error	t Value
Intercept	-6.20	0.64	-9.65
year	-5.03	4.90	-1.03
tCT_percent	0.10	0.03	3.75
tprice	0.45	0.22	2.09
parent	2.34	0.70	3.37
tharvest	3.56	1.00	3.56
CA78	-9.51	0.87	-10.95
tRoundup	0.97	1.31	0.74

As can be seen from the results in Table 5.5, the variables *tCT_percent*, *tprice, parent*, and *tharvest*, have the expected positive sign and are significant at the 95 percent confidence level. The variables *parent* and *CA78* significantly impact the adoption of herbicide tolerant cotton. *CA78* has the expected negative sign and is significant at the 95 percent confidence level.

tRoundup is not significantly different from zero. The estimate of the ratio of glyphosate to the herbicide price index has an unexpected negative sign. This result is consistent with the result from the Cornejo et al. article (2002). Their conclusion was that the benefits from HT Cotton outweigh the fluctuation of price for glyphosate.

5.4.3 Estimation of 3SLS

Estimation of the 3SLS model on Equations 5.2 and 5.3 was accomplished using the PROC SYSLIM procedure in SAS. The results from the 3SLS model are presented in Table 5.6. The weighted R^2 of the model is 0.90. The sign and significance of the parameter estimates and their standard estimates do not change from the OLS and 2SLS models to the 3SLS model.

Table 5.6 3SLS Estimates of the Simultaneous Diffusion Model

Variable	Parameter Estimate	Standard Error	t Value
Intercept	-1.55	0.38	-4.06
year	-0.86	0.27	-3.14
tHT_percent	0.19	0.04	4.99
tprice	0.07	0.15	0.48
tprecipitation	0.25	0.04	7.13
turban	-0.0001	0.00002	-3.00
tHEL	0.94	0.14	6.53
Intercept	-6.43	0.61	-10.55
tCT_percent	0.11	0.03	3.84
Year	-7.47	4.37	-1.71
tprice	0.47	0.22	2.13
parent	2.12	0.63	3.35
tharvest	2.79	0.97	2.88
CA78	-9.92	0.84	-11.75
tRoundup	1.86	1.16	1.60

5.5 Comparing Models

The parameter estimates and standard errors of the OLS, 2SLS, and 3SLS conservation tillage and HT cotton diffusion models are presented in Table 5.7 and Table 5.8. The 3SLS model has smaller standard errors than the previous two models thus correcting for correlated error terms.

Table 5.7 Estimation Results for Conservation Tillage Diffusion Model

Variable	2SLS Parameter Estimate	Standard Error	t Value	3SLS Parameter Estimate	Standard Error	t Value
Intercept	-1.54	0.3818	-4.03	-1.55	0.3817	-4.06
year	-0.86	0.2792	-3.07	-0.86	0.2727	-3.14
tHT_percent	0.19	0.0372	5.10	0.19	0.0371	4.99
tprice	0.08	0.1550	0.53	0.07	0.1549	0.48
tprecipitation	0.25	0.0366	6.87	0.25	0.0357	7.13
turban	-0.0001	0.000021	-3.00	-0.0001	0.000020	-3.00
tHEL	1.03	0.1547	6.65	0.94	0.1433	6.53

Table 5.8 Estimation Results for HT Cotton Diffusion Model

Variable	OLS Parameter Estimate	Standard Error	t Value	3SLS Parameter Estimate	Standard Error	t Value
Intercept	-6.20	0.642	-9.65	-6.43	0.609	-10.55
year	-5.03	4.899	-1.03	-7.47	4.373	-1.71
tCT_percent	0.10	0.027	3.75	0.11	0.029	3.84
tprice	0.45	0.217	2.09	0.47	0.219	2.13
parent	0.02	0.007	3.37	0.02	0.006	3.35
tharvest	3.56	1.000	3.56	2.79	0.969	2.88
CA78	-9.51	0.868	-10.95	-9.92	0.844	-11.75
tRoundup	0.97	1.307	0.74	1.86	1.164	1.60

5.6 Elasticities

After estimating the 3SLS model and obtaining the parameter estimates for *tCT_percent* and *tHT_percent*, I used that parameter estimate to calculate the elasticity of conservation tillage with respect to HT cotton and the elasticity of HT cotton with respect to conservation tillage. The elasticities facilitate interpretation of the results from the 3SLS model of the effects of one technology's diffusion on the other.

The elasticity of conservation tillage diffusion with respect to HT cotton diffusion, e_{CH}, is defined by Equation 5.4.

$$(5.4) \quad e_{CH} = \frac{\partial CT\_percent}{\partial HT\_percent} \bullet \frac{HT\_percent}{CT\_percent} = (1 - CT\_percent) \bullet year \bullet B_1$$

B_1 is the regression coefficient for *tHT_percent* in the 3SLS conservation tillage diffusion equation.

The elasticity of HT cotton adoption with respect to conservation tillage adoption, e_{HC}, is defined by Equation 5.5.

$$(5.5) \quad e_{HC} = \frac{\partial HT\_percent}{\partial CT\_percent} \bullet \frac{CT\_percent}{HT\_percent} = (1 - HT\_percent) \bullet year \bullet B_2$$

B_2 is the regression coefficient for *tCT_percent* in the 3SLS HT cotton diffusion equation. Table 5.9 shows the mean, minimum, and maximum values of the elasticities.

Table 5.9 Descriptive Statistics of Elasticities

	Mean	Minimum	Maximum
$e_{CH} = (1 - CT\_percent) year B_1$	0.48	0.13	1.14
$e_{HC} = (1 - HT\_percent) year B_2$	0.16	0.01	0.46

The interpretation of e_{CH} at the mean value is that a 1 percent increase in the diffusion of HT cotton increases conservation tillage diffusion by 0.48 percent. When diffusion is at a minimum, (1-*CT_percent*) and e_{CH} are at a maximum. At the maximum value of e_{CH}, a 1 percent increase in HT cotton diffusion increases conservation tillage diffusion by 1.14 percent. Conversely, when diffusion is at a maximum, (1-*CT_percent*) and e_{CH} are at a minimum. At the minimum value of e_{CH}, a 1 percent increase in HT cotton diffusion increases conservation tillage diffusion by 0.13 percent.

Similarly, the interpretation of e_{HC} at the mean value is that a 1 percent increase in the adoption of conservation tillage increases adoption of HT cotton by 0.16 percent. At the maximum value of e_{HC}, a 1 percent increase in conservation tillage increases adoption of HT cotton by 0.46 percent. At the minimum value, a 1 percent increase in conservation tillage diffusion increases HT cotton diffusion by 0.01 percent.

As diffusion increases, (1-*CT_percent*) and (1-*HT_percent*) become smaller. When the ceiling is reached (1-*CT_percent*) and (1-*HT_percent*) are equal to zero. The impact of one technology's diffusion on the other diminishes as diffusion approaches the ceiling.

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APPENDIX

Table A.1 Data used in calculations

State	year	HT_percent	CT_percent	precipitation	price	HEL	CA78	parent	harvest	Roundup	urban
Alabama	1	0.01	0.18	4.67	0.76	0.27	0	0.1888	0.98	47.61	1257.677
Arizona	1	0.02	0.025	0.84	0.74	0.83	0	0.5141	1	47.61	3877.838
Arkansas	1	0.05	0.057	4.20	0.75	0.04	0	0.0279	0.95	47.61	1014.526
California	1	0.00	0.001	1.86	0.82	0.07	1	0.0155	0.99	47.61	5324.166
Florida	1	0.00	0.209	4.52	0.73	0.03	0	0.513	0.97	47.61	3437.651
Georgia	1	0.02	0.11	4.12	0.75	0.1	0	0.442	0.97	47.61	1110.948
Louisiana	1	0.01	0.256	4.79	0.7	0.03	0	0.0946	0.98	47.61	1131.909
Mississippi	1	0.11	0.091	4.62	0.72	0.15	0	0.0108	0.98	47.61	860.461
Missouri	1	0.00	0.151	3.34	0.73	0.39	0	0.019	0.95	47.61	1089.987
New Mexico	1	0.01	0.157	1.20	0.79	0.89	0	0.0982	0.86	47.61	1393.925
North Carolina	1	0.10	0.108	4.08	0.77	0.23	0	0.1003	0.99	47.61	1970.361
Oklahoma	1	0.02	0.079	2.51	0.66	0.24	0	0.5027	0.92	47.61	579.58
South Carolina	1	0.04	0.062	4.02	0.79	0.09	0	0.444	0.98	47.61	1142.39
Tennessee	1	0.11	0.292	4.39	0.71	0.44	0	0.0623	0.97	47.61	1917.958
Texas	1	0.02	0.079	2.27	0.7	0.36	0	0.5466	0.88	47.61	706.395
Virginia	1	0.03	0.163	3.56	0.76	0.46	0	0.0351	0.99	47.61	1907.477
Alabama	2	0.13	0.278	4.67	0.71	0.27	0	0.1888	0.98	48.46	1306.078
Arizona	2	0.11	0.029	0.84	0.68	0.83	0	0.5141	1.00	48.46	3938.967
Arkansas	2	0.03	0.092	4.20	0.69	0.04	0	0.0279	0.96	48.46	1067.667
California	2	0.00	0.001	1.86	0.77	0.07	1	0.0155	0.99	48.46	5452.359
Florida	2	0.07	0.225	4.52	0.69	0.03	0	0.513	0.97	48.46	3348.122
Georgia	2	0.35	0.15	4.12	0.71	0.1	0	0.442	0.97	48.46	1181.69
Louisiana	2	0.03	0.263	4.79	0.68	0.03	0	0.0946	0.98	48.46	1098.764
Mississippi	2	0.10	0.108	4.62	0.68	0.15	0	0.0108	0.98	48.46	910.109
Missouri	2	0.02	0.204	3.34	0.72	0.39	0	0.019	0.95	48.46	1171.324
New Mexico	2	0.02	0.18	1.20	0.6	0.89	0	0.0982	0.86	48.46	1430.467
North Carolina	2	0.32	0.19	4.08	0.69	0.23	0	0.1003	0.99	48.46	2021.312

State	year	HT_percent	CT_percent	precipitation	price	HEL	CA78	parent	harvest	Roundup	urban
Oklahoma	2	0.22	0.06	2.51	0.61	0.24	0	0.5027	0.92	48.46	598.101
South Carolina	2	0.45	0.102	4.02	0.73	0.09	0	0.444	0.98	48.46	1202.421
Tennessee	2	0.18	0.291	4.39	0.68	0.44	0	0.0623	0.97	48.46	2042.043
Texas	2	0.27	0.1	2.27	0.63	0.36	0	0.5466	0.88	48.46	726.636
Virginia	2	0.19	0.178	3.56	0.71	0.46	0	0.0351	0.99	48.46	1948.752
Alabama	4	0.60	0.409	4.67	0.49	0.27	0	0.1888	0.98	39.91	1460
Arizona	4	0.56	0.025	0.84	0.45	0.83	0	0.5141	1.00	39.91	4600
Arkansas	4	0.42	0.089	4.20	0.48	0.04	0	0.0279	0.96	39.91	1080
California	4	0.21	0.001	1.86	0.57	0.07	0	0.0155	0.99	39.91	5960
Florida	4	0.83	0.358	4.52	0.43	0.03	0	0.513	0.97	39.91	3340
Georgia	4	0.66	0.2	4.12	0.46	0.1	0	0.442	0.97	39.91	1400
Louisiana	4	0.54	0.227	4.79	0.45	0.03	0	0.0946	0.98	39.91	1110
Mississippi	4	0.53	0.116	4.62	0.46	0.15	0	0.0108	0.98	39.91	983
Missouri	4	0.22	0.309	3.34	0.48	0.39	0	0.019	0.95	39.91	1290
New Mexico	4	0.04	0.193	1.20	0.48	0.89	0	0.0982	0.86	39.91	1440
North Carolina	4	0.65	0.301	4.08	0.49	0.23	0	0.1003	0.99	39.91	2400
Oklahoma	4	0.68	0.122	2.51	0.39	0.24	0	0.5027	0.92	39.91	548
South Carolina	4	0.76	0.127	4.02	0.46	0.09	0	0.444	0.98	39.91	1240
Tennessee	4	0.81	0.458	4.39	0.45	0.44	0	0.0623	0.97	39.91	2240
Texas	4	0.55	0.038	2.27	0.42	0.36	0	0.5466	0.88	39.91	770
Virginia	4	0.49	0.202	3.56	0.48	0.46	0	0.0351	0.99	39.91	2150
Alabama	6	0.96	0.4866	4.67	0.27	0.27	0	0.1888	0.98	39.73	1633.171
Arizona	6	0.59	0.0245	0.84	0.28	0.83	0	0.5141	1.00	39.73	5764.132
Arkansas	6	0.83	0.1809	4.20	0.27	0.04	0	0.0279	0.96	39.73	1114.399
California	6	0.40	0.001	1.86	0.41	0.07	0	0.0155	0.99	39.73	6167.621
Florida	6	0.99	0.4314	4.52	0.29	0.03	0	0.513	0.97	39.73	3544.941
Georgia	6	0.86	0.313	4.12	0.3	0.1	0	0.442	0.97	39.73	1594.743
Louisiana	6	0.77	0.3636	4.79	0.27	0.03	0	0.0946	0.98	39.73	1172.04
Mississippi	6	0.86	0.2643	4.62	0.26	0.15	0	0.0108	0.98	39.73	1037.544
Missouri	6	0.62	0.51	3.34	0.29	0.39	0	0.019	0.95	39.73	1412.212

State	year	HT_percent	CT_percent	precipitation	price	HEL	CA78	parent	harvest	Roundup	urban
New Mexico	6	0.31	0.1935	1.20	0.33	0.89	0	0.0982	0.86	39.73	1392.999
North Carolina	6	0.89	0.3991	4.08	0.31	0.23	0	0.1003	0.99	39.73	2689.928
Oklahoma	6	0.87	0.1431	2.51	0.29	0.24	0	0.5027	0.92	39.73	594.666
South Carolina	6	0.96	0.3255	4.02	0.31	0.09	0	0.444	0.98	39.73	1296.93
Tennessee	6	0.95	0.5021	4.39	0.3	0.44	0	0.0623	0.97	39.73	2296.046
Texas	6	0.58	0.0311	2.27	0.28	0.36	0	0.5466	0.88	39.73	836.76
Virginia	6	0.91	0.5332	3.56	0.29	0.46	0	0.0351	0.99	39.73	2353.687

State	tHT_percent	tCT_percent	tharvest	tRoundup	tprecipitation	tprice	tHEL	Turban
Alabama	-4.61	-1.71	0.98	3.86	4.67	-0.27	0.27	1257.68
Arizona	-3.91	-3.69	1.00	3.86	0.84	-0.30	0.83	3877.84
Arkansas	-3.00	-2.86	0.95	3.86	4.20	-0.29	0.04	1014.53
California	-13.82	-6.91	0.99	3.86	1.86	-0.20	0.07	5324.17
Florida	-5.81	-1.57	0.97	3.86	4.52	-0.31	0.03	3437.65
Georgia	-3.91	-2.21	0.97	3.86	4.12	-0.29	0.10	1110.95
Louisiana	-4.61	-1.36	0.98	3.86	4.79	-0.36	0.03	1131.91
Mississippi	-2.21	-2.40	0.98	3.86	4.62	-0.33	0.15	860.46
Missouri	-7.82	-1.89	0.95	3.86	3.34	-0.31	0.39	1089.99
New Mexico	-4.61	-1.85	0.86	3.86	1.20	-0.24	0.89	1393.93
North Carolina	-2.30	-2.23	0.99	3.86	4.08	-0.26	0.23	1970.36
Oklahoma	-3.91	-2.54	0.92	3.86	2.51	-0.42	0.24	579.58
South Carolina	-3.22	-2.78	0.98	3.86	4.02	-0.24	0.09	1142.39
Tennessee	-2.21	-1.23	0.97	3.86	4.39	-0.34	0.44	1917.96
Texas	-3.91	-2.54	0.88	3.86	2.27	-0.36	0.36	706.40
Virginia	-3.51	-1.81	0.99	3.86	3.56	-0.27	0.46	1907.48
Alabama	-4.08	-2.56	1.96	7.76	9.35	-0.68	0.54	2612.16
Arizona	-4.41	-7.08	1.99	7.76	1.68	-0.77	1.66	7877.93
Arkansas	-7.01	-4.77	1.91	7.76	8.40	-0.74	0.08	2135.33
California	-26.24	-13.82	1.98	7.76	3.72	-0.52	0.14	10904.72
Florida	-5.32	-2.98	1.94	7.76	9.04	-0.74	0.06	6696.24

State	tHT_percent	tCT_percent	tharvest	tRoundup	tprecipitation	tprice	tHEL	Turban
Georgia	-2.10	-3.79	1.93	7.76	8.24	-0.68	0.20	2363.38
Louisiana	-7.01	-2.67	1.95	7.76	9.57	-0.77	0.06	2197.53
Mississippi	-4.61	-4.45	1.96	7.76	9.24	-0.77	0.30	1820.22
Missouri	-7.82	-3.18	1.89	7.76	6.68	-0.66	0.78	2342.65
New Mexico	-7.82	-3.43	1.72	7.76	2.41	-1.02	1.78	2860.93
North Carolina	-2.28	-3.32	1.98	7.76	8.15	-0.74	0.46	4042.62
Oklahoma	-3.03	-5.63	1.84	7.76	5.01	-0.99	0.48	1196.20
South Carolina	-1.60	-4.57	1.95	7.76	8.05	-0.63	0.18	2404.84
Tennessee	-3.43	-2.47	1.93	7.76	8.79	-0.77	0.88	4084.09
Texas	-2.62	-4.61	1.76	7.76	4.53	-0.92	0.72	1453.27
Virginia	-3.32	-3.45	1.97	7.76	7.12	-0.68	0.92	3897.50
Alabama	-2.04	-3.58	3.92	14.75	18.69	-2.85	1.08	5840.00
Arizona	-2.32	-14.76	3.98	14.75	3.35	-3.19	3.32	18400.00
Arkansas	-3.47	-9.68	3.82	14.75	16.81	-2.94	0.16	4320.00
California	-6.24	-27.63	3.96	14.75	7.43	-2.25	0.28	23840.00
Florida	-0.75	-4.11	3.88	14.75	18.07	-3.38	0.12	13360.00
Georgia	-1.66	-6.44	3.86	14.75	16.48	-3.11	0.40	5600.00
Louisiana	-2.46	-5.93	3.90	14.75	19.15	-3.19	0.12	4440.00
Mississippi	-2.54	-8.62	3.92	14.75	18.48	-3.11	0.60	3932.00
Missouri	-6.06	-4.70	3.78	14.75	13.36	-2.94	1.56	5160.00
New Mexico	-12.88	-6.58	3.44	14.75	4.82	-2.94	3.56	5760.00
North Carolina	-1.72	-4.80	3.96	14.75	16.30	-2.85	0.92	9600.00
Oklahoma	-1.54	-8.41	3.68	14.75	10.03	-3.77	0.96	2192.00
South Carolina	-1.10	-8.25	3.90	14.75	16.10	-3.11	0.36	4960.00
Tennessee	-0.84	-3.12	3.86	14.75	17.57	-3.19	1.76	8960.00
Texas	-2.39	-13.08	3.52	14.75	9.07	-3.47	1.44	3080.00
Virginia	-2.85	-6.40	3.94	14.75	14.23	-2.94	1.84	8600.00
Alabama	-0.24	-4.32	5.88	22.09	28.04	-7.86	1.62	9799.03
Arizona	-3.17	-22.25	5.97	22.09	5.03	-7.64	4.98	34584.79
Arkansas	-1.12	-10.26	5.73	22.09	25.21	-7.86	0.24	6686.39

State	tHT_percent	tCT_percent	tharvest	tRoundup	tprecipitation	tprice	tHEL	Turban
California	-5.50	-41.45	5.94	22.09	11.15	-5.35	0.42	37005.73
Florida	-0.06	-5.04	5.82	22.09	27.11	-7.43	0.18	21269.65
Georgia	-0.90	-6.97	5.79	22.09	24.72	-7.22	0.60	9568.46
Louisiana	-1.57	-6.07	5.85	22.09	28.72	-7.86	0.18	7032.24
Mississippi	-0.90	-7.98	5.88	22.09	27.72	-8.08	0.90	6225.26
Missouri	-2.87	-4.04	5.67	22.09	20.04	-7.43	2.34	8473.27
New Mexico	-7.03	-9.85	5.16	22.09	7.22	-6.65	5.34	8357.99
North Carolina	-0.70	-5.51	5.94	22.09	24.45	-7.03	1.38	16139.57
Oklahoma	-0.84	-11.67	5.52	22.09	15.04	-7.43	1.44	3568.00
South Carolina	-0.24	-6.73	5.85	22.09	24.15	-7.03	0.54	7781.58
Tennessee	-0.31	-4.13	5.79	22.09	26.36	-7.22	2.64	13776.28
Texas	-3.27	-20.82	5.28	22.09	13.60	-7.64	2.16	5020.56
Virginia	-0.57	-3.77	5.91	22.09	21.35	-7.43	2.76	14122.12

Table A.2 GDP Price Deflator

	Implicit GDP Price Deflator
1985	0.6971
1986	0.7125
1987	0.7320
1988	0.7569
1989	0.7856
1990	0.8159
1991	0.8444
1992	0.8639
1993	0.8838
1994	0.9026
1995	0.9211
1996	0.9385
1997	0.9541
1998	0.9647
1999	0.9787
2000	1.0000
2001	1.0240
2002	1.0409

Source: U.S. Department of Commerce Bureau of Economic Analysis
"Table 1.1.9. Implicit Price Deflators for Gross Domestic Product."
Available: www.bea.doc.gov/bea/dn/nipaweb/TableView.asp?SelectedTable=13&FirstYear=2002&LastYear=2004&Freq=Qtr
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