The Impacts of GM Seed Technology on Cotton: Cost of Production in Mississippi, 1996 – 2005.

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Abstract

Genetically modified (GM) cotton varieties have changed many aspects of cotton production in the United States. The advent of GM varieties has been the source of altered cropping practices in cotton production. Mississippi is no exception to these changes. The rapid adoption of GM cotton varieties in Mississippi has allowed producers to alter certain aspects of their farming operation because of added flexibility, increased yields, and other benefits of GM varieties. This study analyses the effects of certain changes in some of the most relevant components of cotton production on yield that stem from the adoption of GM varieties in Mississippi by comparing production functions from 1996 to 2005.

Keywords: Mississippi cotton production, Genetically Modified cotton varieties, structural change, production function.

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Agricultural technology has changed a great deal in the past sixty years. Technology has helped us create many different innovations to increase farm productivity. Advanced agricultural research and development techniques have led to production innovations, both products and concepts, and can be considered one of the factors driving this constant change. These innovations have made farming more efficient over time which has allowed farmers to replace labor with capital. The rapid introduction of new agricultural technology has taken producers from mule-drawn plows that tilled one half of a field-row to the current twelve row plows pulled by tractors that can be steered from satellites in outer space.

One of the most important developments in cotton production in the past decade has been genetically modified seed. Transgenic seeds are bred so that the resulting plants have advantageous traits. One example is Bollgard or (Bt) cotton in which a gene is injected into the plant's DNA (Perlack et al., 1990). "In the plant, the gene produces an insecticidal protein that was modeled on a naturally occurring soil bacterium *Bacillus thuringiensis* (Bt) var. kurstaki, with known insecticidal properties" (Peferoen, 1997). This helps protect the plant from specific insects and reduces the number of pesticide applications made by producers. Another example is Roundup ready cotton. This type of modified seed has a tolerance to the herbicide Roundup (glyphosate) which enables farmers to control foreign plants within cotton fields with increased efficiency. Both the (Bt) variety and the Roundup ready variety can be combined or used individually so that the plants possess both or just one of these characteristics. Transgenic seed has made cotton production potentially more profitable and efficient avenue for farmers.

Recent technological innovations have helped producers to produce more efficiently through the introduction of genetically modified seed. These types of seeds produce plants that require less attention throughout the growing season, allow producers to have more control over their crops during the growing season, and reduce the amount of money spent on the crop during that time. These new varieties have also proved to yield more than previous varieties. Genetically modified seed and other technological innovations have changed some of the risks associated with production. This can be observed through the insect resistance associated with Bt cotton. The trait is produced within the plant so that there is continuous protection to a certain level of infestation throughout the life of the plant. The continuous protection of Bt cotton has shifted producer risk and given farmers more options during the growing season. For example, a field that could not be planted due to soil compaction could now be placed back into production because the number of pesticide applications has been reduced which means fewer trips through the field and ultimately less soil compaction. Producers who use these varieties can also reduce their input costs by making fewer pesticide applications, burning less fuel, and eliminating the cost of labor associated with making the application.

Objectives

The objective of this study is to estimate production functions in order to determine changes in the costs of cotton production resulting from the introduction and adoption of transgenic cotton seed varieties. We know from the development of annual enterprise budgets as well as from the experience of producers that the introduction of transgenic cotton seed has changed the relative amounts of capital and labor expenses on Mississippi cotton farms. Previous research has indicated many pros and cons associated to growing genetically modified cotton varieties. Observations at the farm-level over time have verified that the costs of producing cotton have changed since the introduction of genetically modified varieties. This study will examine some of the components most responsible for the observed changes in Mississippi’s cotton yields over the period 1996 to 2005. This paper will also examine interactions between some of the most relevant input components and production practices with GM varieties which have potentially changed not only yields, but the structure of Mississippi cotton farms over the same time period.

Literature Review

The structure of American agriculture has been changing for decades. One of the most common and obvious theories related to structural change is that farms are growing larger in size and fewer in number (Gebremedhin & Christy 1996). This theory has been consistent in U.S. aggregate findings for some many years. Many other studies have attempted to create models that rank the factors most responsible for certain structural changes such as changes in farm size and productivity. Gebremedhin and Christy (1996) postulated through descriptive analysis and a survey of literature that average farm size in the U.S. had doubled, the land in farms had fallen, and the number of farms was declining and as a result larger farms accounted for most of the United States commodity sales. They also found that fewer families were living on farms and that off-farm income was rising. Huffman and Evanson (1997) found results similar to Gebremedhin and Christy using an econometric model as well as production and cost functions to determine structural and productivity changes in U.S. agriculture. Huffman and Evanson (1997) found that public extension, education of farmers, and agricultural commodity programs contributed to productivity on U.S. farms. They also found that the change in farm size was mostly due to changes in input prices and that the change in input prices was a dominant force in increasing crop specialization. Other studies have contradicted the findings of Huffman and Evanson. Studies over smaller regions have contradicted the notion of input prices being the dominant factor in determining farm size. Martin *et al.* (2002) conducted a mail survey of Mississippi Delta cotton farmers and found that farmers were using larger equipment, there were more acres per pieces of equipment, and larger farms were using less labor when compared to the 1997 survey. Other trends indicated by the survey were that farm size and the percentage of rented farmland rather than owned farmland was increasing (Martin *et al.* 2002). In a similar study, Parvin (2004) used the Mississippi State Budget Generator (MSBG) to estimate direct and fixed costs per acre for four different cotton production systems in the Mississippi Delta. Production systems differing in variety, tillage practice, commodity mix, row spacing, and equipment size were compared by the MSBG cost estimates to determine the most efficient combination of techniques. Parvin argued that growers will continue to adopt new technologies, change their production strategies, and utilize larger equipment and that these factors will continue to lead to increased farm size. Ultimately, this argument holds that producers are attempting to realize economies of size by expanding their operations.

The adoption of a new technology that allows the factors of production to be used more efficiently can, depending on the adoption rate and aggregate use of the technology, cause the structure of a market to change. One of the more remarkable recent technological breakthroughs in agriculture has been transgenic seed varieties. The varieties of transgenic crops presently available were introduced separately during the mid 1990's except for hybrid corn which was introduced over half a century ago. Since their introduction, studies have analyzed many effects of transgenic crops on an aggregate level as well as the farm level. Much research has been done to try to estimate the environmental, economic, and social costs and benefits of these crops. Lin *et al.* (2001) researched the difference in yield and pesticide costs associated with adopters and non-adopters of Bt and herbicide tolerant cotton. They found that the pesticide costs were decreased and the yield was increased for adopters of Bt cotton when compared to non-adopters. Edge *et al.* (2001), Klotz-Ingram *et al.* (1999), Brooks & Barfoot (2005), Purcell & Purlack (2004), and Kalaitzandonakes (1999) all found increased yield in Bt cotton when compared to conventional varieties. In herbicide tolerant cotton Lin *et al.* found that there was no difference in pesticide costs between adopters and non-adopters but did find a yield increase for the adopters. Several other studies found that there was a decrease in pesticide costs and pesticide use for GM varieties of cotton when compared to conventional cotton varieties (Marra *et al.* 2002), (Carpenter & Gianessi 2000), (Kalaitzandonakes 1999), and (Edge *et al.* 2001). Previous studies have also considered factors other than yield and pesticide costs. Edge *et al.* (2001) found that Bt cotton improved profitability, worker safety, control of both target and non-target pests, and increased the effectiveness of beneficial insects while also reducing the number of pesticide applications, thus lowering producer risk as well as production costs and fuel usage. Others have analyzed the effects of transgenic cotton on revenue and profitability and found that they were both increased (Marra *et al.* 2002) and (Carpenter &Gianessi 2000). Other benefits include time savings, increased land efficiency, ease of management when compared to conventional varieties, and production flexibility (Kalaitzandonakes 1999) and (Klotz-Ingram *et al.* 1999). There have been many benefits from the implementation of transgenic cotton but there are some negative externalities associated with Bt cotton. One negative externality is outlined in a study which focuses on the “refuge”. For every acre of Bt cotton planted, a certain number of acres of non-Bt cotton must be planted. This non-Bt acreage is called a refuge in the sense that the pests targeted by Bt cotton can take refuge in the non-Bt varieties so that the pests will not become resistant to the Bt gene. Banerjee *et al.* (2005) found that the required planting of refuge cotton decreases returns. Some less-developed countries have a negative view of transgenic crops because of personal beliefs and cultural practices. Others feel that scientists are tampering with natural plant evolution and believe adverse effects related to GM crops are possible in the future. Nevertheless, transgenic crops have been and will continue to be commercialized thus creating changes in the structure of production agriculture.

New technologies are implemented differently depending on the situation. Technological changes also differ by region due to unique regional characteristics, the crop mix within a particular region, and the alternate production methods used within each region. Researchers can employ numerous models and methods to measure technical change depending on the data set, variables within data sets, and the characteristics of the variables. In their study on U.S. agriculture, Zofio & Knox-Lovell (2001) used a hyperbolic efficiency measurement relative to the graph of production technology and the Malmquist Index to measure technological change. Other methods for measuring technological change include nonparametric tests which can also measure efficiency and productivity. Bar-Shire & Finkelshtain (1999) and Morrison *et al.* (2001) both used nonparametric tests in measuring technical change in U.S. agriculture. Morrison *et al.* (2001) found that, at the national level, productivity growth was due to technological innovation rather than input efficiency and that farm size and typology also influenced total factor productivity. They also found that variables such as off-farm income, farm size, and the livestock-to-crop ratio affected total factor productivity differently in different regions. Alfred *et al.* (2005) used several techniques to develop a method to estimate technologies at the farm level. Their techniques included budgeting, linear and quadratic programming, dynamic programming, and econometric approaches. They found that this approach could use whole-farm models, incorporated dynamic and stochastic attributes of certain technologies, and it could be used as an input to determine welfare impacts of technology adoption. Overall, technological change has influenced the structural change in U.S. agriculture and previous research has shown that the degree of influence varies by region.

Data Development and Methods

The data used in this experiment was collected by surveys sent out each year to a set of randomly selected cotton producers in Mississippi. The survey data used in this study was collected from survey covering the 1996 and 2005 crop years. The recipients responded to questions about various production costs, quantities of inputs, types and brands of inputs used, and the types and amounts of labor and capital used during one year for a randomly selected field on their farm. Producers answered questions concerning certain cropping practices used in the selected field such as row spacing, planting pattern, and equipment size. At the end of the growing season, a follow-up call was made to determine the yield, in pounds per acre, for participant's operation. The acreage for the randomly selected field was known as well as the total acreage for each individual's operation. Other significant data collected included share of costs (if applicable for share leases); amount (in acres) of rented, owned and leased farmland; county and soil type; and method of irrigation (if any). The survey also includes a section for tracking operations within the selected field. Within this section, farmers must specify the date of the operation, a description of the operation, the type of machinery used, materials applied (if any), and the terms of custom work (if the work was done by a custom operator). The information in this section is used to estimate the costs associated with performing certain operations.

Survey information from individual farms was collected and entered into the Mississippi State University Budget Generator (MSBG) to determine costs associated with specific operations that were performed within a randomly selected field on each recipient's farm for one year. The MSBG includes price estimates for all cotton production inputs (e.g., fuel, fertilizer, pesticides/herbicides, labor, and equipment). The cost per acre for each survey participant was estimated by dividing the costs required to complete each operation within the selected field by the number of acres within the selected field. For this study, however, units applied per acre were needed to properly estimate production functions. First, the budget generator was used to disaggregate the components of several cost categories (e.g., total cost of all fertilizers, total cost of all herbicides, total cost of all insecticides, total cost of all growth regulators, total cost of all harvest aids) into the per acre cost of each component of the previous categories. This method was used to determine per acre costs for each input incurred by each survey recipient. The per acre input costs were then divided by their respective per unit costs yielding the units per acre of input used by each producer. The next step was to get all of the inputs into similar units. To do this, the amount of active ingredient (A.I.) for each input (in lbs.) was divided by units applied per acre for each producer. The final result was pounds of active ingredient applied per acre for each input. Other inputs such as fuel, labor, and seed, were handled in a similar fashion. For example, total labor cost per acre was divided by the state average price per hour of one employee to get the number of employees per acre. The total cost of diesel per acre was divided by the state average price per gallon for diesel in the given year yielding gallons of diesel used per acre.

As previously stated, several categories of inputs were disaggregated, therefore, a large number of variables needed to be re-aggregated. This was done by re-creating the categories listed in the paragraph above. The A.I. levels of the inputs were categorized according to fertilizers, harvest aids, growth regulators, herbicides, and insecticides. Each category was then summed to get total A.I. applied per acre by category.

Herbicides were categorized as glyphosates and non-glyphosates because glyphosate-tolerance is a fairly common trait available in many GM cotton varieties. The SAS computer program was then used to estimate OLS regressions in order to obtain production functions for 1996 and 2005.

Results

Two production functions were estimated in this study; one for the 1996 crop year and the other for the 2005 crop year. Because of the vast amount of data collected in the producer survey, deciding on variables that best fit each of the years was difficult. Thus, past observations and producer-level knowledge of Mississippi cotton production was considered in order to select the most relevant set variables that affected yields in each of the two years. Due to the nature of this data, caution had to be used when selecting the set of variables so that multicollinearity could be avoided. For example, the amount of diesel used can be highly related to the number of laborers in a farming operation.

The results of the OLS regressions are presented in tables below. Table 1 gives a summary of the regression for 1996 and Table 2 is the summary for the 2005 regression. Descriptions for some of the most relevant variables in each regression will be given directly after each table. The summary of the production function for 1996 will be discussed first.

Table 1.Summary of OLS Regression, 1996

Variable Name	Parameter Estimate	Standard Error	t Value	
Intercept	63.45949	149.29321	0.43	
all_fert	0.66623	0.31309	2.13	*
ct_irr	0.16986	0.08633	1.97	**
glyph	-733.67943	357.41964	-2.05	*
glyph2	748.51528	407.96244	1.83	**
non_glyph	87.38491	46.91591	1.86	**
non_glyph2	-10.24076	4.99000	-2.05	*
d_custom	198.94759	117.18999	1.70	**
ct_oper	224.73839	107.11065	2.10	*
cac_oper	0.15387	0.05441	2.83	*
cac_oper2	-0.00002	0.00001	-2.12	*
soil4	-98.25163	62.85235	-1.56	***
F Value	4.95			
R-Square	0.4050			

* indicates significance at the .05 level
** indicates significance at the .10 level
*** indicates significance at the .15 level

Out of all of the variables included in the 1996 production function, the most relevant to this study were glyph, non_glyph, d_custom, and soil4. The "glyph" variable simply is the amount of A.I. applied per acre of herbicides that contain the chemical glyphosate and "non_glyph" is the amount of A.I. applied per acre of herbicides that do not contain glyphosate. The variable "d_custom" is a dummy-variable that indicates custom work done for a producer. In other words, some type of field operation or task contracted out to an entity outside that particular operation. Most custom work done on farms in Mississippi consists of chemical applications, harvesting, and some tillage which usually is cultivation. The last variable that will be discussed is "soil4". This dummy-variable represents poor soils.

The parameter estimates for glyphosates and non-glyphosates are -733.68 and 87.38, respectively. This indicates that yields decreased when glyphosate herbicides were applied and increased when non-glyphosate herbicides were applied. Glyph2 and non_glyph2 are the squared terms for the variables mentioned previously and must be considered when further interpreting this production function. Together, the parameter estimates for glyphosates and its squared term indicate that yield decreases at an increasing rate when glyphosate herbicides are applied. In contrast, the parameter estimates for non-glyphosates and its squared term indicate that yield increases at a decreasing rate when non-glyphosate herbicides are applied. The parameter estimate for custom work is 198.95 and significant at the ten percent level. This suggests that yields increased on average when some type of custom work was preformed. Lastly, the parameter estimate for soil4 was -98.25 and was significant at the fifteen percent level.

This shows that yields declined on average in poor soils which is not surprising for 1996. The summary for the 2005 is given in Table 2 below.

Table 2. Summary of OLS Regression, 2005

Variable Name	Parameter Estimate	Standard Error	t Value	
Intercept	748.89549	51.93654	14.42	*
all_fert	-0.43262	0.19030	-2.21	*
btrr_fuel	2.08305	1.90340	1.09	
d_skip	237.85320	84.22819	2.82	*
other_chem	28.83607	14.65049	1.97	**
non_glyph	58.05504	19.11664	3.04	*
non_glyph2	-4.25881	1.27112	-3.35	*
delta	65.52734	33.06923	1.98	**
c_ac	0.11075	0.06876	1.61	**
gm_irr	1.05048	0.42665	2.46	*
F Value	7.30			
R-Square	0.3991			

* indicates significance at the .05 level
** indicates significance at the .10 level
*** indicates significance at the .15 level

In this production function, the most relevant for this study are d_skip, other_chem, non_glyph, and delta. The first variable under discussion, d_skip, is a dummy-variable for skip-row planting patterns. Other_chem is the sum of all harvest aids, growth regulators, and fungicides applied per acre (in A.I.). The variable for non-glyphosates is similar to the variable referring to non-glyphosates in the 1996 regression where it represents the total amount of non-glyphosate herbicides applied per acre (in A.I. levels). The number of non-glyphosate herbicides used in 2005 is different from the number used in 1996 because new products have become available and many of the non-glyphosate herbicides used in 1996 have been discontinued. Delta is a dummy-variable representing acres in the delta region of Mississippi.

The parameter estimate for skip-row planting patterns is 237.85 and is significant at the five percent level. This suggests that, on average, yield increased by almost 240 pounds when a skip-row planting pattern was implemented. The variable for other chemicals has a parameter estimate of 28.84 and is significant at the ten percent level. This implies that yields increase by almost 30 pounds per acre on average when some combination of harvest aids, growth regulators, and fungicides were applied. The parameter estimates for non-glyphosates and its squared term are 58.06 and -4.26, respectively. These variables were both significant at the five percent level. This indicates that yield increases at a decreasing rate on average when non-glyphosate herbicides were applied. The estimate for the delta dummy-variable is 65.53 and is significant at the five percent level. This suggests that average yield per acre was almost 66 pounds higher in the delta region of Mississippi in 2005.

Summary and Discussion

Some general information about the changes occurring on Mississippi cotton farms must be specified before discussing certain aspects of the production functions used in this study. The adoption of GM cotton varieties has largely altered cotton production all over the world. Mississippi is no different. In 1996, thirty-four percent of the cotton acres in Mississippi were planted in GM varieties. Out of total cotton acres, Bt varieties accounted for 24% and herbicide tolerant varieties accounted for about 10%. Over time the adoption of GM cotton varieties in Mississippi increased. The percentage of GM acres in Mississippi had grown to ninety-nine percent in 2005. Bt varieties accounted for 20% of total acres, herbicide tolerant varieties accounted for about 5%, and stacked-gene varieties accounted for about 74%. The widespread adoption of GM varieties along with other technologies has made alternate cotton production strategies possible. Many production practices that were common only a decade ago are currently nonexistent. Altered production techniques can help to explain the many differences in the two production functions used in this study. Secondly, because this data is from the farm-level, certain characteristics limit the inclusion of certain variables. As discussed previously, particular variables could not be included in the production function at the same time in order to avoid multicollinearity. Consequently, the variables for each production function were chosen based on observations of previous production strategies and general knowledge of Mississippi of cotton production in each of the two years.

As stated before, the most frequently planted GM varieties planted in Mississippi in 1996 were mostly Bt and some herbicide resistant varieties. Most of the herbicide resistant varieties were not glyphosate-resistant. This explains the effects of glyphosate and non-glyphosate herbicides on yield in 1996. Glyphosate herbicides would have damaged a plant if not applied properly and non-glyphosate herbicides accounted for nearly all weed protection provided by herbicides during this time. In the years following 1996, glyphosate resistant varieties were introduced. At the same time companies such as Monsanto held patents for glyphosate herbicides that were recommended for use on many glyphosate cotton varieties. The numerous patents held by Monsanto in these two markets made the combined use of these types inputs somewhat expensive for producers.

Improvements were made to GM varieties over time and producers were able to observe the benefits of planting these varieties. Producers were also able to determine which varieties preformed better than others. In 2005, most of the cotton grown in Mississippi was stacked-gene and contained some type of glyphosate-resistant trait. This allowed producers to apply glyphosate herbicides at recommended rates during the growing season to better control weeds. Most producers could apply glyphosates at virtually the same rate in 2005 in order for them to gain the desired level of weed control. This provides reasoning as to why glyphosates were not included in the 2005 production function. The same reasoning can help explain why fertilizer has a negative effect in 2005. Producers applied fertilizers at recommended rates and, therefore, there was very little variance in the amount of fertilizer applied per acre. If the fertilizer application rate is too high then the excess fertilizer will be wasted. This could be the reason why fertilizer has a negative effect on yield in 2005. Also, many producers have stopped using anhydrous ammonia since 1996. Anhydrous was used more frequently in 1996 than in 2005 and was considered to be a better fertilizer. It is also a nematocide which could help explain the positive relationship between fertilizer and yield in 1996.

Another important relationship that warrants discussion is the effect of soil types on yield. In 1996, there was a negative relationship between poor soil types and yield. Yield would be almost 100 pounds lower in poor soil types on average when compared to better soil types. Many GM varieties available currently have proved to produce significantly higher yields in poor soil types than varieties planted in poor soil types in 1996. Because the regional dummy-variable was included in the 2005 production function soil type could not also be included. This may be because the delta variable represents the delta region of Mississippi which consists of nearly all good soil types. If variables for both good and poor soil types were included their effects on yield would not be accurate. Some information can be gained from the delta variable. In 2005, average yield in the delta is only 66 pounds higher than the rest of the state. Past cotton yields in the delta have been consistently higher than 66 pounds when compared to the rest of the state. This could show how the new GM varieties are yielding better in poor soils.

Finally, the dummy-variable for skip-row planting pattern indicates that current varieties yield much higher when compared to varieties planted in a solid pattern. Skip-row cotton does usually yield higher but controlling weeds in the skips is usually difficult and can be more expensive when compared to solid-space planting patterns. If weeds are not properly controlled in any planting pattern yield can be significantly decreased. This could indicate one alternate production system that was made more feasible by GM technology. Alternate production systems and increased yields may also be more feasible because new varieties are more compatible with inputs other than herbicides and insecticides such as fungicides, growth regulators, and harvest aids. This can be seen in the positive relationship between other chemicals (referring to harvest aids, growth regulators, and fungicides) and yield in the 2005 production function. GM varieties can allow producers to have more control over their crop which, in turn, can increase yields. Overall, GM varieties, the benefits of growing these varieties, and additional producer flexibility is transforming cotton production systems and altering the cost structure of Mississippi farms.

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