WHY DO FARMERS ADOPT BIOTECH COTTON?

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Abstract

Adoption of cotton biotechnologies is driven primarily by their effectiveness in controlling pests but also by their potential to reduce costs and production risk. Synergies with other technologies are also important. Reduced tillage practices for instance both encourage the adoption of herbicide resistant cotton varieties and are encouraged by them. Patterns of adoption of cotton biotechnologies among small and large farms are equivalent as no scale bias is found.

Introduction

First generation biotechnology crops, including cotton, have been insect resistant and herbicide tolerant. In the US and elsewhere, adoption of first generation biotechnology has been extremely fast by any account (James). Several studies have examined the factors driving such fast adoption (Fernado-Cornejo et al., Gianessi and Carpenter, Carlson et al., Klotz et al.). These studies have generally shown that farmers adopt biotechnology in pursuit of economic benefits from reduced pesticide use and yield increases. Other studies have focused on the distribution of economic benefits from the use of crop biotechnology (Falk-Zepeda et al., Frisvold et al., Traxler and Falk Zepeda). They have generally concluded that a large portion of the benefits accrues to the farmers who adopt the technology, a result that re-enforces the explanation that economics are largely responsible for its quick embrace.

Prior studies have overlooked, however, two essential elements of technology adoption. First, by focusing on effects within a single growing season, prior studies have neglected the underlying dynamics of the adoption process. Potential cost savings and yield increases from the use of crop biotechnologies are stochastic as they can vary significantly from one year to another or from one location to another due to the variability of insect and weed pressures or weather. Under such uncertain conditions farmers must learn how to optimize, both agronomically and economically, the use of biotechnologies on their farms. Farmers may then partially adopt biotechnologies and learn by continuously evaluating their performance. Adoption models that do not explicitly incorporate such dynamic learning effects can yield inefficient and biased estimates and lead to misleading results (Cameron, Abadi Ghadim and Pannell).

Second, existing studies have been preoccupied with the adoption of a single biotechnology. Yet, certain biotechnologies may substitute for each other (e.g. overlapping single and stacked gene traits). Similarly, biotechnologies may influence the performance of other pest control technologies. For instance, herbicide resistant varieties may improve the economics of reduced tillage (Heimlich et al.). Such interdependencies suggest that farmers must pursue optimal pest control solutions by choosing a <u>set</u> of technologies out of many possible bundles (Dorfman). Hence, biotechnology adoption decisions are inherently multivariate. Attempting to analyze them in isolation excludes useful economic information and may yield misleading results.

This study contributes to our understanding of the factors that drive the adoption of cotton biotechnologies and of the impacts on farming. Within our framework, farmers decide on the adoption levels of multiple interdependent pest control solutions, including biotechnologies. Decisions to adopt one or more of such technologies are simultaneous. Farmers may partially adopt one or more of these technologies as a way of optimizing their use through learning by doing.

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Why do Farmers Adopt Cotton Biotechnologies?

Over the last five years, several different cotton biotechnologies have been introduced in the market. The three most dominant, Bollgard, Roundup Ready and stacked Bollgard/Roundup Ready technologies are considered here. Collectively, these three technologies were used on almost fifty percent of the cotton acres cultivated in the US in 1999 (figure 1).

The Adoption of Bollgard Cotton

Bollgard has been engineered to resist insect pests by inserting a gene of the soil bacterium *Bacillus thurigiensis* (Bt) into the DNA of the transformed cotton variety. The gene produces a protein with well-known insecticidal activity making the cotton plant resistant to damaging insects, like the tobacco budworm and the pink bollworm. Bollgard was introduced in the market in 1996.

Farmers may adopt Bollgard cotton in order to reduce production costs, improve pest control, reduce production risk, and capitalize on synergies with certain other technologies and inputs. Specifically:

- Use of Bollgard cotton has been associated with meaningful reductions in the number of sprays for lepidoptera pests (Heimlich et al.). Fewer pesticide applications may translate into lower quantities of synthetic pesticides and associated cost reductions. Fewer sprays may also translate into meaningful labor and capital input savings as less labor and machinery hours may be necessary for mixing and spraying (ReJesus et al.).
- Potential cost efficiencies may be strengthened by more effective pest control. Bollgard varieties have been shown to provide effective protection against target pests relative to conventional programs. Bollgard varieties may also offer effective control against non-target pests. Reduced damage on beneficial insects can improve control over non-target pests and provide further efficiencies.
- Pest damage is a stochastic process influenced by the levels of pest populations, weather conditions and the pest control practices in use. To prevent major infestations, cotton growers make multiple, often complex, decisions before and during the growing season (e.g. scouting, choosing appropriate insecticides, and choosing the timing of application). Use of Bollgard cotton may reduce the risk of unpredictable outbreaks as it provides continuous protection, thereby acting as insurance. Similarly, use of Bollgard cotton can temper uncertainties associated with weather interfering with or negating ill-timed applications for key pests. Hence, use of Bollgard cotton may reduce production risk.
- Use of Bollgard cotton may also positively affect the productivity of other technologies. Synthetic pesticide applications tend to interrupt watering and interfere with efficient use of irrigation systems. Accordingly, farmers using irrigation may be more inclined to use Bollgard technology as a way of improving the efficiency of their irrigation programs.

Adoption of Roundup Ready Cotton

Roundup Ready cotton varieties have been engineered to resist the popular herbicide glyphosate that effectively controls a wide range of grasses and broadleaf weeds. Roundup Ready technology was introduced in the market in 1997.

Much like in the case of Bollgard cotton, farmers may adopt Roundup Ready cotton to reduce production costs, improve pest control, reduce production risk, and capitalize on synergies with certain technologies and inputs. Specifically:

- Use of herbicide-resistant crops has been associated with fewer herbicide applications (Carpenter and Gianessi, Heimlich et al.). As previously, a reduced number of sprays can lead to lower herbicide costs as well as lower labor and equipment costs. Further cost efficiencies may be possible from management input savings. Herbicide programs using selective post-emergence herbicides can be complex. Farmers must scout the fields, correctly identify the type and size of weeds that must be controlled and decide on an appropriate program by mixing relevant selective herbicides. All such activities require not only knowledge but also managerial time. With an effective non-selective herbicide, like Roundup, less management may be required and the effectiveness of the weed control program may improve.
- Use of Roundup Ready cotton may also reduce production risk. Selective post emergence herbicides can control specific weeds while they are small. Only a small window is therefore available for their effective use. Excessive rainfall may keep equipment off the field until weeds are too large to control. With Roundup ready cotton, the potential window for spraying is extended as glyphosate controls larger weeds well. Accordingly, production risk may be reduced.
- Through the use of Roundup Ready cotton, it may also be possible to increase the productivity of other inputs and technologies. Farmers may be in a better position to implement no-till or minimum tillage programs. They may also find Ultra Narrow Row (UNR) cultivation systems profitable. Without the interference of machinery for controlling post-emergence weeds, areas between rows can be reduced to few inches resulting in more efficient land use. Much like in case of Bollgard technology, use of Roundup Ready technology may also improve the efficiency of irrigation programs.

Adoption of Stacked Bollgard/Roundup Ready Cotton

Staked cotton varieties were introduced in 1998 to combine the benefits of Bollgard and Roundup Ready technologies. Areas with high concentration of budworm and bollworm as well as broadleaves and grasses are candidates for adoption and use of stacked Bollgard/Roundup Ready cotton varieties.

Perceptions of Benefits and Learning

As discussed above, adoption of the three cotton biotechnologies considered here is generally driven by potential cost reductions, improvements in pest control, reductions in production risk, and synergies with other inputs and technologies. Clearly, all these impacts are stochastic in nature as they are critically influenced by pest infestations and weather. Yields per acre, for instance, should increase in the long run, but they can increase, decrease or remain stable in any given year. Farmers must therefore weigh the potential benefits from these three biotechnologies against up front extra costs (e.g. technology fees).

Given the stochastic and multidimensional nature of all such effects, forming accurate expectations represents an essential part of the adoption process. Experimentation allows farmers to develop skills in the agronomic management of biotechnologies as well as to reduce the uncertainty about their long-term profitability. Hence to properly represent the underlying decision making process, an adoption model must account for farmers' subjective perceptions of potential benefits and costs. It is perceptions that guide adoption decisions after all. And it is through learning that such perceptions become more accurate, thus further clarifying the value of experimentation.

The Empirical Model

The empirical model specified here formalizes the arguments presented above and guides the empirical analysis. A more detail exposition is provided in Suntornpithug and Kalaitzandonakes.

Four equations are specified to represent the adoption of the three cotton biotechnologies and of reduced tillage practices. The four adoption decisions are interdependent and simultaneous. Accordingly, a simultaneous equation system is specified and estimated. The relevance of the hypothesized interdependencies can then be explicitly tested within this empirical model. For instance, the hypothesis that Roundup Ready and/or stacked technology encourage adoption of reduced tillage practices can be empirically assessed. So can the hypothesis that Roundup Ready and stacked varieties substitute for one another.

Dynamic learning effects are explicitly modeled through the inclusion of lagged dependent variables. Perceived gains from cost savings, more effective pest control and reductions in production risk (or "peace of mind") are considered separate drivers of the adoption decisions. In this way, their relative importance can be measured.

Use of specific inputs, like irrigation, that may encourage adoption due to potential synergies are also considered. Differences across farms –such as size and managerial ability – must also be taken into account to control for their differential impacts on adoption. In this study, computer ownership is used as a proxy of differential tendency towards technology adoption among different farms. A quadratic function of farm size is included to allow for any scale bias in the adoption process. Regional dummy variables are also used to control for systematic regional differences in pest infestations.

More specifically, the following empirical model is specified:

The Bollgard Adoption model:

$\%Bollgard_t$ = f ($\%Bollgard_{t-1}$, $\%RR_t$,$\%Stacked_t$, farm size, farm size squared, perceived cost savings from using Bollgard, irrigated Bollgard acres, perceived effectiveness of Bollgard against major insects, perceived impact of Bollgard on beneficial insects, computer ownership, perceived "peace of mind" from using Bollgard, Texas, Southern Region) + ε_{1t}

The Roundup Ready Adoption Model:

$\%RR_t$ = f ($\%RR_{t-1}$, $\%Bollgard_t$, $\%Stacked_t$, farm size, farm size squared, perceived cost savings from using RR, irrigated acres, perceived "peace of mind" from using RR, perceived effectiveness of RR against major weeds, perceived effectiveness of RR against minor weeds, % reduced tillage acres, computer ownership, Texas , Southern Region) + ε_{2t}

The Stacked Bollgard/RR Adoption Model:

$\%Stacked_t$ = f ($\%Stacked_{t-1}$, $\%Bollgard_t$, $\%RR_t$, farm size, farm size squared, perceived cost savings from using Bollgard/RR, irrigated acres, perceived "peace of mind" from using Bollgard/RR, perceived effectiveness of Bollgard/RR against major weeds, perceived effectiveness RR/Bollgard against minor weeds, % reduced tillage acres, perceived effectiveness of Bollgard/RR against insects, perceived impact on beneficial insects, computer ownership, Texas, Southern Region) + ε_{3t}

The Reduced Tillage Adoption Model:

%Reduced Tillage$_t$ *= f (%RR*$_t$*, %Stacked*$_t$*, farm size, farm size squared, irrigated RR acres, irrigated Bollgard/RR acres, computer ownership, Southern region, Texas) +* ε_{4t}

where:

- *%Bollgard*$_t$ = % of total cotton acres in 1999 planted with Bollgard
- *%Bollgard*$_{t-1}$ = % of total cotton acres in 1998 planted with Bollgard
- *%RR*$_t$ = % of total cotton acres in 1999 planted with Roundup Ready varieties;
- *%RR*$_{t-1}$ = % of total cotton acres in 1998 planted with Roundup Ready varieties;
- *%Stacked*$_t$ % of total cotton acres in 1999 planted with stacked Bollgard/Roundup Ready varieties;
- *%Stacked*$_{t-1}$ = % of total cotton acres in 1998 with stacked Bollgard/Roundup Ready varieties;
- *Farm size*= 1999 total cotton acres (in thousands of acres)
- *Texas*= dummy variable for Texas (Texas = 1, Otherwise = 0);
- *South*= dummy variable for southern region, (Louisiana and Mississippi = 1, otherwise = 0)
- *%Reduced Tillage*$_t$ = percent of total cotton acres in no-till, ridge or strip till;
- *Computer ownership* = during variable indicating computer ownership (own computer =1, otherwise = 0)
- *Perceived effectiveness of Bollgard against major insects* = perceived effectiveness of Bollgard against tobacco budworms, cotton bollworms, and pink bollworms. Measured in Likert scale (1 through 5 where 1 indicates "much better than conventional programs")
- *Perceived impacts on beneficial insects* =measured in Likert scale (1 through 4 where 1 indicates "very satisfied")
- *Perceived effectiveness of RR against major weed control* = perceived effectiveness of RR in controlling grasses, broadleaf weeds, large weeds, and morning glory. Measured in Likert scale (1 through 4 where 1 is "much better than conventional programs")
- *Perceived effectiveness of RR against minor weed control* = perceived effectiveness of RR in controlling smartweed, nutsedge, sicklepod, hempsesbania, and Johnsongrass. Measured in Likert scale (1 is "much better" than conventional program)
- *Perceived "peace of mind" from using Bollgard* = relative to conventional programs. Measured in Likert scale (1 through 4 where 1 indicates Bollgard offers great "peace of mind")
- P*erceived "peace of mind" from using RR* = Relative to conventional programs. Measured in Likert scale (1 through 4 where 1 indicates RR offers great "peace of mind")
- *Perceived "peace of mind" from using stacked RR/Bollgard* = relative to conventional programs. Measured in Likert scale (1 through 4 where 1 indicates stacked Bollgard/RR offers great "peace of mind"))
- *Perceived cost savings from using Bollgard* = Perceived cost savings from use of Bollgard relative to conventional program ($/acre)
- *Perceived cost savings from using RR* = Perceived cost savings from use of Roundup Ready relative to conventional program ($/acre)
- *Perceived cost savings from using stacked* = Perceived cost savings from use of Bollgard/Roundup Ready relative to conventional program ($/acre)
- ε_{jt} = Error terms

The conceptual model outlined above was empirically estimated through the use of grower survey data from all cotton producing states except California and Arizona. Information from 620 complete surveys was included in the estimation. The system of the four adoption equations was estimated using the Generalized Method of Moments (GMM). Three stage least squares (3SLS) and full information maximum likelihood (FIML) procedures were also used to test the robustness of the empirical estimates. Overall, these models produced similar results suggesting empirical robustness. Only the GMM results are presented here.

Empirical Results

The empirical results obtained in this study are presented in tables 1 through 4. Overall, the parameter estimates have signs that are consistent with the hypotheses developed above and are generally statistically significant.

Adoption of Bollgard Cotton

The hypothesis of partial adoption and learning by doing in the adoption of Bollgard cotton cannot be rejected at any conventional level. It is clear that strong dynamics characterize the adoption of Bollgard cotton. Similarly, the hypothesis that stacked Bollgard/RR varieties substitute for Bollgard cannot be rejected either. This might explain the aggregate trends in the adoption of Bollgard illustrated in figure 1.

The effectiveness of Bollgard to control target and non-target pests is probably the most important consideration in the farmers' adoption decision. Perceived cost savings and "peace of mind" do not have a significant influence in the decision to adopt Bollgard cotton. Hence, Bollgard technology appears to be a "pest control tool" in the mind of cotton farmers.

Consistent with the hypothesized effect, more extensive use of irrigation seems to encourage the adoption of Bollgard technology. On the other hand farm size has no effect on the propensity to adopt such technology. Adoption of Bollgard technology does not appear to be scale-biased.

Adoption of Roundup Ready Cotton

Much like in the case of Bollgard technology, the presence of strong dynamic effects and partial adoption is validated for RR technology as well. A primary driver in the adoption decision of RR cotton is grower emphasis on superior pest control, both for minor and major weeds. Reduction in production risk or "peace of mind" does have a significant and positive impact on the adoption of Roundup Ready cotton. It appears that reduction of production risks and increased flexibility are more significant in the case of Roundup Ready than in the case of Bollgard cotton.

Stacked gene technologies substitute for single gene events as in the case of Bollgard. Due to synergies, use of reduced tillage practices and irrigation have positive effects on the adoption of Roundup Ready cotton. Finally, the adoption of RR technology, much like in the case of Bollgard, is not scale-biased.

Adoption of Stacked Bollgard/RR Cotton

The effectiveness of insect and weed control provided by stacked Bollgard/Roundup Ready cotton technologies seems to dominate the adoption considerations of farmers. The substitutability between single gene and stacked technologies is once again verified.

Interestingly, perceived cost savings are significant drivers in the decision to adopt Bollgard/Roundup Ready stacked cotton varieties. The combination of insect and herbicide resistance may be resulting in sufficient reductions in the numbers of sprays that make such cost efficiencies significant. Finally, as in the case of Roundup Ready technologies, use of reduced tillage practices and irrigation encourage adoption of stacked technology.

Reduced Tillage

The synergies between herbicide resistance and use of reduced tillage practices are clearly documented in table 4. The adoption of Roundup Ready and stacked Bollgard/Roundup Ready varieties are found to encourage adoption of reduced tillage practices. The positive impacts of herbicide resistant cotton use on the adoption of reduced tillage practices are very strong. At the mean of the sample, we estimate that for every two new acres of Roundup Ready and stacked cotton varieties, one is turned into reduced tillage practices.

Implications and Conclusions

Cotton farmers consider bundles of possible pest control solutions. Several biotechnologies have been introduced in the market over the last five years. As they substitute for one another they provide multiple pest control solutions for farmers to choose from. Under such conditions, cotton growers and can more readily optimize their use on their farms.

Adoption of cotton biotechnologies is driven primarily by their effectiveness in controlling pests but also by cost savings and reductions in production risks. The emphasis seems to be on their effectiveness as pest control tools.

Synergies with other inputs and technologies are also important. Reduced tillage practices both encourage the adoption of Roundup Ready and stacked Bollgard/Roundup Ready varieties and are encouraged by them. Indeed for every two acres planted in these two biotechnologies, one is also converted to reduced tillage. This result suggests that the environmental benefits of cotton biotechnologies go beyond reduced use of pesticides and extend to soil savings and generally more sustainable farming practices.

The relative benefits from agricultural biotechnologies may expand as farmers continue to learn how to better utilize such technologies under the specific conditions of their farm. Both small and large farms can capitalize on the benefits of biotechnologies. Our empirical results suggest that there is no scale bias in their adoption patterns.

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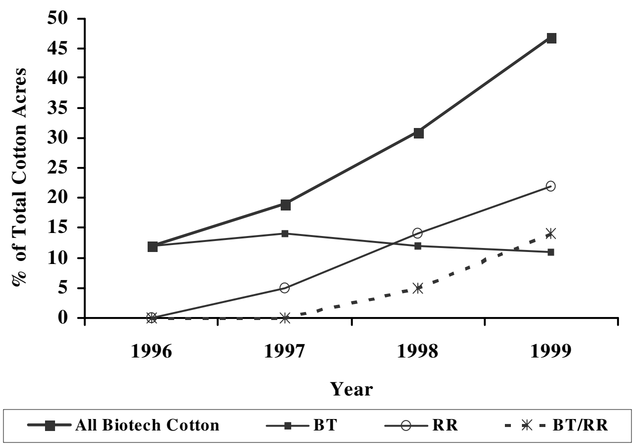

Figure 1. Adoption of Cotton Biotechnologies.

Table 1. Adoption of Bollgard (BT) Cotton.

Explanatory Variables	Parameters Estimated	t Value
Intercept	0.9259**	10.35
% Bollgard (BT) Cotton t-1	0.3174**	9.94
% Roundup Ready Cotton t	-0.0069	-0.49
% Bollgard/Roundup Ready Cotton t	-0.0530**	-2.59
Farm Size	-0.0102	-0.49
Farm Size squared	-0.0044	-0.65
Texas	-0.0039	-0.40
Southern Region	0.0608**	2.74
Cost Savings	0.0029	1.94
Peace of mind	0.0016	0.06
Irrigation Acres	0.0002**	4.33
Major Insect Control Effectiveness	-0.1369**	-4.39
Impacts on beneficial insects	-0.1647**	-8.29
Computer ownership	0.0039	0.42

* and ** indicate significance at 5 and 1 percent level, respectively.

Table 2. Adoption of Roundup Ready Cotton.

Explanatory Variables	Parameters Estimated	t Value
Intercept	1.0802**	11.27
% Roundup Ready Cotton t-1	0.3082**	8.75
% Bollgard (BT) Cotton t	-0.0192	-0.89
% Bollgard/Roundup Ready Cotton t	-0.0544	-1.81
% Minimum Tillage Acres	0.1849**	4.22
Farm Size	-0.0615	-1.91
Farm Size squared	0.0021	0.22
Texas	-0.0210	-1.00
Southern Region	-0.0373*	-3.24
Cost Savings	0.0017	1.35
Peace of mind	-0.1011**	-4.44
Irrigation Acres	0.0002**	5.38
Major Weed Control Effectiveness	-0.0791**	-4.15
Minor Weed Control Effectiveness	-0.1437**	-4.44
Computer ownership	-0.0045	-0.33

* and ** indicate significance at 5 and 1 percent level, respectively.

Table 3. Adoption of Stacked Bollgard/ Roundup Ready Cotton.

Explanatory Variables	Parameters Estimated	t Value
Intercept	1.0250**	15.39
% Bollgard/Roundup Ready Cotton t-1	0.2595**	6.36
% Bollgard (BT) Cotton t	-0.0756**	-3.05
% Roundup Ready Cotton t	-0.0506**	-2.76
% Minimum Tillage Acres	0.2726**	5.51
Farm Size	-0.0434	-1.77
Farm Size squared	0.0039	0.61
Texas	-0.0599**	-4.29
Southern Region	0.0086	0.39
Cost Savings	0.0060**	4.54
Peace of Mind	-0.0042	-0.18
Irrigation Acres	0.0004**	5.87
Insect Control Effectiveness	-0.1451**	-7.74
Weed Control Effectiveness	-0.1613**	-8.87
Computer Ownership	0.0144	1.18

* and ** indicate significance at 5 and 1 percent level, respectively.

Table 4. Adoption of Reduced Tillage in Cotton.

Explanatory Variables	Parameters Estimated	t Value
Intercept	-0.0639**	-2.47
% Roundup Ready Cotton t	0.3094**	7.20
% Bollgard/Roundup Ready Cotton t	0.3028**	7.72
Farm Size	0.0505	1.43
Farm Size squared	-0.0074	-0.79
Texas	-0.0284	-1.43
Southern Region	-0.0028	-0.17
Irrigation Acres for Roundup Ready Cotton	-0.0001	-0.91
Irrigation Acres for Bollgard/RR Cotton	-0.0002**	-3.05
Computer ownership	0.0154	0.93

* and ** indicate significance at 5 and 1 percent level, respectively.