Understanding the Adoption of Cotton Biotechnologies in the US:

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Abstract

By most measures, adoption of first generation crop biotechnologies in the United States and elsewhere has been extremely fast. Yet, only modest research effort has been devoted to understanding why producers in different parts of the world have adopted these technologies at such rapid rates. In this paper, we analyze producer decisions on whether to adopt three separate cotton biotechnologies in the US and to what extent. We find that US cotton producers tend to choose bundles of conventional technologies, agrobiotechnologies and relevant agronomic practices out of many possible ones. Hence, their behavior is characterized by multiple simultaneous and interdependent adoption decisions. Furthermore, US cotton producers partially adopt one or more of the biotechnologies, probably, as a way of optimizing their use through "learning by doing" thereby incorporating complex dynamic considerations in their decision process.

Introduction

By most measures, adoption of first generation crop biotechnologies in the United States and elsewhere has been extremely fast (James, 2006). Yet, only modest research effort has been devoted to understanding why producers in different parts of the world have adopted these technologies at such rapid rates. Indeed, one can find only a few published studies that have empirically examined producer behavior in the adoption of crop biotechnologies (Alexander and Van Mellor, Alexander et al., Fernando-Cornejo and McBride, Kolady and Lesser, Marra et al. 2001, Qaim and deJanvry 2003, Payne et al.). Instead, there has been more interest in measuring the impacts of agrobiotechnologies and their distribution both at the farm-level and at an aggregate level. For instance, just in the case of insect resistant biotech cotton, farm-level and aggregate impact studies include, Barwale, et al.; Bennett, et al. 2004, 2006a, 2006b; Carpenter and Gianessi; Elbehri and MacDonald; Falck-Zepeda, et al.; Frisvold and Tronstad; Frisvold et al.; Gianessi, et al.; Gouse, et al.; Huang, et al. 2002a 2002b 2002c 2003 2004; Ismael, et al.; Klotz-Ingram, et al.; Pray et al. 2001, 2002, Price et al., Qaim, Qaim and de Janvry, 2005; Qaim and Zilberman; Qaim et al., 2003, 2006; Shankar and Thirtle; Thirtle, et al.;Traxler, et al. 2002; Traxler and Godoy-Avila; Traxler & Falck-Zepeda.

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Given the broad interest in the impacts of agrobiotechnologies, the limited number of adoption studies is curious. After all, unless the factors that drive adoption and shape producer behavior are clearly understood, it is difficult to decide how should "impact" be defined and measured.

In this paper, we add to the body of agrobiotechnology adoption studies. Specifically, we analyze producer decisions on whether to adopt three separate cotton biotechnologies in the US and to what extent. Previous adoption (and impact assessment) studies have considered the uptake of agrobiotechnologies one at a time, that is, separately from the adoption of other agrobiotechnologies or related agronomic practices. This approach, however, might be narrow, limiting our understanding of what drives their rapid adoption and, ultimately, of what their impacts might be. As we discuss here, producer adoption behavior in the case of cotton biotechnologies appears to be a great deal richer. Specifically, we find that US cotton producers tend to choose bundles of conventional technologies, agrobiotechnologies and relevant agronomic practices out of many possible ones. Hence, their behavior is characterized by multiple simultaneous and interdependent adoption decisions. Furthermore, US cotton producers partially adopt one or more of the biotechnologies, probably, as a way of optimizing their use through "learning by doing" thereby incorporating complex dynamic considerations in their decision process.

Agronomic Characteristics & Potential Adoption Determinants of Biotech Cotton

Over the last ten years, five different cotton biotechnologies have been introduced in the US market and in 2006 they occupied 83% of all cotton acres (figure 1). The three most dominant of these biotechnologies --Bollgard, Roundup Ready, and stacked Bollgard/Roundup Ready –are considered here.[i] Collectively, these three biotechnologies have been used on more than 65% of the US cotton acres since 2000.

Bollgard Cotton

Fewer applications may translate into lower quantities of synthetic pesticides and associated material input expenses. 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., 1997).

Potential cost efficiencies may be strengthened by more effective pest control relative to that achieved through conventional varieties. BG varieties have been shown to provide effective protection against target pests (Edge et al., 2001). Their relative effectiveness may also improve through depreciation in the effectiveness of conventional pest control methods through insect resistance buildup (Marra et al., 2001, and also Pray and Huang, and Traxler et al.). Furthermore, reduced damage of beneficial insects can improve secondary control over non-target pests and provide further efficiencies (Edge et al., 2001).

Pest damage is stochastic, influenced by the levels of pest populations and weather conditions. 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 BG cotton may reduce the risk of unpredictable outbreaks as it provides continuous protection, thereby acting as

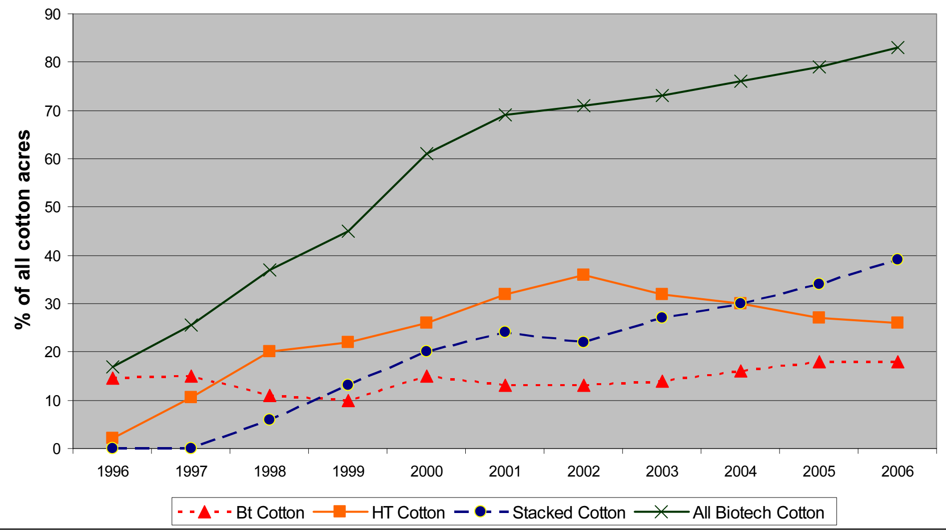

Figure 1 US Biotech Cotton Adoption, 1996-2006

Data Sources: EMAC Biotech Adoption Database (1996-1999) and NASS-USDA (2000-2006)

insurance (Carpenter and Gianessi, 2000). Similarly, use of BG cotton can temper uncertainties associated with weather interfering with or negating ill-timed applications for key pests. Hence, use of BG cotton may reduce production risk and, over time, increase yields.

Synergies with certain agronomic practices might also exist. For instance, use of BG cotton may increase the productivity of mechanized irrigation systems. Synthetic pesticide applications tend to interrupt watering and interfere with efficient use of irrigation systems. Accordingly, producers who use irrigation may be more inclined to adopt BG technology as a way of improving the efficiency of their irrigation programs.

Roundup Ready Cotton

Roundup Ready (RR) cotton varieties have been engineered to resist the herbicide glyphosate, which effectively controls a wide range of grasses and broadleaf weeds. The RR technology was introduced in the US market in 1997.

Use of herbicide resistant cotton has allowed the substitution of low-priced glyphosate for more expensive selective post-emergence herbicides and, in some cases, fewer herbicide applications (see for instance Heimlich et al., 2000). As with BG cotton, 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 postemergence herbicides can be complex. Producers 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 specialized knowledge but also managerial time. With an effective non-selective herbicide, such as glyphosate, less management may be required.

Use of RR cotton may also reduce production risk. Selective postemergence herbicides can control specific weeds while they are in early phases of growth. Only a narrow window is therefore available for their effective use. Excessive rainfall may keep equipment off the field until weeds are too mature to control. With RR cotton, the potential window for spraying is extended, as glyphosate controls larger weeds well. Accordingly, production risk and associated output losses may be reduced.

Potential synergies between RR cotton and certain agronomic practices also exist. The most notable example is the increased ease of implementing no-till or minimum tillage programs in RR cotton acres (Carpenter and Gianessi, 2000). Producers may also find Ultra Narrow Row cultivation systems increasingly profitable with more effective early season burndown (Husman et al., 2001). The decreased need of machinery for controlling postemergence weeds may allow areas between rows to be reduced to few inches, resulting in more efficient land use. As in the case of BG technology, use of RR technology may also improve the efficiency of irrigation programs.

Stacked Bollgard/Roundup Ready Cotton

Stacked Bollgard/Roundup Ready (ST) cotton varieties were introduced in 1998 to combine the properties of BG and RR technologies. The two technologies are employed for different purposes but may find application in the same fields. Hence, producers can evaluate the economics of single traits independently or as a bundle. Use of stacked traits is most likely to occur in areas with high concentrations of budworms and bollworms, as well as broadleaves and grasses.

Perceptions of Economic Advantages and Learning

The potential economic advantages offered by the three cotton biotechnologies are expected to directly influence producer adoption considerations. Accordingly, producers may adopt BG, RR, or ST cotton in order to reduce production costs, ease production risks and associated output losses and exploit potential synergies with relevant agronomic practices. Adoption decisions for these three agrobiotechnologies, however, may not be entirely independent. In many cases, the individual technologies could readily substitute for one another. For instance, single trait and stacked cotton biotechnologies may be close substitutes given their overlapping pesticidal activities. Within this context, the adoption decision of one agrobiotechnology might directly influence the adoption decision of another.

Complementarities between BG, RR, and ST with certain agronomic practices might also exist implying further adoption interdependencies. For instance, use of herbicide resistant technologies may improve the economics of minimum tillage and strengthen its adoption. Increased adoption of minimum tillage could simultaneously encourage adoption of RR and ST technologies in cotton production.

As producer adoption decisions become more interdependent, complexity and uncertainty increase. All the potential technical advantages of agrobiotechnologies are stochastic in nature, as they are critically influenced by the actual levels of pest infestations and by weather. It is up to the producers to separate “noise” from potential.

Producers must therefore weigh the potential technical and economic advantages of agrobiotechnologies in the face of uncertainty and against up-front extra costs (e.g., more expensive seeds and licensing fees for the technologies). Under uncertain conditions, producers may partially adopt such technologies to slowly evaluate their performance (Abadi Gadim and Pannell, 1999, Cameron, 1999; Kalaitzandonakes and Boggess, 1993, Marra et al., 2001). Over time and through "learning by doing," producers can then sharpen their expectations about the profitability of the three technologies and gain knowledge on how to optimize their use, both agronomically and economically, on their farms.

Given these potential influences, in this study we explicitly consider and test for learning and technological interdependencies in the adoption of cotton biotechnologies. US cotton producers are hypothesized to decide on the adoption of multiple interdependent agrobiotechnologies and other related agronomic practices. Decisions to adopt one or more of such technologies and agronomic practices are simultaneous. Producers may partially adopt one or more of these technologies as a way of optimizing their use through learning by doing.

The Empirical Model

The theoretical study of technology adoption in agriculture dates back to the seminal work of Griliches. Since then, a variety of economic decision models have examined how producers might behave when faced with the possibility of new technology adoption. In all cases, producers are assumed to choose between the traditional and the new technology in order to maximize their expected utility or profit. Along these lines the qualitative effects of risk, risk attitudes, firm size, credit constraints and other relevant factors on technology adoption have been derived (e.g. Feder, Just and Zilberman). A number of empirical studies have added detail and have generally shown that producer adoption tends to be a function of farm and farmer characteristics, institutional factors and features of a particular technology.

Feder extended previous theoretical considerations and showed that technology adoption could be viewed as a multiple choice problem. Producers consider a set of possible new technologies or technology bundles and choose the bundle that maximizes their expected utility or profit. Dorfman examined empirically the simultaneous adoption of multiple technologies within a multivariate adoption model. Each adoption decision was assumed dichotomous (adopt/not adopt) resulting in a multinomial probit model.

Following Feder and Dorfman, we also model producer adoption of the three cotton agrobiotechnologies and of reduced tillage practices in US cotton production[ii]by a system of simultaneous equations. Producers can adopt the technologies of interest both independently and as bundles. Adoption decisions can, therefore, be interdependent and simultaneous. Our empirical specification departs from that of Dorfman in two ways: first we assume that adoption decisions are not dichotomous but rather farmers can plant a portion of their land with one of the new technologies. Hence, partial adoption is possible. Furthermore, instead of the Bayesian framework employed by Dorman we use an *ad hoc* learning rule. Accordingly, we specify and estimate the following simultaneous equation system:

$$A_{it} = a_{i0} + a_{ii} A_{it-1} + \sum_{j \neq i} a_{ij} A_{jt} + \sum_{k} b_{ik} X_{ikt} + \sum_{m} c_{im} Z_{imt} + \varepsilon_{it}$$

with (*i,j* = BG, RR, ST, TIL); *k* = 1... N; *m* = 1...M. A_{it} represents a producer's land allocation in period t to the three cotton biotechnologies and related agronomic practices whose adoption is considered simultaneously – reduced tillage (TIL) in our case (i=BG,RR,ST,TIL). X_{ikt} denotes the kth indicator of the perceived relative effectiveness of biotechnology i in period t. Z_{it} is a vector of M other variables that can affect the producer adoption decisions for the ith technology and include farm and farmer characteristics and regional influences. Dynamic learning effects are explicitly modeled through the inclusion of lagged dependent variables, which are intended to capture the iterative nature of the adoption process.

The relevance of the hypothesized synergies with agronomic practices can be explicitly tested within this empirical model. For instance, the hypothesis that RR and/or ST technologies encourage adoption of reduced tillage practices can be empirically assessed by evaluating the statistical significance of a_{24} and a_{34}. So can the hypothesized substitutability of agrobiotechnologies. Uses of other agronomic practices, such as irrigation, that may encourage adoption due to potential synergies are also considered and empirically tested.

The impacts of the perceived effectiveness of the new technologies on the adoption decision of the producers are captured through three separate indicators: producer perception of effectiveness in pest control, cost savings, and risk reduction. These indicators are relative in the sense that they measure performance against conventional technologies, which serve as the numeraire. Through learning, perceptions become more accurate, thus further clarifying the value of experimentation (Abadi Gadim and Pannell, 1999).

Differences across producers -such as size and managerial propensity to adopt new technologies- 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 effects in the adoption process. Two regional dummy variables are also used to control for systematic differences in pest infestations and in the limited availability of bioengineered cotton varieties in a certain area (e.g. Texas). Table 1 lists the variables used in the empirical estimation of the adoption and clarifies their measurement while Table 2 provides descriptive statistics.

The adoption model outlined above was empirically estimated using producer survey data. In order to capture the rich substitution effects among the three cotton biotechnologies, adoption data was sought for the years where BG adoption was still increasing and ST was coming into the market. In more recent years, ST technology has dominated adoption patterns, while BG adoption has stabilized (Figure 1). Several market research companies were contacted for such data availability and an appropriate dataset was located. The data set used includes information on the use of the three biotechnologies of interest by cotton producers from all cotton growing states[iii]except California and Arizona and it was collected through a survey conducted by the market research firm Marketing Horizons Inc. in 1999. From the 620 producers in the sample, 497 used one or more biotech cotton technology and 123 did not use any.

Table 1. Variables used in the empirical model

Variable	Definition
A1t	Percent of total cotton acres in 1999 planted with Bollgard varieties
A1t-1	Percent of total cotton acres in 1998 planted with Bollgard varieties
A2t	Percent of total cotton acres in 1999 planted with Roundup Ready varieties
A2t-1	Percent of total cotton acres in 1998 planted with Roundup Ready varieties
A3t	Percent of total cotton acres in 1999 planted with stacked BG/RR varieties
A3t-1	Percent of total cotton acres in 1998 with stacked BG/RR varieties
A4t	Percent of total cotton acres in no-till, ridge or strip till
X11	Perceived relative effectiveness of BG against tobacco budworms, cotton bollworms, and pink bollworms. Measured in Likert scale (1 through 4, where 4 indicates "much better than non-BG programs")
X12	Perceived impact of BG on beneficial insects. Measured in Likert scale (1 through 4, where 4 indicates "very satisfied")
X13	Perceived risk reduction from using BG, relative to conventional programs. Measured in Likert scale (1 through 4, where 4 indicates BG offers greater "peace of mind" relative to non-BG programs)
X14	Perceived cost savings from use of BG, relative to non-BG program ($/acre)
X21	Perceived effectiveness of RR in controlling grasses, broadleaf weeds, large weeds, and morning glory. Measured in Likert scale (1 through 4, where 4 is "much better than non-RR programs")
X22	Perceived risk reduction from using RR, relative to conventional programs. Measured in Likert scale (1 through 4, where 4 indicates RR offers greater "peace of mind" relative to non-RR programs)
X23	Perceived cost savings from use of RR, relative to non-RR programs ($/acre)
X31	Perceived effectiveness of stacked BG/RR in controlling insects. Measured in Likert scale (1 through 4, where 4 indicates "much better than conventional programs")
X32	Perceived effectiveness of stacked BG/RR in controlling weeds. Measured in Likert scale (1 through 4, where 4 indicates "much better than conventional programs")
X33	Perceived risk reduction from using stacked BG/RR, relative to conventional programs. Measured in Likert scale (1 through 4, where 4 indicates stacked BG/RR offers greater "peace of mind" than conventional programs)
X34	Perceived cost savings from use of BG/RR, relative to conventional program ($/acre)
Z11	Irrigated Bollgard acres
Z21	Irrigated Roundup Ready acres
Z31	Irrigated stacked BG/RR acres
Z2	1999 total cotton acres (in thousands of acres)
Z3	Own computer = 1, otherwise = 0
Z4	Dummy variable for Texas (Texas = 1, otherwise = 0)
Z5	Dummy variable for southern region (Louisiana and Mississippi = 1, otherwise = 0)

Table 2. Descriptive statistics of variables used in the empirical model

Explanatory variables	Mean	Std Dev	Minimum	Maximum
% BG cotton in 1999	0.158	0.301	0	1
% RR cotton in 1999	0.266	0.363	0	1
% ST cotton in 1999	0.198	0.323	0	1
% total Min Tillage Acres in 1999	0.105	0.257	0	1
% BG cotton in 1998	0.169	0.311	0	1
% RR cotton in 1998	0.198	0.331	0	1
% ST cotton in 1998	0.105	0.241	0	1
Estimated cost savings from BG ($/acre)	1.003	5.749	-30	50
Estimated cost savings from RR ($/acre)	1.671	7.672	-40	60
Estimated cost savings from ST ($/acre)	1.921	7.744	-25	60
Irrigation -BG acres	31.352	161.510	0	3000
Irrigation -RR acres	73.705	292.331	0	4200
Irrigation -ST acres	32.605	141.764	0	1500
Perceived BG insect control effectiveness	2.838	0.378	1	4
Perceived Impacts of BG on beneficial insects	2.662	0.721	1	4
Perceived RR weed control effectiveness	2.449	0.738	1	4
Perceived ST weed control effectiveness	2.700	0.598	1	4
Perceived ST insect control effectiveness	2.748	0.553	1	4
Perceived risk reduction from BG	2.866	0.544	1	5
Perceived risk reduction from RR	2.662	0.713	1	5
Perceived risk reduction from ST	2.839	0.579	1	5
% of RR in Min Tillage	0.060	0.202	0	1
% of ST in Min Tillage	0.045	0.175	0	1
Farm size (1000 acres)	0.821	0.623	0.065	4.2
Farm size^2	1.061	2.036	0.004225	17.64
Computer ownership	0.483	0.500	0	1
Dummy for Texas	0.338	0.473	0	1
Dummy for South (LA & MS)	0.180	0.385	0	1

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. Only the GMM results are presented here.

Few a priori restrictions were imposed on the parameters of the estimated system. For instance, since there are no synergies between minimum tillage practices and BG technology, TIL does not appear in the adoption model for BG. Similarly BG does not appear as explanatory variable in the adoption of minimum tillage practices (TIL). Similarly, effectiveness in weed control does not appear in the BG adoption equation and effectiveness in insect control does not appear in the RR adoption equation as they do no have a relevant meaning. However, such types of parameter restrictions have been kept to a minimum in the empirical models estimated here.[iv]

Empirical Results

The empirical results obtained in this study are presented in Tables 3 through 6. Overall, the parameter estimates have signs that are consistent with the behavioral hypotheses developed and are generally statistically significant.

Table 3. Adoption of Bollgard **cotton**

Explanatory Variables	Parameters Estimated	*t* Value
Intercept	-0.7327**	-7.310
% Bollgard (BT) Cotton t-1	0.3158**	9.230
% Roundup Ready Cotton t	-0.0044	-0.310
% Bollgard/Roundup Ready Cotton t	-0.0570**	-2.640
IrrigationBollgard Acres	0.0002**	3.560
Perceived Cost Savings	0.0024*	1.980
Percevied Risk Reduction	0.0051	0.260
Perceived Insect Control Effectiveness	0.1389**	4.430
Impacts on Beneficial Insects	0.1634**	7.770
Farm Size	-0.0090	-0.410
Farm Size2	-0.0045	-0.640
Computer Ownership	0.0058	0.640
Region 1	-0.0065	-0.640
Region 2	0.0652**	2.860

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

Adoption of Bollgard Cotton

The hypothesis of "learning by doing" cannot be rejected at any conventional level in the case of BG cotton. The results clearly point to strong partial adoption dynamics. Similarly, the hypothesis that ST technologies substitute for BG cannot be rejected either. This implies substitution possibilities between these two cotton biotechnologies exist and might explain the aggregate trends in the adoption of BG illustrated in Figure 1.

Hypothesized synergies with certain agronomic practices also play a significant role in the adoption of BG technology. Specifically, more extensive use of irrigation encourages the adoption of BG technology.

The effectiveness of BG to control target pests against that of conventional practices is one of the most important factors in the farmers' adoption decision[v]. This maybe as much a reflection on the limited effectiveness of some conventional pest control practices. Resistance to certain synthetic pesticides has limited their effectiveness in recent years and could have motivated the fast adoption of BG technologies. Hence, our results are in agreement with those of Mara et al., who argued that depreciation of conventional technologies explain much of the adoption of BG cotton in the US.

Producers also value the perceived selective action of BG technologies and account for it in their adoption decisions. Those producers who perceive effective preservation of beneficial insects, and concomitant benefits from secondary pest control, increase their level of BG adoption.

Perceived cost savings have a weak but positive impact on the level of adoption of BG technologies.[vi] Producer land allocation to BG technologies increases with the size of perceived cost savings. Perceived reductions of production risk do not have, however, a significant separate influence on the decision to adopt BG cotton.[vii]

Farm size has no effect on the propensity to adopt such technology. As such, adoption of BG technology does not appear to be scale-biased. Given the perfect divisibility of the technology, this result is not surprising.

Adoption of Roundup Ready Cotton

Much like in the case of BG technology, the presence of strong partial adoption dynamics, which are consistent with "learning by doing," are validated for RR technology as well. Hence, the hypothesis that producers allocate portions of their land resources with intent to learn through experience, cannot be rejected.

The hypothesis that stacked trait technologies readily substitute for single trait RR technologies can be rejected at the conventional 5% level. Hence, ST technologies may not provide a sufficient flexible alternative for RR adopters.

Table 4. Adoption of Roundup Ready **cotton**

Explanatory Variables	Parameters Estimated	*t* Value
Intercept	-0.5049**	-6.920
% Roundup Ready Cotton t-1	0.3640**	9.360
% Bollgard (BT) Cotton t	-0.0427	-1.720
% Bollgard/Roundup Ready Cotton t	-0.1530**	-5.130
% Minimum Tillage Acres	0.2709**	6.230
IrrigationRR Acres	0.0002**	3.660
Perceived Cost Savings	0.0027	1.810
Perceived Risk Reduction	0.0582**	2.600
Perceived Weed Control Effectiveness	0.1525**	7.990
Farm Size	-0.0620	-1.760
Farm Size2	0.0032	0.300
Computer Ownership	-0.0092	-0.650
Region 1	-0.0228	-1.030
Region 2	-0.0316*	-2.520

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

Use of reduced tillage practices and irrigation are also found to have positive effects on the adoption of RR cotton. Hence, due to apparent synergies, as producers expand their use of reduced tillage and irrigation they also tend to allocate a larger portion of their land to RR cotton.

As in the case of BG, adoption of RR technology is strongly influenced by its relative weed control effectiveness. The importance of perceived cost and risk reductions, however, is reversed. The perceived effectiveness of RR cotton in reducing production risks play a significant role in the producer adoption decision. As the perceived effectiveness to reduce risk becomes stronger, land allocated to RR cotton also tends to increase. Perceived cost reductions, however, is not found to have significant separate influence on the adoption decision. This suggests that risk reduction and increased flexibility maybe more significant in the case of RR.

As previously, the adoption of RR technology, is not scale-biased. Hence, both small and large producers have similar propensities to adopt RR technology.

Adoption of Stacked Bollgard/Roundup Ready Cotton

As in the case of BG and RR, partial adoption dynamics characterize the adoption of ST technologies. We also find that the speed of adjustment is about the same for all three technologies. Hence, it appears that partial adoption and "learning by doing" is an overall producer strategy applied uniformly across all agrobiotechnologies. The substitutability between single trait and stacked technologies is once again verified. Single trait BG and RR technologies are found to act as strong substitutes for ST technologies. As expected, the degree of substitutability between single and stacked trait technologies is not symmetric.

The effectiveness of insect and weed control provided by ST relative to that of conventional pest control technologies seems, once again, to provide strong incentives for adoption. Perceived cost savings become a significant driver in the decision to adopt ST cotton varieties. The combination of BG and RR traits may be resulting in a reduction in the numbers of sprays sufficient to make such cost efficiencies significant. Perceived effectiveness in reducing production risk does not have a significant separate influence in the decision to adopt ST cotton.

As with RR cotton, use of reduced tillage practices and irrigation encourage adoption of ST technology in cotton production. Hence, the synergy between reduced tillage practices and herbicide resistant cotton is confirmed for both RR and ST technologies as reduced tillage practices encourage their adoption. A key question of interest then is whether such synergies are reciprocal. That is, whether the adoption of RR and ST technologies tends to encourage the adoption of reduced tillage in cotton production as well?

Reduced Tillage

From the fourth and final equation of our empirical model, this last question can be readily answered. The synergies between herbicide resistance and use of reduced tillage practices are once again documented in Table 6. Specifically, adoption of both RR and ST varieties encourages the 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 RR or stacked cotton varieties, one is turned into reduced tillage practices. These results are important as, for the first time, they lend statistical support to prior anecdotal evidence.

Table 5. Adoption of stacked Bollgard/Roundup Ready cotton

Explanatory Variables	**Parameters Estimated**	***t* Value**
Intercept	-0.8228**	-11.050
% Bollgard/Roundup Ready Cotton t-1	0.2621**	5.990
% Bollgard (BT) Cotton t	-0.0786**	-3.240
% Roundup Ready Cotton t	-0.0462**	-2.760
% Minimum Tillage Acres	0.2784**	4.870
IrrigationBollgard/RR Acres	0.0003**	5.620
Perceived Cost Savings	0.0063**	4.540
Perceived Risk Reduction	0.0003**	5.620
Perceived Insect Control Effectiveness	0.1469**	7.800
Perceived Weed Control Effectiveness	0.1652**	8.710
Farm Size	-0.0477*	-1.950
Farm Size2	0.0054	0.820
Computer Ownership	0.0159	1.320
Region 1	-0.0602**	-4.510
Region 2	0.0137	0.620

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

Table 6. Adoption of reduced tillage in cotton acres

Explanatory Variables	**Parameters Estimated**	***t* Value**
Intercept	-0.0656**	-2.670
% Roundup Ready Cotton t	0.3292**	8.130
% Bollgard/Roundup Ready Cotton t	0.3012**	7.850
Irrigation Acres for Roundup Ready Cotton	-0.0001	-0.890
Irrigation Acres for Bollgard/RR Cotton	-0.0002**	-3.170
Farm Size	0.0503	1.480
Farm Size2	-0.0073	-0.770
Computer Ownership	0.0176	1.080
Region 1	-0.0016	-0.100
Region 2	-0.0318	-1.690

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

Implications and Conclusions

From our analysis, we conclude that US cotton producers consider bundles of agro-biotechnologies and synergistic agronomic practices in their adoption decisions. Several agrobiotechnologies have been introduced in cotton production over the last ten years. As some of them substitute for one another, they provide alternative pest control solutions for producers to choose from. Depending on the specific pest pressures and other relevant local conditions, cotton growers can then more readily optimize their use on their farms.

Synergies with certain agronomic practices are strong for all three cotton biotechnologies considered here. Reduced tillage practices both encourage the adoption of RR and ST varieties and are encouraged by them. This result suggests that the potential environmental benefits of cotton biotechnologies may go beyond reductions in pesticide use found in previous studies and could extend to soil savings.

The perceived relative effectiveness of agrobiotechnologies against that of conventional pest control practices is a key driver of adoption. This supports arguments made in a previous study (e.g. Marra et al.) that the depreciation and diminished effectiveness of conventional pest control practices is the most significant factor contributing to the rapid adoption and diffusion of BG and ST technologies.

The separate importance of perceived reductions in costs and risks is somewhat less clear. Our results suggest that perceived cost savings encourage adoption of BG and ST technologies while it is perceived risk reductions that are important for the adoption of RR technologies. Perhaps, BG and ST are viewed more as cost reducing technologies while RR is regarded as a risk management technology. Alternatively, the weaker statistical significance and reversal of signs across the three technologies may indicate that perceptions of cost and risk advantages are somewhat subsumed in the perceptions of pest control effectiveness and have only weak separate effects in the estimation.

Dynamics consistent with partial adoption and "learning by doing" behavior were found to be strong in all agrobiotechnologies considered here. This is hardly surprising given the complexity of the adoption decisions confronting the producers. The finding that the speed of adjustment is similar across all three agrobiotechnologies suggest that a common "rule of thumb" maybe used by producers. Partial adjustment and learning suggest that the relative benefits of the three agrobiotechnologies may expand as farmers continue to learn how to better utilize such technologies under their specific production conditions.

Both small and large producers can capitalize on the perceived benefits of the three cotton biotechnologies considered here. Our empirical results suggest that there is no scale bias in their adoption patterns.

What do these results mean for impact assessment? Our adoption models uncover a rather rich and complex decision process. Producer behavior is shaped by a multitude of economic incentives that emerge from intertwined substitution possibilities, synergies, uncertainties, and dynamics. These results suggest that producer behavior in the adoption of the three agrobiotechnologies is considerably more complex than that typically incorporated in our impact assessment models. Since assumed producer behavior decides the analytical boundaries of impact assessment, the direct implication then, is that our empirical measures of the impact of agrobiotechnologies are partial and somewhat narrow in scope. Hence, increased emphasis on producer behavior analysis might be necessary in order to broaden the scope and effectiveness of impact assessment in the case of cotton agrobiotechnologies, and beyond.

Notes

[1] BXN cotton,which is resistant to the herbicide bromoxynil, was introduced to the US cotton market in 1995. Adoption of BXN cotton has bee limited by a restriction on the amount of cotton acres that can be treated with bromoxynil –roughly 4% of US cotton acreage. Another herbicide-resistant cotton, the Liberty Link cotton system, was introduced in 2004 and has also seen limited adoption.

[2] We also allow other agronomic practices (e.g. use of irrigation) to affect the adoption decisions of BG, RR and ST technologies but we do not explicitly model their adoption.

[3] The survey consists of samples in the following states: Alabama, Arkansas, Florida, Georgia, Louisiana, Missouri, Mississippi, North Carolina, New Mexico, Oklahoma, South, Carolina, Tennessee, Texas, and Virginia.

[4] The question that solicited the respondents' perceptions was worded as follows in the survey: "How would you compare Bollgard to non-Bollgard cotton and traditional insecticide programs in terms of control of tobacco budworms, cotton bollworms and pink bollworms? Would you say your Bollgard cotton program is: (4) much better, (3) somewhat better, (2) not as good, or (1) not nearly as good as non-Bollgard cotton and traditional insecticide programs?"

[5] The question that solicited the respondents' perceptions was worded as follows in the survey: "On a cost per acre basis, how much [more/less] would you say it costs for just labor and equipment for insect control in Bollgard cotton as compared to non-Bollgard cotton."

[6] The question that solicited the respondents' perceptions was worded as follows in the survey: "In evaluating Bollgard cotton, taking in account any differences in convenience and peace of mind, do you believe that Bollgard cotton as compared to non-Bollgard cotton, is: (5) a much better value than non-Bollgard cotton; (4) a somewhat better value; (3) about the same; (2) not as good a value; (1) not nearly as good a value as non-Bollgard cotton.

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