**Farm Profits from Stochastic and On-Farm Yields of Bt and Non-Bt Cotton
in the Mississippi Delta**

Swagata "Ban" Banerjee, Steven W. Martin, and Michael E. Wetzstein

Abstract
Net per acre returns and total returns for an average cotton farm in Mississippi Delta were
calculated from observed and simulated yields. Results indicate higher mean profits on Bt cotton
with insecticide spray than without. For any refuge percentage, mean returns are higher with less
risk when spray is applied.

Keywords: Bt cotton, refuge, returns, risk, simulated yield, spray

Swagata Banerjee is a post-doctoral associate at the Delta Research and Extension Center of Mississippi State
University. Steven Martin is an assistant professor and extension economist at the Delta Research and Extension
Center of Mississippi State University. Michael Wetzstein is a professor in the Department of Agricultural and
Applied Economics, University of Georgia.

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Introduction

Bt cotton is a genetically engineered variety of cotton named after a soil bacterium,

Bacillus thuringiensis (Bt), whose genetically introduced toxins generally protects or provides

high levels of suppression in cotton plants from certain lepidopteran insect pests including

tobacco budworms, pink bollworms, cotton bollworms, armyworms, loopers, and other leaf- and

fruit-feeding caterpillar pests in cotton. When larvae feed on Bt cotton plants, the toxic proteins

protect the plants by reducing larval survival and associated plant-foliage damage. In most cases,

the requirement for remedial insecticide treatments for these pests is either reduced or

eliminated.

However, lepidopteran cotton pests have demonstrated an ability to develop resistance to

many chemical insecticides. Cotton insect pests' exposure to insecticides is a common property

natural resource. As the pests develop resistance to the insecticides, this natural resource is being

mined. For avoiding the externality problems associated with this common property resource, Bt

cotton should be managed with an objective of delaying resistance development. In this regard,

the U.S. Environmental Protection Agency (EPA), in pursuit of its interest in the social welfare

benefit of Bt cotton, has mandated an Insect Resistance Management (IRM) program that

attempts to preserve the benefits and insect protection of this technology. According to that

mandate, growers planting Bt cotton are required to follow the IRM practices designed so that

some lepidopteran populations are not exposed to the Bt protein. This allows the reintroduction

of susceptible pests into the selected populations, which delays pests' resistance. Thus, insects

are provided a refuge food source and that does not contain the Bt protein. This refuge is

provided by farmers planting Bt cotton along with simultaneously planting either 5% unsprayed or 20% sprayed non-Bt cotton as refuge. Comparison of the per acre net returns from Bt and non-Bt cotton will determine the importance of maintaining and managing this common natural resource of pest vulnerability.

Data

The study broadly uses three resources of data: (1) USDA data (1996 – 2003) – National Agricultural Statistics Service (NASS) data on marketing year (August to July) average price for Mississippi [from NASS online]:- http://usda.mannlib.cornell.edu/reports/nassr/price/zap-bb, NASS-Quick Stats Agricultural Statistics Data Base for county-level data from 1970 through 2003: http://www.nass.usda.gov:81/ipedbcnty/c_MScrops.htm, and cost data from Mississippi State budget publications; (2) state and county level on-farm data (1997 – 2000) on field trials for Mississippi; (3) economic threshold studies (1971, 1972) of *Heliothis spp*. larval infestation on cotton for Mississippi.

Objectives

Our primary goal in this analysis was to calculate farm-level returns based on simulated farm-level yields and then determine the optimal proportion of non-Bt (conventional) cotton that will provide the farmer with the maximum expected return over time. The immediate objective of this study (as embodied in this paper) was to see how net returns per acre and total for a cotton farm of average size compared between Bt and non-Bt, both with and without insecticide or pesticide spray application for non-Bt cotton over the period of our study – 1997 through 2000 for observed data and 1983-2003 for simulated data.

Methods and Procedures

Yield data for district D40 (Lower Delta, Mississippi) – the district most representative of the Mississippi Delta cotton farming – was obtained from NASS-Quick Stats Agricultural Statistics Data Base for county-level data from 1970 through 2003:

http://www.nass.usda.gov:81/ipedbcnty/c_MScrops.htm

and regressed on a constant and a time trend. A positive trend was observed, reflecting changes in technology over time. The Glesjer test of heteroscedasticity of the residuals was performed, i.e., a regression of the estimated residuals against time to test for a possible relationship. The test statistic was insignificant at the 5% level of significance. Using the regression results, the yield data was detrended by scaling (multiplying) each data point by the ratio of the most recent available (2003) predicted yield to the relevant predicted yield associated with that particular data point.

Following Coble et al. (2001) and Miller et al. (2003), the four years of available on-farm yield data (1997-2000) for both Bt and non-Bt (conventional) cotton were used to calculate absolute farm yield deviations and come up with the mean absolute deviations for Bt and non-Bt cotton, respectively:

$$\bar{d}_b^{\,f} = (1/T_f) \sum_{t=1}^{T} (y_b^{\,f} - y^r) \tag{1}$$

and

$$\bar{d}_c^{\,f} = (1/T_f) \sum_{t=1}^{T} (y_c^{\,f} - y^r) \tag{2}$$

where d bar represents mean absolute deviations, the subscripts b and c symbolizing Bt and non-Bt (conventional) cotton, respectively. T is the number of years of farm-level data available (four

for the Mississippi Delta), y is yield, with superscripts f and r representing farm and region (district), respectively.

This allows us to decompose the farm-level residual variability, for both Bt and non-Bt cotton, respectively, as the following:

$$e_{t,b}{}^f = d_{t,b}{}^f - \bar{d_b}{}^f \tag{3}$$

$$e_{t,c}{}^f = d_{t,c}{}^f - \bar{d_c}{}^f \tag{4}$$

The minimum and maximum values of the above residuals from farm-level data were used to simulate a series of residuals for the years 1970 through 2003 in the following manner:

   i.)   Manipulating a standard uniform distribution to follow the uniform distribution with minimum and maximum defined by the minimum and maximum of the residual variability above for Bt and non-Bt cotton, respectively.

   ii.)   Calculating the mean of the above vector for Bt and non-Bt cotton, respectively, and subtracting the mean from each element.

Equations (3) and (4) and points (i) and (ii) above allowed us to obtain a time series of randomized residuals (residual variability) for the entire period 1970-2003 so that the sum of those residuals (and hence the mean) equaled zero for both Bt and non-Bt cotton. Glesjer test was performed on the absolute values of these randomized residuals to test for heteroscedasticity, and insignificant effect of time on these residuals was observed at the 5% level of significance.

Simulated farm yield was obtained for 1970-2003 by adding the mean absolute deviations from (1) and (2), and the simulated residual variability for Bt and non-Bt cotton, respectively:

$$y_{s,b}{}^f = y_{s,b}{}^r - \bar{d_b}{}^f + e_{s,b}{}^f \tag{5}$$

$$y_{s,c}{}^f = y_{s,c}{}^r - \bar{d}_c{}^f + e_{s,c}{}^f \tag{6}$$

Since all yields used for further analysis are simulated yields at the farm level, subscript 's' and the superscript 'f' will be dropped in the rest of the paper to avoid notational clutter.

Marketing year (August to July) average prices over 1996 through 2003 for Mississippi were obtained online from the NASS site: http://usda.mannlib.cornell.edu/reports/nassr/price/zap-bb. Lint Price was calculated as Max(Marketing Year Average, $0.52), $0.52 being the government program price. The average of this price series was used in the calculation of net returns to follow: $0.5777625/lb. (approx. 58 cents per pound) for lint and $0.0480625/lb. (approx. 0.05 cents per pound) for cottonseed. Variable input costs (denoted by k and K's) used in the production of Bt and non-Bt cotton were assumed fixed at the 2002 level. They were obtained from the Mississippi state budgets.

Per acre returns[1] for Bt and non-Bt cotton (respectively) were calculated separately following Hurley et al. (2004), with minor revisions to include cottonseed along with lint:

$$\pi_b = (p^L - k)y_b{}^L + p^S y_b{}^S - K_b - T \tag{7}$$

$$\pi_c = (p^L - k)(1-\lambda)y_c{}^L + p^S(1-\lambda)y_c{}^S - K_c + [(p^L - k)\lambda_s{}^L y_c{}^L + p^S \lambda_s{}^S y_c{}^S - c_s]\tau \tag{8}$$

where π_b = per acre returns for Bt cotton,

π_c = per acre returns for non-Bt cotton,

p^L = price of cotton lint, fixed at $0.58 (approx.),

p^S = price of cotton seed, fixed at $0.05 (approx.),

k = per acre cost of production depending on harvested yield

  = cost of gin and haul, fixed at $0.10 per pound of lint,

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[1] All returns calculated in this analysis are net returns (after subtracting all relevant costs), even if not noted.

$y_b{}^L$ = observed per acre farm yield for Bt cotton lint,

$y_b{}^S$ = observed per acre farm yield for Bt cotton seed = 1.55 * $y_b{}^L$,

K_b = per acre cost of production of Bt cotton not depending on harvested yield but

exclusive of cotton acreage costs, fixed at the 2002 level, $345.54,

T = non-random cost per acre of Bt cotton, i.e., the technology fee, fixed at the

2002 level, $26.80,

λ = proportional yield loss due to uncontrolled pests, obtained from on-field trials

in 1972 by Joe Reed Townsend, Jr., fixed at 45%,

$y_c{}^L$ = observed per acre farm yield for non-Bt cotton lint,

$y_c{}^S$ = observed per acre farm yield for non-Bt cotton seed = 1.55 * $y_c{}^L$,

K_c = per acre cost of production of non-Bt cotton not depending on harvested

yield but exclusive of cotton acreage costs, fixed at the 2002 level, $399.92,

$\lambda_s{}^L$ = proportion of non-Bt cotton lint yield saved by an insecticide/pesticide

application, obtained by subtracting percentage reduction in lint yield due to

bollworm/budworm (from annual reports/publications on cotton losses in

Reports on Cotton Insect Research and Control section of Beltwide Cotton

Conferences Proceedings) from total reduction due to all pests (λ),

$\lambda_s{}^S$ = proportion of non-Bt cotton seed yield saved by an insecticide/pesticide

application = 1.55 * $\lambda_s{}^L$,

c_s = per acre cost of insecticide/pesticide application(s), also obtained from annual

reports/publications on cotton losses in Reports on Cotton Insect Research

and Control section of Beltwide Cotton Conferences Proceedings, and

τ = indicator variable for insecticide/pesticide application,

= 1 when applied, and

= 0 otherwise.

Percentage reduction in yield data was not available for the year 1982 and so was the per acre cost of insecticide application prior to 1986. So the data for further analysis was started at 1983, with the per acre cost of insecticide application(s) for each of the years 1983-85 estimated as moving averages of the next three years.

Following Hurley et al. (2004), total returns for a representative farm that typically plants both Bt and non-Bt cotton are given by

$$\pi = A[z\pi_c + (1-z)\pi_b] - C(A) \tag{9}$$

where A = average cotton farm size in acres per farm in the Mississippi Delta, taking into account irrigated, partly irrigated and non-irrigated land, obtained from USDA-NASS 2002 Census of Agriculture, fixed at 725 acres (approx.),

z = proportion of non-Bt cotton (refuge) planted per farm on average, and

C(A) = per farm average of irrigated and non-irrigated acreage costs (rent) of land in the Mississippi Delta, obtained from Doane's Agricultural Report, fixed at the 2004 level, $51,852.37.

Note: The terms within brackets vary while those outside are fixed.

Total farm returns were calculated for different scenarios[2]: viz.,

   a. $z = 0\%$, $\tau = 0$,

   b. $z = 1\%$, $\tau = 0$,

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[2] Note 1: The omitted case of $z = 0\%$, $\tau = 1$ would give us identical results as $z = 0\%$, $\tau = 0$, as shown in Table 2, because in equation (9) when $z = 0$ (no conventional cotton), the first term within brackets becomes zero, and hence it becomes irrelevant if $\tau = 0$ or 1 (see equation (8)).
Note 2: The sum of actual proportions (0.16 and 0.58, respectively) of insect-resistant (Bt) and stacked gene varieties observed in 2003-2004 was 0.74. Choosing this to be the proportion of Bt cotton, the proportion of non-Bt cotton is the difference of the Bt proportion from unity (i.e., $z = 1-0.74 = 0.26$) (USDA-NASS, 2004). Hence the arbitrary inclusion of the cases of $z = 26\%$.

c. $z = 5\%$, $\tau = 0$,

d. $z = 10\%$, $\tau = 0$,

e. $z = 20\%$, $\tau = 0$,

f. $z = 26\%$, $\tau = 0$,

g. $z = 1\%$, $\tau = 1$,

h. $z = 5\%$, $\tau = 1$,

i. $z = 10\%$, $\tau = 1$,

j. $z = 20\%$, $\tau = 1$,

k. $z = 26\%$, $\tau = 1$.

Numerous iterations were done for each of the above scenarios. Results tended to maintain the same pattern as seen in the "Results" section below.

Results

Each year (1997-2000) per acre returns obtained from Bt cotton were found to be slightly higher than that obtained from non-Bt cotton with insecticide or pesticide application(s), which in turn were found to be considerably higher than the returns from non-Bt cotton without insecticide or pesticide application(s). Standard deviations (Std. Dev.) followed the same pattern and hence coefficients of variation (C.V.s) followed the reverse comparison. These results are shown in Table 1 below.

Note: All returns calculated in this analysis are net returns (after subtracting all relevant costs), even if not noted.

Mean-Variance Analysis

Regime 1 (Table 2, first half): $\tau = 0$ (scenarios a through f): z = 0% gives more mean net return and standard deviation (positive square root of variance) than for z = 1%, which in turn gives more net return and standard deviation than when z = 5%, and so forth. So, lower the z, higher are mean return and standard deviation, though the differences in means and standard deviations between series (i.e., between 0% and 1%, 1% and 5%, and so forth) are not statistically significant at the 5% level of significance.

Regime 2 (Table 2, second half): $\tau = 1$ (scenarios g through k): z = 1% gives more mean net return and standard deviation than for z = 5%, which in turn gives more net return and standard deviation than when z = 10%, and so forth. So, lower the z, higher are mean return and standard deviation, though the differences in means and standard deviations between series (i.e., between 1% and 5%, 5% and 10%, and so forth) are not statistically significant at the 5% level.

Within a given regime, the differences in mean returns among different levels of z are not of significant amounts. For the same level of z, these differences are larger across regimes. That is, it matters more whether or not a spray application is allowed than what portion of the planted acreage is non-Bt (refuge).

We may also note that, with observed data for 1997-2000, as z rises, there is an increasing trend in coefficient of variation (C.V.) for no spray application ($\tau = 0$). Therefore, there is a typical trade-off between risk and return for the case of no spray application. But for spray application ($\tau = 1$), C.V. remains fairly constant. These results are shown in Table 2.

With simulated data for the period 1983-2003, for any given iteration, as z rises, while there is still an increasing trend in C.V. at all levels of refuge (z) when spray is not applied ($\tau = 0$), a spray application ($\tau = 1$) causes C.V. to remain relatively constant. These results are not reported.

Observed and simulated total farm returns for a given iteration are shown in Figure 1 and Figure 2, respectively. Table 2 shows total returns for an average farm planting Bt and non-Bt (conventional) cotton in the Mississippi Delta, 1997-2000, under different scenarios with differing refuge levels. Per acre returns from simulated yield data on Bt and non-Bt (conventional) cotton in the Mississippi Delta for the period 1983-2003 for a particular iteration are shown in Table 3.

Table 1. Per acre returns ($) from observed yields on Bt and non-Bt (conventional) cotton in the Mississippi Delta, 1997-2000.

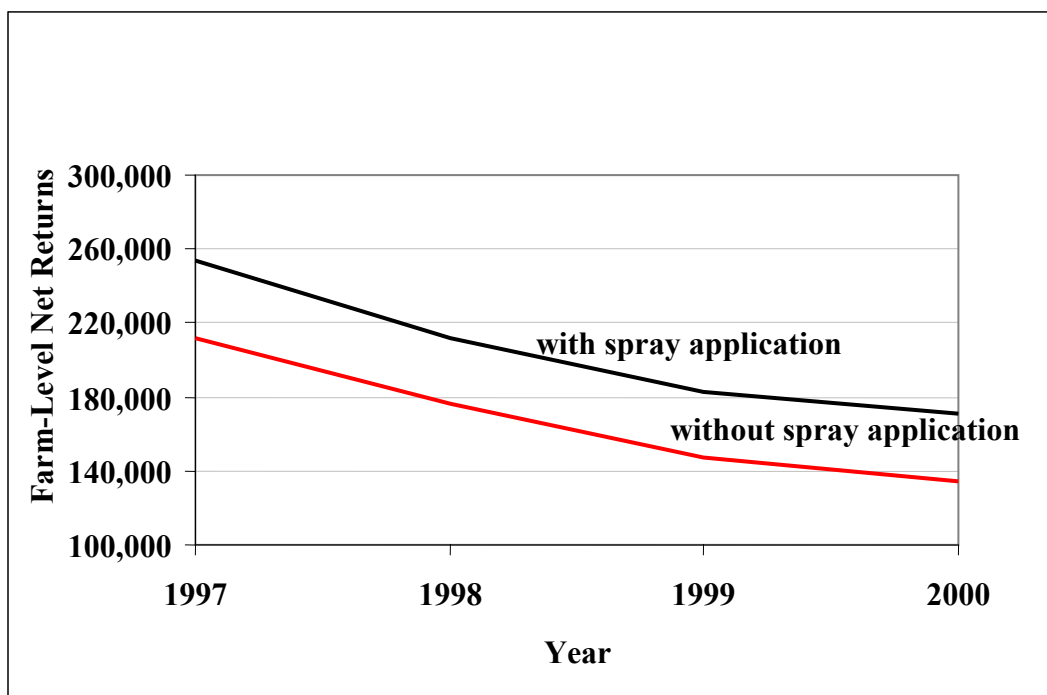|		Non-Bt returns	
Year	Bt returns	with spray application	without spray application
1997	419.51	384.28	161.29
1998	374.62	277.87	89.08
1999	322.07	293.61	106.79
2000	310.50	279.29	82.71
Mean	356.67	308.76	109.97
Std. Dev.	50.33	50.84	35.70
C.V.[1]	7.09	6.07	3.08

[1] C.V. = Std. Dev. / Mean.

Figure 1. Observed farm-level net returns ($) from Bt and non-Bt cotton, with and without spray application, in the Mississippi Delta over the period 1997-2000.
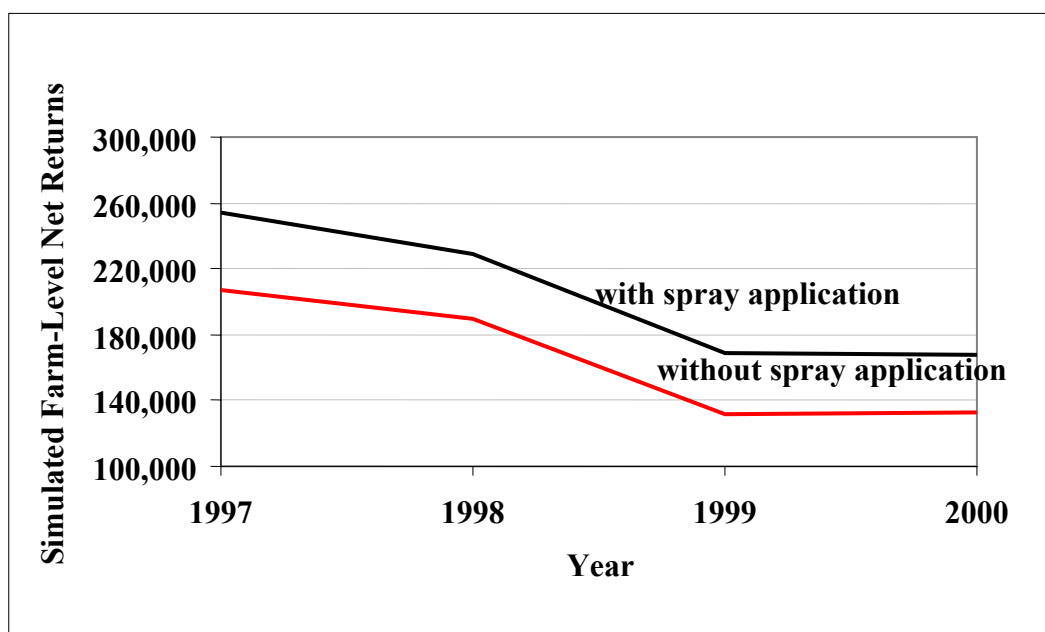

Figure 2. Simulated farm-level net returns ($) from Bt and non-Bt cotton, with and without spray application, in the Mississippi Delta over the period 1997-2000.

Table 2. Total returns ($) for an average farm planting Bt and non-Bt (conventional) cotton in the Mississippi Delta, 1997-2000, under different scenarios, with and without spray application.

z^a	1997	1998	1999	2000	Mean	Std. Dev.	C.V.[b]
$(\tau = 0)^c$							
0%	260,645.28	229,908.30	188,166.37	177,313.32	214,008.32	33,324.71	0.15572
1%	258,772.65	227,837.53	186,605.19	175,661.36	212,219.18	33,180.22	0.15635
5%	251,282.11	219,554.44	180,360.44	169,053.56	205,062.64	32,607.92	0.15901
10%	241,918.94	209,200.59	172,554.50	160,793.80	196,116.96	31,905.79	0.16269
20%	223,192.60	188,492.89	156,942.63	144,274.29	178,225.60	30,549.57	0.17141
26%	211,956.80	176,068.26	147,575.50	134,362.59	167,490.79	29,769.51	0.17774
$(\tau = 1)^d$							
0%	260,645.28	229,908.30	188,166.37	177,313.32	214,008.32	33,324.71	0.15572
1%	260,389.81	229,206.59	187,959.98	177,087.00	213,660.84	33,254.50	0.15564
5%	259,367.92	226,399.78	187,134.42	176,181.71	212,270.96	32,984.95	0.15539
10%	258,090.55	222,891.27	186,102.46	175,050.11	210,533.60	32,673.90	0.15520
20%	255,535.83	215,874.24	184,038.54	172,786.91	207,058.88	32,141.21	0.15523
26%	254,002.99	211,664.03	182,800.19	171,428.98	204,974.05	31,880.81	0.15554

[a] Proportion of non-Bt cotton planted as refuge.
[b] C.V. = Std. Dev. / Mean.
[c] A spray application does not occur.
[d] A spray application occurs.

Table 3. Per acre returns ($) from simulated yields on Bt and non-Bt (conventional) cotton in the Mississippi Delta, 1983-2003.

Year	Bt returns	Non-Bt returns with spray application	Non-Bt returns without spray application
1983	394.31	330.96	119.44
1984	489.67	492.77	203.09
1985	421.15	397.23	152.68
1986	320.49	222.57	68.79
1987	452.14	405.62	171.49
1988	409.89	392.99	161.64
1989	382.62	374.85	156.61
1990	395.52	377.63	152.98
1991	540.51	472.59	183.94
1992	355.00	256.13	117.37
1993	267.16	184.97	51.19
1994	396.39	344.28	145.09
1995	298.10	243.11	86.33
1996	376.54	326.87	116.57
1997	482.48	388.50	151.66
1998	381.68	297.85	110.49
1999	340.02	318.73	108.51
2000	274.44	248.28	68.68
2001	298.94	259.72	81.07
2002	372.82	328.94	119.27
2003	422.22	410.46	155.68
Mean	384.39	336.91	127.74
Std. Dev.	69.41	79.52	39.88
C.V.[1]	0.18	0.24	0.31

[1] C.V. = Std. Dev. / Mean.

Conclusions and Further Research

Fixed prices and costs make higher farm yields for Bt over non-Bt cotton as the sole

determinants for higher Bt returns in both observed and simulated data. For non-Bt cotton itself,

higher yields with application of insecticides/pesticides resulted in higher returns over non-Bt

cotton without application.

From our mean-variance results, we see that whether $\tau = 0$ or 1, the rule of thumb is:

lower z (percentage of refuge in farmer's portfolio) gives higher mean returns even for a short

period of time, such as four years, for which on-farm data on yield were available. However,

standard deviations (and hence variances) associated with lower z's are also higher, signifying

higher risks. When coefficients of variation (C.V.) are considered, per-dollar risks are as

expected relative to mean returns. For both observed and simulated data, as z rises, the C.V. for

no spray application ($\tau = 0$) rises. For spray application ($\tau = 1$), C.V. remains relatively constant.

Comparing across regimes, for any positive z, a spray application ($\tau = 1$) provides higher

mean returns but higher standard deviations (nominal risks) over no application ($\tau = 0$).

Considering relative risk, as given by a C.V. comparison between regimes, for any positive z,

returns are not only higher but also more stable when spray is applied. However, if there were no

restrictions on refuge requirements, and no concern for risk, with or without spray application, a

lower z would be preferred regardless of a spray application, using both observed and simulated

data (results not reported for simulated data).

But how low is low enough? That is, what is the optimum z (say z^*)? We do not know for

sure yet from this discrete analysis. The ongoing research in this area will attempt to address this

issue. However, there is a caveat that needs mentioning here: The Environmental Protection

Agency (EPA) stipulates the minimum proportion of refuge (conventional/non-Bt cotton) the

farmer is allowed to plant along with Bt cotton is 5% if unsprayed or 20% if sprayed. Refuge levels below 5% are not allowed, and refuge levels between 5% and 20% are not allowed to be sprayed. So, for $\tau = 1$, i.e., when spray is applied, if z^* comes out to be less than 20%, our research will suggest the need to change the existing policy.

One limitation of this current study is the lack of availability of farm yield data for any longer than four years. We simulated farm yield data for 1983-2003 using data at the district (region) level from NASS and taking into account the deviations in yield between farm and region (Coble et al., 2001; Miller et al., 2003). As a next step in the ongoing research, assuming constant relative risk aversion, a certainty equivalent mean value of returns for each scenario will provide us with a more comprehensive picture of the comparison between returns from Bt and non-Bt cotton, with and without spray application, under different scenarios.

Additionally, assuming the farmer is optimizing his/her profits, we may want to look at the farm-level marginal welfare effects of changing allocation arrangements between Bt and non-Bt cotton. Another option would be to adopt the willingness-to-pay approach and observe how farmers' willingness to pay would change in response to a 1% reduction (from both the 20% and 5% marks) in requirement to plant refuge cotton.

Unlike past studies estimating the *ex post* value of Bt cotton to farmers, proving the benefit of these refuge requirements, the ongoing study incorporates an *ex ante* expected value approach and is an attempt to show how planting Bt cotton affects farmer risk and welfare.

References

Coble, Keith H., James C. Miller, Barry J. Barnett, and Thomas O. Knight. "Potential for
Multicrop Revenue Insurance to Serve the Needs of Mississippi Crop Procedures,"
Bulletin 1109, Office of Agricultural Commissions, August 2001.

Cooke, Fred T., Jr., William P. Scott, Steven W. Martin and David W. Parvin. "The Economics
of Bt Cotton in the Mississippi Delta 1997-2000," in *Proceedings of the 2001 Beltwide
Cotton Conferences*, January 9-13, Anaheim, CA, Reprinted in Volume 1:175-177, 2001.

Hurley, Terrance M., Paul D. Mitchell, and Marlin E. Rice. "Risk and the Value of Bt Corn,"
American Journal of Agricultural Economics, 86(2)(May 2004):345-358.

Michael R. Williams. "Cotton Insect Losses 1997 – Compiled for National Cotton Council,"
Proceedings of the 1998 Beltwide Cotton Conferences, San Diego, CA, January 5-9,
1998, Reprinted in Volume 2:904-925, 1998.

Michael R. Williams. "Cotton Insect Losses 1998," *Proceedings of the 1999 Beltwide Cotton
Conferences*, Orlando, FL, January 3-7, 1999, Reprinted in Volume 2:785-806, 1999.

Michael R. Williams. "Cotton Insect Losses 1999," *Proceedings of the 2000 Beltwide Cotton
Conferences*, San Antonio, TX, January 4-8, 2000, Reprinted in Volume 2:887-913,
2000.

Michael R. Williams. "Cotton Insect Losses 2000," *Proceedings of the 2001 Beltwide Cotton
Conferences*, Anaheim, CA, January 9-13, 2001.

Miller, J. Corey, Barry J. Barnett, and Keith H. Coble. "Analyzing Producer Preferences for
Counter-Cyclical Government Payments," *Journal of Agricultural and Applied
Economics*, 35,3(December 2003):671-684.

Townsend, Joe Reed, Jr. *Economic Threshold Studies of Heliothis spp. on Cotton*, Unpublished

MS Thesis, Department of Entomology, Mississippi State University, May 1973.

Doane's Agricultural Report. "Agricultural Land Values and Cash Rents," 2004, Available

online at http://www.edoane.com.

USDA-NASS (2002 Census of Agriculture). Available online at

http://www.nass.usda.gov/census/2002.