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**Can GM-Technologies Help African Smallholders?  
The Impact of Bt Cotton in the Makhathini Flats of KwaZulu-Natal**

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**Abstract:** *Analysis of a survey of the 1998-99 and 1999-2000 seasons for the same 100 smallholders in the Makhathini Flats region of KwaZulu-Natal shows that Bt cotton has performed better than other varieties. Having two years of data for the same farmers allows innate efficiency differences, due to factors such as farm size, to be separated from the effects of the new technology, which is not normally possible. Farmers who adopted Bt cotton in 1999-2000 benefited according to all the measures used. Higher yields and lower chemical costs outweighed higher seed costs, giving higher gross margins. These measures showed negative benefits in 1998-99, which conflicts with continued adoption, but stochastic efficiency frontier estimation, which takes account of the labor saved, showed that adopters averaged 88% efficiency, as compared with 66% for the non-adopters. In 1999/2000, when late rains lowered yields, the gap widened to 74% for adopters and 48% for non-adopters.*

**Key words:** KwaZulu-Natal, Bt cotton, Stochastic Frontiers, Efficiency

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**Abstract:** *Analysis of a survey of the 1998-99 and 1999-2000 seasons for the same 100 smallholders in the Makhathini Flats region of KwaZulu-Natal shows that Bt cotton has performed better than other varieties. Having two years of data for the same farmers allows innate efficiency differences, due to factors such as farm size, to be separated from the effects of the new technology, which is not normally possible. Farmers who adopted Bt cotton in 1999-2000 benefited according to all the measures used. Higher yields and lower chemical costs outweighed higher seed costs, giving higher gross margins. These measures showed negative benefits in 1998-99, which conflicts with continued adoption, but stochastic efficiency frontier estimation, which takes account of the labor saved, showed that adopters averaged 88% efficiency, as compared with 66% for the non-adopters. In 1999/2000, when late rains lowered yields, the gap widened to 74% for adopters and 48% for non-adopters.*

### **1 INTRODUCTION**

The recent report on rural poverty by the International Fund for Agricultural Development (IFAD, 2001) states that effective use of biotechnology will be essential to meet the poverty alleviation targets that have been set by governments and aid agencies. One genetically modified (GM) crop, Bt cotton, is already being grown successfully in developing countries. Bt cotton incorporates genes that produce a natural insecticide, *bacillus thuringiensis* (hence Bt). The Bt-toxin acts specifically on Lepidoptera, which include the cotton bollworm and stem borers in maize, and is harmless to all other insect species.

There is now evidence from China (Pray et al, 2001) and Mexico (Traxler et al, 2001) that Bt cotton has positive impacts on yields, the environment and health, and that the reduction in pesticide use increases profits. In South Africa, studies of smallholder production in Makathini Flats, KwaZulu-Natal (Bennett, 2002, Ismael et al, 2001) suggest that the benefits include higher yields and gross margins, but the expectation is that the early adopters are usually the better farmers. Since these studies attribute all the gains to the new technology and do not attempt to allow for any innate advantages of the adopters, they may be misleading. This paper exploits the fact that there are two years of observations on the same farmers, to differentiate between the effects of the Bt variety and the innate differences between adopters

and non-adopters, in order to evaluate the technology more accurately than in the somewhat simplistic attempts that have been made to date.

The next section briefly provides the necessary background on cotton production in Makathini Flats. Section three reports on the sample data and the farm accounting measures used to compare Bt cotton with the alternative technologies. However, reduced chemical application saves labour, which is not taken into account in the gross margin calculations. Thus, section four applies stochastic frontier models to estimate the efficiency of the Bt technology with respect to all four inputs and the final section concludes by summarising the results.

## **2 BACKGROUND**

Most Bt cotton is grown by commercial farmers in the Northern Province and by some in the Free State, but since 1998, smallholder farmers in Makhathini Flats, which is one of the lower potential cotton areas of South Africa, have been adopting a GM variety, NuCOTN 37-B with Bollgard™. There are about 3,000 Zulu cotton farmers in Makathini and about another 500 in Tonga in Mpumalanga, where Bt cotton has also been released. Together, these areas account for nearly 98% of the smallholder cotton grown in South Africa (Hofs and Kirsten, 2002). By 2000/01, 3000 hectares of cotton were grown in Makhathini, producing 1000 tons of lint, and 850 hectares in Tonga, accounting for 300 tons of lint. Thus, almost 70% of smallholder cotton is grown in Makhathini.

A Monsanto report (Bennett, 2002) shows that in 1998/99, there were 75 adopters, growing less than 200 hectares of Bt cotton. In 1999/00, this rose to 411 adopters with a little under 700 hectares, and in 2000/01, to 1184 adopters with about 1900 hectares. Thus, in only three years, 40% of the producers, representing almost two thirds of the area, had adopted the new technology. Preliminary figures for the 2001/2 season show that in this fourth year adoption has now exceeded 90%. This leaves little doubt that the farmers judge the Bt variety to be superior and this should be reflected in the analysis that follows. The advantage of the Bt

variety is confirmed by the fact that in the second year of the survey, none of the farmers who had used the Bt variety in the previous year dropped it.

Compared with the rest of Africa, South Africa has a very low percentage of smallholder cotton producers, largely due to the reluctance of the pre-1994 government to promote commercial agriculture for the black communities. However, Makhathini Flats has a large development scheme with an experimental farm and an extension service that is far better than in other areas. Therefore, Makhathini is not typical, so even if Bt cotton is successful there, any problems will be harder to overcome in less favoured areas.

Monsanto owns the Bt gene and Delta Pineland developed the Bt cotton variety NuCOTN 37-B. VUNISA Cotton is a private company that sells the cottonseed varieties to the farmers in the region and supplies the chemicals and the necessary support for farmers through their extension officers. The Land Bank of South Africa provides credit to the farmers through VUNISA. This credit is offered to the small-scale farmers based on their credit worthiness, providing funds for land preparation, chemicals and seed. VUNISA buys all the cotton from the farmers and grades it, paying prices fixed by Cotton South Africa. The farmers belong to a farming association, which provides essential support and information through organised meetings where farmers can discuss mutual concerns and problems.

Apart from the Makhathini Flats Scheme, the area is typical of smallholder farming. Land is allocated by tribal chiefs, tenure is uncertain and good cropping land is scarce, unfenced, and under threat from livestock that devastate crops due to the communal grazing systems. Mixed cropping is common, with an assortment of maize, beans and other vegetables, but cotton accounts for most of the acreage. Male labour is scarce due to migration to the towns and mines, leaving a predominance of females, the elderly and children.

The survey is a stratified sample of one hundred farmers, selected with a view to having a reasonable number of adopters. In the 1998/99 season, when adoption began, only eighteen

grew Bt cotton (only 75 farmers had adopted in total), but this increased to sixty in the 1999-2000 season. Personal interviews were conducted with heads of households, using a questionnaire that covered household background, farming practices and problems, the reasons for adopting Bt cotton and input costs and returns. The responses show that pests were their major problem and the bollworm was the most troublesome pest, so it is not surprising that they have adopted the bollworm resistant variety.

The survey showed that especially in the first year, the Bt variety was adopted by a disproportionate number of older, more experienced, male farmers, with non-farm income, more livestock and larger farms (see Table 1). The vast majority stated that lack of capital was the most restrictive factor in their farming activities, so it is not surprising that the resource rich farmers adopted first.

### **3 DATA AND FARM ACCOUNTING MEASURES OF EFFICIENCY**

This section concentrates on the differences between the key variables, for adopters and non-adopters, which are reported in Table 1. The first row reports that after the infeasible responses and those with missing data were removed, the sample has 73 non-adopters (All Non-Bt) and 16 adopters (Bt year 1) in the first season. The non-adopters are also divided into those who do not adopt at all (Non-Bt) and those who adopt in the next year (Bt year 2). The next two rows show that in the first season the small sample of adopters were those with considerably larger farms and twice as much area planted to cotton as the non-adopters. Indeed, there is a hierarchy, in which those with the largest farms adopt first and those who adopt in the next year have considerably larger farms and cotton acreage than those who do not adopt at all. This is not surprising, as most new technologies are adopted first by the farmers who are well informed and can afford the investment.<sup>1</sup> The problem is then that the difference in performance due to the

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<sup>1</sup> Fitting a logit adoption model gave very poor results for the first season, when there were few adopters. For the second season, the results were better, but showed only that the adopters were the more experienced farmers, with larger farms, more livestock and sources of non-farm income.

technology is biased upwards as the adopters have innate advantages and would have performed better with the same technology.

**Table 1: Scale, Yields and per Hectare Costs and Returns, by Adoption Category**

<b>Averages 1998/99 season</b>	<b>All Non-Bt</b>	<b>Non-Bt</b>	<b>Bt year 2</b>	<b>Bt year 1</b>
Number of farmers	73	35	38	16
Farm size (ha)	5.37	4.84	6.85	9.06
Cotton area (ha)	4.31	3.97	4.72	8.63
Yield (kg/ha)	470	430	490	680
Seed (kg/ ha)	13.59	13.96	13.20	10.91
Yield per kg seed	34.58	30.80	37.21	62.33
Seed cost / ha (Rand)	120	122	115	266
Chemical cost / ha (Rand)	133	145	120	105
Gross Margin / ha (R 2.14)	807	693	890	1137
<b>Averages 1999/2000 season</b>	<b>Non-Bt</b>	<b>Bt year 2</b>	<b>Bt year 1</b>	<b>All Bt</b>
Number of farmers	33	41	17	58
Farm size (ha)	4.98	6.80	8.65	7.34
Cotton area (ha)	3.98	5.21	8.24	6.09
Yield (kg/ha)	300	440	631	483
Seed (kg/ ha)	12.55	14.22	10.27	13.06
Yield per kg seed	23.90	30.94	61.44	36.98
Seed cost / ha (Rand)	127	214	335	248
Chemical cost / ha (Rand)	126	84	107	91
Gross Margin / ha (R2.24)	428	679	938	752

Thus, the next row shows that in the first season the non-adopters produced an average of 470 kgs per hectare. This is a weighted average of the 430 kgs achieved by those who never adopt and the 490 kgs of the second year adopters. Thus the second year adopters are 14% more efficient than the non-adopters, when using the same technology, but the Bt adopters are 39% better still, with 680 kgs.<sup>2</sup> This is despite the seeding rate, which is 20% lower than for the full set of non-adopters. This is a reaction to the cost of the Bt seed, which was almost three times as expensive and the non-Bt seed. Even so, the seed costs for adopters more than doubled with the Bt variety, but the payoff is also evident in that the yield per kg of seed is almost doubled by the Bt variety, while chemical cost fell by 21%. The gross margin per ha (output value, minus the cost of intermediate inputs) for Bt users was 40% higher than for the non-adopters and the

<sup>2</sup> The usual inverse relationship between farm size and yields is reversed for these smallholders and van Zyl, Binswanger and Thirtle (1995) shows that it does not hold for the commercial sector in South Africa either.



results for the three groups follow the same ordering as the yields. The second year adopters' margin is 28% greater than for the non-adopters, and the difference between them is also 28%.

The lower yields in the 1999/2000 season are attributable to rainfall that was 50% above average, causing flooding and delayed planting, whereas the lower than average rainfall at the beginning of the 1998/1999-season favoured the cotton crop (KwaZulu-Natal Annual Reports, 1998 and 1999). The yields of the non-adopters fell by 30%, whereas the reductions for the second year adopters and first year adopters were 10% and 8% respectively. Thus, the Bt variety performed well in adverse conditions, because the bollworm is a greater problem in the wetter season, when pesticide residues wash off.

The Bt users yield of 483 kg per hectare is 61% higher than that of the non-adopters, but the first year adopters retain an advantage of 43% over the new adopters, who are in turn 47% ahead of the non-adopters. The proportion of the yield difference that is attributable to the Bt variety is the 47% difference between these two groups, minus the 14% innate difference that existed in the previous season, when they were using the same technology. Thus, the payoff to the Bt variety is a 33% higher yield, in this wet season.

The same reasoning allows calculation of the gain due to Bt in the first season, since the second year adopters are now using the same technology as the first year adopters, who retain a 190kg (43%) advantage. In the first season, when the two groups used different technologies the gap was also 190kg, which was 39%, so there is either zero gain or even a 4% loss. However, this calculation is more doubtful than the first one, since by the second season, the first year adopters had a year of learning by doing, whereas the other did not. Thus, their yield advantage when using the same technology is not all due to innate difference such as farm size and access to credit, but it is still not possible to show that there is a clear return to Bt in the good year. This is quite different from Monsanto's field trials for the first season, which show a 27% yield gain for the Bt variety (Bennett, 2002, Table 1).

Seed costs for the Bt variety are again about double and the saving on chemicals is about 28%. These differences and the yield are all taken into account in the gross margin calculations, which follow the same pattern as the yields. The gross margins are lower for all three groups, due to the late rains and the Bt users, who are now the majority, have a 76% advantage. The second year adopters have gross margins that are 59% higher than the non-adopters. In the first year, the difference was 28%, so the gain attributable to the Bt technology was 31%, which is close to the yield advantage of 33%. However, the first year adopters' margins are 259 Rand, or 38% higher still. In the first season, the Bt users were 247 Rand, or 28%, ahead of the second year adopters, so there is no obvious gain attributable to the Bt variety in the first year.

The farm accounting data provides clear evidence that in the second season, the Bt adopters had higher yields and higher gross margins. These basic farm accounting measures are obviously useful, but say very little about the reasons for any observed differences between farms. Yield is a partial measure of productivity and is of limited use when non-land inputs, particularly labour, differ between farms and in this case less labour is used for spraying. Gross margins do take account of intermediate inputs, such as seed and chemicals, but still ignore the efficiency with which labour and land are used. Since land and labour are the major inputs, this is also unsatisfactory. Net margins include the land and labour costs, but this requires input prices that are not well defined, especially for family labour and land.

Because of these limitations, a production frontier approach is taken, which only requires input and output quantities and avoids using price data. The dependent variable is simply kgs of cotton, as there was little price variation. The independent variables are land, labour, seed and plant protection chemicals. Land is measured in hectares and labour is the number of days of family and hired labour used for spraying, weeding and harvesting. Planting labour was omitted, because there is no variance, as all the farmers hire a tractor and

driver for ploughing, at a cost of 350 Rand per hectare. Chemicals are in value terms, as they are an aggregate of the different types. Finally, seed is also in values, to make the expensive Bt seed comparable to the other varieties, which can be considered an attempt at quality adjustment.

#### **4 STOCHASTIC PRODUCTION FRONTIERS**

The review by Bravo-Ureta and Pinheiro (1993) shows that the measurement of farm level efficiency has become commonplace with the development of frontier production functions. Whereas OLS estimation takes the average line of best fit through the observations (hence it is sometimes called a mean response function) and tacitly assumes that all the farms are efficient, this can be misleading if there are considerable differences in efficiency levels. Tests show that the appropriate approach is a production frontier, which will give results that are more accurate and also generate efficiency levels for all the farms.

The approach can be deterministic, where all deviations from the frontier are attributed to inefficiency, or stochastic, which discriminates between random errors and differences in inefficiency. This section fits a stochastic frontier model, of the type originally proposed by Aigner, Lovell and Schmidt (1977), which is extended to include the characteristics of the farm that specifically explain inefficiency levels, following the work of Battese and Coelli (1995). First, the frontier model determines the efficiency levels of the sample farms, with respect to those that represent best practice and then the inefficiencies are explained. The method of maximum likelihood is used to estimate the unknown parameters, with the stochastic frontier and the inefficiency effects estimated simultaneously. The theory is not explained here as the method is reviewed by Coelli (1995), fully documented in Coelli, Rao and Battese (1998) and applications to agriculture are reviewed in Battese (1992) and Bravo-Ureta and Pinheiro (1993).

Model selection is based on three hypothesis tests. Generalised Likelihood Ratio (LR) tests were used to confirm the adequacy of the functional form of the model, to determine

whether the appropriate model is a frontier or a mean response function and to determine the presence of inefficiencies effects.<sup>3</sup> First, the functional form of the stochastic frontier was determined by testing the adequacy of the log-linear Cobb Douglas model relative to the less simplistic translog, which includes cross products and square terms to allow for interactions and non-linearities in the data. The first section of Table 2 shows that for both seasons, the log linear model is accepted as an adequate representation of these data. The next test reported is the t test on  $\gamma$ , discussed above, and suggests that the frontier model is preferred to a mean response function. The log-likelihood ratio test (LR), which is more powerful than the t test on  $\gamma$ , also confirms that both models are frontiers. Thus, in the last test reported, the power of the LR test is increased by testing jointly the null hypotheses that both the frontier parameter and all the inefficiency effects are jointly zero, that is, the inefficiency effects are not present in the model<sup>4</sup>. This is also clearly rejected, which means that the frontier model, with inefficiency terms is the preferred model for both seasons.

**Table 2: Log-likelihood Ratio Tests for the Stochastic Frontier and Inefficiency Model**

	1 <sup>st</sup> Year	2 <sup>nd</sup> Year
Choice of Functional Form - $H_0: \beta_{ij} = 0, i,j = 1, \dots, 4$ . Test statistic: $\chi^2_{v, 0.95}$ , Where $v$ = number of additional restrictions = 10		
Test statistic	9.94	16.12
Critical value	18.31	18.31
Test result	Accept $H_0$ : Cobb Douglas is adequate	Accept $H_0$ : Cobb Douglas is adequate
Choice of Stochastic Frontier vs. Mean Response Function - $H_0: \gamma = 0$ . Test statistic: One tailed t-statistic; 95% confidence level		
Test statistic	8.097	21.17
Critical value	1.96	1.96
Test result	Reject $H_0$ : It is a Frontier	Reject $H_0$ : It is a Frontier
Presence of Inefficiency Effects – $H_0$ : All inefficiency coefficients ( $\delta_i$ ) and $\gamma = 0$ . Test statistic: mixed- $\chi^2_{v, 95\%}$ confidence level, where $v$ = number of restrictions (5 in 1998/9 and 3 in 1999/2000)*		
Test statistic	12.25	24.48
Critical value	10.36	7.05
Test result	Reject $H_0$ : It is an inefficiency model	Reject $H_0$ : It is an inefficiency model

\* Critical values for the mixed  $\chi^2$  are from Kodde and Palm (1986).

<sup>3</sup> The likelihood-ratio test statistic,  $\lambda = -2\{\log(\text{Likelihood}(H_0)) - \log(\text{Likelihood}(H_1))\}$  has approximately  $\chi^2_v$  distribution with  $v$  equal to the number of parameters assumed to be zero in the null hypothesis.

<sup>4</sup> Since  $\gamma$  takes values between 0 and 1, any LR test involving a null hypothesis which includes the restriction that  $\gamma = 0$  has been shown to have a mixed  $\chi^2$  distribution, with appropriate critical values (Kodde and Palm, 1986).

The left side of Table 3 reports the results of fitting a stochastic frontier model for the 1998/99 growing season. Fifty percent of the variance is explained and since the variables are in logarithms, the coefficients can be interpreted as elasticities (or shares in total cost, if there is constant returns to scale), which are bounded between zero and unity to conform to production theory. Since the input values cannot be negative, one-tailed significance tests are appropriate. All the elasticities are significantly different from zero and labour has the biggest impact (0.476), followed by chemicals (0.265), land (0.211) and then seed (0.177).

**Table 3: Production Frontier and Inefficiency Model Results**

Table 5.1 Production Frontier and Inefficiency Model Results				
Variable	1 <sup>st</sup> Year		2 <sup>nd</sup> Year	
	Coefficient	t – statistic	Coefficient	t – statistic
Production frontier	Adjusted R <sup>2</sup> = 0.50 (from OLS)		Adjusted R <sup>2</sup> = 0.73 (from OLS)	
Dependent variable: kgs of cotton				
Constant	-1.874***	-2.103	0.643**	1.816
Land	0.211*	1.583	0.276****	2.823
Chemicals	0.265****	2.4	0.059**	1.818
Seed cost	0.177*	1.404	0.282****	2.671
Labour	0.476****	3.538	0.341****	3.002
Sum of elasticities	1.129		0.958	
Inefficiency model				
Adoption	-0.444*	-1.383	-2.755**	-1.64
Planting date	0.41*	1.282		
Experience	-0.118***	-1.955		
σ <sup>2</sup>	0.89	2.818	1.06	1.672
γ	0.81	8.097	0.94	22.171
Sum of elasticities	0.958			
Average Efficiencies		1 <sup>st</sup> Year		2 <sup>nd</sup> Year
	Full Sample	0.70	Full Sample	0.64
	All Non-Bt	0.66	All Non-Bt	0.48
	All Bt	0.88	All Bt	0.75
	Non-Bt	0.62	Non-Bt	0.48
	Bt Year 2	0.70	Bt Year 2	0.76
	Bt Year 1	0.88	Bt Year 1	0.74

\*Critical t-value at 90% confidence level = 1.29: \*\*95% = 1.66: \*\*\*97.5% = 1.96: \*\*\*\*99% = 2.32

These results are very pleasing as measuring the labour input at all adequately is a problem in sample surveys of this nature. The elasticity for labour of 0.476 indicates that a 1% increase in labour would increase output by 0.48% and is significantly different from zero at the 1% confidence level. In this first season, when only 18% of the sample had adopted, the extent of

the pest problem is indicated by the large elasticity and equally high significance level of pesticides, which have more impact than land or seeds. The sum of the elasticities is 1.129, which is an indication that there may be increasing returns to scale (IRS), since if all the inputs were increased by 1%, output would rise by 1.13%. This would indicate that the farms are currently too small and would achieve greater efficiency if they were larger. However, the  $\chi^2$  test shows that the null hypothesis of constant returns to scale (elasticities sum to unity) cannot be rejected.

The variables in the inefficiency model are the decision to adopt Bt cotton, the month planting took place and the farmers' years of experience in growing cotton. Adoption of Bt cotton has a negative sign, meaning that it reduces inefficiency. The planting date variable indicates that the later farmers planted, the less output they got, which is a common result in African agriculture. Indeed, a review of the Kenyan agricultural sector (USAID, 1986) showed that timely planting had a greater impact than using fertilizer or improved seed. Lastly, the negative sign on farmer experience means that the more experienced farmers were less inefficient.

The  $\gamma$  statistic helps to determine whether this is indeed a frontier model and not simply a mean response function. Here  $\gamma = 0.81$ , which is close to unity and significant, which corroborates the second LR test in Table 2, by indicating that the frontier model is appropriate. This is not surprising, since the mean level of efficiency of the full sample was 0.70, or 70%.<sup>5</sup> The adopters had a far higher mean efficiency of 0.88, as compared with the mean of 0.66 for those who did not use Bt cotton. This suggests that when all the inputs are included in the efficiency calculations, the adopters are 30% more efficient. Thus, the Bt variety did perform well, when the land and labour inputs are taken into account. This explains why none of the adopters discontinued the Bt variety and many more adopted in the second year.

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<sup>5</sup> An average efficiency level of 70% is a reasonable result for South African smallholders, especially if some have alternative sources of income. Indeed, it is rather higher than in similar production studies of smallholder farming in South Africa, such as Piesse et al. (1996), which investigated efficiency in the former Homelands of the Northern Transvaal.

The same exercise is repeated for the 1999/2000 season, for which the data should be better, since the harvest had just been collected when the survey was conducted. This is reflected in the  $R^2$ , which shows that 73% of the variance in output is now explained in the OLS model, an unusually high result for cross section data of this nature. The stochastic frontier results are reported in the right hand side of Table 3, which shows that labour again has the biggest impact, with an elasticity of 0.34, followed by seeds and land, while the impact of chemicals is far lower than in the first year. With 60 % adopters in the sample, the importance of pesticides has fallen to 22%, while seed has risen by 60%. The seed input is now significant at the 1% confidence level, while the significance of pesticides is reduced. Indeed, all the frontier variables are significant at the 95% level or better. The sum of the elasticities is 0.96, which suggests that there is now decreasing returns to scale, so if anything, the farms are too large. However, 0.96 is very close to unity and again the  $\chi^2$  test shows that the null hypothesis of constant returns to scale cannot be rejected.

The next section of the Table shows that the only variable that was effective in explaining the inefficiencies in the second year was adoption of Bt cotton, which is now significant and has a positive effect on efficiency. The  $\gamma$  statistic is 0.94, which is even closer to unity and is again highly significant, indicating that the frontier is the preferred model. The lower section begins by showing that the mean efficiency for the full sample is now 0.64, which is 9% lower due to the wet growing season. The average for the non-adopters falls to 0.48, a decline of 27% and for the adopters, 0.74, a smaller reduction of 16%, indicating the Bt variety is less affected by the weather.<sup>6</sup> The key result is that the efficiency advantage of the adopters has now risen to 54%, compared with 33% in the first season.

The gains due to the Bt variety can again be separated from the innate differences by using the efficiencies for the three groups, shown in the last section of Table 3. In the first

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<sup>6</sup> The fall in efficiency for the full sample is less than the average of the two sub-samples, which seems odd, but this results from the change in the relative sizes of the two sub-samples over the two years.

season, the second year adopters' efficiency was 0.70, which was 13% higher than for those who did not adopt in either year, whose efficiency was 0.62. In the second year, when they are using Bt, this rises to 58%, so the Bt variety improves their performance by 45%, when all four inputs are taken into account. Similarly, in the 1999/2000 season, the second year adopters now have a 3% efficiency advantage over the first year adopters. Thus, the 26% efficiency advantage of the adopters in the first year is not due to innate differences. Instead, since the first year adopters are less efficient in the second season, the gain due to using Bt in the first year is 29%.

## 5 CONCLUSION

This study analyses a survey of the 1998-99 and 1999-2000 seasons for the same 100 smallholders in the Makhathini Flats region of KwaZulu-Natal, to determine if there are gains to using Bt cotton. Since the results are scattered throughout the text, Table 4 collects the necessary information. Although Monsanto's field trials showed that Bt gave a 27% higher yield in the first season, with favourable weather for cotton growing, the farm accounting measures showed that neither yields nor gross margins were better, after adjusting the gains to allow for the innate difference between farms. Both yields and gross margins are useful information, but they are partial measures of efficiency, which fail to take account of major inputs such as labour and land. Thus, here they were supplemented by stochastic frontier estimation, to consider the efficiency with which all inputs are converted into outputs. The efficiencies generated by the stochastic production frontier approach show that Bt performed considerably better, even after adjusting for the innate differences between adopters and non-adopters.

**Table 4: Percentage Gain from Using Bt Cotton After Adjusting for Innate Differences**

Season	Yields	Gross Margins	Stochastic Frontier Efficiencies
1998/1999	0 to - 4	0 to -10	29
1999/2000	33	31	45



The second season results are entirely unambiguous, showing that adopters benefited substantially from the new technology, according to all the measures used. Average yield per hectare and per kilogram of seed was 33% higher for adopters than for the non-adopters. The increase in yields and reduction in chemical application costs outweighed the higher seed costs, so that gross margins were also 31% higher for adopters. This was a bad year, due to unusually heavy rainfall and the Bt adopters suffered a lower fall in yields than those who did not adopt. This supports Monsanto's claim that the use of Bt cotton reduces the effect of weather on bollworm control, as rains wash off the pesticides and necessitate re-spraying. These positive results are confirmed by the stochastic frontier estimation, which shows a gain of 45%.

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