CAN GM-TECHNOLOGIES HELP THE POOR? THE EFFICIENCY OF BT COTTON ADOPTERS IN THE MAKHATHINI FLATS OF KWAZULU-NATAL[1]

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The results of this survey of 100 smallholders in the Makhathini Flats, KwaZulu-Natal give cause for cautious optimism regarding the impacts of Bt cotton. Farmers who adopted Bt cotton benefited from the new technology, according to all the measures used. Average yield per hectare and per kilogram of seed was higher for adopters than for non-adopters. The increase in yields and the reduction in chemical application costs outweighed the higher seed cost, even in a poor production season due to unusually heavy rainfall. Bt adopters suffered far less of a fall in yields than those who did not adopt. As yields and gross margins are partial measures of efficiency, deterministic and stochastic efficiency frontiers were measured. Both methods confirm the farm accounting results, showing that Bt cotton adopters were more efficient. For 1998, the results showed that adopters averaged 88% efficiency, as compared with 66% for non-adopters. In 1999, the equivalent figures were 74% and 48%. Similarly, the determinist frontier results for both years show that adopters were over 62% efficient, while non-adopters averaged only 46%.

1. INTRODUCTION

The aim of this study is to analyse the production efficiency of smallholder cotton growers who adopted genetically modified Bt cotton, compared to producers who use conventional seed in KwaZulu-Natal. Section 2 gives a brief account of the current situation regarding GM crops. Section 3 provides descriptive statistics to give a broad overview of the characteristics of the smallholders in the sample. Section 4 analyses adoption and section 5 outlines the farm accounting results, comparing yields, input levels, costs and gross margins. Section 6 reports the efficiencies from fitting stochastic production

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frontiers and section 7 extends the analysis of returns to scale by using data envelopment analysis (DEA).

2. BACKGROUND

The recent International Fund for Agricultural Development report (IFAD, 2001) makes a strong case that effective use of biotechnology will be essential to the alleviation of rural poverty in the developing countries for the foreseeable future. Higher yields, lower levels of labour and pesticide use and higher producer prices for cotton are cited as the main impacts of adopting GM crops at the household level (Fernandez-Cornejo and Klotz-Ingram, 1998; Gianessi and Carpenter, 1999). However, these benefits must be set against fears of damage to the environment, the breakdown of resistance, reduction in biodiversity and the impoverishment of small farmers in developing countries.

Herbicide and insecticide tolerant traits account for more than 85% of the types of GM crops grown worldwide. Insect resistance has also been a popular target for the GM companies. Here, the focus has primarily been on the transfer of a set of genes controlling production of a natural insecticide in a bacterium called *Bacillus thuringiensis* (or Bt) to crops. The Bt-toxin acts specifically on *Lepidoptera* (including bollworm in cotton, stem borers in maize), and is harmless to all other insect species.

If the use of Bt resistance for control of *Lepidoptera* pests generates a yield advantage, and Bt technology is cheaper than the use of a pesticide with conventional seed, then Bt-technology should provide farmers with an economic advantage. Nevertheless, all the studies except Pray, *et al.* (2001), which examined Bt cotton in China, were conducted in the USA and most of the data comes from the biotechnology industry and it is typically based on controlled conditions and extrapolations from small plots.

Thus, the motivation for this study is to provide an impartial account of GM crop adoption based on empirical evidence from a developing country. The focus is on South Africa, but the results should prove relevant to other countries in the region. Since 1998, smallholder farmers in the Makhathini Flats, one of the lower potential cotton areas of South Africa, have been adopting a genetically modified cottonseed variety (NuCOTN 37-B with Bollgard™). The survey, carried out in November 2000, covered a stratified sample of forty non-Bt cotton growers and sixty Bt cotton growers. Only 12% of the 4,000 farmers in the region have adopted the new GM-cotton, so the rationale for using a stratified sample is to have enough Bt farmers to allow comparisons. Interviews with farmers provided data on household background, farming practices, rationale for adopting Bt cotton, input costs and returns, for the 1998/1999 and 1999/2000-seasons.

3. DESCRIPTIVE STATISTICS FOR THE SAMPLE

Respondents, who are the heads of the households, were categorised into four age groups and 76% of the farmers were reported to be forty years and older. Of the hundred respondents, 48% are female and 52% are male, while 25% reported that they earn additional off-farm income from various sources. Most of the farmers owned less than five hectares of land, with the largest concentration in the category of 2.5ha to 5ha. Activities on the farm were carried out mainly by family labour, along with some hired labour. Farmers were asked to cite the main agronomic constraints to cotton cultivation. Pests, excessive rain and drought were ranked as the major agronomic constraint by 71%, 42% and 12% of the respondents, respectively. The major pests in the region are the bollworm complex[6], cotton aphids, and jassids or leafhoppers. Access to capital was identified by 82% of farmers as the main non-agronomic constraint. The majority of respondents have access to credit from VUNISA and use VUNISA-credit either exclusively, or in combination with savings. VUNISA Cotton is a private company that sells the cottonseed varieties to the farmers in the region. VUNISA also supplies the chemicals and the necessary support for farmers through their extension officers.

4. CHARACTERISTICS OF ADOPTERS AND REASONS FOR ADOPTION

Farming experience ranged from one to forty years, and those who adopted the technology were amongst the most experienced farmers, particularly those who only adopted in the second season. While 18% of the farmers used the modified cotton variety (NuCOTN 37-B) in the 1998/1999-production year, 60% used it in the 1999/2000-production year. All the farmers who adopted in the first year (1998/1999) continued using Bt cotton in the second year (1999/2000). This alone suggests that the farmers were satisfied with the performance of the Bt variety.

Adopters of Bt cotton reported that pests were their major problem and this prompted them to adopt the bollworm resistant variety. Non-adopters considered excessive rain and weed invasion as their main problems. Most of the surveyed farmers did not identify any problems with Bt cotton, except that the cost of the seed was too high. While 90% of the non-adopters were willing to adopt the technology, their main objection was the high technology fee incorporated in the seed cost and lack of information about the variety. This is not surprising, for the majority stated the lack of capital as the most restrictive factor in their farming activities. Thus, credit availability may play a role in adoption, but it is also possible that farmers always complain about lack of credit.

5. PRODUCTION: YIELD, COST AND PROFITABILITY FOR ADOPTERS AND NON-ADOPTERS

The questions on reasons for adoption show that the expectation of better performance was the main reason for adoption, given the higher cost of seed. Farm size, age and technology adoption all explain substantial differences in production efficiency and profitability. These relationships were established using cross-tabulations of yields, seed and chemical costs for adopters and non-adopters. The results are fully discussed in Ismaël, *et al.* (2001), which shows that the adopters of Bt cotton experienced substantial yield increases, insecticide cost decreases and improved gross margins, relative to non-adopters. These general results held for both the comparatively dry first season and the wet second season of the survey.

However, gross margins take account of intermediate inputs, such as seed and chemicals, but ignore the efficiency with which labour and land are used. Since land and labour are major inputs (Ismaël, *et al.*, 2001), this is also unsatisfactory. Net margins, which include the land and labour costs, can be calculated but this requires prices for all inputs. These are not well defined, especially for family labour and land. In addition, neither yields nor margins tell us anything about the existence, or otherwise, of scale economies.

6. STOCHASTIC PRODUCTION FRONTIERS

The measurement of farm level efficiency has become commonplace with the development of frontier production functions. 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 study uses both approaches, since they are complementary, both in providing different information and in double-checking the veracity of estimates from muddled survey data.

We use a stochastic frontier model, of the type originally proposed by Aigner, Lovell and Schmidt (1977), extended to include the characteristics of the farm that specifically explain inefficiency levels, following the work of Battese and Coelli (1995). Firstly, the frontier model is constructed to determine 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. Model selection is based on three hypothesis tests. They are generalised Likelihood Ratio (LR) tests conducted to confirm the adequacy of the functional form of the model, to determine if the appropriate model is a frontier or a regular production function and to determine the presence of inefficiency effects. The last test is of the hypothesis that the technical efficiency effects are simply random errors, in which case the model reduces to a mean response function in which the inefficiency variables enter directly (Battese and Coelli, 1995).

6.1 Data, estimation and tests

The output is bales of cotton, which is a physical measure of output. The four inputs are land (measured in hectares), chemicals (which is a value because it is an aggregate of different types), seed (which is measured in 25kg-bags, except in one case where the seed costs worked better) and labour. The labour variable is the number of days of family and hired labour used for spraying, weeding and harvesting. All the variables are in natural logarithms, so that the coefficients can be interpreted as elasticities, which must have values of between zero and unity to conform to production theory. Since the values cannot be negative, one-tailed significance tests are appropriate.

Table 1: Production frontier and inefficiency model (1998/1999)

reports the results of fitting a stochastic frontier model for the first season. All the elasticities are significant and labour has the biggest impact (0.476), followed by chemicals (0.265), land and seed. The sum of the elasticities indicates increasing returns to scale (IRS). The variables that explain inefficiency are the adoption of Bt cotton, the planting date and the farmer's years of experience in growing cotton. Adoption of Bt cotton has a negative sign, meaning that it reduces inefficiency. Thus, using the Bt variety increases the efficiency of the farms that adopted. The planting date variable shows that the later planting led to less output, which is a common result in African agriculture. Indeed, a World Bank study of Kenya in the mid 1980s (World Bank, 1986) showed that timely planting had a greater impact than using fertiliser or improved seed. Lastly, the negative sign on farmer experience means that the more experienced farmers were less inefficient. Taken together, these are remarkable results, especially since the survey was conducted during the second season and the first season data must suffer since the farmers may misremember their results.

The fact that the Gamma statistic is close to unity (0.81) and highly significant indicates that the frontier model is appropriate rather than the mean response function. It implies that one or more of the firms in the sample form an efficiency frontier of best practice, while the remainder are some measurable distance from the frontier. This dispersion is not surprising, since the mean level of efficiency of the full sample was 70%. The adopters had a far higher mean efficiency (0.88), as compared with the mean (0.66) for those who did not use Bt cotton. Even more convincing is that the minimum efficiency level amongst the adopters was 0.80, as compared with 0.15 for the non-adopters. This suggests that despite the slightly lower gross margins for adopters (Ismaël, *et al.*, 2001), the Bt variety did perform well when the land and labour inputs are taken into account. This would explain why none of the adopters discontinued the Bt variety and many more adopted in the second year.

The same exercise was 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. The results in Table 2 show that labour again has the biggest impact, followed by seeds and land, while the impact of chemicals is far lower than in the first year. Summing the elasticities suggests that there are now decreasing returns to scale, meaning that the farms are, if anything, a little too large. However, summing elasticities is a crude means of determining returns to scale, so this issue is pursued further in the next section.

The only variable that was effective in explaining the inefficiencies was adoption of Bt cotton, which is now highly significant and has a positive effect on efficiency. There is now a greater dispersion of efficiencies, in this poor season, with a lower mean efficiency level of 0.64 and the minimum efficiency falling to 0.10 for the non-adopters and 0.33 for those who did adopt. The maximum is the same for both groups, but the mean efficiency of the adopters is again far greater. The Gamma statistic of 0.94 is even closer to unity and is again highly significant, indicating that the frontier is the preferred model.

Table 1: Production frontier and inefficiency model (1998/1999)

Variable	Coefficient		t – statistic		
Production frontier					
Intercept	-1.874		-2.103		
Land	0.211		1.583		
Chemicals	0.265		2.400		
Seed cost	0.177		1.404		
Labour	0.476		3.538		
Sum of elasticities	1.129				
Inefficiency model					
Adoption	-0.444		-1.383		
Planting date	0.410		1.282		
Experience	-0.118		-1.955		
σ^2	0.89		2.818		
γ	0.81		8.097		
Statistics					
Mean efficiency: Total	0.70	Minimum	0.15	Maximum	0.92
Mean efficiency: Non-adopters	0.66	Minimum	0.15	Maximum	0.89
Mean efficiency: Adopters	0.88	Minimum	0.80	Maximum	0.92

*Critical t-value at 95% confidence level = 1.66; ** Critical t-value at 90% confidence level = 1.29

Table 2: Production frontier and inefficiency model (1999/2000)

Variable	Coefficient		t – statistic		
Production frontier					
Intercept	0.643		1.816		
Land	0.276		2.823		
Chemicals	0.059		1.818		
Seed cost	0.282		2.671		
Labour	0.341		3.002		
Sum of elasticities	0.958				
Inefficiency model					
Adoption	-2.755		-1.640		
σ^2	1.060		1.672		
γ	0.940		22.171		
Statistics					
Mean efficiency: Total	0.64	Minimum	0.10	Maximum	0.91
Mean efficiency: Non-adopters	0.48	Minimum	0.10	Maximum	0.91
Mean efficiency: Adopters	0.74	Minimum	0.33	Maximum	0.91

*Critical t-value at 95% confidence level = 1.66; ** Critical t-value at 90% confidence level = 1.29

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 model. For both seasons, the log linear model was accepted as an adequate representation of these data, as the first results in Table 3 show. The next test reported is the t–test on γ, which has been discussed, 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 the Gamma statistic[7], also confirms that both models are frontiers. In the last test reported, the power of the LR test is increased by testing jointly the null hypothesis that both the frontier parameter and all the inefficiency effects are jointly zero: that is, the inefficiency effects are not present in the model[8]. This proposition is also clearly rejected, which means that the frontier model with inefficiency terms is the preferred model for both seasons.

Table 3: Log-likelihood ratio tests for the frontier and inefficiency model

	1998 / 1999 Season	1999 / 2000 Season
Choice of Functional Form - H_o: $\beta_{ij} = 0$, $i,j = 1,\ldots,4$. 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_o: Cobb Douglas is adequate	Accept H_o: 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_o: It is a Frontier	Reject H_o: It is a Frontier
*Presence of Inefficiency Effects – H_0: All inefficiency coefficients (δ_l) 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 Ho: It is an inefficiency model	Reject Ho: It is an inefficiency model

[a] Critical values for the mixed χ^2 are from Kodde and Palm (1986).

7. DETERMINISTIC FRONTIER PROGRAMMING MODELS

Whilst the stochastic frontier model results are entirely acceptable, deterministic frontier efficiency models are perhaps more reliable and easier to follow. The data envelopment analysis (DEA) model has been widely applied to efficiency measurement problems. For example, Piesse et al. (1996) reports on a typical appilcation of DEA to smallholder agriculture in South

Africa. DEA provides both a check on the stochastic frontier results and further information, especially on the farm size issue.

The model used for measuring farm-level efficiency follows the framework introduced by Farrell (1957) and extended by Fare et al, (1985), to include the decomposition of overall efficiency into measures of technical and scale efficiency. The method is non-parametric and deterministic, with the best practice frontier constructed by minimising inputs per unit of output. Then, the efficiency of each farm is measured as a ratio of actual to best practice performance. Therefore, the sources of inefficiency can be identified and policies to procure efficient production can consider these findings. The basic DEA efficiency results are extended by decomposing the efficiency measure into pure technical efficiency and scale efficiency and then determining if the farms that are not scale efficient are too small or too large.

The results for 1998/1999 are summarised in the upper section of Table 4, which shows that the DEA analysis confirms the stochastic frontier results. The first column shows that the total technical efficiency is 0.56, as compared with 0.7 for the stochastic frontier, because DEA attributes all deviations from the frontier to inefficiency. The adopters are again far more efficient, on average, than the non-adopters and have a much higher minimum efficiency level. The next two rows show that the programme finds that the cause of the superior efficiency of the adopters is scale efficiency, rather than pure technical efficiency. This is surprising, since the yield and gross margin analysis (Ismaël, *et al.*, 2001) showed that the smaller farms had higher yields and gross margins. The DEA result says that once land and labour are taken into account, it is the larger farmers (a greater percentage of whom adopted Bt cotton) who have the higher efficiency levels.

The 1998/99 efficiency frontier is defined by six farms, only one of which was an adopter. This is a sufficient number to ensure that the frontier is meaningful, rather than being determined by a couple of observations that might be outliers (which is a serious danger in the stochastic model). The returns to scale results show that apart from the six efficient farms, which have an overall efficiency score of unity, and are scale efficient by definition (shown as constant returns to scale, CRS), all but one of the enterprises is too small. This is why the DEA programme is attributing the greater efficiency of the adopters to farm size: adopters, on average, owned larger farms.

Table 4: DEA results for both seasons

	Efficiency			Frontier farms(#)	Returns to Scale		
	Total	Technical	Scale		IRS	CRS	DRS
Season 1: 1998 / 1999							
Mean: Total	0.56	0.78	0.71	6	82	6	1
Mean: Non-Adopters	0.45	0.84	0.53	5	67	5	1
Mean: Adopters	0.62	0.77	0.81	1	15	1	0
Minimum Efficiency: Total	0.08	0.29	0.08				
Minimum Efficiency: Non-Adopters	0.08	0.29	0.08				
Minimum Efficiency: Adopters	0.35	0.39	0.51				
Season 2: 1999 / 2000							
Mean: Total	0.50	0.83	0.61	9	79	9	3
Mean: Non-Adopters	0.46	0.84	0.56	2	31	2	0
Mean: Adopters	0.66	0.79	0.84	7	48	7	3
Minimum Efficiency: Total	0.05	0.30	0.10				
Minimum Efficiency: Non-Adopters	0.05	0.30	0.10				
Minimum Efficiency: Adopters	0.19	0.50	0.19				

*Maximum values are all unity.

In the second season, reported in the lower section of Table 4, the first column shows that the mean total efficiency was a little lower at 0.50 (as compared with 0.64 for the stochastic model). Change is caused by the greater number of adopters, who have a slightly higher total efficiency than before, (0.66 rather than 0.62), whereas the non-adopters level is almost unchanged (0.46 rather than 0.45). Again, the adopters have a higher minimum efficiency level of 0.19 and the minimum for the non-adopters (in this bad season) falls to only 0.05. The next two columns show that the pure technical efficiency level of the adopters is still slightly lower than for the non-adopters, but again the programme attributes most of their advantage to scale. Again, the DEA has been fooled to some extent by the fact that more larger farmers adopted: we suspect that it has misallocated between purely technical and scale efficiency differences.

In this season, the frontier is very well defined by nine farms, seven of which are now adopters. These nine farms are scale efficient, however, the level of scale efficiency has decreased to 0.61 for the total sample. This is reflected in the returns to scale results, which as well as showing more CRS farms now show that three farms are actually too big. However, the dominant problem is still that 79% of the farms are too small. This shows that the higher yields of the smaller farms do not mean they are more efficient. Land scarcity is not the main problem in KwaZulu-Natal, so to look only at land efficiency makes little sense. Providing credit to allow adoption and increase the area planted is the obvious policy prescription.

8. CONCLUSIONS

The results of this survey of 100 smallholders in the Makhathini Flats region of KwaZulu-Natal give considerable cause for cautious optimism regarding the impacts of Bt cotton. The farmers who adopted the Bt-cotton variety benefited from the new technology, according to all the measures used. Average yield per hectare and per kilogram of seed was higher for adopters than for the non-adopters, as were gross margins.

Both yields and gross margins are useful, but they are partial measures of efficiency, which fail to take account of major inputs such as labour. Thus, they are supplemented by both deterministic and stochastic frontiers, the first applying programming techniques and the second relying on econometric estimation. In either case, the results confirm the farm accounting results, showing that the Bt cotton adopters were considerably more efficient than those who used the non-Bt varieties were.

The tendency was for the older, more experienced farmers and those with larger farms to have higher percentages of adopters. This can be explained by the fact that these were the farmers who were more likely to be granted credit, or be able to finance the higher seed costs from savings or from other income sources. Indeed, almost all in the sample said they would adopt Bt cotton if they had the financial resources to do so. There did not appear to be any agronomic or other technical impediments to adoption. All smallholders could benefit, provided that credit is made available. So there is no reason to expect that the ceiling has been reached, provided that the seed supplier does not decide to exploit its monopoly by raising the prices.

NOTES

1. *Bollworms consist of a complex number of species, which include American bollworm (Helicoperva armigera), Red bollworm (Diparopsis castenea) and Spiny bollworm (Earis* biplaga*, Erias insulana)*

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

3. *Since γ 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 χ^2 distribution, with appropriate critical values (Kodde and Palm, 1986).*

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