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Assessing the Performance of GM Maize Amongst Smallholders in KwaZulu-Natal, South Africa

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This study uses data for the 2006/07 maize production season, for the Hlabisa, Dumbe, and Simdlangentsha districts in KwaZulu-Natal, South Africa, to investigate the relative efficiencies of conventional, insect-resistant (Bt), and herbicide-tolerant (RR) maize grown by small-scale farmers. The article fits a stochastic efficiency frontier using maximum likelihood methods. The results show that both GM technologies have very little impact on efficiency and that the tillage system is an important determinant of efficiency levels. This is despite the fact that farmers who used RR seed had substantially higher yields. Higher expenditure on seed cancels out this gain in the efficiency estimates, and there is every reason to believe that these are the better farmers. Employment effects are also investigated, as the RR technology is intended to be labor saving. The results mostly serve to show how dangerous it is to make any inferences from small sample surveys in one production season.

Key words: efficiency, genetically modified, maize, KwaZulu-Natal, smallholders, stochastic frontiers, South Africa.

Introduction

The distributional impact of biased technological change depends both on the factor-saving (or using) biases and the factor endowments in the economy. If a labor-saving technology is introduced in a land-scarce/labor-abundant economy, labor incomes will fall and poverty will increase. GM white maize, developed in the United States, is now being used by both large-scale commercial farmers and smallholders in South Africa (SA). In Asia, importing labor-saving machinery increased unemployment, and interviews with the few early adopters in SA suggest that herbicide-tolerant (RR) maize adoption can result in a reduction in labor use per unit of output by about 50% (Gouse, Piesse, & Thirtle, 2006). But, the ultimate impact depends on the change in output as well as the bias. In addition, labor for land preparation, planting, and weeding is the constraint in much of Sub-Sahara Africa (SSA). If land is infertile but plentiful, planting area and output could double and labor demand for all other tasks increase substantially. Thus, a labor-saving technology need not displace labor. It depends on the factor endowments and urbanization, and, in addition, high levels of HIV/AIDS now exacerbate labor scarcity in many communities, including rural KwaZulu-Natal where our study areas are located.

This article investigates the efficiency of the different technologies using a series of techniques, starting with yields—which are the simplest partial-productivity measures—and allowing for seed costs. Then, farm accounting—particularly gross margins—is used to compare profitability, before fitting a stochastic frontier production function, to estimate relative efficiency levels with respect to all inputs. The more original part investigates the impacts of the GM varieties on labor use. The approach taken focuses on labor use by task and by laborer, which is unusual if not entirely original (see, for instance, Fernandez-Cornejo, Hendricks, & Mishra, 2005).

The next section provides some background on GM maize in SA. Then, we describe the current samples, with summary statistics and partial productivity measures. Next, we give a brief review of stochastic frontiers, followed by the results. The final section and the conclusion provide a warning that this type of analysis of relatively small samples is very dangerous unless the researchers actually know the farmers and the enumerators well enough to scrutinize the results carefully.

Background

Bt yellow maize has been produced in South Africa since the 1998/99 season, and large-scale commercial farmers appear to have benefited from it. Despite paying more for seeds, adopters enjoyed increased income over conventional varieties through savings on pesticides and increased yield due to better pest control. Irrigated and dryland commercial farms surveyed in Mpumalanga, Northern Cape, and the North West province enjoyed statistically significant yield increases of 11% and

Table 1. Percentage and hectares planted to transgenic maize in South Africa (estimated).

Event	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07
Bt yellow %	3%	5%	14.5%	19.5%	19.7%	22.6%	17.8%	35.5%
Area	3,000	59,000	160,000	176,000	197,000	249 000	107 000	391 000
Bt white %	0	0	0.4%	2.8%	8%	7.9%	22.8%	43.8%
Area	0	0	6,000	60,000	144,000	142,000	221,000	712,000
RR yellow %	0	0	0	0	0	1.3%	11.3%	12.5%
Area	0	0	0	0	0	14,000	68,000	137,000
RR white %	0	0	0	0	0	0.3%	6.0%	8.5%
Area	0	0	0	0	0	5,000	60,000	139,000

Source: Gouse, Kirsten, and Van Der Walt (2008).

10.6%, respectively (at a 95% confidence level), on average during the 1999/00 and 2000/01 seasons (Gouse, Pray, Kirsten, & Schimmelpfennig, 2006). Planting of insect-resistant (Bt) and RR white and yellow maize increased from 14.6% in 2004/05 to above 45% in 2006/07 (Gouse, Kirsten, & Van Der Walt, 2008). Much of this increase is due to GM white maize increasing from 8.6% of the total white maize area in 2004 to more than 50% in 2006 (Table 1).

Commercial farmers produce more than 90% of the total South African maize crop and thus it follows that almost all GM maize is produced by this group. Most of the small plots of GM maize are planted in the communal areas of KwaZulu-Natal (KZN), Mpumalanga, and the Eastern Cape. Our research focused on three areas in the northeast and northern parts of KZN: Hlabisa, Simdlangetsha, and Dumbe (Paulpietersburg). Depending on rainfall, planting usually takes place in October/November and harvesting in May/June, and more than 75% of harvested maize is for household consumption and chicken feed. The low marketed surplus is indicative of both the level of poverty in the region and the lack of an effective market for surplus grain outside the local community. The majority of households, particularly in Hlabisa, own an old, small hand mill, which produces fairly coarse maize meal.

The Agricultural Research Council and government extension officers have been recommending conservation tillage practices or planting without ploughing (PWP) for some time, partly due to erosion problems in parts of the former homeland areas. Monsanto has also been holding workshops to demonstrate the benefits to farmers of minimum tillage practices, as these form the backbone of a maize production system in which transgenic RR technology is used. Bt white maize has been in use since 2001/02, when small quantities of free seed were supplied to an estimated 3,000 small-scale farmers following the Monsanto workshops in nine areas. A survey of 368 farmers in four provinces in 2001/02, and of 104 and 196 farmers in Hlabisa and Simdlangentsha in 2002/03 and 2003/04, respectively, found statistically significant yield increases with Bt maize (Gouse et al., 2006). An average yield increase of 32% was found for the six sites surveyed in 2001/02, a season with significant stalk borer pressure, but with the caveat that farmers did receive free seed and that yield advantages might have been overestimated due to small seed quantities and the method used to estimate the size of the harvest. In the drier 2002/03 season, the gain was about half that of the previous year, about 16.8%. In the next year, 2003/04, the drier conditions led to no gain at all, as there were almost no stalk borers. Thus, the yield increases are justifiable as it can be directly linked to the stalk borer pressure in the three seasons.

Data

For this article, we use data collected in the three areas for the 2006/07 maize production season. A future extension to this study will utilize data for the 2006/07 and 2007/08 production seasons when these are available and the size of the sample is available now. The sample distribution with respect to districts and seed type is shown in Table 2. There was insufficient GM seed available in the focus area in 2006/07, but in 2007/08 there are adequate numbers of farmers using Bt and RR, and also some planted the new stacked gene seed that contains both the Bt and RR events. For 2006/07 and this article, only Hlabisa has an adequate sample of GM varieties.

The survey concentrates on accurate measures of output, household characteristics, income, expenses, consumption, farming practices, and production budgets. The important contribution is the completeness of the labor by use and the area planted. The yield data also includes green mealies (fresh maize), which are eaten around January/February, before the main harvest.

Table 2. Number of farms by district and seed type.

	Conventional	Bt	RR	Stacked	Total
			2006/07		
Simdlangentsha	59	3	7	0	69
Dumbe	76	9	0	0	85
Hlabisa	39	21	35	0	95
Total	174	33	42	0	249
			2007/08		
Simdlangentsha	45	29	45	9	128
Dumbe	66	22	15	1	104
Hlabisa	32	11	38	20	101
Total	143	62	98	30	333
Grand total	317	95	140	30	582

Table 3. Data: Means of output and inputs by seed type.

Seed type	Output kg	Area ha	Labor Days	Seed cost Rand	Fertilizer cost Rand	Chemical cost Rand	Power cost Rand	Own oxen %
Roundup Ready (RR)	380	0.317	17	340	343	629	142	40
Bt	280	0.416	20	325	329	250	173	15
Conventional	275	0.382	20	210	511	352	250	3

Farmers were surveyed with the help of enumerators who know the area and the farmers and who had already been trained through their involvement in previous studies. Each respondent was visited at least seven times during the course of the season in order to collect accurate labor data, rather than relying on farmer recall at the end of the season. Farmers who planted Bt, RR, and conventional hybrids, such as the non-GM isoline and other hybrids, were included in the sample. Those using open pollinated varieties and traditional seed were not included in this study.

The initial visits to each household in October/November/December 2006 were to collect household information in addition to the labor data and input use for the first maize land preparation and planting activities. During a visit in February, information was collected on pest incidence and on quantities of green mealies harvested, in addition to the ongoing collection of data on labor and input use. Previous studies showed that the March-May period is rather quiet, with little maize production activities. The major labor-using periods are during land preparation and planting and the first six weeks after planting for weeding and pesticide application. In May and June, data were collected on the quantities of maize harvested, again in addition to the corresponding labor data.

Table 3 reports the summary statistics of the variables used. Considerable care was taken to ensure that the data were accurately measured. Output is in kilograms of maize, with an average of 380 kg of grain per farm for the RR users and substantially less for the other farms, despite the fact that RR users have the smallest plots and a wide dispersion. Many farmers had more than one maize plot, in which case only the main focus plot was used in the survey. Land area is in hectares. There are some very small plots and the average maize area is less than half a hectare. Total labor is measured in physical units—in this case, man-days. The land is all relatively marginal, that is with low production potential, and there is little variation in quality or bio-physical characteristics, so there is no significant quality adjustment problem. The appropriate model is closer to that of Hansen (1979), which assumes unlimited supplies of marginal land, than to the Asia model, where maximizing yield is the major objective.

The intermediate production inputs are seed, fertilizer, and power, all measured in the South African Rand (R). Seed cost is used rather than quantity, to allow for the fact that in some cases GM seed was more than 50% more expensive than conventional seed. Published prices indicate a 27-30% price increase due to the technology fee. Fertilizer quality (organic and chemical) varies, too, so it is included as a cost rather than a quantity. Here, the conventional seed users are spending less on seed and therefore are able to purchase more fertilizer. As expected, the RR users have the highest chemi-

Table 4. Output and inputs per hectare for the full sample.

Seed type	Output kg	Seed cost	Fertilizer cost	Chemical cost	Power cost
			Full sample		
RR	1386	1168	1066	629	454
Bt	794	879	917	250	486
Conventional	750	663	1390	352	810
			Hlabisa		
RR	1493	1237	830	609	452
Bt	697	808	584	0	405
Conventional	751	589	721	29	372
			Simdlangentsha		
RR	851	820	2245	727	463
Bt	949	816	2308	963	539
Conventional	865	470	1951	686	524
			Dumbe		
RR	na	na	na	na	na
Bt	970	1067	1232	590	660
Conventional	660	850	1299	576	1072

cal costs as they use chemical herbicides to control weeds, and the Bt users have the lowest, as their crop is resistant to a major pest. The power costs vary greatly, as the RR users kill the weeds with herbicide and shallow plough with oxen to plant. The last column shows that 40% of the RR users have their own oxen, whereas for the conventional seed users it is less than 4%. To allow comparable calculations of gross margins, the oxen owners have been imputed a cost of hiring oxen, based on their plot size. For the others, it is the cost of hiring a contractor to plough, which was the case for half the sample, or the running costs for a tractor if one is owned. This underestimates the cost, but only seven farmers had a tractor, so imputation was not used. Most farmers prepared the land and planted using hand hoes only.

Production and Labor Use Impacts

Effect on Yields and Intermediate Costs

The impact of the two new technologies on output is considered next. Table 4 reports the output and inputs on a per hectare basis, beginning with yield, or output per hectare, with the area planted measured by our enumerators. This is perhaps the most common measure of the performance of a seed variety and is frequently all that is measured and reported in studies of GM crops. For the full sample, this shows that RR outperforms the conventional seed by a factor of 85%, and, at this point, many studies conclude on a self congratulatory note. Unfortunately, reality is rarely that simplistic and the findings need to be understood in context.

The next section of the table shows that this result is due to the 35 RR adopters in Hlabisa, who actually have nearly double the yield of conventional seed users in this district. However, whereas Bt gave a small advantage in yield of 5.9% more than the conventional seed for the total sample, in Hlabisa the Bt users had a 7.2% lower yield. In Simdlangentsha the Bt users had 9.7% higher yields and in Dumbe, which had overall lower yields (possibly partly due to stalk borers) the Bt yield advantage was an impressive 47%. Unfortunately, this result is based on only 9 observations, so it may be due to farm and farmer characteristics rather than the seed itself.

Column two shows that RR is the most expensive seed, followed by Bt, but the differential costs between Bt and RR varies from near zero in Simdlangentsha to R 289 in Hlabisa. The reason for this is known and it raises serious doubts as to how the yield results should be interpreted: Due to an increase in the demand for RR seed by commercial farmers and a management/communication/ planning blunder by Monsanto, small bags of RR seed were not available for smallholders in 2006/07. One farmer in Hlabisa was able to secure a couple of large bags of RR seeds used by the commercial farmers and divided and sold the seed to local farmers who wished to use it. It is important to note that these were smaller seeds for machine planting, compared to larger seeds preferred by smallholders who plant by hand. These cost substantially more per kilogram than the seed Monsanto supplies to smallholders, but there were obviously more seeds per kg. Most maize seed companies in SA sell seed to commercial farmers according to the number of seeds in the bag (60,000 or 80,000). The packages sold to smallholders are in small amounts and are sold by weight, such as 2, 5, or 10 kg bags, rather than number of seeds.

This selection bias was identified due to the local knowledge of our enumerators and an extension officer, who say that this group of farmers work together and are above average in their abilities. This is perhaps obvious from the very fact that they managed to obtain RR seed when none was for sale through the normal channels. Thus, it is quite impossible to determine how much of any advantage is attributable to the seeds and how much to the superior innate abilities and farmer-specific characteristics of this group.

The comparison with the seven RR farmers in Simdlangentsha show how different the two groups are. These farmers did acquire some of the very limited amount of RR seed of the type Monsanto has been selling to smallholders or saved the seed from the previous year. It cost more or less the same as the Bt seed, but still looks like a inferior outcome as the average yield was lower than either Bt or conventional seed. All used the tractor services provided by contactors, which is expensive, rather than PWP, and all seem to have done poorly. Either they suffered from lack of prior experience with the new technology, or it is possible that farmers who were able to secure seed did so at the cost of planting at the right time. This issue clearly needs further investigation and will be considered when the next survey is available.

With respect to the Bt seed, the averages for the full sample suggest that in 2006/07 it did not give enough yield advantage to justify the high price. The district results show that in Hlabisa it performed poorly compared to the less expensive conventional hybrids. In Simdlangentsha, it increased yields just enough to justify the higher seed price. However, in Dumbe, the 47% yield increase came at an extra seed cost of only 25%. Since Bt users save on chemical costs and labor, this is a good investment, as indeed Bt is as long as there is a significant stalk-borer infestation.

Fertilizer, chemical, and power costs at the aggregate level follow the same pattern as in the previous table, as the per-hectare basis does not change anything. However, the district results are enlightening, as they vary considerably. The Bt growers in Hlabisa had poor yields, but this may result from the substantially lower fertilizer applications. The Simdlangentsha farmers did get the best yields with Bt, but at a cost, as they used the most fertilizer and also spent more on chemicals than both the RR users and the conventional seed users. In contrast, the Bt users in Dumbe enjoyed higher yields without using more fertilizer or more chemicals. Rather, the Dumbe Bt farmers saved on power, as the last column shows. They actually spent 38% less on tractors and oxen than the conventional seed users, whereas those in the other two regions spent a little more.

Table 5. Gross margins by district and seed variety.

	Full sample	Hlabisa	Simdlangentsha	Dumbe
RR	3987	4738	232	na
Bt	1653	1874	376	1562
Conventional	738	1886	931	0

It becomes clear that there are too many variables, moving in different directions, to determine the impacts of the new seed technologies without aggregating the effects in some way. The obvious approach is to calculate gross margins, so this is done in the next section.

Effect on Gross Margins

The second approach to investigating the impact of GM seeds is to calculate gross margins, which are the difference between the value of output and the costs of the intermediate inputs—in this case, seed, fertilizer, chemicals, and power. The last of these is the sum of tractor hire costs and oxen hire costs, for those who bought such services. For the half of the sample that owned at least one ox and used their own animals, a cost was imputed using the hire costs and attributing these according to the land area planted. For the eleven farmers who owned a tractor, the fuel costs were used, which under-counts the real value, but the number is not large enough to affect the results.

The complication is that farmers were selling surplus maize grain at about R 2.40 per kg, but it is far more expensive to buy maize meal. The proportion that replaced purchases is not known, so the price was set to make the least profitable group just break even. This group was the conventional seed users in Dumbe, who had a zero gross margin at a price of R 5.27, so all the other figures are relative to this yardstick. Table 5 shows that for the full sample, RR users had a mean gross margin that is five times that for conventional seed and more than double that for Bt. However, this result rests on the group of 35 farmers in Hlabisa, where RR had 2.5 times the margin for conventional and Bt seed. By contrast, for Simdlangentsha, the RR users had the worst

Table 6. Labor use by task and seed technology in Hlabisa.

	Child	Male	Female	Hired	Workgroup	All
Roundup Ready						
Land preparation	1.66	6.15	9.99	0.00	0.00	**17.80**
Planting	1.31	5.41	12.11	0.00	3.16	**22.00**
Herbicide pre-planting	0.10	1.33	1.28	0.00	0.00	**2.72**
Herbicide post-planting	0.00	1.24	1.14	0.00	0.00	**2.38**
Weeding	0.00	0.00	0.00	0.00	0.00	**0.00**
Insecticide application	0.00	0.27	0.00	0.00	0.00	**0.27**
Harvesting	3.12	5.85	9.20	0.00	0.44	**18.61**
All	**6.19**	**20.25**	**33.73**	**0.00**	**3.59**	**63.77**
Bt						
Land preparation	1.85	2.52	1.37	1.10	0.00	**6.83**
Planting	1.66	3.03	3.79	0.00	0.00	**8.48**
Herbicide pre-planting	0.00	0.00	0.00	0.00	0.00	**0.00**
Herbicide post-planting	0.00	0.00	0.00	0.00	0.00	**0.00**
Weeding	3.57	6.45	13.22	0.00	1.80	**25.04**
Insecticide application	0.00	0.00	0.00	0.00	0.00	**0.00**
Harvesting	1.97	4.43	6.30	0.00	0.00	**12.69**
All	**9.04**	**16.43**	**24.67**	**1.10**	**1.80**	**53.04**
Conventional						
Land preparation	1.10	3.73	1.77	0.69	0.00	**7.29**
Planting	1.23	5.81	5.91	0.28	1.73	**14.98**
Herbicide pre-planting	0.00	0.00	0.00	0.00	0.00	**0.00**
Herbicide post-planting	0.00	0.00	0.00	0.00	0.00	**0.00**
Weeding	3.05	10.28	17.82	0.39	4.80	**36.34**
Insecticide application	0.42	0.34	0.30	0.00	0.00	**1.06**
Harvesting	0.53	6.17	7.53	0.00	0.00	**14.23**
All	**6.33**	**26.33**	**33.34**	**1.36**	**6.54**	**73.90**

gross margins and the conventional seed by far the best. Finally, in Dumbe, the Bt users have margins comparable to the Hlabisa farmers, unlike any others in the two less-efficient districts.

The lack of robustness and possibility of misinterpretation that is inherent in small sample surveys such as this is well demonstrated by these results. There are three districts and three winners as a different seed variety proves best in each case.

Employment Effects

The impact of GM crops on employment in developing countries has attracted little attention to date, but this survey made a point of repeated visits in order to gather accurate labor data. Our experience with labor data based on farmer recall at the end of the season suggests massive margins of error. Similarly, planted area estimations are subject to this error, and the vast majority of farmers considerably overestimated their maize plot sizes. This was minimized by asking the enumerators to measure each plot. The employment data are reported in Table 6, according to task and type of labor used. Table 6 is confined to Hlabisa, where the sample is better balanced, but the other two districts are considered below.

These data require careful analysis to determine why some of the effects occur, but it does look as if Bt actually saves more labor than RR. Indeed, Bt seems to be twice as labor saving, reducing the input by 28% relative to conventional seed, whereas RR reduces labor by only 13.7%. The important caveat here is that all 35 RR farmers were PWP users and this uses more labor as tractor land preparation and planting is replaced by chemical weed control, shallow ploughing with oxen, and planting by hand (Gouse, Piesse, & Thirtle, 2006). This result needs to be compared with that for Simdlangentsha, where tractors were used instead of PWP.

The breakdown of the labor use was intended to give accurate totals, but also illustrates which class of labor was affected. For instance, if less child labor is used, there may be benefits to greater school attendance. Here, the picture is just as mixed as in the previous results. Relative to conventional seed, Bt seems to increase the child-labor input for all tasks, whereas RR reduces the total. The fall is from the zero weeding labor, which is enough to outweigh the need for help from the children to harvest the bigger crop.

Reducing male family labor may allow more employment off the farm. In Hlabisa, it does seem to be male labor that is most reduced, but Bt reduces female labor almost as much. RR has no effect. The common assumption is that this may allow the women to spend more time on childcare and cooking, which should have benefits for the new generation as well as improve the lives of the adults by allowing some release from drudgery.

RR clearly reduces hired labor to zero in this sample, but this is a small group that may not have required non-family labor when using conventional seed. Nor does their approach get fully recorded under workgroups, perhaps because their collaborations are longstanding and informal. Further study based on the next year's data is badly needed in this important area. There is relatively little hired labor with the conventional seed, but if those who lose this employment are the most resource poor and have insufficient land of their own, these job losses will cause a serious loss of welfare for the most vulnerable.

Table 7 extends the labor analysis to Simdlangentsha and Dumbe, but there were only seven RR users and three Bt farmers in Simdlangentsha and only nine Bt farmers in Dumbe. The RR users in Simdlangentsha clearly use less child labor, but there is a 40% reduction in hired labor, in a district where it was relatively important, so this negative aspect needs more investigation. The odd results for the Bt users are ignored for now, as a sample of three is simply too small to justify any discussion. Finally, there is Bt in Dumbe, which has a very different impact on labor use. Hired labor is unaffected, which has positive welfare effects, while family labor is approximately halved, or even more reduced in the case of children. Any further statements must wait until more data are available on these two districts.

Choice of Model, Functional Form, and Results

The partial productivity measures used above are useful, but like any partial approach they can be misleading, because they do not present the total picture. To deal with this shortcoming, a stochastic frontier model is used, which generates farm-level efficiencies that can be compared across technologies. Thus, the effects on land and labor use are also considered but at the cost of relying on econometric estimation, which may raise more questions than it answers.

The Model

The survey by Battese (1992) shows that fitting frontier production functions to agricultural data has become common in the literature. Stochastic frontiers of the type originally suggested by Aigner, Lovell, and Schmidt (1977) discriminate between random errors and farm-level differences in efficiency. Battese and Coelli (1995) introduced the inefficiency model, in which the efficiency differences are simultaneously estimated from the stochastic frontier and explained by farm-specific variables. Their models incorporate tests that choose between functional forms and between frontier and mean regression models.

The general form of the production frontier is

$$Y_i = \alpha + \sum_J \beta x_{ij} + \varepsilon_i \text{, where } \varepsilon_i = V_i - U_i$$

$$\text{with } U \sim |\, N(0, \sigma_U^2) \,| \text{ and } V \sim N(0, \sigma_V^2). \qquad (1)$$

The V_i's are independently and identically distributed random errors and uncorrelated with the regressors, and the U_i's are non-negative random variables associated with the farm-level technical inefficiency.

The technical efficiency of an individual farm is defined as the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by that farm. Thus, the technical efficiency of farm i is defined as

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(x_i : \beta)\exp(v_i - u_1)}{f(x_i : \exp(v_i))} = \exp(U_i). \qquad (2)$$

In the Battese and Coelli (1995) inefficiency model, the U_i's in Equation 1 are defined as

Table 7. Labor use by task and seed technology in Simdlangentsha and Dumbe.

	Child	Male	Female	Hired	Workgroup	All
Roundup Ready – Simdlangentsha						
Land preparation	0.00	1.57	0.81	1.75	0.00	**4.13**
Planting	0.00	3.33	5.74	4.57	5.69	**19.32**
Herbicide pre-planting	1.17	0.51	0.61	0.00	0.00	**2.28**
Herbicide post-planting	2.74	0.91	2.23	0.00	0.00	**5.89**
Weeding	0.00	0.00	0.00	0.00	0.00	**0.00**
Insecticide application	0.00	0.76	0.20	0.00	0.00	**0.96**
Harvesting	3.04	4.97	6.60	2.84	1.62	**19.08**
All	**6.95**	**12.06**	**16.19**	**9.15**	**7.31**	**51.67**
Bt – Simdlangentsha						
Land Preparation	0.51	3.37	4.80	1.43	0.00	**10.10**
Planting	3.57	10.31	7.35	7.96	12.76	**41.94**
Herbicide pre-planting	1.63	1.63	1.63	0.00	0.00	**4.90**
Herbicide post-planting	1.63	2.24	1.33	0.00	0.00	**5.20**
Weeding	0.00	2.45	2.45	12.24	0.00	**17.14**
Insecticide application	0.00	0.00	0.00	0.00	0.00	**0.00**
Harvesting	1.94	6.22	5.51	8.57	0.00	**22.24**
All	**9.29**	**26.22**	**23.06**	**30.20**	**12.76**	**101.53**
Conventional – Simdlangentsha						
Land Preparation	0.74	1.76	0.93	1.46	1.48	**6.37**
Planting	2.63	2.62	3.57	4.57	2.86	**16.25**
Herbicide pre-planting	1.96	0.69	1.68	0.00	0.00	**4.32**
Herbicide post-planting	1.86	0.65	1.58	0.00	0.00	**4.09**
Weeding	2.18	0.94	2.44	4.11	2.91	**12.58**
Insecticide application	0.49	0.29	0.61	0.00	0.00	**1.39**
Harvesting	1.66	4.52	6.77	5.13	0.89	**18.98**
All	**11.52**	**11.47**	**17.58**	**15.27**	**8.14**	**63.98**
Bt – Dumbe						
Land Preparation	0.92	1.86	0.31	1.17	0.00	**4.26**
Planting	1.38	2.53	0.82	0.54	0.00	**5.26**
Herbicide pre-planting	0.00	0.49	0.41	0.00	0.00	**0.89**
Herbicide post-planting	0.00	0.49	0.05	0.00	0.00	**0.54**
Weeding	1.38	2.66	3.12	0.92	0.00	**8.07**
Insecticide application	0.00	0.10	0.00	0.00	0.00	**0.10**
Harvesting	0.92	1.84	2.55	4.14	0.00	**9.45**
All	**4.60**	**9.96**	**7.25**	**6.77**	**0.00**	**28.58**
Conventional – Dumbe						
Land Preparation	1.91	1.75	0.74	1.90	0.12	**6.43**
Planting	1.94	2.23	2.19	3.20	0.06	**9.61**
Herbicide pre-planting	0.01	0.27	0.12	0.00	0.00	**0.40**
Herbicide post-planting	0.28	0.81	0.30	0.00	0.00	**1.38**
Weeding	4.91	6.71	11.06	1.45	0.00	**24.14**
Insecticide application	0.23	0.17	0.25	0.00	0.00	**0.64**
Harvesting	0.79	3.38	3.73	0.46	0.00	**8.36**
All	**10.07**	**15.33**	**18.38**	**7.01**	**0.19**	**50.98**

Table 8. Hypothesis tests.

	Log-likelihoods		LLR test	DoF	χ^2_{15} critical value at 5%	Outcome
(1) Functional form test						
Parameter restrictions	H_0: CD	H_1: Translog	Statistic			
H_0: All $\beta_{jk} = 0$	-237.36	-226.66	21.4	15	25	Accept H_0 - CD is adequate
(2) Frontier tests						Parameter restrictions: H_0: $\gamma = \delta_i = 0$
	Gamma	t stat	Statistic	DoF	Critical value	Outcome
Restrictions: H_0: $\gamma = 0$	0.717	7.019	35.40	8	14.85	Reject H_0– frontier not OLS
(3) Inefficiency model	H_0: $\delta = 0$	H_1: $\delta \neq 0$				
	-252.29	-237.36	29.46	7	13.40	Reject H_0– the δ_i belong in the frontier

Notes. The likelihood-ratio (LLR) test statistic, $\lambda = -2\{\log[\text{Likelihood}(H_0)] - \log[\text{Likelihood}(H_1)]\}$ is distributed approximately χ^2_ν where ν is the number of parameters assumed to be zero in H_0.

Where the null hypothesis involves the parameter γ, which as a ratio of two variances is necessarily positive, the test statistic has a mixed chi-squared distribution. The critical values are found in Kodde and Palm (1986).

$$U_i = \mathbf{z}_i\,\delta + W_i\,, \tag{3}$$

where $\mathbf{z}_i$ is a vector of explanatory values associated with farm-level technical inefficiencies in production, δ is a vector of unknown parameters to be estimated and the W_i's are the remaining errors. First, the functional form of the stochastic frontier is determined by testing the adequacy of the Cobb-Douglas production function relative to the less restrictive translog. These frontier models are defined as

$$Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j x_{ji} + \sum_{j=1}^{n}\sum_{k=1}^{n} \beta_{jk} x_{ji} x_{ki} + V_i - U_i \tag{4}$$

where all of the variables are in logarithms, so that their coefficients are elasticities. If terms under the double summation are not significantly different from zero, the translog reduces to the Cobb-Douglas. Y is maize output in physical terms and the independent variables (x_i) are labor, land, seed, and fertilizer costs and a dummy for owning oxen. This gives 21 independent variables in the translog due to the squared and cross-product terms.

In the inefficiency term in Equation 4, there are seven explanatory variables (**z** in Equation 3). There are dummy variables for Dumbe, gender of the head of household, hired labor and intercropping (with pumpkins), plus the number of cattle, the education level of the best educated household member, and surplus labor, that is the number of household members who would like a full-time job but cannot find work.

Hypothesis Tests

First, three hypothesis tests were conducted to select the functional form and to choose between the frontier model and the standard average production function. The results are reported in Table 8, showing the first tests for the preferred functional form. The null hypothesis (H0) is that all $\beta_{jk} = 0$, i,j = 1,...,n, in Equation 4. This tests whether the Cobb-Douglas frontier is an adequate representation for these data by comparing it with the more general translog function. The appropriate Log Likelihood Ratio (LLR) test shows that this hypothesis is accepted, as the test statistic value is below the critical value.

Having selected the Cobb-Douglas form, the next section of Table 8 reports the test results of the hypothesis that the technical efficiency effects are not simply random errors. The key parameter is $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$, which is the ratio of the errors in Equation 1. So, γ is defined between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and if $\gamma = 1$, there is no random noise. The null hypothesis is thus that $\gamma = 0$, indicating that the mean response function (OLS) is an adequate representation of the data, whereas the closer γ is to unity, the more likely it is that the frontier model is appropriate. If γ is not significantly different from zero, the variance of the inefficiency effects (W_i in Equation 3) is zero and the model reduces to a mean response function in which the inefficiency variables enter directly (Battese & Coelli, 1995). This test is unambiguous, with the value of 0.717 and the t-test indicating that the frontier is the appropriate model.

The next column in this section reports the LLR test values for the more powerful test with the null hypothesis that $\gamma = \delta_0 = \delta_i = 0$, which means that in addition to γ

Table 9. Stochastic production frontier and inefficiency model results (full sample).

	Labor	Land	Seed	Fertilizer	Chemicals	Own oxen	Sum
Frontier model							
Coefficients	0.134	0.139	0.415	0.126	0.077	0.158	1.049
t-stat	1.613	2.663	5.307	2.010	3.852	1.532	
Inefficiency model	**Dumbe dummy**	**Gender head HH**	**Inter crop**	**Cows**	**Education**	**Hired labor**	**Surplus labor**
Coefficient	1.140	0.288	-0.66	3.252	-0125	-1.101	-0.212
t-stat	2.971	1.214	-1.11	1.592	-1.300	-1.650	-1.142

Note. Critical values for a one-tailed test are: 10%, 1.282; 5%, 1.645; 2.5%, 1.96; 1%, 2.232. For a two-tailed test, the 10% level is 1.645.

being insignificant, the inefficiency effects are not present in the model. The null hypothesis, H_0, can be rejected at the 5% level, with degrees of freedom equal to the numbers of parameters set to zero. Thus, the frontier model is the correct specification rather than the mean response function. The third test is to see if the Battese and Coelli inefficiency model is the appropriate form of frontier model. The null hypothesis that the δ_i's are jointly equal to zero is rejected, meaning the inefficiency model is preferred to a frontier without the inefficiency terms.

Results

The tests above establish that the Cobb-Douglas function is an adequate representation of the unknown underlying production function. They also show that the frontier is preferred to a mean response function (OLS) and that the inefficiency terms have explanatory power. Table 9 reports the parameter estimates and t-statistics for the preferred version of this model. The small number of observations for RR and Bt in Simdlangentsha and Dumbe make estimation by district impossible, so only the full sample is used.

The first part of Table 9 shows that all the output elasticities are significantly different from zero and that they sum to just above unity, indicating slightly increasing returns to scale. Since the sum is close to unity, the elasticities should approximate factor shares in output. A one-tailed t-test is appropriate as the elasticities are constrained by the theory to take values between zero and unity. The seed cost variable dominates the others—at 0.415—meaning that a 1% increase in seed expenditures increases output by 0.415%. This is large relative to the elasticities of land and labor, which are normally viewed as the most important inputs in smallholder agriculture. However, it is well below the seed elasticity for the 2004/05 sample, which Gouse, Piesse, and Thirtle (2006) estimated at 0.66%. The dummy for owning oxen was included as the power variable because the elasticity for the cost of power variable used in the gross margin analysis above was not significant.

The inefficiency variables are far less successful. As these coefficients can be positive (meaning that the variable increases inefficiency) or negative (inefficiency reducing), a two-tailed t-test is appropriate. The positive sign on the dummy variable for Dumbe indicates that this region has lower efficiency levels, which is shown in the descriptive statistics, too. However, the gender of the head of the household and the use of intercropping were insignificantly different from zero in a two-tailed test, at the 10% significance level. This is also true of fertilizer use, but this variable is almost significant and increasing inefficiency. Table 3 shows that it is the farmers using conventional seed who compensate by using more fertilizer, so this suggests that GM seed is a better strategy. Chemical inputs would reduce inefficiency if it was significant, and referring back to Table 3 shows that the RR farmers are the heavy users, so this is like the previous variable. The estimates seem to be picking up the GM effect but attributing some of it to the variable associated with GM use. The only unambiguously significant inefficiency effect is for hired labor. This has a negative sign, which means that it reduces inefficiency. This is a reasonable result as a farmer will only hire labor if it is profitable to do so.

Finally, the inefficiencies from the frontier model add a further element of doubt to this study (Table 10). The results for the full sample, shown in the first row, suggest that RR is clearly a superior seed technology, with an almost 10% yield efficiency advantage over conventional seed. Likewise, Bt seems to reduce efficiency by 2.4%, which is quite possible in a dry year, when stalk borers are not much of a problem. Gouse, Piesse, and Thirtle (2006) reached similar conclusions.

Unfortunately, this conveniently simple story does not survive disaggregation to the district level. The gain to RR in Hlabisa is reduced to 0.77%, while in Simdlangentsha using RR results in a 6.8% reduction in effi-

Table 10. Efficiency estimates from the frontier model.

	Efficiencies by district and seed type			Gain as % relative to conventional seed	
District and seed variety	RR	Bt	Conventional	RR	Bt
All farms	0.700	0.622	0.638	9.80	-2.42
Hlabisa	0.698	0.656	0.692	0.77	-5.15
Simdlangentsha	0.714	0.783	0.766	-6.81	2.14
Dumbe	na	0.489	0.510	na	-4.06

Table 11. Ranking of seed varieties by district and method.

Method	Yields			Gross margins			Efficiency levels		
District/rank	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Full sample	RR	Bt	Con	RR	Bt	Con	RR	Con	Bt
Hlabisa	RR	Con	Bt	RR	Con	Bt	RR	Con	Bt
Simdlangentsha	Bt	Con	RR	Con	Bt	RR	Bt	Con	RR
Dumbe	Bt	Con		Bt	Con		Con	Bt	

ciency relative to conventional seed. Thus, the convenient aggregate results must have rested on the average efficiency of conventional seed being reduced by the Dumbe average of only 0.510. Likewise, Bt shows a 5% loss in Hlabisa, but a 2.14% gain in Simdlangentsha in efficiency terms. The oddest result is that Bt appears not to work at all in Dumbe, whereas the gross margin results suggested it was highly successful.

Alternative Measures of Impact and Sample Selection

The results serve mostly as a warning against putting any faith in the results of studies of GM crops that are based on small samples, especially if the researchers are not well acquainted with the areas and the farmers and particularly when recall data is used. Having surveyed some of these farmers since the 2001/02 season, the authors feel reasonably well qualified to judge the veracity of the findings and the verdict is very harsh indeed. A sample of 253, with 249 useable observations seems reasonable and, even though almost all GM maize seed adopters in the areas were included in the sample, it remains inadequate. The analysis shows that the alternative methods that are used to judge the impact of GM seeds are a cause of confusion and concern.

The following serves to substantiate these claims. The simplest measure of the impact of a new seed variety is yield. The full sample shows that RR has an 85% yield advantage. Many studies seem to regard yields as sufficient evidence, but how much do yields matter if land is not the constraint? The second approach used is to calculate gross margins, and these show that RR has more than five times the gross margin of conventional seed. The third approach is to take account of land and labor as well, by estimating the individual farm efficiencies relative to a stochastic production frontier. These results show that RR is almost 10% more efficient than conventional seed. These results show that different methods give different levels of advantage, but nothing worse.

The Bt results fit well too, although they are not unambiguously good. There is a slight yield advantage, which translates into gross margins more than twice those of conventional seed, but the average efficiency level comes out at 2.5% less than that for conventional seed. However, since it has been well documented that the cost of Bt seed is often not justified if the stalk-borer infestation level is low, it is not a difficult result to explain.

If this sample of 249 maize plots was from the same district, there would be no further questions. However, the observations are drawn from three districts that are essentially similar and it would be quite possible to have drawn a sample with these distinct differences from a single area. If this was done, the disparities would never come to light; here, however, as soon as the results are disaggregated to district level, they fall apart. The most obvious example is the gross margin rankings. RR ranks top in Hlabisa, conventional seed is top in Simdlangentsha (and RR bottom), while in Dumbe Bt is ranked first. Thus, the ranking changes entirely according to region, as Table 11 shows. It also shows the rankings for average yields and average efficiency levels. Of course, all these problems can be avoided by discarding the small gains to be had from adding Simdlangentsha and Dumbe and only considering Hlabisa. But, is Hlabisa misleading in representing the wider region, when its results depend mainly on the performance of 35 exceptionally good farmers? Researchers need to be far more wary and put less trust in small sample surveys.

Conclusions

This study reports and analyzes the results of a sample survey of 249 smallholders growing genetically modified and conventional white maize hybrids in the districts of Hlabisa, Simdlangentsha, and Dumbe in KwaZulu-Natal, South Africa. A special amount of effort was expended on visiting the farmers numerous times throughout the 2006/07 growing season in order to collect task-specific labor data. Really, the conclusion to this study awaits the more balanced sample based on the data currently being processed for 2007/08. However, the within-district samples are still small because there are not yet many GM growers, so the inter-district comparisons will still have to be faced. Thus, the 2006/07 results mostly serve to show how dangerous it is to make any inferences from small sample surveys.

The positive aspect of this research is that the disaggregated labor data show that neither of the GM crops seems to cause very large reductions in family labor use. The reduction in child labor may mean more schooling, for women may leave more time for important child-rearing tasks, and for men may allow more off-farm employment. The reduction in hired labor is not large either, so it seems unlikely that GM crops will cause those who are land scarce and rely on wage incomes to be seriously affected. However, we still have no way of discovering whether less labor use per unit of output will simply mean a diversion of labor to other tasks or whether the area planted can be expected to expand and hence output to increase substantially. We are also left with questions such as whether labor is a constraint or not. What policies are needed to cause output expansion in these times of high global food prices?

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