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Impact of Genetically Modified Maize on Smallholder Risk in South Africa

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This research adds to previous literature by examining the impact of genetically modified (GM) maize on net return risk for smallholders in South Africa. Producers of GM maize pay 35% more for seed but 42% less per hectare for labor than non-GM maize producers. Stochastic dominance reveals that net returns of Roundup Ready® (RR) maize are second-degree stochastically dominant to all other varieties in one region, while no variety is stochastically dominant in the other region. Stochastic efficiency with respect to a function (SERF) indicates that RR maize is the preferred variety for producers over the entire range of risk preferences in both regions. While average gross returns for all maize plots are $713 per hectare, risk premiums between $18 and $221 per hectare must be paid to RR maize producers—depending on region and farmer risk preference—to persuade them to switch to the second-most preferred variety.

Key words: genetically modified, maize, net returns, risk, SERF, South Africa, stochastic dominance.

Introduction

The welfare effects of GM maize on smallholders in low-income countries—especially in Africa—have received little attention. Net return risk is a particularly important issue for smallholder maize producers, as maize production is a game of high risk. For smallholders who lack risk-mitigation tools such as insurance or their own safety net of cash reserves, the risk of failure is even greater since it could mean inadequate caloric intake and reduced productivity, the inability to pay loans, or send children to school. Therefore, risk assessment is vital for the long-term success of any new agricultural technology, including GM maize. The objective of this research is to examine the effect GM maize has on net returns for smallholder risk in KwaZulu-Natal, South Africa. Stochastic dominance and stochastic efficiency with respect to a function (SERF) are the techniques used to test if GM maize production increases net returns, reduces risk, or both. The benefit of using a stochastic approach is that it allows for comparison across farmers who plant different varieties, providing valuable insight from a single season of data as demonstrated in previous studies (Bryant et al., 2008; Shankar, Bennett, & Morse, 2007; Shively, 1999).

Literature Review

Most previous studies examining the farm-level impact of GM crops in low-income countries have focused on Bt cotton; these studies show that Bt cotton leads to lower pesticide use and higher yields (Pray, Huang, & Qiao, 2001; Qaim & de Janvry, 2005; Qaim & Zilberman, 2003; Shankar & Thirtle, 2005), as well as higher profits—even after controlling for selection bias (Crost, Shankar, Bennett, & Morse, 2007; Huang, Hu, Fan, Pray, & Rozelle, 2002). Studies on Bt maize in the Philippines show higher yields and net returns (Yorobe & Quicoy, 2006)—even after controlling for selection bias (Mutuc & Yorobe, 2007)—although the yield advantage is much smaller when controlling for censoring (Mutuc, Rejesus, Pan, & Yorobe, Jr., 2012). Research on Bt and RR maize in South Africa reveals higher output and less labor, although the Bt maize output advantage declines as pest pressure decreases, and net returns to Bt maize do not always outweigh the high cost of Bt seed (Gouse, Piesse, & Thirtle, 2006; Gouse, Piesse, Thirtle, & Poulton, 2009). Gouse (2012) provides a synthetic overview of the South African smallholder experience with GM maize and finds evidence of its advantage throughout several years of study.

Several studies have used stochastic dominance analysis to compare several risky alternative agricultural technologies at the farm level, including Shively (1999) and Barrett, Moser, McHugh, and Barison (2004). Only Shankar et al. (2007) use stochastic dominance to examine the impact that GM crops have on risk among smallholders. Cumulative distribution functions (CDFs) are compared for yield and net returns of Bt and non-Bt cotton in KwaZulu-Natal, South Africa. In all three years, the CDF of Bt cotton yield is to the right of non-Bt, which confirms that Bt cotton is first-degree stochastically dominant (FSD) and therefore a superior technology. The CDF of Bt cotton profits are also first-degree stochastically dominant in the first two years of analysis, but in the third year it is neither FSD nor second-degree stochastic dominant (SSD). This suggests that although Bt cotton reduces the probability of very low-yield outcomes, it does not necessarily reduce it strongly enough to reduce the probability of very low-returns outcomes due to the price premium of Bt seed (Shankar et al., 2007).

Stochastic efficiency with respect to a function (SERF) analysis, which is used in this study, has been used previously to evaluate crop production systems using net return distributions based on empirical data (Barham, Robinson, Richardson, & Rister, 2011; Bryant et al., 2008; Hignight, Watkins, & Anders, 2010; Pendell, Williams, Boyles, Rice, & Nelson, 2007; Ribera, Hons, & Richardson, 2004; Williams, Pachta, Claassen, Roozeboom, & Llewelyn, 2011). SERF provides a more restrictive approach to compare risky alternative technologies by evaluating technology dominance across a wide range of plausible risk preferences.

Bryant et al. (2008) is the only study to apply SERF to compare GM and non-GM crops. In the study, SERF is used to compare four types of cotton—conventional, Roundup Ready®, Bollgard (insect resistant), and stacked-gene varieties. Farm-level yield and production data reveal stacked cotton to be the preferred variety regardless of farmer risk preferences in Southeast Arkansas. Risk premiums between $34 and $127 per acre must be paid to cotton growers in the Southeast to convince them to use an alternative type of cotton. In Northeast Arkansas, where pest pressure was low during the study period, Roundup Ready® cotton was preferred to all other varieties. In both cases, the extra seed cost and technology fee is more than compensated by the gains in net returns, implying widespread expected adoption of stacked and Roundup Ready® cotton in Northeast and Southeast Arkansas, respectively. Although the findings are applicable to this research, no studies have used SERF to explain the risks that smallholders face in Africa, especially regarding net returns to GM and non-GM maize.

Data

Background

Data was collected during the 2009-2010 maize production season from 184 households with a total of 212 maize plots in two regions—Hlabisa and Simdlangetsha, located in KwaZulu-Natal, South Africa. Information was gathered by experienced enumerators supervised by researchers from the University of Pretoria on the timing, quantity, and prices of inputs and labor used during each stage of production, from land preparation until harvest during seven visits throughout the season in order to reduce recall bias (see Gouse [2012] for details). Other information was collected on demographics, education, experience using herbicide, access to extension and credit, household consumption habits, assets, expenses, and non-farm income.

The regions of Hlabisa and Simdlangetsha lie within close proximity to each other and share many similar agro-ecological characteristics. Average rainfall is around 980mm (38 inches) per year, much of it falling during the maize production season (Gouse, Piesse, Poulton, & Thirtle, 2008). Average maize yield is approximately 1,500 kilograms/hectare (24 bushels/acre) due to marginal land quality (Gouse et al., 2009). Smallholders own 39% of land in KwaZulu-Natal, as compared to only 10% in the rest of the country (Republic of South Africa, Department of Agriculture, Forestry, and Fisheries, 2011). Previous literature suggests that KwaZulu-Natal farmers face a constrained labor supply due to urban migration of agricultural workers and a high HIV/AIDS infection rate (Gouse et al., 2009).

More than half of the producers in this study, of which the average age is 55 years old, report that their monthly pension check from the government is their top source of income. Many of these farmers also have livestock, and a majority have access to credit. The majority of maize produced by the farmers is consumed within the farmers' own households, suggesting that these are subsistance farmers. Farmers planted five primary types of maize. Two were improved hybrid varieties, referred to as Pannar and Carnia after the names of the seed companies which released these varieties. The other three were GM hybrid varieties—Bt (insect resistant), RR (herbicide tolerant), and BR ("stacked," containing both Bt and RR traits). Producers reported that rainfall was good in both Simdlangetsha and Hlabisa throughout the entire production season, and pest pressure was low on all fields, as 98% of producers reported that there were either "no worms" or "a couple worms."

Production Costs, Labor Costs, and Net Returns

The average farm size is 1.85 hectares and the average maize plot is 0.49 hectares, with farmers growing primarily maize, but also beans, pumpkins, groundnuts,

Table 1. Biochemical and mechanical input costs ($/hectare).[a]

Site	Seed type	Seed	Fertilizer	Herbicide	Insecticide	Oxen	Tractor	Total costs
Hlabisa	BR	185	98	216	0	32	0	531
	Pannar	124	121	22	0	30	0	297
	RR	169	87	187	0	16	0	458
	GM	172**	88	192**	0	19	0	471**
	Non-GM	124	121**	22	0	30	0	297
Simdlangetsha	BR	175	271	106	1	3	54	609
	Bt	151	259	124	0	7	64	600
	Carnia	131	307	123	13	5	65	642
	Pannar	111	280	76	20	3	64	549
	RR	159	247	68	7	11	66	556
	GM	163**	259	105	2	6	60	595
	Non-GM	121	290*	100	16**	4	64	596

Note: N=212; BR=35, Bt=18, Carnia=34, Pannar=48, RR=77; Hlabisa=97; Simdlangetsha=115

***,* Indicates significantly higher at the 0.01 and 0.05 level, respectively, using a one-sided t-test.*

[a] All monetary units are converted from South Africa Rand to US dollars ($) at the constant exchange rate of 7.44 Rand per US dollar, based on 2009-2010 exchange rates.

Table 2. Labor by task (hours/hectare).

Seed type	Land preparation	Planting	Weeding	Insecticide	Herbicide	Top dress	Harvest	Total labor
BR	27	64	0	0	24	31	72	219
Bt	17	75	23	0	57	68	87	327
Carnia	19	76	15	36	64	53	87	350
Pannar	43	86	127	24	29	44	66	421
RR	26	89	4	5	21	9	54	207
GM	25	80	6	3	27	23	63	227
Non-GM	33**	82	81**	29**	44**	48**	75	391**

Note: N=212; BR=35, Bt=18, Carnia=34, Pannar=48, RR=77; GM=130, non-GM=82

***,* Indicates significantly higher labor use at the 0.01 and 0.05 level, respectively, using a one-sided t-test.*

sweet potatoes, and other crops. Production and labor costs vary between the five maize types and with each region. A summary of the biochemical and mechanical input costs, not including fixed costs such as land and depreciation of equipment, is presented in Table 1. In Hlabisa, GM maize plots have significantly higher seed and herbicide costs than non-GM maize, resulting in significantly higher total-purchased-input costs. Producers of RR maize spent significantly less on oxen than both BR and Pannar producers, as a higher percentage of them planted the maize using no-till with pre-emergent herbicide and hand hoes. In Simdlangetsha, GM maize also has significantly higher seed costs, but total input costs are not significantly different. Insecticide costs are significantly higher for Carnia, Pannar, and RR plots; this is expected since Bt and BR maize do not require insecticide.

Significant differences exist in labor use between varieties (Table 2). Non-GM maize uses a significantly higher number of hours of land preparation, weeding, insecticide, herbicide, top dressing, and total labor per hectare than GM maize. The main reason is that producers planting RR and BR maize typically plant no-till, allowing them to reduce weeding labor and spray herbicide to control weeds instead. Most of the labor savings from GM maize go to family labor, not hired labor. Non-GM maize plots use significantly more child, male, and female labor than GM maize, while total hired labor is not significantly different between GM and non-GM maize.

Because non-GM maize has significantly higher labor use, labor costs are significantly higher in both regions (Table 3). Labor costs were calculated using the average wage rate paid to hired labor. These rates were

Table 3. Maize yields, revenues, costs, and net returns across region and maize type.

	Seed type	N	Yield (kg/ha)	Maize price ($/kg) [a]	Maize revenue ($/ha)	Input cost ($/ha)	Labor cost ($/ha)	Total cost ($/ha)	Net returns $/ha)
Hlabisa	BR	15	1,910	0.48	918	531	143	674	244
	Pannar	15	1,788	0.48	866	297	335	632	234
	RR	67	1,880	0.48	910	458	149	606	304
	GM	82	1,885	0.48	912	471**	148	619	293
	Non-GM	15	1,788	0.48	866	297	335**	632	234
Simdlangetsha	BR	20	1,347	0.38	512	609	186	794	-283
	Bt	18	1,351	0.37	502	600	251	851	-349
	Carnia	34	1,227	0.38	463	642	268	910	-447
	Pannar	33	1,659	0.38	640	549	317	866	-226
	RR	10	1,953	0.38	737	556	230	786	-48
	GM	48	1,475	0.38	555	595	219	814	-259
	Non-GM	67	1,440	0.38	550	596	292**	888**	-338

***,* Indicates significantly higher at the 0.01 and 0.05 level respectively using a one-sided t-test.*
[a] Average maize price of $0.38 and $0.48 per kilogram is equal to $9.40 and $12.19 per bushel, respectively, based on 56 lbs. per bushel of maize

$0.81 and $0.79 per hour in Hlabisa and Simdlangetsha, respectively. The full wage rate was applied to both hired and family labor to account for the opportunity cost of time. While the KwaZulu-Natal labor market may be thin and this assumption artificial for the specific context, it does provide general insight to the net cost advantage of labor-saving technologies.

Table 3 presents a summary of maize yields, revenues, costs, and net returns. Maize revenue is maize yield multiplied by maize price. Net revenue is calculated on a per-hectare basis by taking maize revenue less total variable costs, which includes both input and labor costs. Large variation in net returns occurs between regions due primarily to yield and maize price. Net returns also vary within each region between maize types because of differences in seed, herbicide, and labor costs.

In Hlabisa, the tradeoff between input costs and labor costs is obvious. GM input costs are significantly higher due to higher seed and herbicide costs (Table 1), while non-GM labor costs are significantly higher. The result is that total costs are not significantly different. In Simdlangetsha, net returns are negative due to including family labor costs at $0.79 per hour and a lower maize price received by farmers in the region. Although non-GM maize has similar input costs as GM maize, labor costs are significantly higher, resulting in significantly higher total costs for non-GM maize.

Methods and Results

The previous section shows that biochemical input costs vary between GM and non-GM maize, and that non-GM maize consistently has significantly higher labor costs. In this section, both stochastic dominance and SERF provide a more technical approach to analyze the differences in net returns (as calculated in Table 3) between all five maize types. Because of several differences between the two regions, they are analyzed separately. We portray the entire distribution of data for our analysis in an attempt to downplay any potential source of unobservable bias captured in “average” findings. This, combined with a long-term experience with GM seeds, reduces possible inference bias that might arise from farmer-specific characteristics or germplasm effects (Gouse, 2012).

Stochastic Dominance

Methods. Stochastic dominance compares at least two risky alternatives that are mutually exclusive and assumes that the net returns distribution for each alternative is representative of the entire population of net returns for each alternative. The concepts of first-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) were first introduced by Hadar and Russell (1969) and Hanoch and Levy (1969). FSD simply assumes that producers prefer higher net returns to lower net returns, and that decision-makers have abso-

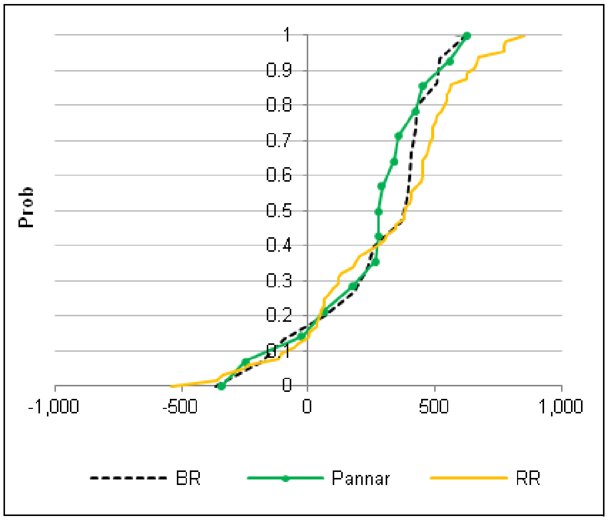

Figure 1. Cumulative distribution functions of maize net returns, Hlabisa.
Note: N=97; BR=15, Pannar=15, RR=67

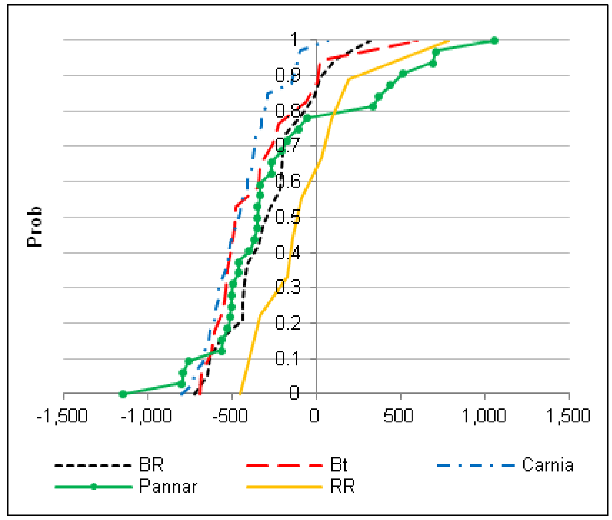

Figure 2. Cumulative distribution functions of maize net returns, Simdlangetsha.
Note: N=115; BR=20, Bt=18, Carnia=34, Pannar=33, RR=10

lute risk aversion with respect to wealth, x, between the bounds $-\infty \leq r_a(x) \leq +\infty$. The absolute risk aversion coefficient (ARAC) is defined by Pratt (1964) as $r_a(x) = -U''(x)/U'(x)$, which represents the ratio of the second and first derivative of the decision-maker's utility function, $U(x)$. SSD, a more restrictive approach, assumes that decision-makers are risk averse by restricting the bounds of absolute risk aversion with respect to wealth between $0 \leq r_a(x) \leq +\infty$ (Dillon & Anderson, 1990; Hardaker, Richardson, Lien, & Schumann, 2004).

Results. CDFs were formed from the probability distribution of net returns of the different maize types in each region, and stochastic dominance was performed using SIMETAR©, developed by Schumann, Feldman, and Richardson (2011). Results in Figure 1 reveal multiple lower-tail crosses between maize types until a cumulative probability of 0.50 is reached, thus implying that risk-averse decision-makers will be incapable of discerning a preferred "dominant" maize variety in Hlabisa. RR maize is the variety with the highest net returns above a net returns level of $382 (at about the 50% or average point), but none of the maize varieties in Hlabisa are first-degree or second-degree stochastically dominant. Net returns are higher than $450 per hectare 35% of the time with RR maize, but only 16% and 14% of the time for BR and Pannar maize, respectively.

In Simdlangetsha, RR maize is FSD to BR, Bt, and Carnia since the CDF of RR maize lies below and to the right of these varieties. The CDF of RR maize also lies below and to the right of Pannar until a cumulative probability of 0.78 is reached, where it crosses with Pannar maize (Figure 2). This indicates that RR has the highest net returns about 78% of the time and Pannar maize 22% of the time above net returns of $87. Figure 2 also reveals that 63% of RR maize producers are expected to have negative net returns, compared to almost 80% of Pannar producers, 90% of Bt and BR producers, and nearly 100% of Carnia producers. It was also found that RR maize is SSD over all other varieties. As mentioned earlier, net returns are calculated using a full wage rate for family labor, resulting in negative net returns for a majority of producers in Simdlangetsha. This does not impact the results, as the dominance would exist for any reasonable wage rate applied to labor.

Results from Hlabisa and Simdlangetsha indicate no clear result of the impact that GM crops have on net return risk, as no variety is consistently superior. Since SSD only places general restrictions on the value of the absolute risk-aversion coefficients, the ARAC values can range from zero to infinitely positive. This implies that a producer of RR maize is so risk averse that a very small change in net returns would result in an extraordinarily large change in utility, which is not a reasonable assumption (Hardaker et al., 2004). SERF can offer more conclusive results by using more restrictive assumptions.

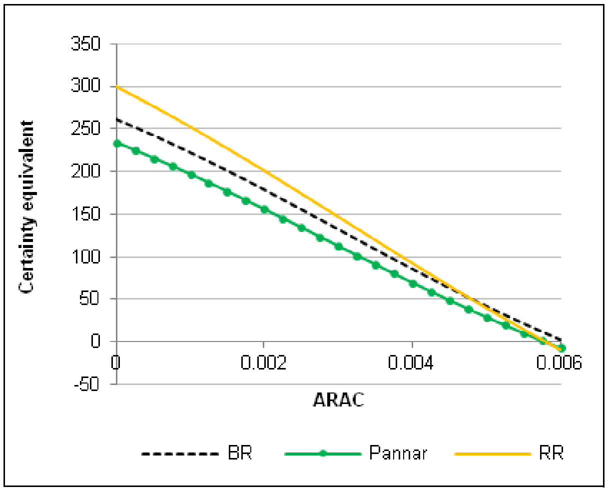

Figure 3. SERF results for net returns ($/hectare), Hlabisa.
Note: N=97; BR=15, Pannar=15, RR=67

Stochastic Efficiency with Respect to a Function

Methods. Stochastic efficiency with respect to a function (SERF) provides a more restrictive approach than stochastic dominance. SERF orders alternatives in terms of certainty-equivalent (CE) values within a range of risk-aversion coefficients. Certainty equivalents, defined as the amount of net returns necessary to make the decision-maker indifferent to alternatives, are calculated using the inverse of the utility function. A negative exponential utility function is used to calculate CE values in this analysis since it has a concave slope, which characterizes smallholders that are risk averse. Babcock, Choi, and Feinerman (1993) note that this functional form is often used to analyze farmers' decisions under risk. A higher CE is expected for alternatives with higher net returns, and it is preferred to a lower CE. The CE values of each alternative are then graphed against the range of lower and upper bounds of risk-aversion coefficients, from $r_L(x)$ to $r_U(x)$. The range of ARAC is determined by the relationship between absolute and relative risk aversion, $r_a(x) = r_r(x)/x$, where x is wealth. The range of relative risk-aversion coefficients used is from 0.00 to 4.00, representing risk-neutral to extremely risk-averse decision-makers, respectively (Hardaker et al., 2004).

Results. SERF was carried out using SIMETAR© (Schumann et al., 2011). The range of ARAC needed for the analysis was calculated by dividing the relative risk-aversion coefficients of 0.00 and 4.00 by the average net worth of $1,607 and $465 per hectare for each household in Hlabisa and Simdlangetsha, respectively.[1] Thus, the corresponding range of ARAC is from a lower limit of 0.00 to an upper limit of 0.0025 and 0.0086. However, the upper limits were expanded to 0.006 and 0.01 to show a wider range of risk aversion, including even the most extremely risk-averse producers that follow the maxi-min decision criteria and prefer the variety (net return distribution) that has the highest minimum net return.

The results of SERF for Hlabisa are displayed in Figure 3 and show that RR maize is the superior choice since it has higher certainty equivalents across the range of expected producer risk preferences of 0.00 to 0.0025. The second-most preferred choice is BR maize. The CE curve for all maize types decreases as the individual becomes more risk averse, since the net returns necessary to make the decision-maker indifferent between alternatives decreases. None of the CE curves cross, and there is little variation in the differences between the CE values as the ARAC values change; this matches up with stochastic dominance results (Figure 1), where the CDF curves of all three maize varieties are very close together.

A utility-weighted risk premium is calculated as the difference between the CE values using RR as a baseline and graphed over the range of risk aversion (Figure A1). A risk premium is defined as the additional net returns that producers would have to be compensated to convince them to switch to an alternative maize type. In Hlabisa, risk-neutral RR producers, defined by both an absolute and relative risk aversion value of 0.00, would have to be paid $40 and $65 per hectare to switch to BR and Pannar maize, respectively. RR producers that are extremely risk averse where $r_a(x) = 0.0025$, representative of a relative risk-aversion value of 4.00, would require only $18 and $40 to switch to BR and Pannar maize, respectively. The results of SERF in Hlabisa assume that producers have equal opportunity to plant any variety, while some farmers may choose to plant RR or BR maize no-till since they are unable or unwilling to weed.

In Simdlangetsha, RR maize once again has the highest CE regardless of the ARAC value (Figure 4). The second-most preferred choice depends on the risk-

1. *Net worth, not including outstanding debt, was calculated as: farm assets (such as plows and planters) divided by total arable land per farmer. It does not include non-farm assets or livestock.*

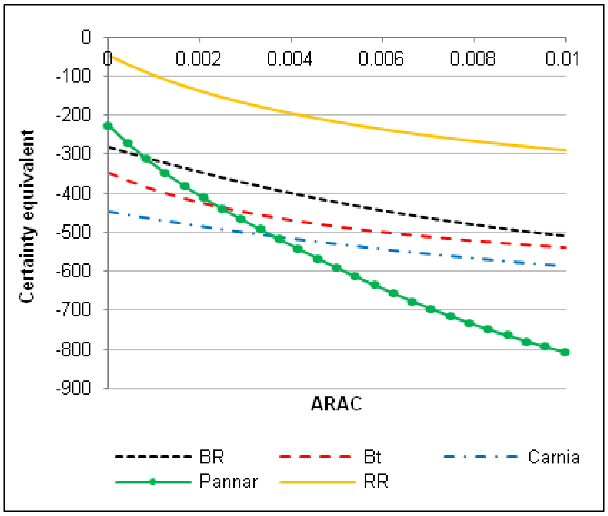

Figure 4. SERF results for net returns ($/hectare), Simdlangetsha.

Note: N=115; BR=20, Bt=18, Carnia=34, Pannar=33, RR=10

aversion preference of the producer. The CE curves of Pannar and BR cross where $r_a(x) = 0.0008$, which is equal to a relative risk-aversion value of 0.37, representing slight risk aversion.[2] Thus, producers with a relative risk-aversion value between 0.00 and 0.37 will prefer Pannar as their second choice of maize seed to plant, while producers who are slightly to extremely risk averse, with relative risk-aversion values between 0.37 and 4.00, will prefer BR maize.

In Simdlangetsha, both risk-neutral and extremely risk-averse RR maize producers must be paid much higher risk premiums to convince them to switch to the second-most preferred variety (Figure A2). Risk-neutral producers must be paid almost $200 to switch to Pannar, and extremely risk-averse producers must be paid approximately $225 to switch to BR maize. RR maize producers must be paid even more to switch to the third-most preferred variety. In general, the results of the SERF analysis indicate that GM maize varieties provide a useful risk-management tool for moderately to highly risk-averse maize farmers.

Conclusions

The results show that smallholders planting GM maize typically face lower net-return risk, as observed from the 2009-2010 maize production season in KwaZulu-Natal, South Africa. These results are provided using stochastic dominance, which reveals that RR maize is second-degree stochastically dominant to all other varieties in Simdlangesha, while no variety is stochastically dominant in Hlabisa. In addition, SERF indicates that RR maize is the preferred variety for producers over the entire range of risk preferences in both regions, and BR is the second preferred choice among most producers. In Hlabisa, where average gross returns to maize are $904 per hectare, risk premiums between $18 and $40 per hectare must be paid to RR maize producers to persuade them to switch to BR, the second-most preferred variety within the expected range of risk preferences. This is largely due to higher yield and lower labor costs associated with both RR and BR maize. In Sindlangetsha, where average gross returns to maize are $552 per hectare, producers must be compensated with much higher risk premiums of $180 to $221 per hectare to convince producers to switch from RR to either Pannar or BR, depending on the risk preference of the producer. RR maize is the superior choice due to its high yield and low labor costs, while Pannar maize is high-yielding and BR maize has low labor costs.

RR and BR maize stand out from other varieties since they contain the Roundup Ready® trait, allowing farmers to plant them no-till; this significantly reduces labor requirements, as herbicide application replaces weeding labor. This makes them especially attractive varieties to smallholders with a high opportunity cost of time or those who cannot handle the physical activity required for weeding. When opportunity cost of time is considered for family labor, the additional cost often outweighs the premium that GM maize producers pay for seed. The results of this research show that Roundup Ready® should be considered as an important trait to reduce net return risk for smallholders adopting hybrid maize varieties.

References

Babcock, B.A., Choi, E.K., & Feinerman, E. (1993). Risk and probability premiums for CARA utility functions. *Journal of Agricultural and Resource Economics*, *18*(01), 17-24.

Barham, E.H., Robinson, J.R., Richardson, J.W., & Rister, M.E. (2011). Mitigating cotton revenue risk through irrigation, insurance, and hedging. *Journal of Agricultural and Applied Economics*, *43*(4), 529-540.

Barrett, C.B., Moser, C.M., McHugh, O.V., & Barison, J. (2004). Better technology, better plots, or better farmers? Identifying changes in productivity and risk among malagasy rice farmers. *American Journal of Agricultural Economics*, *86*(4), 869-888.

2. *This point is called the breakeven risk root (BRAC), calculated as* $r_a(x) * \text{net worth} = 0.0008 * 465 = 0.37$.

Bryant, K.J., Reeves, J.M., Nichols, R.L., Greene, J.K., Tingle, C.H., Studebaker, G.E., et al. (2008). Valuing transgenic cotton technologies using a risk/return framework. *Journal of Agricultural and Applied Economics*, *40*(3), 767-775.

Crost, B., Shankar, B., Bennett, R., & Morse, S. (2007). Bias from farmer self-selection in genetically modified crop productivity estimates: Evidence from Indian data. *Journal of Agricultural Economics*, *58*(1), 24-36.

Dillon, J.L., & Anderson, J.R. (1990). *The analysis of response in crop and livestock production*. Elmsford, NY: BPCC Wheatons, Ltd.

Gouse, M. (2012). GM maize as a subsistence crop: The South African smallholder experience. *AgBioForum*, *15*(2), 163-174. Available on the World Wide Web: http://www.agbioforum.org.

Gouse, M., Piesse, J., & Thirtle, C. (2006). Output and labour effects of GM maize and minimum tillage in a communal area of KwaZulu-Natal. *Journal of Development Perspectives*, *2*(2), 192-207.

Gouse, M., Piesse, J., Poulton, C., & Thirtle, C. (2008, September 5). *Efficiency and employment effects of GM maize in KwaZulu-Natal*. Paper presented at the Harvard International Institute for Advanced Studies Workshop, "African agricultural development—Improving African agriculture for accelerated growth," Accra, Ghana.

Gouse, M., Piesse, J., Thirtle, C., & Poulton, C. (2009). Assessing the performance of GM maize amongst smallholders in KwaZulu-Natal, South Africa. *AgBioForum, 12*(1), 78-89. Available on the World Wide Web: http://www.agbioforum.org.

Hadar, J., & Russell, W.R. (1969). Rules for ordering uncertain prospects. *The American Economic Review*, *59*(1), 25-34.

Hanoch, G., & Levy, H. (1969). The efficiency analysis of choices involving risk. *The Review of Economic Studies, 36*(3), 335-346.

Hardaker, B.J., Richardson, J.W., Lien, G., & Schumann, K.D. (2004). Stochastic efficiency analysis with risk aversion bounds: A simplified approach. *The Australian Journal of Agricultural and Resource Economics*, *48*(2), 253-270.

Hignight, J.A., Watkins, K.B., & Anders, M.M. (2010, February 6). *An economic risk analysis of tillage and cropping systems on the Arkansas grand prairie*. Paper presented at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL.

Huang, J., Hu, R., Fan, C., Pray, C.E., & Rozelle, S. (2002). Bt cotton benefits, costs, and impacts in China. *AgBioForum*, *5*(4), 153-166. Available on the World Wide Web: http://www.agbioforum.org.

Mutuc, M.E., Rejesus, R.M., Pan, S., & Yorobe, Jr., J.M. (2012). Impact assessment of Bt corn adoption in the Philippines. *Journal of Agricultural and Applied Economics*, *44*(1), 117-135.

Mutuc, M., & Yorobe, Jr., J.M. (2007). *Farm level impacts of Bt corn adoption in a developing country: Evidence from the Philippines*. Paper presented at the American Agricultural Economics Association Annual Meeting, Portland, OR.

Pendell, D.L., Williams, J.R., Boyles, S.B., Rice, C.W., & Nelson, R.G. (2007). Soil carbon sequestration strategies with alternative tillage and nitrogen sources under risk. *Applied Economic Perspectives and Policy*, *29*(2), 247-268.

Pratt, J.W. (1964). Risk aversion in the small and in the large. *Econometrica*, *32*(1/2), 122-136.

Pray, C., Huang, J., & Qiao, F. (2001). Impact of Bt cotton in China. *World Development*, *29*(5), 813-825.

Qaim, M., & de Janvry, A. (2005). Bt cotton and pesticide use in Argentina: Economic and environmental effects. *Environment and Development Economics*, *10*, 179-200.

Qaim, M., & Zilberman, D. (2003). Yield effects of genetically modified crops in developing countries. *Science*, *299*(5608), 900-902.

Republic of South Africa, Department of Agriculture, Forestry, and Fisheries. (2011). *Abstract of agricultural statistics*. Pretoria, South Africa: Author. Available on the World Wide Web: http://www.nda.agric.za/docs/statsinfo/Abstract_2011.pdf.

Ribera, L.A., Hons, F.M., & Richardson, J.W. (2004). An economic comparison between conventional and no-tillage farming systems in Burleson County, Texas. *Agronomy Journal*, *96*(2), 415-424.

Schumann, K.D., Feldman, P.A., & Richardson, J.W. (2011). *SIMETAR©: Simulation & econometrics to analyze risk*. College Station, TX: Agricultural and Food Policy Center, Texas A&M University.

Shankar, B., Bennett, R., & Morse, S. (2007). Output risk aspects of genetically modified crop technology in South Africa. *Economics of Innovation and New Technology*, *16*(4), 277-291.

Shankar, B., & Thirtle, C. (2005). Pesticide productivity and transgenic cotton technology: The South African smallholder case. *Journal of Agricultural Economics*, *56*(1), 97-116.

Shively, G.E. (1999). Risks and returns from soil conservation: evidence from low-income farms in the Philippines. *Agricultural Economics*, *21*(1), 53-67.

Williams, J.R., Pachta, M.J., Claassen, M., Roozeboom, K., & Llewelyn, R. (2011). Wheat stubble to burn or not to burn: An economic analysis. *Western Economics Forum*, *10*(1), 32-42.

Yorobe, J.M., & Quicoy, C.B. (2006). Economic impact of Bt corn in the Philippines. *The Philippine Agricultural Scientist*, *89*(3), 258-267.

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Appendix

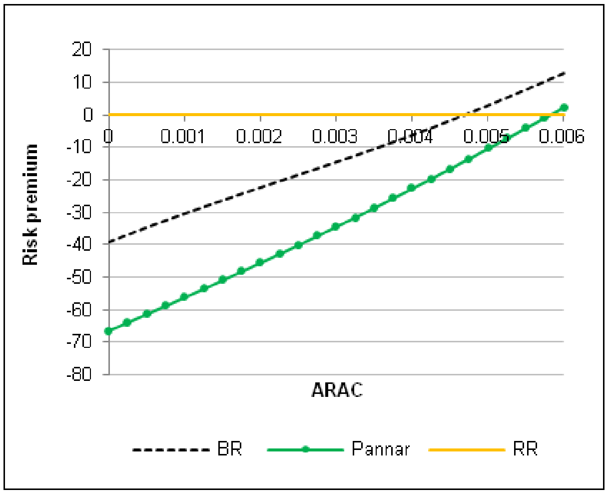

Figure A1. Risk premiums relative to RR maize ($/hectare), Hlabisa.

Note: N=97; BR=15, Pannar=15, RR=67

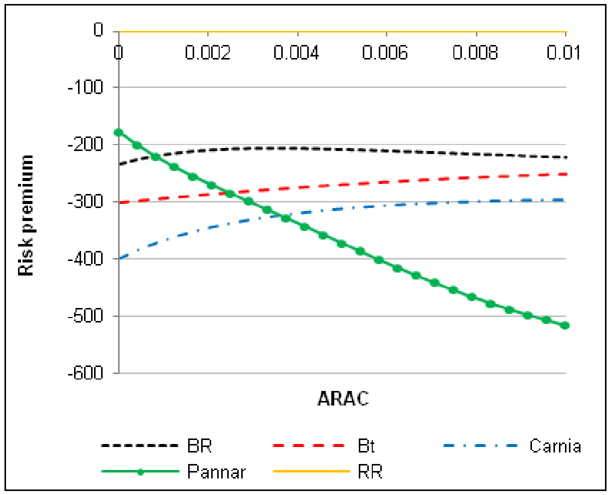

Figure A2. Risk premiums relative to RR maize ($/hectare), Simdlangetsha.

Note: N=115; BR=20, Bt=18, Carnia=34, Pannar=33, RR=10