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Prospects for BT Cotton In Mozambique

By

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EXECUTIVE SUMMARY

Mozambique's cotton sector is very important to the economy and to poverty reduction in the rural sector. Cotton production in Mozambique is characterized by low levels of productivity, low prices and low returns. Cotton farmers in Mozambique are often no better off than their neighbors who do not grow cotton. Not surprisingly, many cotton farmers have switched to other crops such as sesame. But the Government of Mozambique and the National Cotton Institute (INE) are committed to improving the profitability of the cotton sector and encouraging new investments by international companies.

Looking at cotton production globally, the most important innovation in recent years has been the introduction of transgenic Bt cotton. Bt cotton varieties have built-in resistance to bollworm, a devastating insect pest. Cotton production in countries that have introduced Bt varieties, like India, China and the United States, has soared. Yet no country in Sub-Saharan Africa (SSA), with the exception of South Africa, has yet introduced Bt cotton. Burkina Faso is at an advanced stage of testing.

Mozambique should not ignore the single most important technical advance in rain-fed cotton production in the past decade. What are the potential benefits and costs to Mozambique from the introduction of Bt cotton? Would it be profitable for farmers to adopt? What would be the effects of adoption on poverty? If the results are potentially profitable what steps need to be taken and by who to realize the potential gains? This working paper answers these questions by conducting first a detailed review of the experience of other countries who have adopted Bt cotton, and then an economic 'experiment' to estimate the expected profitability of cotton production based on farm-level cotton pest control and crop management data.

The review of experience with Bt cotton outside Mozambique generally shows significant yield and profitability gains for farmers who adopt the technology. The only exception to this generally positive picture occurs in areas where bollworm incidence is not a major problem (e.g., western China), or in areas which are not climatically well-suited to rain-fed cotton production (e.g., the Makathini Flats in Kwazulu-Natal in South Africa). Simulations of the effects of widespread adoption of Bt cotton indicate that the expected large increases in global production will result in lower world prices, making it more difficult for countries that do not adopt Bt cotton to maintain the competitiveness of their sectors in the international market. The impact of widespread adoption of Bt cotton is likely to be much larger than that of international subsidies. A major factor affecting the profitability of Bt cotton adoption at the farm level is the technology fee that must be paid to the owner of the patent, generally international seed companies.

The 'experiment' consists of a detailed analysis of the financial and economic profitability of cotton production if Bt cotton varieties were to be used in Mozambique. A financial analysis uses current prices of raw cotton and inputs, whereas the economic analysis takes account of costs and benefits, such as under-valuation of the raw cotton farmers sell and the value of health benefits gained from not applying insecticides. The estimated yield gains and pesticide savings at farm level are obtained by regression analysis of the determinants of raw cotton yield on a sample of 215 cotton farmers' fields in Nampula and Cabo Delgado provinces.

The results of the financial and economic analysis are quite different, indicating that the country may have much to gain from moving ahead with the introduction of Bt cotton introduction even though it is not financially attractive to farmers at current prices and with current crop management practices. From the farmer's perspective, an estimated yield gain of 20% combined with savings from using 1.5 sprays less does not compensate for an expected seed cost of US$50 per hectare because of low raw cotton prices paid to Mozambican farmers (financial loss of US$10.50 per hectare). But if Mozambican farmers were to receive the same prices as cotton farmers in neighboring countries, and the savings in health costs from pesticide exposure are added in, the introduction of Bt cotton is profitable even at the expected seed cost (economic gain of US$22.50 per hectare). Improvements in farmers' crop management practices, especially timely weeding and planting, when combined with cheaper sources of Bt cotton seed, could significantly improve both the financial and economic profitability of Bt cotton. Introduction of the technology would have an important effect on reduction in the severity of poverty among cotton producers who are currently very poor and have few other options.

An analysis of the introduction of cotton at an aggregate level indicates that it would be a very positive investment, with a net present vale (NPV) of US$18 million and an internal rate of return (IRR) of 25% even at a seed cost of US$50 per hectare. Both the NPV and IRR are sensitive to the length of time it takes to make the technology available to farmers with a loss of economic benefits equivalent to US$1 million for every year of delay. Our results make a strong case that Bt cotton has sufficient promise to warrant field testing. It is only through field testing that the size of the yield gain can be estimated with precision. Unfortunately, the inter-ministerial National Biosafety Working Group has taken no concrete action to facilitate testing of Bt cotton varieties since it was established in 2001.

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ACRONYMS

Bt	*Bacillus thuringiensis*
CESE	Center for Socio-economic Studies
CFA	African Financial Community
CIMMYT	International Maize and Wheat Improvement Center
CPB	Cartagena Protocol on Bio-safety
DE	Directorate of Economics
EC	European Community
EPA	Environmental Protection Agency
EPTD	Environment and Production Technology Division
ICABR	International Consortium on Agricultural Biotechnology Research
ICAC	International Cotton Advisory Council
IIAM	Institute of Agricultural Research of Mozambique
IAM	National Cotton Institute
ISAAA	International Service for the Acquisition of Agri-Biotech Applications.
GM	Genetically Modified
IRR	internal rate of return
MADER	Ministry of Agriculture and Rural Development (former name, now MINAG)
MINAG	Ministry of Agriculture
NBWG	National Bio-safety Working Group
NPV	net present value
OECD	Organization for Economic Co-operation and Development
RSA	The Republic of South Africa
SADC	Southern African Development Community
SEI	Stockholm Environment Institute
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VIP	Vegetative Insecticidal Protein
WTO	World Trade Organization

1. INTRODUCTION

Seventeen of the top 40 cotton-producing nations in the world are located in Africa (ICAC 2005). One of these is Mozambique where more than 200,000 poor rural households rely on cotton as their primary and often only cash crop. Although Mozambique is not in the top echelon of producing countries in Africa, the importance of cotton should not be underestimated; cotton ranks second in merchandise exports (Osorio and Tschirley 2003).

In the late 1990s, a productivity assessment from the Head of the Technical Information Section of the International Cotton Advisory Council (ICAC) concluded that "world cotton yields are not increasing any more." (Chaudhry 1998, p. 1). This evaluation signaled that new technology was essential to increase productivity as the scope for applying on-the-shelf technology was exhausted. Bt cotton has responded to this challenge and has broken the stagnancy in cotton productivity documented in the 1990s. In several major cotton producing countries, the introduction of Bt cotton has fueled growth in yields and production. For example, India was forecast to have an unprecedented fifth consecutive record cotton crop in the 2007/08 growing season as production almost doubled from 10.6 million bales in 2002/03 to 21.1 million bales in 2006/07 (USDA 2007a). Bt cotton has played an important role in contributing to India's surging cotton production. About half of India's five million cotton growers now plant more than 60 Bt cultivars that are produced on over five million hectares equivalent to over 50% of cotton-growing area (USDA 2007a).

Since 1938 the soil bacterium *Bacillus thuringiensis* (Bt) has been used by farmers, including organic gardeners, as a naturally occurring microbial pesticide in crop protection (Kameswara Rao 2005). Bt produces crystalline proteins that are toxic to chewing insects that ingest plant tissue. In 1986, the Environmental Protection Agency (EPA) in the United States began testing genetically engineered varieties that contained specific Bt-toxin encoding genes. These Bt transgenic varieties were subsequently approved and were released in 1996 for the production of several major field crops including cotton, maize, and potatoes. Globally, cotton has been the most successful of the Bt crops.

Success in increasing cotton production with the adoption of Bt cultivars is not surprising. Cotton is a disproportionately high user of pesticides because chewing insects, particularly the bollworm complex, are a major source of crop loss when pest management is not efficacious.

Bt cotton has engendered several large success stories and has endured several smaller setbacks during its first decade in farmers' fields. Both successes and setbacks are examined in Section 2, which reviews the impact assessment literature on Bt cotton. The major source of disappointment is the slowness in participation in transgenic technological change by several countries that depend heavily on cotton as a source of export earnings or as a major contributor to agricultural value of production. Exporters in Sub-Saharan Africa (SSA) and in central Asia and Pakistan figure prominently on the Bt cotton non-participation list. Because of the intensity, depth, and severity of poverty in SSA, the cost of not deploying Bt cotton could be very large (Eicher, Maredia, and Sithole-Niang 2006). The conventional wisdom suggests that producers in non-adopting regions always lose when technological change results in lower producer prices, and several modeling exercises show that cotton-growing households in Sub-Saharan Africa are no exception (Elbehri and Macdonald 2004; Anderson, Valenzuela, and Jackson 2008; and Falck-Zepeda, Horna, and Smale 2007). Indeed, Anderson and Valenzuela (2007) estimate that the opportunity cost of not deploying Bt cotton in SSA is greater than the deleterious effects of subsidized production of cotton in the United States, Greece, and Spain on export earnings in SSA.

It is important to recognize that technological change in Bt cotton is dynamic as various Cry genes (from the crystalline proteins that they potentially express) can be exploited to more fully abate damage. Bollgard I cotton developed by Monsanto in the early 1980s relied on the Cry 1 Ac gene. Second-generational technological change in Bt cotton features gene stacking in the form of adding the Cry 2Ab gene to derive Monsanto's Bollgard II. Dow's Widestrike technology uses Cry 1 Ac and Cry 1F genes. Syngenta's Vegetative Insecticidal Protein (VIP) cotton is further back in the pipeline, and it employs an exotoxin secreted by Bt. It may be combined with Bt genes when it is commercialized. The stacked Bt varieties have two advantages over the single gene varieties: (1) they target more chewing-insect pests of cotton more fully, and (2) they do not require as stringent a refuge policy to protect against the development of bollworm resistance to Bt, because multi-gene varieties significantly reduce the odds of a favorable resistance event. For both of these reasons, the stacked varieties should further add value to cotton production. Hence, the opportunity cost of not deploying Bt technology in Sub-Saharan Africa is increasing over time.

As many as 20 studies have assessed the impact of Bt cotton in SSA. The Republic of South Africa (RSA) released Bt cotton to farmers in 1998, where 14 impact assessments on Bt cotton have been carried out (Smale et al. 2006). Almost all of these have focused on a very specific, smallholder rainfall-challenged growing area in KwaZulu-Natal. Since 2003, Bollgard varieties have also been field tested in Burkina Faso. The rest of the literature on the impact of Bt cotton in Sub-Saharan Africa has centered on ex ante assessment in Francophone Africa where the major exporters of cotton in SSA are located. Cotton is also an important cash crop in several countries of Anglophone and Lusophone Africa.

This ex ante assessment is different than the others not only in terms of location but also in emphasis. The largest area of uncertainty in predicting the effects of Bt cotton is in ascertaining the magnitude of the yield increase in seed cotton from the deployment of the technology. It is now commonly accepted that on-farm yields will increase with the adoption of Bt cotton in developing country agriculture (Qaim and Zilberman 2003). But the size of that productivity increase is unknown. We analyze detailed information on cost of production in Mozambique to begin to define the size of the yield advantage to Bt cotton.

Two other differences between this ex ante assessment and others warrant mention. As discussed in the next section, all the other ex ante assessments draw positive inferences about the prospects for Bt cotton in Francophone Africa. But the comparative profitability of Bt cotton in Mozambique is not a foregone conclusion. Compared to other cotton-producing countries, Mozambique is characterized by lower yields (only about 16% of the global average according to ICAC 2005), lower prices and lower infestation of chewing Lepidopteron pests. Finding that the expected profitability of Bt cotton in Mozambique is robust could be tantamount to encountering impact in a worst-case scenario for the economic prospects of the technology. Although the size of the yield advantage and expected profitability of Bt cotton are uncertain, one aspect of cotton production is certain: smallholders in Mozambique belong to the ranks of the poorest cotton growers in the world. Therefore, the potential of Bt cotton to alleviate household income poverty is another theme that is addressed in this paper. Hence, expected yield advantage, expected profitability in both a private and social sense, and the potential for the alleviation of absolute poverty are the core analytical sections of this paper. We begin with a literature review that sets the stage for the analysis that follows.

This paper provides one of the first examples of ex ante technology assessment in Mozambique and is a companion piece to the ex post assessment conducted by McSween et al. (2006). During the course of the paper, several standard techniques in the economist's toolkit, such as multiple regression, partial budgeting, project appraisal, and absolute poverty analysis, are illustrated.

2. THE IMPACT ASSESSMENT LITERATURE ON BT COTTON IN DEVELOPING COUNTRY AGRICULTURE

2.1. Bt Cotton Successes and Setbacks

Since its introduction in RSA and China in 1997, the area under Bt cotton is steadily increasing in developing countries (James 2006). But whether measured in hectares, bales, or number of farmers, over 95% of Bt cotton in developing countries is now grown in India and China. Argentina, Brazil, RSA, Mexico, and Colombia produce relatively and absolutely small amounts of Bt cotton. In both India and China, Bt cotton is probably approaching a ceiling in the level of adoption following dynamic diffusion in recent years. The ability to replace low-yielding, largely intercropped, *desi* cotton varieties with high-yielding Bt hybrids is compromised by dry land marginal production conditions in several regions of peninsular India. In China, Bt varieties account for about 85% of area in the Yangtze and Yellow River provinces, but these varieties have not penetrated into Xinjiang Province, the highest yielding and leading cotton producing province, because of the supposedly low levels of pest populations in higher elevation western China where one-fourth of area is cultivated and one-third of output is produced (USDA 2007b).

The tremendous economic successes of Bt cotton in China and India have taken place in a setting characterized by institutionally established bio-safety regulations and procedures. No marked adverse consequences related to bio-safety regulations have been scientifically documented. Globally, hundreds of studies have failed to encounter significant negative effects on non-target organisms (OECD 2007). More specifically, no adverse effects on non-target natural enemies resulting from direct toxicity of Bt crops have been observed in the field (Pehu and Ragasa 2007). Bt toxins have not accumulated following several years of cultivation and lethal or sub-lethal effects on soil organisms have not been observed in field studies. Most impressively, resistance has not developed in the field; adopters have not increased spraying following the adoption of Bt cotton (Huang et al. 2006). In both India and China evidence of disadoption is scanty. Indeed, the demand for recently released stacked Bt hybrids in India seems strong as farmers are crossing state lines to procure those cultivars.

Improvements to the impressive stories of Bt cotton in China and India does not have much to do with precautionary bio-safety regulations; blemishes on the Bt cotton record center on the need for allied agronomic and pest management research in this dynamic new setting and for improved seed regulation (Kameswara Rao 2006). Because of its robustness in controlling bollworm species, Bt cotton has extended cotton production beyond the limits of its profitability in India. Cultivating cotton on red soils is a losing proposition in Peninsular India, and was a persistent problem long before the introduction of Bt cotton. In China, an outbreak of mirids, a secondary pest, occurred in 2004 that supposedly reversed the gains from the adoption of Bt cotton in five provinces (Wang, Just, and P. Pinstrup-Andersen 2006). Bt cotton was responsible for a sharp reduction in broad spectrum insecticide application that led to an usually heavy infestation in a year when conditions were especially propitious. The finding of reversal of benefits is contested (Hu et al. 2006). Based on farm-level data collected from 1999 to 2004, the level of insecticide targeted for secondary pests did increase but only by about 3-4% of the amount of insecticide saved by the adoption of Bt cultivars. Although the mirid outbreak does not appear to have jeopardized the gains from or sustainability of Bt cotton, it does call attention to the fact that the new technology does not obviate the need for maintenance research in a substantially changed environment for pest management.

In summary, the main setback to Bt cotton as an innovative new technology ten years after its introduction is synonymous with its limited spread across developing countries outside of India and China. Developing countries, such as the Philippines, who are enlightened enough to have legislated bio-safety procedures for transgenic varieties in other major commodities can provide farmers access to Bt cotton to their farmers (Aguiba 2007). Unfortunately, the link between need and access may not be strong. Moreover, Bt cotton with its limited expected risk as a genetically modified crop has not been successful in acting as a catalyst and paving the way for the generation and implementation of bio-safety procedures on genetically modified food crops.

2.2. Bt Cotton Production in the Makhathini Flats: Similarities and Contrasts to Cotton Production in Central and Northern Mozambique

Ex post impact assessments of Bt cotton in Sub-Saharan Africa are confined to RSA, and almost all of the 14 studies that are in the published literature focus on the Makhathini Flats in KwaZulu-Natal (Smale et al. 2006). Bt cotton was tested in accordance with bio-safety procedures between 1994, when it was introduced by Monsanto, and 1996. It was released and made available for commercial production in 1997. Bt cotton subsequently performed well in field trials in a smallholder scheme in the Makhathini Flats. The results of those tests suggested returns in the form of increased yields and savings on insecticides on the order of US$85/ha compared to conventional varieties (Gouse, Kirsten, and Jenkins 2005). The technology was extended to smallholders via a cotton company that utilized credit from the Land Bank formal sector enterprise. Diffusion started in 1998 and several thousand farmers adopted Bt cotton during the first two seasons. Adoption and credit were curtailed when a new company—a public and private sector development initiative—built a gin near the company's depot. Excess ginning capacity precipitated side selling. Farmers defaulted on their loans which precipitated widespread foreclosures and the eventual demise of the company.

The experience of Bt cotton in the Makhathini Flats has been called a technological triumph but an institutional failure (Gouse, Kirsten, and Jenkins 2005). Whether, in its short life, it was economically successful is another matter. Some insightful analysis, such as Shankar and Thirtle (2005) was carried out, however, persuasive evidence that Bt cotton paid for itself in an unsubsidized setting and generated an attractive rate of return on investment has not been forthcoming. The assessments conclusively show that farmers were better off with the Bt cotton variety selected by the company compared to the one or two conventional varieties that were on offer. Bt cotton was on average higher yielding and generated savings in insecticide costs, but these benefits do not appear to have been sufficient to significantly exceed the cost (increased seed plus technology fee) in an unsubsidized setting. If the company shared these costs instead of passing them on to the farmer, sufficient return to investing in Bt cotton did not seem to have been realized. In field surveys, yield differences ranged from about zero in a dry growing season to about 40% in favor of Bt cotton in a wet growing season. Contested enterprise budgets based on company records indicate higher profitability of Bt cotton than the field survey results (Bennett, Morse, and Ismael 2006a), but even these do not support an attractive rate of return on investment. Bt cotton's economic performance in farmers' fields does not begin to approach the levels of profitability reported by (Gouse, Kirsten, and Jenkins 2005) in the Monsanto trials.

In spite of its apparent lack of economic success, the experience with Bt cotton in the Makhathini Flats carries a number of important lessons for countries in SSA contemplating the introduction of Bt cotton. First, efficient cotton production is all about striking a balance between coordination and competition (Poulton et al. 2004). Excessive ginning capacity and side selling are threats to schemes. In Mozambique, schemes similar to the erstwhile one in the Makhathini Flats are the common mode of production. Cotton production is coordinated by joint-venture companies operating in spatial monopolies authorized by the government. The company supplies the seed and pesticides to the growers on credit, and, in turn, receives seed cotton for ginning to repay the loan. The decision on what variety to grow is made by the company with the farmer offered a small range of choice. We assume that the on-farm profitability of Bt cotton will be a major determinant of the company's decision-making, because higher farm profits will attract more farmers and more area into the crop, resulting in increased firm's profits. In this type of coordinated setting, the potential for volatility in cultivar adoption is a fact of life, and technology introduction requires considerable planning and commitment in both the private and public sectors.

Secondly, the Makhathini Flats experience is an important reference point that shows that low base yields inferior to 500 kgs/ha of seed cotton and low prices of about US$0.19 cents significantly darken the prospects for Bt cotton even in the presence of very inefficient pest control where poor farmers have to walk miles for water in a drought-prone environment. Production of rain-fed cotton in northern KwaZulu-Natal takes place in the dry semi-arid topics, an extremely harsh agro ecology for cotton cultivation. Cotton is not produced in neighboring southern Mozambique. Rather, cotton is grown in the wet semi-arid tropics of central and northern Mozambique where rainfall usually exceeds 1000 mm/annum.

With the benefit of hindsight, it is clear that the institutional failure in the Makhathini Flats did not revolve around inadequate private and public sector support and coordination. The source of failure was the decision to support the dry land production of a commodity in a very marginal agro-ecology where rainfall variability results in sharp fluctuations not only in yield but also in planted area. About 67,000 hectares were cultivated in dry land cotton in RSA in the late 1990s. In spite of an impressive burst in productivity over the past decade, irrigated cotton production has also plummeted from about 20,000 hectares in the late 1990s to 8,000 hectares today. The 2006/07 crop was the smallest in 40 years and was attributed to low international cotton prices in recent years; the appreciation of the Rand against the US dollar; more favorable prices of competing crops (which are protected by tariffs); and the absence of tariff protection on cotton because 99% of imports are from Southern African Development Community (SADC) countries where a free trade agreement applies to cotton. In 2006/07, only about 850 small farm households produced cotton in KwaZulu-Natal. With the exception of a productivity spike of about 800 kgs/ha in the 2000/01 growing season, dry land yields have been stagnant, fluctuating between 400-600 kgs/ha.

2.3. Ex Ante Assessments in Sub-Saharan Africa

This study is not the first and most probably will not be the last ex ante assessment of Bt cotton in Sub-Saharan Africa. Previous assessments have focused on Francophone Africa where expanding cotton area and increasing yield since independence are widely hailed as one of the success stories in agricultural development (Lele, Van de Walle, and Gbetobouo 1989). Animal traction, inorganic fertilizer, insecticides, and expansion of area southwards into more favorable sub-humid areas have all figured as ingredients in this successful recipe (Elbehri and MacDonald 2004; Vitale et al. 2007). However, in the recent past, cotton production in Francophone Africa has stagnated as manifested by declining yields, rising costs of production, and eroding profitability. The African Financial Community (CFA) franc devaluation in 1994 (discussed later in this section) and the phasing out of input subsidies have led to the *extensification* of cotton production (Elbehri and MacDonald 2004).

Procrastination in the use of Bt cotton has also contributed to the cotton problem in Francophone Africa (Baffes 2005). Using a general equilibrium global trade model, Elbehri and MacDonald estimated that the status quo of non-adoption of Bt cotton combined with the deteriorating trend in productivity was costing West and Central Africa's producers about 88 million in 1997 US dollars. Diffusion of Bt cotton on 25% of area would offset the recent deteriorating trend in productivity and generate an annual welfare gain of US$82 million. Anderson, Valenzuela, and Jackson (2008) built on the Elbehri and MacDonald (2004) model to address the welfare gains from adopting Bt cotton for SSA as a whole and from the removal of subsidies in major producing countries. Their results showed that by 2001 adoption of Bt cotton in the United States, China, and Australia generated US$0.7 billion of global benefits, but reduced the value of cotton exports from SSA by 7.5% which was equivalent to US$17 million. Adoption of Bt cotton by all nonadopters except SSA in 2001 was projected to add a further loss in welfare of US$18 million annually to SSA. Most interestingly, removal of subsidies and tariffs generated a global gain in welfare of US$283 million per year but was only about one-eight of the value of completing the adoption of Bt cotton in all regions (US$2.3 billion). The gains to SSA were projected to be US$147 million from the removal of policy distortions and US$221 million from adoption of Bt cultivars.

Applications employing partial equilibrium models have also pointed to the desirability of providing access to Bt transgenic change in West Africa. Based on whole-farm linear program models, Cabanilla, Abodoulaye, and Sanders (2004) showed that the annual aggregate benefits from the adoption of Bt cotton from varying adoption ceilings of 30, 50, and 100% ranged from US$61 to 103 to 205 million, respectively, in Mali, Burkina Faso, Benin, Cote d'Ivoire, and Senegal. The relative profitability of Bt cotton also elicited an area response as cotton growing area in the optimal solution increased by 5-6%. Vitale et al. (2007) *aggregated up* the results of Cabanilla, Abodoulaye, and Sanders (2004) in the form of an agricultural supply-demand model for 12 regions in Mali. For adoption to take place, Bt cotton had to satisfy a profit hurdle established by an embedded whole-farm model. Bt cotton is projected to generate a welfare gain of about US$45 million per annum.

The above four ex ante assessments have quantified the annual value of adopting Bt cotton which has also been evaluated over time in a project appraisal format by Falck-Zepeda, Horna, and Smale 2007 who combined a conventional economic surplus model with a Montecarlo simulation to examine various scenarios related to the prospects for Bt cotton in West Africa. Three scenarios of the five estimated scenarios are of particular interest: (1) West Africa adopts private sector varieties; (2) West African varieties are backcrossed to private sector varieties; and (3) the same as (2) but the technology *premium* or fee is negotiated downwards. Estimated aggregate net present value of Bt cotton technology in Burkina Faso, Benin, Mali, Senegal, and Togo totals about US$80 million in scenarios 1 and 2 but falls to 63 million in Scenario 3 for reasons that do not appear to be discussed in the text. The internal rate of return on investment by country ranges from about 18% in Mali to 44% in Burkina Faso where the technology is expected to be made available to producers three years sooner than in the other countries. Falck-Zepeda, Horna, and Smale (2007) assume a relatively short project life of 23 years and peak adoption is assumed only for seven years. These assumptions contribute to estimates of present value that were perceived to be lower than expected.

2.4. Important Variables in Determining On-Farm Profitability: Lessons from the Literature

This subsection sets the stage for the analytical sub-sections that follow by identifying the most important variables that are expected to condition the expected profitability of Bt cotton in Mozambique.

The decision the cotton farmer faces in adopting a Bt variety is summarized in (1) which says that Bt cotton is profitable if the marginal rate of return on investing in Bt seed is greater than or equal to 100%.

(1) $\Delta NB/\Delta TVC > 100\%$

where ΔNB = the change in net benefits in switching to a Bt cultivar from a conventional variety;
ΔTVC = the change in total variable costs of changing to a Bt genotype from a conventional genotype.

The formula in (1) describes a basic normative investment relationship in a developing country setting in a partial budgeting context (Perrin et al. 1977 and CIMMYT 1988). The 100% target as a desirable marginal rate of return is not derived from rigorous study but is a heuristic rule of thumb. The initial International Maize and Wheat Improvement Center (CIMMYT) manual (Perrin et al. 1977) recommended 40% as a minimal cut-off threshold on expected profitability, but the subsequent manual (CIMMYT 1988) effectively raised the bar to 100% in recognition that in many developing countries, such as Mozambique, capital is extremely scarce and capital markets are fragmented and incomplete. Because many biological technologies are not that costly and are divisible, specifying a 100% rate of return on annual investment is not a formidable challenge. If the technology works in farmer circumstances, it may surpass the 100% rate of return criterion by several orders of magnitude.

In China, the cost savings from fewer insecticide applications more than compensated for the increased seed cost of the technology, which is ΔTVC is negative. In terms of the prospects for Bt cotton, the generic adoption decision summarized in (1) is partitioned into its five main components in (2) which will always have a positive denominator as long as the seed cost of the Bt cultivar exceeds the seed cost of the conventional variety.

(2) $((p\Delta Y + \Delta S - \Delta HC)/ \Delta C) > 100\%$

where p = the price of seed cotton in US$/kg;
ΔY = the difference in seed cotton yield in kgs/ha between Bt and conventional cultivars;
ΔS = the savings in insecticide costs between Bt and conventional cultivars in US$/kg
ΔHC = the increase in harvesting costs
ΔC = the increase in seed costs between Bt and conventional cultivars in US$/kg

The expected profitability of Bt cotton is determined by these factors that are discussed in the rest of this section.

2.4.1. The Price of Seed Cotton

As discussed earlier in this section, the price producers receive for seed cotton is an obvious but somewhat neglected consideration in determining the economic profitability of Bt cotton. The economic size of the yield advantage in (2) is directly mediated by price; higher prices translate into increased gross margins if yield gains are positive. Higher producer prices also indirectly set the stage for greater insecticide cost savings as pesticide use intensity is positively related to output price.

The ex ante impact analyses cited above do not pay much attention to seed cotton price in the form of sensitivity calculations or as a deciding factor in profitability. The lack of explicit consideration of seed cotton price probably stems from the repeated observation in ex post studies that Bt and conventional cultivars fetch the same price, i.e., cotton from Bt cultivars is not discounted in the market and the Bt trait has no effect on the quality of lint cotton of a given genotype. Moreover, it is easy to think that there is only one global price for cotton exports that determines seed prices to producers.

Like many primary commodities real cotton prices have declined over time, reaching historic lows in 2001-02 (Baffes 2005). In Mozambique, the average seed cotton price in 2001-02 was only equivalent to US$0.11/kg. Since 2001 prices have rebounded somewhat with the strong demand for textiles in China, which has become a net importer of cotton. In 2005/06, China imported about 4.2 million metric tons of cotton with about 0.5 million tons coming from SSA (USDA 2007b). Double digit consumption growth in China is outstripping domestic production, and imports were forecast to increase to five million metric tons, about 70% of domestic production, in 2007 (USDA 2007b).

The 1993 devaluation of the CFA franc relative to the French Franc had a major effect on seed cotton prices in US$ terms. Prior to devaluation in the 1980s and early 1990s in West Africa, seed cotton prices oscillated between US$0.40-0.70/kg. Following devaluation until the slump of international prices in 2001/02, prices varied within a band of US$0.25-0.40/kg. Price levels in Anglophone and Lusophone SSA are even lower than those in West Africa. Mean seed cotton price between 1998-2002 were estimated at 17 cents (on the dollar) per kg for Ghana, 16 cents per kg for Mozambique, 22 cents per kg for Tanzania, Uganda, and Zambia and 25 cents per kg for Zimbabwe (Poulton et al. 2004). All these countries have recovered somewhat from these low price levels but none have attained a level significantly above 30 cents per kg (Poulton, Labaste, and Boughton 2009).

Both Cabanilla, Abodoulaye, and Sanders 2004 and Vitale et al. 2007 use a price level of US$0.40 to value the productivity benefits of Bt cotton. But Poulton, Labaste, and Boughton 2009, from the perspective of crop enterprise budgets believe that a price level of US$0.40 is not sustainable in Mali in the medium run. They opt for a price of US$0.33 to value output.

In contrast, farmers in ex-post impact assessments of Bt cotton in India and China received prices that have approached or exceeded US$0.50 per kg (Bennett et al. 2006b; Qaim et al. 2006, and Huang et al. 2002). In 2007, the seed cotton price in China was predicted to be about US$0.70 which was a decline from 2006. China has also embarked on a multi-year seed cotton subsidy program that was envisaged to cover about two million hectares in 2007 (USDA 2007b).

Multiple reasons explain the regional variation in seed cotton prices. In Mozambique, low varietal ginning out-turn ratios, inefficient ginning, monopsony power of concessionaires, and poor infrastructure, particularly passable all-weather roads, antiquated collection procedures, and an absence of indicative information all contribute to dampened prices. Although the exact contribution of each determinant is uncertain, the stylized fact of depressed cotton seed prices poses a challenging hurdle for the expected profitability of Bt cotton in SSA. Had Bt cotton appeared in the 1980s or had cotton producers in SSA received the Asian price regime, the economic prospects for Bt cotton in SSA would be bright indeed.

The price we use to value Bt cotton in Section 4 is US$0.21 per kg of seed cotton. This level of remuneration appears to be the current and is barely profitable to concession companies and to their producers in Mozambique (Pitoro, Govene, and Boughton 2006).

2.4.2. The Savings in Pest Management Costs

The savings in pesticide costs consists of the reduction in expenditures on insecticides and the labor used to apply pesticides. The size of expected savings is strongly linked to the intensity of pesticide use in cotton production prior to the introduction of Bt varieties. Based on single-year with-and-without comparisons, the mean number of sprays fell from 19 to 6 in China with the adoption of Bt cotton in Hebei and Shandong provinces (Huang et al. 2002). On average about 10 days of spraying labor per hectare were also saved with the deployment of Bt cotton in China. Although the savings on sprays and labor is impressive in the Chinese context, the reduction in kgs of insecticide is remarkable: about 3.3 kgs per saved spray. Comparable estimates for peninsular India across five states and two cropping seasons indicate about a 50% reduction in the incidence of spraying from about 5.5 to 2.9 applications (Bennett et al. 2006b; Qaim et al. 2006). Ex ante analyses in West Africa also specify pesticide savings at the levels observed in India, e.g., Vitale et al. (2007) suppose a reduction from six to two, saving four sprays, with the introduction of Bt cotton in Mali.

It is important to realize that farmers still apply some insecticide to manage bollworm even in the presence of Bt cotton although in China Huang et al. (2002) have documented that farmers overuse insecticide on Bt cotton. In general, the cost savings of insecticide application in SSA should be similar to India because the intensity of spraying on the bollworm complex is about the same. Given that the average spray intensity in Mozambique is about 2-4 sprays on bollworms, we assume that adoption of Bt cotton will result in a cost savings of 1.5 sprays.

2.4.3. The Increase in Seed Costs and the Technology Fee

Bt cotton is not a cheap technology. In contrast to output price, the increase in seed costs and a lump-sum payment per hectare in the form of a technology fee has received considerable attention from impact assessment analysts. In the most telling ex-post evaluation, Qaim and de Janvry (2003) have shown that the private sector's adherence to uniform global pricing resulted in a high technology fee that choked off adoption in Argentina. Reducing the fee to US$60/ha would not only have increased adoption and innovators' rents but would also have eroded the profitability of black market seed production. Vitale et al. (2007) persuasively show that a technology fee above US$60 per hectare severely and adversely affects the prospective gains from Bt cotton in Mali. But, in the United States, Monsanto's technology fee averaged over US$80/ha in 2006 (Brookes and Barfoot 2005).

The technology fee is one of the focal points for sensitivity analysis in Falck-Zepeda, Horna, and Smale (2007) simulations on the impact of Bt cotton. For four scenarios, they use a triangular distribution with minimum, mean, and maximum value for the technology fee of US$15, $36, and $56 per hectare. For a negotiated scenario, a lower fee is assessed with a specification of US$9, $19, and $34 for the minimum, mean, and maximum value. These low values for the technology fee are based largely on the RSA and Chinese experiences, which are characterized by the lowest relative increase in seed costs in the developing country literature (Pehu and Ragasa 2007). The cases of Argentina and India, where the cost of the technology exceeds US$50/ha, probably offers better guidance on the dearness of Bt cotton when it is initially introduced in other countries in SSA.

The costs of Bt technology should decline over time as more suppliers of Bt cultivars enter the market. Farmers in China have benefited from private and public sector competition in the provision of Bt cotton as the seed of transgenic varieties is only twice as expensive as the seed of non-transgenic cultivars (Pehu and Ragasa 2007). Higher fees may also result in political pressure to impose price ceilings on the seed costs of Bt technology which has recently occurred in India (Kameswara Rao 2006). The size of the technology fee should also reflect the cost of doing business in the country of interest.

A marked preference by the private sector for Bt hybrids has not commanded much attention in the literature. With hybrids, the private sector seed company avoids the problem of weak intellectual property protection to combat farmer-saved seed in poorer developing countries because yield in the F2 and later generations deteriorates over time eroding the incentives to save seed. Without hybrids, the incentives for private sector participation are negligible unless intellectual property can be protected. The alternative to hybrids is to invest in a *closed loop system* that traces all Bt cotton seed by-product from ginning through to final use to guarantee that the seed would not be replanted by farmers, instead being bought every year. In principle, cotton with a well-defined processing system in the form of centralized gins seems to lend itself to a closed loop system that has been effectively established in a few countries such as Mexico (Traxler and Godoy-Avila 2004). But, establishing a closed-loop system requires a fairly high level of institutional sophistication—good organization and management, good use of information, which Mozambique will not easily attain.

On the other hand, Mozambique does not have much experience with hybrid cotton as almost all cultivars are varieties. Hybrids offer greater yield potential but are more costly to produce. At least initially, the carriers of Bt genes in Mozambique will most likely be hybrids with increased seed costs. Countries in SSA that have an active private sector hybrid maize industry would seem to be better targets for investment than weaker economies where hybrid maize production has not attracted the interest of the private sector. For this reason, it is difficult to see how the private sector could charge less than US$50 for the Bt technology in Mozambique. In Section 4, we assume that the increased cost of seed and the technology fee totals to US$50.

2.4.4. The Yield Advantage

Bt varieties could yield higher or lower than non-transgenic varieties that farmers now grow (Zilberman, Ameden, and Qaim 2007). Bt varieties could lose yield because they may not be well-adapted to other location-specific factors of production. But, relative to local varieties, they *recover* yield that would be lost to the bollworm complex unless plant protection is technically efficient. Isogenic Bt varieties that are essentially the same as local popular varieties except for the Bt trait should always be associated with a gain in productivity in smallholder circumstances in developing countries (Zilberman, Ameden, and Qaim 2007).

Only one case has been reported in the literature where the productivity of Bt cotton is slightly inferior to conventional cotton or where Bt cotton has not given a significant yield response that confirms the thinking that yield effects will be large in South Asia and Africa because these regions suffer from high pest pressure, limited chemical availability, and inefficient pest control practices (Qaim and Zilberman 2003). The outlier is the state of Andhra Pradesh in India where two studies have concluded that Bt cotton is neither significantly more productive or more profitable than conventional cotton (Qaim et al. 2006 and Qayum and Sakkhari (2006) as cited in Pehu and Ragasa (2007)). Poor adaptation is cited as the main reason for the lack of competitiveness, although why this should be so seems puzzling because production conditions in Andhra Pradesh are not markedly different from the rest of peninsular India and adoption of Bt cotton is continuing at a healthy pace in the Andhra Pradesh.

The literature defines the outline of the expected size of the productivity advantage to Bt cotton. Field trials conducted in Burkina Faso since 2003 are consistent with a productivity advantage of 20% for Bollgard II cotton over conventional varieties (Glick, Greenplate, and Vitale 2006), and 20% is the point estimate that Vitale et al. (2007) use in their ex ante assessment of Bt cotton in Mali. Based on these field trials, the economic advantage of Bt cotton results in a gain of US$65/ha. In China, any yield gains to Bt cotton are dominated by the value of pesticide savings as the yield of conventional varieties in this highly intensive mode of production exceed three metric tons of seed cotton per hectare. Likewise, a careful analysis suggests that there is no yield advantage to Bt rice in China as production levels exceed six metric tons per hectare (Huang et al. 2008). Unlike China, yields are significantly below their potential in India, but the initial enthusiasm for Bt cotton led to overestimates of yield advantage from multi-location production trials (Qaim 2003). Later studies have confirmed that the yield advantage is not 80-90% but more like 27-48% (Qaim et al. 2006; Bennett et al. 2006b).

Determining the absolute yield advantage is more important than estimating the relative yield advantage in understanding the economic prospects of Bt cotton. For example, the average base yield was about 1300 kgs/ha of conventional cotton in the two aforementioned surveys in India. With a 35% yield advantage, Bt hybrids generated an additional 455 kgs of seed cotton. The relative yield advantage in the Makhathini Flats in RSA in the second growing season was over 40% (Gouse, Kirsten, and Jenkins 2005), but this was equivalent to only 120 kgs because the yield of non-adopters was so low in that season (300 kgs/ha).

The yield advantage depends on the level of bollworm infestation, the intensity and efficacy of pest management, mainly pesticide use, and the potential on-farm yield. The potential on-farm yield depends on both climatic and edaphic conditions as well as the level of agronomic management. Cotton production in Hebei and Shandong provinces in China is at the opposite end of the spectrum from cotton cultivation in KwaZulu-Natal in RSA in terms of intensity of pesticide use and potential on-farm yield.

3. ESTIMATING YIELD ADVANTAGE TO BT COTTON IN MOZAMBIQUE

3.1. Data

Reliable estimates of the yield advantage of Bt varieties can only come from field testing under farmers' management. However, we believe that the analysis of a good data set on existing crop management and production practices can be informative on the prospects for Bt cotton in a specific context. We use a data set collected by Strasberg in the mid 1990s from two schemes in Monapo District, Nampula Province, and Montepuez District, Cabo Delgado Province. Farmers were visited five times during the growing season to gather detailed information on the cost of production. Although these data were carefully collected, they are not perfect for our purposes. We do not have complete information on active ingredients, pest targets, and varieties.

To redress these data deficiencies, we interviewed entomologists and other crop specialists to shed light on farmers' pest management practices (MADER 2003). An earlier survey of cotton growers (MADER 2001) and a rapid rural appraisal on the farm-level profitability of cotton (Pitoro, Govene, and Boughton 2006) also contributed information on structuring the analysis of the Strasberg data set.

Discussions with scientists reconfirmed our thinking on the timing and targets of insecticide applications. Sprays that occurred in the first eight weeks of the crop were targeted at sucking- and piercing-insects such as aphids, jassids, and other non-Lepidopteran pests; applications later than eight weeks were aimed at the bollworm complex.

The representativeness of the Strasberg data set for current conditions of cotton production in Mozambique warrants comment. The level of technology has not changed appreciably since the mid-1990s. Technological change has mainly been confined to ultra-low volume sprayers that have significantly reduced water requirements in pest management[1]. Some schemes have also invested in a chemical seed dressing that targets early season pests and in application of small amounts of foliar fertilizer. National rural household survey data collected in 2002, 2003, 2005, and 2006 show that fertilizer use is common in tobacco production, but is negligible in cotton production. Herbicide use is also rare, but is commanding increasing interest in the more forward-looking, schemes (Pitoro, Govene, and Boughton 2006). Interestingly, the Strasberg data set of the mid-1990s contains observations that used both inorganic fertilizer and herbicide as the scheme in Montepuez was experimenting with intensifying cotton production Therefore, the Strasberg data set reflects a level of technological sophistication that may be slightly superior to present day cotton production practices in Mozambique.

3.2. Explaining the Variation in Yield with a Simple Multivariate Model

The analysis focuses on the determinants of yield in a simple regression that emphasizes the interaction between plant protection and productivity. Yield is posited to be a function of crop management, plot characteristics, perceived weather, perceived pest infestation, and village effects. (Household characteristics such as age and education were also included as regressors in an exploratory analysis, but they were not statistically significant and are not reported in this paper).

[1] Marcos Freire, personal communication, 2007.

Table 1. Summary Statistics and Expected Signs of the Variables Used in the Regression Model in Northern Mozambique.

Variable	Summary Statistics		Expected signs[b]
	Description	**Mean or frequency[a]**	
Yield (kg/ha)	Dependent variable	801	
Pesticide Applications (0-1):			
0 sprays	Sucking pests	61%	R
1 spray	Sucking pests	29%	+
2-4 sprays	Sucking pests	10%	+
0 sprays	Bollworm complex	23%	R
1 sprays	Bollworm complex	8%	+
2 sprays	Bollworm complex	13%	+
3 sprays	Bollworm complex	33%	+
4 sprays	Bollworm complex	19%	+
5-6 sprays	Bollworm complex	4%	+
Fertilizer (0-1)	No use	79%	R
	Use	21%	+
Herbicides (0-1)	No use	73%	R
	Use	26%	+
Weeding labor	Total adult equivalent days	50	+
Planting date (0-1)	On time	65%	R
	Late	35%	-
Soil quality (0-1)	Fertile	61%	R
	Fairly fertile	32%	-
	Less fertile or infertile	7%	-
Perceived rainfall (0-1)	Normal	81%	R
	Abnormal	18%	-
Perceived pest infestation (0-1)	Normal	93%	R
	Excessive	7%	-

[a] Means for continuous variables and frequencies for (0-1) variables.
[b] R indicates the reference levels for the (0-1) variables.
Note: 16 village dummy variables are not included.

The data for the regression analysis are summarized in Table 1. By global standards, seed cotton yield was low and variable across farmers. Seed cotton yield averaged about 800 kgs/ha and ranged from about 50 to 1950 kgs/ha across the 215 observations in the 17 cotton-growing villages.

Most of the independent variables pertain to aspects of crop management. Sprays were divided into two types: early applications targeted to sucking pests and later applications targeted to chewing pests of the bollworm complex. The majority of households did not apply pesticides during the first eight weeks of the growing season; only about one farmer in ten made more than two applications during this period. Some of the non-applying households may have been cultivating *hairy* varieties with a low yield potential. The hairy trait is associated with less damage from jassids and aphids. The data suggest a greater frequency of application in targeting the bollworm complex as about 2/3rds of the farmers sprayed 2-4 times. The other third of farmers did not spray against chewing pests.

We expect to see a positive response to spraying, particularly for applications targeted to the bollworm complex as all varieties are susceptible. Although pesticide use is somewhat subsidized by schemes in the form of access to backpack sprayers and modest reductions in the market price of pesticides, cotton farmers are poor.

Growing area averages only about one hectare per household. Cash constraints combined with low seed cotton prices could dampen pesticide use. In these conditions, it is common to observe farmers spraying with doses significantly below recommendations. Scouting does not occur and the harsh economic reality does not permit intensive prophylactic spraying. Pest management on the bollworm complex could best be described as limited prophylactic applications with curative treatments based on observed heavy infestation. Late spraying with low doses of active ingredients can lead to severe damage when infestations are moderate to heavy. Although we do not have information on when pesticides were applied and on what dose was used, yield should be responsive to number of sprays.

The positive expectation between yield and spraying is based on the assumption that level of infestation is the same for all spraying levels. If infestation varied inversely to number of sprays, then estimated yield differences by level of application may not emerge or may not be statistically significant. Likewise, if pest management were technically efficient across the sample as a whole, we would not expect to see significant differences in yield by level of application. In summary, we expect to encounter a positive response to spraying which points to a yield recovery response to Bt cotton. The size of that response depends on the efficiency of technical assistance on plant protection in the scheme. Under present circumstances of extensive cotton production with limited technological variation across schemes, the yield advantage of Bt cotton will be greater in those schemes with less effective technical assistance and extension programs.

Aside from the timing intensity of insecticide spraying, the most important expected determinant of cotton productivity is the timing and intensity of weeding labor use. Cotton production in central and northern Mozambique takes place in a land abundant setting where the use of animal traction is negligible. Heavier yields hinge on the ability of the household to mobilize labor on a timely basis for weeding. Recent crop budget data from focus-group interviews show that Mozambique is characterized by higher labor use intensity among six cotton producers in West, East, and Southern Africa (Poulton, Labaste, and Boughton 2009). For three of the four higher yield focus groups, total labor use approached or exceeded 200 days/ha in Mozambique. The mean estimate of 50 days allocated to weeding in Table 1 reflects this elevated labor use intensity.

The other crop management variables in Table 1 index timely planting and the diffusion of a fertilizer and/or herbicide package that was partially used in the Montepuez scheme. Because levels of application of this agronomic package were essentially the same for all participants, the use of inorganic fertilizer and herbicide are specified as binary variables in Table 1.

Independent variables that complete the expected determinants of seed cotton yield in Table 1 are perceived soil quality, rainfall, and pest infestation level. Most farmers felt that their fields were fertile or fairly fertile, that the 1994-95 cropping season was a normal rainfall year, and that pest infestation was not excessive.

The determinants of yield are modeled with a Cobb-Douglas specification in terms of logarithms of the dependent and continuous independent variable which is days of weeding labor. All the other independent variables, including village effects, are specified as binary 0-1 variables. Aside from ease of interpretation, the normalization of the dependent variable is one of the attractive features of a Cobb-Douglas specification as yields are often non-normally distributed. This is a substantially revised version of the specification given in Pitoro (2004) who discusses the use of this functional form vis-à-vis others. A damage recovery model along the lines of Lichtenberg and Zilberman (1986) was not estimated because data on pesticide active ingredients were not available. Moreover, the emphasis in the analysis is to let the data express itself in as discontinuous a fashion as possible to generate more information on the productivity prospects of Bt cotton. Modeling sprays as additive dummy variables accommodates that emphasis. Nor was a two-stage process entertained where pesticide use was first specified and predicted use figured in a subsequent multivariate analysis on the determinants of yield to address simultaneity bias. Such an analysis is complex for first-stage categorical variables and could be a topic for further research with this data set.

3.3. Interpreting the Estimated Coefficients

The model described in Table 1 explains about 60% of the variation in yield across the 215 cotton farmers (Table 2). In terms of cross-sectional data on commodity productivity in rain-fed agriculture, capturing 55-60% of the variation in yield is a more than adequate performance. Moreover, the signs of almost all the estimated coefficients in Table 2 are consistent with expectations in Table 1.

Before turning to the estimated spray coefficients that are our center of attention, we briefly review several of the estimated effects of some of the other independent variables. As expected, the use of weeding labor is positively and significantly associated with yield. A proportional 1% increase in weeding labor results in a 0.45% increase in seed cotton yield. The potential for weed damage to reduce yield is also reflected in the estimated coefficient on herbicide use. Ceteris paribus, the herbicide package conferred a hefty 71% advantage in yield. The estimated effect of the fertilizer package was less but was still a sizeable 41%. Late planting diminished yield by 30%. If the scheme in Montepuez selected better farmers to make fertilizer and herbicide available to, then these effects are overestimated because of selectivity bias. Nevertheless, taken together, these results suggest that there is ample scope to intensify yield in Mozambican cotton production if the access to inputs improves on a timely basis.

The estimated coefficients on applications targeted at sucking pests indicated a positive response to spraying once, but more intensive spraying was not associated with significantly higher yields. The pattern of the estimated coefficients on the five bollworm spray variables is particularly interesting. The estimates in Table 2 tell us that farmers who sprayed once had the lowest yields. Their yields were 41% less than farmers who did not spray. Intensifying from one to four or more sprays was associated with an almost linear increase in yield. The higher yield of the no spray farmers suggests lower levels of bollworm infestation. Many of these farmers did spray for sucking pests as the correlation between the two types of sprays was not statistically significant. In any case, the farmers who sprayed three or more times were characterized by significantly higher yields than those who engaged in one or two applications. Additionally, the small minority of farmers who believed that pest infestation was heavy suffered a 33% decline in yield, signaling that they were not able to cope with this event.

Table 2. Estimated Coefficients and Statistical Significance of the Independent Variables Explaining Cotton Yield in Northern Mozambique

Independent variable	Coefficient	t-value	[95% confidence interval]	
Bollworm 1 spray	-0.41	-2.43	-0.74	-0.08
Bollworm 2 sprays	-0.22	-1.56	-0.50	0.06
Bollworm 3 sprays	0.05	0.42	-0.08	0.27
Bollworm 4 sprays	0.26	2.04	0.01	0.50
Bollworm 5-6 sprays	0.59	2.81	0.18	1.01
Sucking Pests 1 spray	0.22	2.14	0.02	0.43
Sucking Pests 2-4 sprays	0.19	1.24	-0.11	0.48
Ln total weeding labor	0.45	5.05	0.27	0.62
Fertilizer use	0.41	2.03	0.11	0.80
Herbicide use	0.71	3.47	0.31	1.11
Soil less fertilizer	-0.11	-1.26	-0.29	0.07
Soil least fertilizer	-0.24	-1.46	-0.56	-0.08
Heavy pest infestation	-0.33	-2.16	-0.64	-0.03
Abnormal rain	0.01	0.13	-0.18	0.22
Late planting	-0.29	-3.07	-0.48	-0.10
Constant	4.61	12.30	3.87	5.35

Dependent variable is ln cotton yield in kg/ha.
R^2 = 0.64, adjusted r^2 = 0.58; F (30, 184) = 10.67
Village effects are included in the analysis, but are not presented.

3.4. Assumptions on Spraying Levels and Bt Cotton Yield Advantage

Translating the results of the regression model into expectations on the yield advantage of Bt cotton requires several strong assumptions. Research by Shankar and Thirtle (2005) provides some guidance on the choice of assumptions. Based on the 100 farmer sample in the Makhathini flats in KwaZulu-Natal, they employed a damage control framework to estimate the yield recovery of Bt cotton vis-à-vis pesticides. They found that at an average application rate of 1.1 liters per hectare a Bt adopter attained 55% of potential output. With a mean level of 2.2 liters, a non-adopter only recouped 36% of potential output. The monotonic recovery rate curves for adopters and non-adopters approached potential yield as application levels reached a maximum of 8-10 liters. At all levels, the estimated recovery rate for non-adopters was below the recovery rate of adopters for a given level of application. For example, no spraying resulted in a recovery of only 20% of potential output for non-adopters; the equivalent estimate was 40% for Bt adopters. The divergence in recovery rates narrowed gradually as more insecticide was applied. The authors do not provide estimates of yield potential—mean yields were only 439 kgs for the sample—but a doubling of the recovery rate implies a 100% yield advantage to Bt cotton at the lowest insecticide application levels.

Our regression results in summary Table 3 signal yield advantages from adopting Bt cotton for farmers who sprayed 1-3 times; they obviously had a problem in controlling chewing-pests as their yields were not significantly lower than or not significantly different from farmers who did not spray. With well-adapted varieties of Bt cotton, farmers in these three groups should be able to achieve a level of control equivalent to farmers who sprayed four times. This assumption is equivalent to a yield increase of 94%, 60%, and 22% for farmers who sprayed one, twice, and thrice. In the same spirit, farmers who sprayed 4 times should be able to begin to approach yields of farmers who sprayed 5 or 6 times. We assume that adoption of Bt cotton will increase yields by 50% of the difference between these two groups which is equivalent to a 20% increase in yields for farmers who sprayed 4 times. We further assume that the most intensive users of pesticide (those in the 5-6 sprays group) will not derive a significant yield benefit from Bt cotton.

These assumptions are in the spirit of the Shankar and Thirtle (2005) analysis that shows a marked but gradually narrowing difference in recovery of yield potential with the adoption of Bt cotton by level of insecticide use. At the 0-level of spraying, our assumption diverges from their analysis. The regression results suggest that some farmers who did not spray experienced lower levels of bollworm infestation than farmers who sprayed. Some of these farmers also applied insecticides early in the season targeted at sucking pests; they would seem to have been in a position to spray later in the season if infestation warranted chemical control. A lower expected yield advantage accrues to Bt cotton with lower infestation levels. We assume that for these farmers Bt cotton would have resulted in attaining about one-half of the difference between their yield levels and those of farmers who sprayed four times. This supposition is equivalent to a presumed 12% increase in yield.

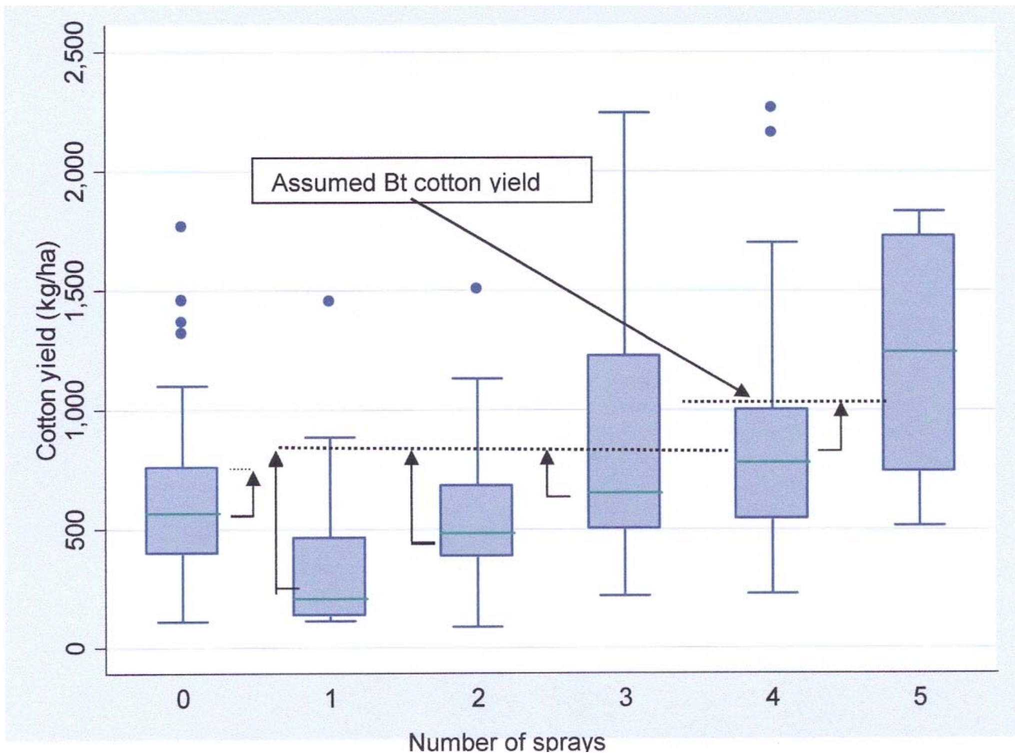
These assumptions on yield advantage are graphed in Figure 1. Overall, the yield advantage of Bt cotton is estimated at 25%, equivalent to about 200 kgs/ha of seed cotton.

Table 3. Distribution of Spraying Rrequency and Estimated Yield Effects

Number of insecticide sprays	Frequency (%)[a]	Estimated yield effect (%)[b]
0	23	-
1	8	-41*
2	13	-22
3	33	5
4	19	26*
5-6	4	59*

[a] Based on 215 observations
[b] Relative to 0 sprays
* Statistically significant at the 0.05 level

Figure 1. The Distribution of Predicted Seed Cotton Yields by Spray Group Targeted at Chewing Pests and Assumed Levels of Bt Cotton Yield



4. ESTIMATING ON-FARM PROFITABILITY

For varietal change, a 25% yield increase is very respectable and rivals the productivity gains from the initial maize hybrids at the turn of the 20th century and from the semi-dwarf rice and wheat varieties at the beginning of the green revolution. But the increased costs of Bt cotton are considerably higher than either of these other two revolutionary developments in plant breeding. Is our best estimate of a 25% yield increase sufficient to drive the adoption of Bt cotton in Mozambique?

We analyze the on-farm profitability of Bt cotton from financial and economic perspectives in Table 4. The financial calculation is based on our discussion in Section 2: increased yield evaluated at US$0.21/kg (Poulton, Labaste, and Boughton 2009); a reduction in 1.5 sprays, and total technology costs assigned at US$50. The savings in sprays is evaluated at a subsidized cost of US$3.31/application. Another cost is the maintenance of resistance which is equivalent to a production loss from a 5% unsprayed embedded refuge (USDA 2001). From the financial viewpoint of the farmer, an assumed 25% yield advantage and a relatively small savings in subsidized pesticide costs equivalent to 1.5 sprays does not generate enough revenue to cover the technology fee of US$50/ha (Table 4). To satisfy Formula (1) in Section 2 and meet the marginal rate of return criterion of 100% the yield advantage to Bt cotton in Mozambique would have to approach 70% at a base yield level of 800 kgs/ha. Low output prices and the relatively high technology fee place the technology outside the grasp of poor cotton farmers.

From the viewpoint of society, the value of Bt cotton is considerably higher. The economic perspective in Table 4 factors in all costs and benefits and uses international prices to reflect scarcity value.

Table 4. Financial and Economic Appraisal of the Expected Profitability of Bt Cotton in US$/ha.

Item	Profitability	
	Financial	Economic
Additional benefits		
Yield (US$/ha)	42.00	58.00
Increased production (Kg/ha)	200	200
Seed cotton price (US$/Kg)	0.21	0.29
Savings in insecticide cost (US$/ha)	5.00	14.00
Health (US$/ha)	0.00	7.00
Total	47.00	79.00
Additional costs		
Seed (US$/ha)	50.00	50.00
Refuge (US$/ha)	2.50	2.50
Harvesting (US$/ha)	5.00	5.00
Total	57.50	57.50
Net benefit (US$/ha)	**-10.50**	**22.50**

Source: Authors' computations

The calculations in the economic column of Table 4 differ from those in the financial column in four ways. First, and most importantly, we increase the price of seed cotton to US$0.29 per kg. As discussed in Section 2, Mozambique is characterized by the lowest seed cotton prices in the region. Tanzania, with a fully liberalized output market and transport costs probably comparable to Mozambique, has recently paid US$0.28 per kg of seed cotton (Poulton, Labaste, and Boughton 2009). By 2003-04, prices in Mozambique had rebounded from their all-time lows of 2001-2002 as farmers received US$0.25 per kg. Although estimates varies considerably by study, subsidies to producers, mainly in the United States and the European Community (EC), are reckoned to depress international prices by around 10% (Baffes 2005). Given the higher level of regional prices and the effects of subsidy payments in developed countries, an economic price of US$0.29 per kg of seed cotton seems reasonable. Although this price is considerably higher than its financial counterpart in Table 4, it is important to point out that this economic price level is inferior to that specified in any other ex ante or ex post study on Bt cotton.

Secondly, we value pesticide at international market prices. Without subsidies, pesticide cost increase and, consequently, the pesticide savings rise from US$5 to 14/ha.

Thirdly, we recognize that pesticide savings generate a health benefit. According to Maumbe and Swinton (2003), pesticides pose health hazards that impose hidden costs on African cotton growers. They found that in Zimbabwe, acute pesticide-related illnesses impose costs equivalent to at least 45% to 83% of annual pesticide expenses by smallholder cotton farmers. We assume that 50% of cost savings on insecticides correspond to reduced health costs. Given the labor intensity of cotton production in Mozambique, farmer's health status is an important determinant of planted area and productivity.

In a social pricing application, we could improve the odds that Bt resistance is sustainable and increase the refuge costs over and above the 5% area allocated in the financial budget. But we do not believe that an additional expenditure is warranted for two reasons. First, cotton production in Mozambique takes place in spatially dispersed fields in the bush in an environment that seems especially hostile to the development of resistance. Secondly, the advent of stacked Bt varieties leads to reduced refuge requirements and potentially results in enhanced returns to producers and seed companies. In essence, this thinking emphasizes the potential for natural refuges to substitute for crop refuges (Qiao 2006; Piggott and Marra 2007).

With these three differences, the economics of Bt cotton improve, but a marginal rate of return of about 40% is not sufficient to overturn the results based on private prices. In other words, Bt cotton appears to be socially profitable but is not likely to be adopted in an unsubsidized environment unless the technology fee drops to levels that are outliers in the literature.

The estimates in Table 4 likely err on the conservative side. We assumed that the no-spray group could achieve a 12%-yield increase with Bt cotton and remove half of the difference between themselves and the productivity level of the 4-spray group. Using the full regression result would push net economic benefits towards US$30/ha. Moreover, it is important to remember that the soonest Mozambique farmers could adopt Bt cotton would be about 2013 as it takes 5-6 years to fully comply with bio-safety regulations and field-testing requirements. Between now and then, it is likely that progress in intensifying cotton production in one or more schemes will result in higher on-farm yield that will set the stage for Bt cotton to make a stronger contribution to productivity than is estimated in Table 4. Moreover, technological change and the production and export of Bt cotton varieties in countries with strong national agricultural research, particularly in China, may increase the affordability of these transgenic cultivars. Six years from now some definitive evidence on the value of Bt cotton in West Africa in general and Burkina Faso in particular should be forthcoming. Success in West Africa will expand the range of cultivars available for planting as Mozambique has experience with West African elite materials to improve varietal ginning out-turn ratios.

Based on expectations about positive outcomes in the future on Bt affordability, cultivar adaptation, and the intensification of production in Mozambique, we proceed with a scenario analysis that asks whether or not the benefits from Bt cotton at US$30/ha are sufficient to justify an investment in bio-safety regulations and field testing. In other words, is Mozambique a sufficiently attractive opportunity to warrant a seed company's investment in a Bt cotton event.

5. PROJECT APPRAISAL OF BT COTTON

Bio-safety regulations in Mozambique are still in their infancy. Mozambique, after ratifying the Cartagena Protocol on Bio-safety (CPB) in 2001, established the National Bio-safety Working Group (NBWG), to co-ordinate the bio-safety activities in the country (Bhagavan and Virgin 2002). The NBWG is an inter-institutional and multi-disciplinary team with the task of setting up proper systems for regulatory and administrative issues, decision making process (risk assessment and management), and mechanisms for public participation. The work of the NBWG is compromised by inadequate financial resources, lack of personnel with sufficient competence, and poor infrastructure and equipment. Since the group was formed in 2001, the only output available is a legislative proposal that establishes conditions at which Bt maize can be imported.

The investment costs of bio-safety regulations vary considerably by country. Both Zimbabwe and South Africa legislated regulations expeditiously, but in Kenya a Dutch project spent several million dollars over several years attempting to make regulations a reality (Paarlberg 2006).

Our project appraisal addresses the likely costs and benefits of a transgenic Bt cotton variety in Mozambique. Such an introduction is called an event. Costs vary by country and type of product introduction. Delays are more of a concern to the private sector than costs per se (Pray, Bengali, and Ramaswami 2004). We base our assumptions on cost on Manalo and Ramon (2007), which is a detailed accounting of the cost of Bt corn event MON810 in the Philippines. Manalo and Ramon estimated that the total cost of making this Bt maize hybrid commercially available was US$2.6 million in 2004 prices. Expenditures in the Philippines were mainly incurred on activities in compliance with government regulatory requirements. The gestation period from introduction to release of the material was six years and approvals had to be obtained for import, contained use, field testing, and commercial propagation. Like most emerging technologies, the highest costs were incurred in later years in field testing and in gearing up for commercial production. We use the same cost profile as Manalo and Ramon documented in the Philippines: US$50,000 in year one, US$150,000 in year two, US$225,000 in year three, US$585,000 in year four, US$515,000 in year five, and US$465,000 in year six.

Turning to assumed benefits, adoption starts in year seven in this back of the envelope calculation. We assume a conventional logistic adoption trajectory for Bt cotton with value for the constant of -4, an estimated speed of diffusion of 0.45, and a ceiling level of adoption of 60% of cotton growing area. The latter assumption is the same as saying that about three in five concessionaires will eventually adopt the technology. The project lasts 30 years. Our estimate of per hectare benefit is US$30 as argued at the end of Section 4.

Based on these assumptions, the internal rate of return on investment is a healthy 25%. The Bt variety generates a net present value of US$18 million and annual benefits approach or exceed US$3 million for most of the life of the project.

A simple sensitivity analysis shows that every year of delay in implementing the bio-safety regulations is associated with a loss of about US$1.0 million. As expected, doubling investment cost only reduces net present value to US$16 million; the internal rate of return is more sensitive to assumptions on costing as it declines to 19%.

Results are usually most affected by assumptions on the ceiling level of adoption. But our estimates are quite robust: as long as about 35% of area is sown to Bt cotton, the internal rate of return exceeds 20% and net present value still approaches US$10 million.

If the cost of the technology were reduced by half—equivalent to increasing the net benefit per hectare to US$55, then the net present value would almost double to US$34 million and the internal rate of return would increase to 32%. The expected profitability of Bt cotton in Mozambique is highly sensitive to the affordability of the technology.

6. BT COTTON AND POVERTY IN MOZAMBIQUE

Conventional wisdom suggests that producers of cash crops are likely to be better off in terms of consumption, income, and assets than other rural households in developing countries. Analysis of national survey data indicates that conventional wisdom is rejected in Mozambique: cotton growers are not richer than other rural households. In a national rural income survey conducted in 2002, 6-7% of the 4908 sample households grew cotton. A multivariate regression analysis showed that household income of cotton producers was not significantly different from income of other rural households (Walker et al. 2004). In contrast, tobacco producers were characterized by significantly higher income. Ceteris paribus, participation in tobacco production conferred a 25% advantage in household income. Tobacco households also benefited from significantly higher production of maize, their staple food crop. Unlike some tobacco companies, the cotton concessionaires have not invested significantly in improving the food crop productivity of their cash-crop clientele (Pitoro, Govene, and Boughton 2006).

As discussed earlier in this paper, cotton prices were at an all-time low in 2001-02; therefore, the finding of no superiority in income from cotton production was expected. However, a similar analysis of national household income data in 2005 generated essentially the same result: no significant income difference between cotton-growing and other households.

These surveys and their related regression analyses provide a basis for developing a profile of cotton growers in Mozambique. Based on the 2002 national survey, cotton-growing households are more likely to be headed by men, to cultivate more area, to live in *new* villages formed after independence, to reside near roads that are impassable in the rainy season, to have less secondary school education, to own more bicycles but not more radios or oil lanterns, and to cite insect pests as sources of crop loss compared to other non-cotton-growing rural households in the same districts of Mozambique. Only about 10% of cotton-growing households had access to animal traction; the vast majority relied on hand hoes to prepare land. The median size of total cultivated area including both food crops and cotton was small at about two hectares; 25% of growers cultivated 1.25 hectares or less and 75% cultivated 3.00 hectares or less.

The expected impact of the adoption of Bt technology is simulated with the 2002 national rural household income data for the 316 cotton-growing households. The benefit from adopting the technology is valued at US$30 per hectare. The methodology is described in Walker et al. (2006) and features the evaluation of changes in the intensity, depth, and severity of poverty that correspond to the head count index, the poverty gap, and the squared poverty gap, respectively. Of these, the squared poverty gap is the preferred measure of poverty because it places more weight on outcomes accruing to the poorer of the poor.

Using a price US$0.21/kg of seed cotton (Table 4), the baseline squared poverty gap was 0.36. With the adoption of Bt cotton, the estimated squared poverty gap falls to 0.27 by about 25% for the 316 cotton-growing households. The observation that such a seemingly small difference in household income can leverage such a large relative change in income poverty underscores the severity of poverty among cotton producers in central and northern Mozambique. The vast majority fell below the poverty line which was equivalent to only about US$0.25 per person per day in 2002 prices. Bt cotton does not make a large dent in national rural poverty because of the small proportion (6-7%) of households that grow cotton.

Using a variation of this same methodology, Minot and Daniels (2002) estimated that the 40% slump in cotton prices in 2001 and 2002 increased consumption expenditure poverty (as measured by the squared poverty gap) by about three-fold among cotton producers in Benin. Although the estimated levels of the squared poverty gap are not comparable because the Mozambique application focuses on per capita income and the Benin application addresses per capita consumption expenditure, both applications underline the sensitivity of poverty outcomes to changes in price and yield of a cash crop. Like many cash-crop producers in SSA, cotton farmers in Mozambique are characterized by less diversified sources of income than other households. Less diversification translates into large changes in rural welfare when income from the cash crop is affected by fluctuations in yield and price and by technological change.

7. CONCLUSIONS, POLICY IMPLICATIONS, SUGGESTIONS FOR FURTHER RESEARCH, AND STUDY LIMITATIONS

Our analysis suggests that Bt cotton is not a highly attractive opportunity at this time in Mozambican agriculture. Expected profitability is eroded by the low existing yield levels, low output prices, the cost of the technology, and assumed low levels of bollworm infestation compared to other cotton producing countries. It is hard to recover yield if the potential for recovery is low. The results underscored the need for improvements in weed management to intensify productivity potential to enhance the prospects for Bt cotton. The testing and evaluation of pre-emergent herbicides is a priority in the short-term; the introduction of animal traction is a longer term priority. Higher yielding cultivars would also enhance the desirability of Bt technology. We also documented that fertilizer has a positive role to play in intensifying cotton production, but for now the emphasis needs to be improved weed management.

Suggesting actions that will have favorable consequences on low seed cotton prices is a more difficult undertaking. Adoption of varieties with higher ginning out-turn ratios, the deepening of road infrastructure, and the development of cash-cropping alternatives, such as sesame, are all small steps to more remunerative seed cotton prices. The World Trade Organization's Doha Cotton Initiative and actions taken by major developing country producers in the World Trade Organization (WTO) provide some ground for optimism in the medium term.

Our findings are based on several strong assumptions. Perhaps the greatest area of uncertainty concerns the yield advantage of Bt cotton for a significant minority of farmers who did not spray and who had significantly higher yields than those who sprayed once. We assumed that low levels of infestation were partially responsible for the absence of pesticide application and argued that, because of the spatially dispersed location of bush fields, infestation levels from bollworm species could be lower than in more conventional contiguous cultivation. The spatial and temporal incidence of bollworm infestation warrants more research. At a minimum, anecdotal information and expert opinion should be compiled on the incidence of infestation to better predict the expected productivity effects of Bt cotton across concessionaires in Mozambique and across cotton-growing countries in SSA.

The absence of a ringing economic endorsement for Bt cotton in this ex ante assessment does not mean that Mozambique should *go slow* on bio-safety regulations which are characterized by inertia in their development. We showed that the social profitability of Bt was likely to be substantially higher than its private profitability. Although bio-safety working groups have been convened and consensus recommendations have been reported, these recommendations have not been legislated and enacted. The import of Bt maize in food relief is still the center of attention in bio-safety recommendations. Because of its negligible expected risk, other countries, such as China and India, have *fast-tracked* Bt cotton long before the release of Bt food-crop varieties which are still under deliberation. For example, Mexico approved Bt cotton for field testing as early as 1988 (Traxler and Godoy-Avila 2004). The example of these countries points to the priority for taking a sequential approach to bio-safety regulations to allow forward movement on fiber-Bt cultivars before a full bio-safety framework is in place for food-Bt cultivars. Our analysis is only indicative. Field testing is a first and necessary step to determining the contribution these varieties can make to cotton productivity, export expansion, and poverty alleviation.

As our spreadsheet analysis suggests, the option value of Bt cotton could be large in Mozambique. In 5 to 10 years, one or more of the more progressive concessionaires will probably be characterized by intensified cotton production that makes Bt cotton a viable economic option. Such production would probably feature the diffusion of one or more high-yielding varieties with an improved ginning out-turn ratio, a chemical seed treatment to combat sucking pests, the use of pre-emergent herbicides, and the application of soil amendments at very low rates. These concessionaires should be rewarded with access to Bt technology to further intensify cotton production. For that to happen, sustained progress in bio-safety regulations needs to be made.

We also argued on-going technological change is very likely to make Bt transgenic varieties more effective and perhaps even more affordable. The rapid emergence of China in general and RSA in particular as major importers of cotton is a favorable development for Mozambique. Both of these importers have released Bt cotton varieties and targeting exports towards them diminishes the need for a *coexistence* production system that separates the output of conventional and transgenic varieties at all stages of production and marketing (Pehu and Ragasa 2007).

Facilitating the establishment of private-sector hybrid maize production is another positive step towards the access to transgenic varieties. A well-developed seed industry has contributed mightily to the success story of Bt cotton in India.

Low output prices and high technology fees may block the entry of Bt cotton to the 16 important producers (excluding RSA) in Africa particularly in the weaker economies. Expected profitability is particularly sensitive to assumptions about the technology fee. The present impasse of 12 years and still waiting is untenable for millions of poor farm households in Africa. But there does not seem to be any viable alternative to a private sector solution. Attention is now focused on Burkina Faso in the hope that Bt cotton is finally released after years of field testing and that it can make a transparent contribution to the welfare of poor people. Positive results in Burkina Faso could provide the basis for a domino effect in the rest of Francophone Africa (Vitale et al. 2007).

There is another experiment that is not commanding much attention, but which may have implications for breaking the Bt cotton impasse in Africa. The Philippines is importing Bt varieties from China which is increasingly engaged in the exploitation of natural resources from and the provision of infrastructure in Sub-Saharan Africa. Trade between SSA and China is flourishing, and demand for cotton is robust in China. Compared to other national and international public-sector institutes, China has invested heavily in biotechnology. One does not have to be much of an observer to connect the dots and see that it is in the interest of both parties to field test in and if necessary adapt the Chinese Bt cultivars to the growing conditions of cotton farmers in SSA. The longer the impasse continues the more imminent a partnership with China becomes. China should be able to exert more leverage over bio-safety outcomes than the results of international, regional, and national conferences, workshops, and initiatives have thus far.

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