AgBioForum, 16(1): 14-26. ©2013 AgBioForum.

Estimating the Potential Economic Benefits of Adopting Bt Cotton in Selected COMESA Countries

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Cotton farmers in the Common Market for Eastern and Southern Africa (COMESA) face pest challenges, the most destructive of which is the African bollworm (*Helicoverpa armigera*). Reduction in these pest infestations can increase yields and improve welfare of cotton producers, consumers, and innovators. Currently, the control of bollworms in this region is done through application pesticides, which is a costly exercise in terms of cost of pesticides, spray equipment, and labor. A more effective and less costly way to control damage from bollworms and other insects that frequently damage cotton in the region is by adopting Bt cotton. Governments in COMESA region are debating whether to approve Bt cotton for commercial production. This decision requires empirical evidence showing the likely magnitude of anticipated gains for producers, consumers, and innovators of the technology. Using an economic surplus framework, this study shows that there are welfare gains from adopting Bt cotton in the region, and countries that are not adopting Bt cotton are losing. Overall, most gains accrue to Egypt while Kenya gains the least. However, gains per hectare are similar in all countries except Egypt, which gains about four times the other countries.

Key words: Bt cotton, COMESA economic benefits, economic surplus model, impact assessment, risk.

Introduction

There is growing debate about the potential value and constraints of modern biotechnology, and in particular of transgenics, in helping to achieve Africa's development and food security goals. These include, but are not limited to: a) whether genetically modified organisms (GMOs) offer a sustainable food security option; b) what the biosafety implications of transgenic technologies on human health and the environment are for biosafety as well as for human health and well-being; and, c) the extent of existing African capacity to undertake research and effectively monitor and evaluate genetically modified (GM) products and their use. In addition, according to Gouse, Pray, and Schimmelpfennig (2004), there are other factors that influence farmer adoption of technologies. These include technical considerations, risk aversion, profitability, social acceptability, and environmental considerations. Further, farmers' benefits from adoption might also depend on other resources at their disposal, their social condition, and household priorities. In crop agriculture, genetic engineering has been used to improve appearance, taste, nutritional quality, drought tolerance, and insect and disease resistance (Makoni, Mohamed-Katerere, & Chenje, 2007). In cotton production, the main pest targeted for control by transgenics is the African bollworm (*Helicoverpa armigera*).

Cotton production in the Common Market for Eastern and Southern Africa (COMESA) region is dominated by smallholder farmers (see Table 1). For instance, the cotton sector in Tanzania comprises about 350,000-500,000 smallholder producers. A substantial 70-80% of all cotton production in the country takes place on small farms averaging only 0.4-0.8 ha. Medium farms up to 20 ha make up the remaining 20-30% of production (Paarlberg, Wafula, Minde, & Wakhungu, 2006). Gordon and Goodland (2000) and Baffes (2004) reported that there are approximately 250,000 to 400,000 low-income cotton households in Uganda. In Zambia, it is estimated that more than 200,000 farmers grow cotton, with about 90% of these farmers growing cotton on areas ranging between 0.5-2.5 ha (Paarlberg et al., 2006), while in Ethiopia there are about 53,000 smallholder cotton farmers with areas ranging from 0.25 to 0.75 ha (Mekuria, 2012).

These smallholder farmers and others in the region face several challenges including the high cost of labor (more than 50% of variable costs in some countries); minimal use of necessary inputs for intensification (e.g., fertilizer, herbicides, etc.); inadequate availability of quality seed; and unstable and low seed cotton prices paid to farmers (Chitah, 2010; Gitonga et al., 2010). In addition, the farmers face pest challenges, with the most destructive being the African bollworm (*Helicoverpa*

Table 1. Production, yields, area, and number of cotton farmers in COMESA countries.

	Uganda	Kenya	Tanzania	Zambia	Ethiopia	Egypt
Production (MT)	78,000	30,000	337,500	180,0000	82,500	325,000
Seed cotton yield (MT/ha)	0.75	0.65	0.75	0.8	0.75	2.5
Area under cotton (ha)	105,000	46,000	450,000	225,000	110,000	130,000
Number of farmers	250,000	200,000	350,000-500,000	200,000	53,000	750,000

***Source**: FAOSTAT (2011); Mekuria (2012); International Trade Center (2011); TCB (2010); Gitonga et al. (2010); Abdel-Salam and El-Sayed (2009); Chitah (2010)*

Table 2. Cost of production (USD per hectare) in selected COMESA countries.

Country	Uganda		Kenya	Tanzania		Zambia	Ethiopia
Activities/inputs	Low input	High input*		Eastern cotton-growing area	Western cotton-growing area**		
Seed/sowing	2.5	3.0	4.0	2.4	2.4	8.3	55.59
Land rent	76.7	70.9	-	30.0	30.0	-	-
Land preparation	-	-	58.8	40.0	12.0	33.3	230.07
Chemical fertilizer	-	24.9	3.8	-	7.6	-	-
Organic fertilizer	-	21.4	-	-	-	-	-
Pesticides	25.3	39.3	16.7	24.0	16.2	83.4	93.25
Pesticides spraying labor	5.9	14.1	13.5	8.0	6.0	55.0	53.80
Weeding labor	61.6	97.0	94.7	60.0	36.0	24.8	71.13
Labor for other activities	122.2	176.8	75.0	76.8	52.0	71.6	146.74
Other costs, e.g. bags, transport	-	-	22.4	20.0	12.0	-	-
Total cost	**294.2**	**447.4**	**288.8**	**261.2**	**174.2**	**276.5**	**650.57**

***Source**: Horna et al. (2009); TCB (2010); Poulton, Labaste, and Boughton (2009); Chitah (2010); Terefe and Mohammed (2010), and author's estimations*

***** *The high input system represents farmers who use fertilizer and more than average amount of pesticide, and they comprise about 18% of all farmers in Uganda.*

***TCB (2010) estimates that 99% of total cotton produced in Tanzania comes from the western cotton growing area (WCGA).*

armigera). Currently, the control of these bollworms is done through application pesticides, which is a costly exercise in terms of cost of pesticides, spray equipment, and labor (Mbwika, 2006).

Table 2 presents production costs in five selected countries considered in the study. From this table, the cost of pesticides and pesticide application labor ranges from 10.5% in Kenya to 50% in Zambia. In Tanzania—where pesticide and pesticide application costs are about 13%—infestation levels are internationally rated as "medium high," and most farmers in Tanzania do not spray enough to control bollworms (Tanzania Cotton Board [TCB], 2010). About 50% of total cotton area is sprayed only twice per season, while 10% of area is not sprayed at all. Only 5% of fields get the recommended six sprays per season. This could be generalized as the trend in most countries in the region, hence low pesticides and pesticide application costs. This situation leads to a dilemma where, to improve on cotton yields, farmers with limited incomes are required to use a lot of resources to control bollworms. Alternatively, they could maintain the status quo where little or no pesticides are applied in some farms and get little or no yields.

The actual losses caused by cotton bollworms across the COMESA countries are not known, but Waturu (2007) indicates that in severe cases, the losses could be 100%. Studies in other countries outside COMESA have given estimates of the actual damage (see Gandhi & Namboodiri, 2006; Traoré, Héma, & Ilboudo, 1998; Vitale, Ouattarra, & Vognan, 2011). For example, in Burkina Faso, researchers claim that on unprotected fields, insect pests can damage up to 90% of the cotton crop (Traoré et al., 1998). In a typical year, Burkinabé farmers spend roughly \$60 million[1] on protecting their

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[1] *All figures in this article are in US dollars unless otherwise noted.*

fields from bollworms and other insects using conventional spray-based approaches. Reduction in these pest infestations can lead to an increase in yields that can provide several benefits, including welfare gains to cotton producers and consumers in COMESA region.

A more effective and less costly way to control damage from bollworms and other insects that frequently damage cotton in Africa is by adopting Bt[2] cotton. This is because it has benefits to both producers and consumers. For producers, Bt cotton provides improved control of insects and weeds, reduced input costs such as labor and chemical application costs, increased yields, reduced exposure to chemical, and increased incomes. Past studies have shown that use of Bt cotton for commercial planting might save some of developing countries' (including Africa's) cotton crop from bollworm damage and provide farmers with higher levels of income (Paarlberg et al., 2006). For example, Perlak et al. (2001) noted that adoption of Bt cotton has brought major economic advantages with benefits in many countries, exceeding $50/ha relative to conventional cotton. James (2000) observed that in India, Bt cotton yields were 40% higher (14.64 q/ha)[3] over the country's non-Bt cotton (10.45 q/ha). Naik (2001) showed that 78.8% of the increase was due to better yields, while 14.7% was due to reduction in pesticide cost associated with growing Bt cotton. Finger et al. (2011) reported that, globally, the estimated yield increase due to Bt cotton adoption ranges from almost zero (United States, Australia, China) to about 50% in India. These improved Bt cotton yields are as a result of a reduction in insect pests, and costs are reduced by requiring fewer insecticide spray treatments.

Qaim and Zilberman (2003) and Barwale, Gadwal, Zehr, and Zehr (2004) reported that on average, Bt cotton hybrids received three times fewer sprays against bollworm compared to non-Bt cotton. From their analyses, the general germplasm effect was negligible and the yield gain was largely due to the Bt gene itself. Other studies in different developing countries show that farmers who have adopted Bt cotton have substantial pesticide savings and higher effective yields (see Bennett, Ismael, Kambhampatti, & Morse, 2004; Nazli, Orden, Sarker, & Meilke, 2012; Qaim & de Janvry, 2005; Pray, Bengali, & Ramaswami, 2005; Thirtle, Beyers, Ismael, & Piesse, 2003). In Burkina Faso, Bt cotton has been shown to reduce pesticide use by 67% (from an average of six sprays under conventional practices down to two) and increase yields by an average of 21.3% (Vitale et al., 2011). For consumers, Bt cotton provides less costly foods with less pesticide and pathogen loads (Huesing & English, 2004; Keetch, Webster, Ngqaka, Akanbi, & Mahlanga, 2005; Laibuni, Miriti, Waturu, Wessels, & Njinju, 2012).

According to Finger et al. (2011), in South Africa Bt cotton farms recorded average yields of 1,133 kg/ha compared to 880 kg/ha for conventional cotton—which translates to about a 29% yield advantage. At the same time, the cost of pesticides reduced by more than half and seed cost almost doubled, while management and labor costs remained unchanged. In Burkina Faso, based on three years of field trial data (2003-2005) which used higher yields and savings in pesticide costs, Bt cotton was reported to increase farm incomes within the range of $79 to $154 per ha depending on seed costs and year and improved yields by about 21.3% (Vitale et al., 2011). Adoption of Bt cotton brings with it other costs such as increased cost of seed and increased cost of labor due to increased output. These increments in costs are unlikely to outweigh the benefits accruing to producers and consumers from adoption of Bt cotton, but it should be noted that the impact of Bt cotton technology will depend on the magnitude of cost reductions or increases and yield changes.

Besides the positive economic impacts, James (2010, 2011) reports that transgenic crops are also contributing to sustainability and can help mitigate the effects of climate change by: a) contributing to food, feed, and fiber security and self-sufficiency—including more affordable food—by increasing productivity and economic benefits sustainably at the farmer level; b) contributing to the alleviation of poverty and hunger; c) reducing agriculture's environmental footprint; d) increasing efficiency of water usage in order to have a major impact on conservation and availability of water globally; and e) reducing greenhouse gases.

The enumerated potential gains from Bt cotton notwithstanding, some studies have down-played the potential benefits of Bt cotton, and some have even argued that it's not an economically viable option. For instance, Sahai and Rahman (2003) and Shiva and Jafri (2004) said that in India the performance of Bt cotton was worse than non-Bt cotton both in yields and quality. Qayum and Sakkhari (2005) reported that Bt cotton had totally failed in India and was not favorable for small

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[2] *Bt protein is produced by a ubiquitous soil bacterium (Bacillus thuringiensis). When ingested by an insect, the digestive system activates a toxic form of the Bt protein and kills the target insect within a few days (Kunert, 2011).*

[3] *1 quintal=100kg*

farmers and in rainfed areas. This is because it yielded nearly 30% less than non-Bt cotton. But according to Qaim, Subramanian, Naik, and Zilberman (2006), Bt cotton technology might not be suitable for all farmers because pest pressure and access to effective alternatives vary from farmer to farmer. Those who do not benefit eventually abandon the technology, while the rest continue. But given the current increasing trends in international Bt cotton adoption, it can be argued that the technology is beneficial for a vast number of cotton growers. For example, by 2008, Bt cotton represented 46% of global cotton production. In 2010, about 21 million ha of Bt cotton were planted, representing almost two-thirds (64%) of 33 million hectares of world cotton cultivation (James, 2011). In India, in 2008-09, more than 80% of total cotton area was under Bt cotton, a fact that could be attributed to improved yields of Bt cotton. In South Africa, within four years of its introduction, the adoption rate of Bt cotton rose from 2.5% to nearly 90%.

The situation is different in the COMESA region. For example, approval to introduce Bt cotton technology in Kenya was granted by the National Biosafety Committee (NBC) in 2003, and the Kenya Agricultural Research Institute (KARI) was given the mandate to import Bt cotton seeds from Monsanto for trials in response to Sessional Paper No. 1 of 1999 on the Revitalization of the Cotton Industry in Kenya. By 2012, importation and transit of GMOs had to be approved by the National Biosafety Authority (NBA) in accordance with the Biosafety Act 2009. However, in Nov. 21, 2012, the Minister for Public Health and Sanitation, citing health reasons, issued a total ban on importation of GM products. While announcing the ban, the Minister said,

> “The protection of the consumer and assurance to the public on the safety of the foods is extremely important in making decisions about food importation, distribution, and consumption.... Where there is apprehension and uncertainty regarding the safety of food products, precaution to protect the health of the people must be undertaken.” (Mwaniki, 2012)

This move is likely to negatively impact the development of the transgenic crops sector in the country.

In Tanzania, importation of GMOs for food, feed, and processing has to be subjected to an “Advance Informed Agreement” which is contrary to the requirements of the Cartagena Protocol; while in Zambia, import of all GMO produce has been banned—except for food aid, provided it has already been milled (Environmental Rights Action [ERA], Friends of the Earth-Nigeria, 2005). In Uganda, according to Clinard (2012), Bt cotton has undergone two years of research trials with results that were quite inconclusive because the Bt cotton plants expressed themselves in unexpected ways morphologically and chemically. The recommendations were to undertake more trials to determine how to effectively manage Bt cotton at smallholder farm level. With the current status of regulatory regime, the anti-GM stance and acceptance issues, adoption of Bt cotton is greatly deterred in the region and with it a loss in potential economic benefits.

Based on these arguments and potential gains of adopting Bt cotton, governments in COMESA region are debating whether to approve Bt cotton for commercial production. This is because, despite unclear economic gains to the region, different governments in COMESA have different stands on GM products which range from total bans to partial acceptance. In addition, the legislation varies in different countries and some of them have no policy on GMOs.

Bouët and Gruère (2011) argue that countries in the region stand to lose by non-adoption of Bt cotton. To demonstrate the potential gains that would be lost by non-adoption of Bt cotton requires empirical evidence showing the likely magnitude of anticipated gains for producers, consumers, and innovators of the technology. It’s against this background that this study aims to estimate the change in gains that might be expected from adopting Bt cotton for six countries in the COMESA region: Egypt, Ethiopia, Kenya, Tanzania,[4] Uganda, and Zambia. Currently none of these countries produces Bt cotton commercially, hence the justification of *ex ante* impact assessment of adopting Bt cotton. This study uses the economic surplus framework, which aims at maximizing the consumer, producer, and innovator surpluses—or total economic surplus.

Methodology

The approach used in this study is an *ex ante* ‘with and without’ approach, where the current situation without Bt cotton is compared against a virtual situation that assumes that Bt cotton technology will be adopted in the six COMESA countries. Many impact assessments of

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[4] *It should be noted that Tanzania is not a member of COMESA but has been considered for inclusion due to its high trading volumes with Kenya and Uganda.*

this type, especially on GM crops, have used the approach presented in Falck-Zepeda, Traxler, and Nelson (2000a, 2000b), which is an adjustment to the standard economic surplus model described by Alston, Norton, and Pardey (1995, 1998). A major disadvantage of the economic surplus approach is that it relies on underlying parameters (such as elasticities) for estimation. In cases where there is very little or no information, or where information is not reliable (as is mostly the case with *ex ante* assessments), estimates may not be as robust as desired (Falck-Zepeda, Horna, Zambrano, & Smale, 2009).

Empirical Model

The change in total economic surplus used in this study is given by the sum of change in consumer surplus, change in producer surplus, and change in innovator surplus. The formula for these surpluses are given by

$$\Delta CS_t = P_o C_o Z_t \,(1 + 0.5 Z_t \mu), \tag{1}$$

$$\Delta PS_t = P_o Q_o \,(K_t - Z_t)(1 + 0.5 K_t \varepsilon), \tag{2}$$

$$\Delta IS_t = A_t \,(P_{Bt} - P_{conv}) = A_t TF_t \text{, and} \tag{3}$$

$$\Delta TS_t = \Delta CS_t + \Delta TS_t + \Delta IS_t - \Delta C_{Dev}\,, \tag{4}$$

where ΔCS_t is the change in consumer surplus in year t; ΔPS_t is the change in producer surplus in year t; ΔIS_t is the change in innovator surplus in year t; ΔTS_t is the change in total surplus in year t; and TF_t is the technology fee. P_o is the world price of cotton, C_o is the consumption of cotton, and Q_o is the production of cotton in the country of analysis. K_t is the proportional shift in supply in year t, μ is the absolute value of demand elasticity, and Z_t is the reduction in price of Bt cotton relative to price prior to Bt cotton adoption in year t.

$$Z_t = (K_t \varepsilon)/(\varepsilon + \mu) \tag{5}$$

K_t is estimated as;

$$K_t = \left[\frac{E(Y)}{\varepsilon} + \frac{E(C)}{1+E(Y)} - \frac{TF_t}{TC}\right] \alpha A_t \,(1 - \delta_t), \tag{6}$$

where $E(Y)$ is the expected proportionate change in yield per ha due to adoption of Bt cotton in each country; $E(C)$ is the expected proportionate reduction in variable cost per ha after adoption of Bt cotton; α is the success rate, or the probability that Bt cotton is going to achieve the desired increases in yield—100% in this case; A_t is the adoption rate at year t, i.e., the proportionate area under Bt cotton to the total area; and TC is the cost of production. S_t is share of hectares under Bt cotton in each country; and δ_t is the expected reduction in yield of Bt cotton at year t (annual depreciation rate). This has been fixed at zero because no depreciation has been observed for other commercialized transgenic crops.

The change in total economic surplus each year is discounted to present values using a discount rate equivalent to the real interest rate (market interest rate less the inflation rate). This is used to calculate the net present value (NPV) of economic surplus and is given by

$$\text{NPV} = \textstyle\sum_{t=0}^{T} \Delta TS_t \,.\, (1 + r)^{-t}. \tag{7}$$

The corresponding internal rates of return (IRR) are estimated by determining the interest rates that makes NPV zero.

To implement the economic surplus model, different authors have used different software such as the Economic Surplus Analysis Model (MODEXC$^{\text{TM}}$; Rivas et al., 1999) and the Dynamic Research Evaluation for Management (DREAM$^{\text{TM}}$; Wood, You, & Baitx, 2001). The drawback of these software packages is that in their current versions, they do not allow stochastic simulation, which allows for inclusion of risk and uncertainty of the parameters used in the estimation. To overcome this problem a few authors (Falck-Zepeda, Horna, & Smale, 2008; Falck-Zepeda et al., 2009; Hareau, Mills, & Norton, 2006; Pemsl, Waibel, & Orphal, 2004) have used the @Risk$^{\text{TM}}$ software. In our study, we used SimulAr$^{\text{TM}}$ software, which works the same way as @Risk$^{\text{TM}}$. To estimate the surpluses, we inputted our model in spreadsheets and ran Monte Carlo simulations. This program calculates and saves values of designated output variables—for example, producer surplus, consumer surplus, innovator surplus, total surplus, net present value, internal rate of return—from repeated draws (‘iterations’) as specified by the user. To incorporate risk in our analysis, we used the triangular distribution, which, according to Falck-Zepeda et al. (2009), is parsimonious as the minimum, most likely, and maximum values and fully describes the distribution. In addition, the triangular distribution approximates the normal distribution over repeated sampling draws.

To take care of the sensitivity analysis, a base scenario (*worst case scenario*) for each country and different other scenarios—*doubling of base scenario*, *most*

Table 3. Model scenario assumptions.

Assumptions	Scenario 1 (Worst case)	Scenario 2	Scenario 3 (Most likely)	Scenario 4 (Optimistic)	Sources of assumptions
Maximum adoption rates	20%	40%	70%	90%	Mbwika (2006); Paarlberg et al. (2006); James (2011); Finger et al. (2011); Bouët and Gruère (2011); own estimations
Total R&D and biosafety lag (years)	3	3	3	3	Napasintuwong and Traxler (2009)
Adoption lag (years)	3	3	6	8	Own estimates
Year at maximum adoption level	6	6	9	11	Own estimates
Total years simulated	25	25	25	25	Sum of years of adoption pattern

likely scenario, and *optimistic scenario*—were run by varying the key parameters. Using the model, the annual producer, consumer, innovator, and total surpluses for the period of the simulation were estimated for each scenario and each country. These were then discounted using different real discount rates for the respective countries to get the Net Present Value (NPV).

Sensitivity Analysis Scenarios Used in the Estimation Welfare

Scenario 1. We call this the *worst case scenario* (see Table 3). In this scenario, it is assumed that 20% of the total current area under cotton in the six countries is planted with Bt cotton. A three-year research and development (R&D) lag to first adoption period has been assumed, and another three years of adoption lag—between initial adoption and 20% adoption—has also been assumed. Therefore, full adoption will be achieved at Year 3 after first commercial release. A total time of 25 years has been simulated. In estimating the potential gains of Bt cotton in West Africa, Falck-Zepeda et al. (2009) used minimum, most likely, and maximum technology fees of $15, $32, and $56 per hectare, respectively. In our estimation we used more conservative values for technology fee[5] of $8, $20, and $30 per ha for minimum, most likely, and maximum, respectively.

Scenario 2. In this scenario, we retain all the parameters remain Scenario 1 (*worst case scenario*), but we double the adoption rates to 40%. The aim is to demonstrate the change in surpluses if adoption was to double while holding all other parameters constant. As in the worst case scenario, a three-year R&D lag to first adoption period has been assumed, and another three years of adoption lag—between initial adoption and 40% adoption—has also been assumed. A similar period of 25 years has been used in the simulation. Other parameters used in Scenario 1 have been replicated in this scenario.

Scenario 3. This is dubbed the *most likely scenario*. In this scenario, it is assumed that 70% of the total current area under cotton in all six countries is planted with Bt cotton. It was noted earlier that adoption rates of Bt cotton in India and South Africa increased to nearly 90% within a span of five years or less. These countries had sensitized farmers and created an enabling environment for farmers to adopt Bt cotton, hence the high response. In the COMESA region, however, different countries have different views on Bt cotton and transgenic crops in general. For this reason, the adoption rate was reduced to about 70%. A three-year R&D lag to first adoption period has been assumed, and another six years of adoption lag—between initial adoption and 70% adoption—have also been assumed. We have assumed that the minimum, most likely, and maximum technology fees increase to $10, $30, and $50 from the figures used in Scenario 1 and 2.

Scenario 4. This is the called the *optimistic scenario*. In this scenario, we have assumed that 90% of total current area under cotton in the six countries is planted under Bt cotton. This figure is borrowed from the adoption levels obtained in South Africa and India. Technology and adoption lags have been assumed at three and eight years, respectively. Other parameters in Scenario 3 have been used in this scenario. For this scenario to be realized, however, COMESA countries have to create the right legislation and policies regarding Bt cotton and harmonize them within the region.

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5. The price difference between the conventional and Bt cotton seed (Falck-Zepeda et al., 2009).

Table 4. Bt cotton model parameters.

Assumptions	Scenario 1 (Worst case)	Scenario 2	Scenario 3 (Most likely)	Scenario 4 (Optimistic)	Sources of assumptions
Supply elasticity	Triangular (0.3, 1, 1.5)	Triangular (0.3, 1, 1.5)	Triangular (0.3, 1, 1.5)	Triangular (0.3, 1, 1.5)	Falck-Zepeda et al. (2008); Falck-Zepeda et al. (2009)
Demand elasticity	Triangular (0.01, 0.06, 0.1)	Triangular (0.01, 0.06, 0.1)	Triangular (0.01, 0.06, 0.1)	Triangular (0.01, 0.06, 0.1)	Goreux (2003), ICAC (2004)
Yield advantage of Bt over conventional varieties (%)	Triangular (0, 0.15, 0.2)	Triangular (0, 0.15, 0.2)	Triangular (0, 0.2, 0.3)	Triangular (0, 0.4, 0.5)	Falck-Zepeda et al. (2008); Finger et al. (2011); Vitale et al. (2011)
Cost advantage of Bt over conventional varieties	Triangular (0, 0.15, 0.25)	Triangular (0, 0.15, 0.25)	Triangular (0, 0.15, 0.25)	Triangular (0, 0.15, 0.25)	Huang et. al. (2004); Mbwika (2006); Falck-Zepeda et al. (2008)
Technology fee per ha	Triangular (8, 20, 30)	Triangular (8, 20, 30)	Triangular (10, 30, 50)	Triangular (10, 30, 50)	Falck-Zepeda et al. (2008); Falck-Zepeda et al. (2009)
Adaptive R&D / Biosafety regulatory costs	$2,000,000 distributed over 4 years in each country	$2,000,000 distributed over 4 years in each country	$2,000,000 distributed over 4 years in each country	$2,000,000 distributed over 4 years in each country	Pray et al. (2005)

Model Parameters

Time Lags. These include technological and adoption time lags (see Table 4). Technological time lag is the sum of the time required for adaptive R&D and biosafety regulatory process in the innovating country. For all scenarios, R&D lags to first adoption have been estimated at three years. The lag to maximum adoption for Scenario 1 and 2 have been set at three years, while those of Scenarios 3 and 4 have been set at six and eight years, respectively.

Elasticities. Falck-Zepeda et al. (2008) and Falck-Zepeda et al. (2009) report that there is limited information concerning the supply elasticity of cotton in West Africa—which is also the case in the COMESA region—and hence unitary elasticity was assumed as the most likely value. In their analysis, they used a triangular distribution and used a minimum value of 0.5 and a maximum of 1.5, with a mode value of 1.0 but chose a more conservative value of 0.3. To incorporate risk, we chose triangular distribution values of 0.3, 1, and 1.5 for the minimum, most likely, and maximum values. The international absolute demand elasticity of cotton has been estimated 0.06 (International Cotton Advisory Committee [ICAC], 2003, 2004), and from this we used triangular distribution values of 0.01, 0.06, and 0.1. Assuming a small open economy model, a demand elasticity of 0 can also be used since the world cotton demand is infinitely elastic.

Yield Advantage. This represents the difference between Bt and conventional cotton. In the absence of pest attack, we don't expect to observe any difference between the two varieties and any yield difference is due to the germplasm used and not the Bt trait. To introduce risk in our model, we used triangular distribution for the different scenarios. Yield advantages of Bt cotton have been reported at 0% in China and the United States (Finger et al., 2011); 21.3% in Burkina Faso (Vitale et al., 2011); and 29% and 50% in South Africa and India, respectively (Finger et al., 2011). From these figures we used different triangular distributions for different scenarios: a) in Scenario 1 and 2 we used distributions of 0%, 15%, and 20% for the minimum, most likely, and maximum yields, respectively; b) in Scenario 3, we used yield advantages of 0%, 20%, and 30% for the minimum, most likely, and maximum yields, respectively; and c) in Scenario 4 we used 0%, 40%, and 50% for the minimum, most likely, and maximum yields, respectively.

Cost Advantage. One of the advantages of Bt cotton is decline in the cost of pesticides. However, it should be noted that overall production cost may decline, increase, or remain unchanged due to seed and labor costs. The difference in returns between conventional and Bt cotton is determined by the gross margins. Naik (2001) reports a cost reduction of 14.7% in India, while Vitale et al. (2011) report a 67% reduction in pesticide costs in Burkina Faso. Using these and other literature (Falck-

Table 5. Annual economic surpluses (million USD) for different cotton actors (Scenarios 1 and 2).

	Scenario 1: 20% adoption					Scenario 2: 40% adoption				
Country	**Consumers**	**Producers**	**Innovators**	**Total**	**IRR**	**Consumers**	**Producers**	**Innovators**	**Total**	**IRR**
Egypt	2.42	1.53	0.13	4.05	155.01%	4.86	3.11	0.26	8.14	211.04%
Ethiopia	0.28	0.55	0.11	0.86	73.31%	0.55	1.11	0.22	1.81	106.32%
Kenya	0.13	0.17	0.05	0.28	39.50%	0.27	0.34	0.09	0.63	61.48%
Tanzania	0.83	1.43	0.45	2.64	127.78%	1.65	2.89	0.89	5.37	176.45%
Uganda	0.28	0.35	0.10	0.66	63.45%	0.55	0.71	0.21	1.40	94.28%
Zambia	0.35	0.99	0.23	1.50	96.03%	0.69	2.02	0.45	3.10	136.44%
Overall	**4.29**	**5.02**	**1.07**	**9.99**		**8.57**	**10.18**	**2.12**	**20.45**	

NB: Consumer, producer, and innovator surpluses do not exactly add up to total surplus since each of the surplus measure is a mean of many iterations.

Table 6. Annual economic surpluses (million USD) for different cotton actors (Scenarios 3 and 4).

	Scenario 3: 70% adoption					Scenario 4: 90% adoption				
Country	**Consumers**	**Producers**	**Innovators**	**Total**	**IRR**	**Consumers**	**Producers**	**Innovators**	**Total**	**IRR**
Egypt	7.30	4.79	0.61	12.67	200.72%	16.22	11.22	0.71	28.08	258.81%
Ethiopia	0.96	2.02	0.51	3.42	91.57%	1.73	3.82	0.59	6.06	95.61%
Kenya	0.43	0.57	0.21	1.14	69.00%	0.86	1.18	0.25	2.22	86.45%
Tanzania	2.33	4.20	2.07	8.54	173.92%	5.57	10.54	2.40	18.44	218.25%
Uganda	0.80	1.06	0.48	2.28	95.78%	1.84	2.59	0.56	4.92	124.64%
Zambia	1.12	3.36	1.05	5.47	142.04%	2.25	7.11	1.23	10.51	171.53%
Overall	**12.94**	**16.00**	**4.93**	**33.52**		**28.47**	**36.46**	**5.74**	**70.23**	

NB: Consumer, producer, and innovator surpluses do not exactly add up to total surplus since each of the surplus measure is a mean of many iterations.

Zepeda et al., 2008; Huang, Hu, van Meijl, & Tongeren, 2004; Mbwika, 2006), we used triangular distribution values of 0%, 15%, and 25% for minimum, most likely, and maximum values in all scenarios. The minimum value represents a situation where advantages from reduced pesticide use are completely eliminated. According to Falck-Zepeda et al. (2008), after controlling primary pest using Bt cotton, secondary pest infestations may attain economic significance and their control could offset benefits from reduced applications of pesticides to control the target pest.

Adaptive R&D/Biosafety Regulatory Costs. These represent the cost of compliance with biosafety regulations and/or R&D. A figure of $2,000,000 distributed over four years was used in all countries. This was borrowed from a study done in India by Pray et al. (2005).

Results and Discussion

Bt cotton welfare analysis for COMESA countries shows that every country gains in all four scenarios that were simulated. The highest gains from adopting Bt cotton can be seen in Egypt, while Kenya gains the least and other countries lie between the two. The distribution of gains varies between the different categories of players in the Bt cotton industry, with most of the gains accruing to producers and consumers and the least accrues to innovators of the technology. Assuming a 20% adoption rate, Kenya—which has the least area under cotton in the six countries, about 46,000 ha—gains $0.28 million per year, or $6.90 per ha; Egypt, with its current area of 130,000 ha gains $4.1 million per year, or $31 per ha. The overall gains in different countries vary, but when converted to a per-ha basis, the returns in sub-Saharan countries in COMESA range from $5.90 to $7.80 per ha, while Egypt earns about four times this amount. Doubling the adoption rate while maintaining other parameters constant results in doubling Bt cotton gains in all countries, as shown in Table 5. In this scenario, gains per ha range from about $12/ha to $16.50 in sub-Saharan COMESA countries, while Egypt gains $63 per ha.

The most likely scenario of 70% adoption shows that the least gains ($1.41 million per year) will accrue to Kenya, while Egypt will gain $12.67 million per year. The country with the highest gains in sub-Saharan

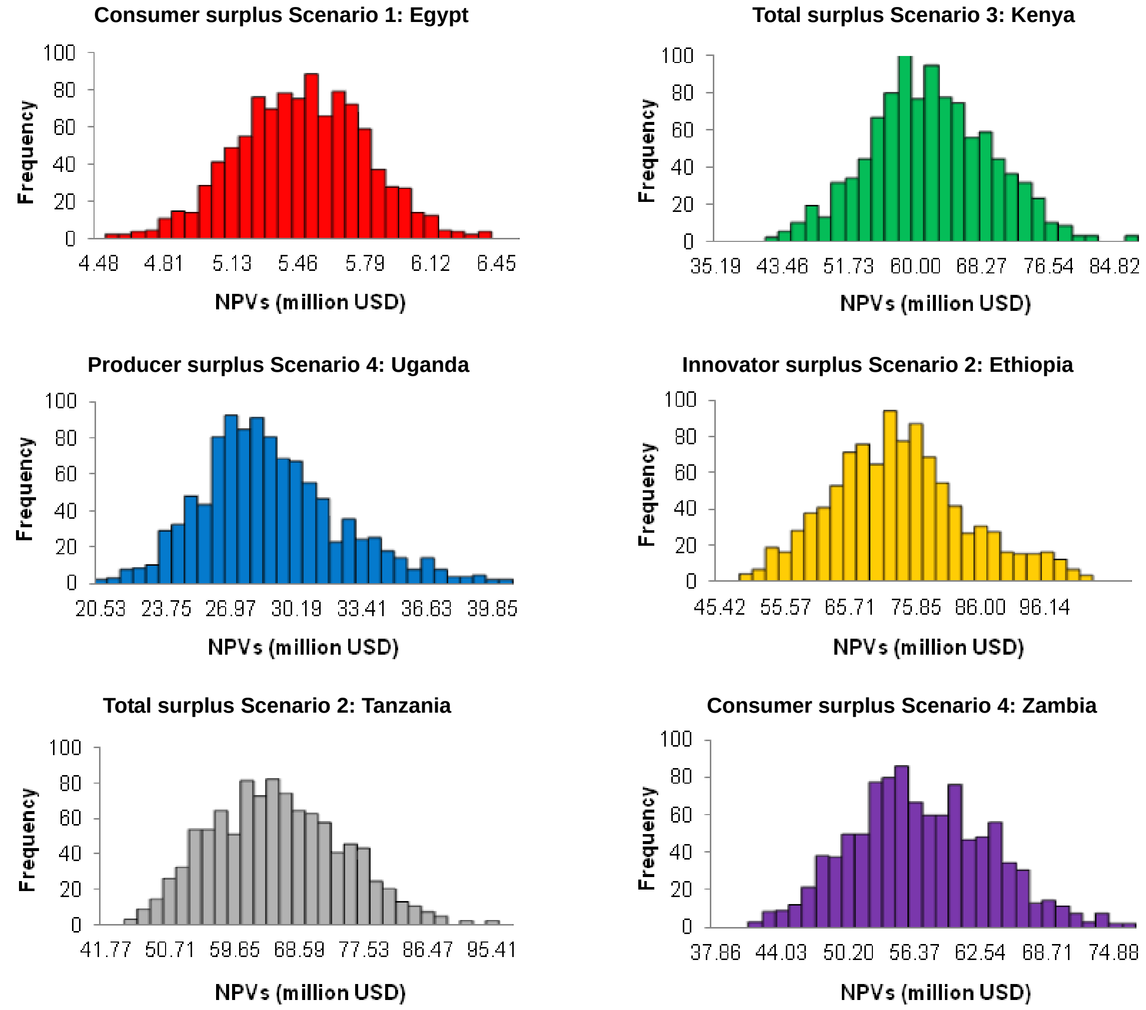

Figure 1. NPV distributions per year for different welfare measures in different countries.

Africa is Tanzania, which records earnings of $8.54 million per annum (Table 6). It was shown in Scenarios 1 and 2 that doubling the adoption rate without affecting changes on other parameters also doubles the gains. Following the same argument, increasing the adoption rate by 30% without altering other parameters should increase gains by a similar proportion. In this scenario however, adoption rate was increased by 30% from Scenario 2, lag period increased to six years, technology fee increased, but also yield advantage was increased. A combination of these increased gains by more than 30% from Scenario 2, an indication that yield advantage has substantial impact on the overall gains.

It was also stated earlier that farm income increases of more than $50 per ha (Perlak et al., 2001) and $79 to $154 per ha (Vitale et al., 2011) have been reported. COMESA countries in sub-Saharan Africa will manage to achieve gains of about $50 per ha and more if adoption rates are 90% or more. On the other hand, Egypt will manage to achieve and surpass this with only 40% adoption rates (Table 7). At 90% adoption rate, the gains per ha in Egypt will be $216/ha, which by far surpasses the $79 to $154/ha gains recorded in Burkina Faso. The variability in gains for the different countries could be explained by productivity and areas under cotton in the different countries. For instance, yields of seed cotton in Egypt is high (2.5 MT/ha) compared to other countries in the study which have yields of 0.8 MT/ha or less. These results, however, are dependent on the stochastic form of other biotic and abiotic constraints such as secondary pests and droughts due to climate change. This is because control of the target pest with Bt technology does not prevent damage from drought and may not be fully effective against secondary pests. In addition, very

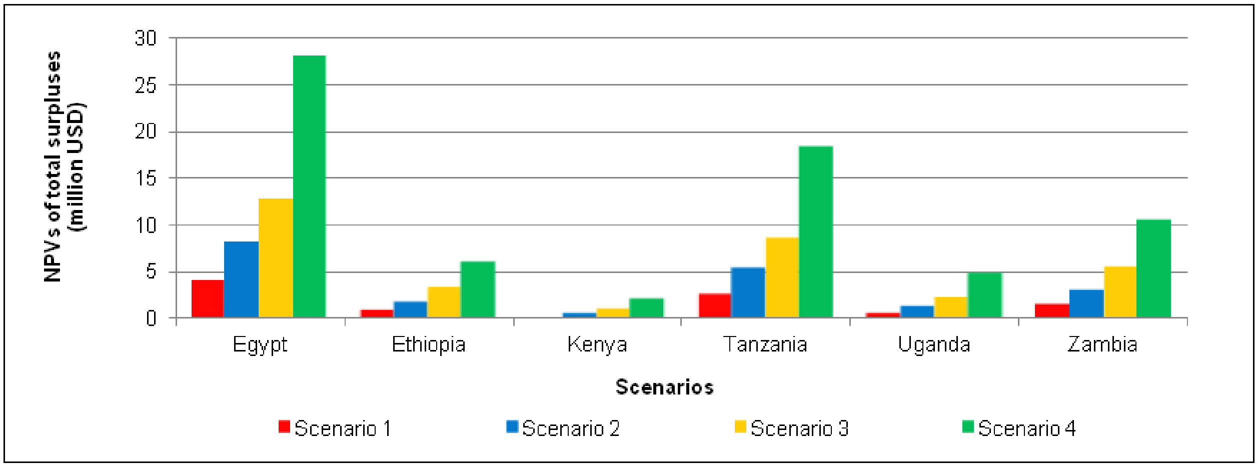

Figure 2. Total economic surpluses.

high adoption rates of Bt cotton without an accompanying yield increase may not be beneficial to farmers. Therefore, Bt cotton would be more profitable in environments with high bollworm infestation for its potential to be realized.

The use of triangular distributions in our analysis was to enable us to introduce stochasticity, and hence risk in our analysis. Figure 1 illustrates the distributions of different NPVs for the different countries for the whole 25-year period simulation. In all scenarios, the range of distributions was positive, indicating that there is no probability of having negative returns in any of the scenarios in any of the countries. For example, the simulation of consumer surplus in Egypt shows that at 20% adoption, the NPV value for the entire 25 years cannot go below $35.19 million ($1.26 million per year) and cannot exceed $84.42 million ($3.39 million per year) but will lie within this range. There is a high probability that the return will be around the mean value of $60.4 million ($2.42 million per year). Other simulations of different measures in different countries are showing similar distributions. This shows that given the production and price risks assumed in the model, all countries in the region would gain if other biotic and abiotic stresses are held constant.

Figure 2 gives an overview of the gains in all countries. From this figure, the overall gains for Egypt are highest in all scenarios, followed by Tanzania, Zambia, Ethiopia, Uganda, and Kenya. The difference in gains from other countries except Egypt can be explained by acreage under cotton because, as shown earlier in Tables 1 and 7, production and gains per ha in these countries are similar. This is an indication that these countries need to improve on management of cotton in order to increase productivity.

Table 7. Bt cotton gains per ha in different countries (USD).

Country	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Egypt	31.15	62.62	97.46	216.00
Ethiopia	7.82	16.45	31.09	55.09
Kenya	6.09	13.70	24.78	48.26
Tanzania	5.87	11.93	18.98	40.98
Uganda	6.29	13.33	21.71	46.86
Zambia	6.67	13.78	24.31	46.71

Conclusions and Recommendations

Bt cotton welfare analysis for COMESA countries shows that every country gains in all four scenarios. The highest gains from adopting Bt cotton accrue to Egypt, while Kenya gains the least. However, returns per ha are similar in all countries in the sub-Saharan part of COMESA. The distribution of gains varies between the different categories of players in the Bt cotton industry, with most of the gains accruing to producers and consumers while the least accrues to innovators of the technology.

Despite the illustrated potential gains, it should be noted that Bt technology would not yield more than a conventional unless in the presence of the target pest, and it is limited to the damage caused by the pest. In a year with no pest infestation, the difference in yield between Bt cotton and conventional cotton will be determined by the germplasm of the two varieties. In this situation there is no advantage in using the Bt cotton technology. In fact, it may even lead to a negative benefit if the producer paid the technology premium or fee. However, this has to be put in the context of production over time where one has to measure gains or losses over time.

The benefits of Bt cotton may be dependent on the stochastic form of other biotic and abiotic constraints, such as secondary pests and droughts due to climate change. For the full benefits to be realized, the respective countries should invest in adoption of climate-change adaptation strategies to mitigate the negative effects of droughts. In addition, innovators should consider stacking Bt cotton technology with drought-tolerant traits to guard against adverse effects of droughts.

Bt cotton benefits will also depend on institutional arrangements and policy frameworks required to support technology development and deployment. These include seed delivery systems, efficient extension and crop husbandry services, post-harvest management practices, and access to other necessary inputs and credit. Different countries in the region are operating at different stages of formulating and adopting legislation to govern the production and trade of GM crops. This requires harmonization of Bt cotton regulatory framework in the region to ensure the countries are negotiating on the same platform.

Finally, there is need to create public awareness on what Bt cotton technology really is, and advocate for adoption of GM technologies. This will help create public acceptance and help people appreciate the benefits of genetically modified crops.

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