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Refining opportunity cost estimates of not adopting GM cotton: An application in seven Sub-Saharan African countries

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Abstract

A computable general equilibrium model is applied to evaluate the opportunity costs of not adopting Bt cotton, a genetically-modified (GM) insect resistant cotton, in Benin, Burkina-Faso, Mali, Senegal, Togo, Tanzania, and Uganda when it is adopted in other countries. Our model uniquely employs country-specific partial adoption rates and factor-biased productivity shocks in the cotton and oilseed sectors of all adopting regions. Assuming a 50% adoption rate, the opportunity cost of not adopting Bt cotton in the seven surveyed countries amounts to $41 million per year, which is a significant but lower cost than that suggested by the results of previous studies. Trade liberalization only marginally increases this estimate.

Keywords: Biotechnology, international trade, Sub-Saharan Africa, cotton.

JEL classification: Q16, Q17, Q18.

1. Introduction

The rapid adoption of genetically modified (GM) cotton, which was produced on an estimated 14.8 million hectares, or 48% of the global cotton production area[1] in 2008, is a clear indication of how successfully that crop has spread across the world, especially in developing countries, leading to dramatic changes in both production and trade. In particular, the adoption of insect-resistant *Bacillus Thurengiensis*(Bt) cotton by millions of farmers (especially in Asia) has had a significant effect on the world cotton market by increasing global supply and lowering prices to the detriment of non-adopting exporting nations (Frisvold et al. 2006).

In this context, the opportunity costs of non-adoption have become a key factor in discussions about the use of this technology in the non-adopting countries of Sub-Saharan Africa. Estimates of these opportunity costs can be derived from simulation models, but the results of these ex-ante models depend on both assumptions and scenarios. As is true for any study of GM crops, the question of methodology is critical (Smale et al. 2008).

A number of studies have measured the expected economy-wide effects of Bt cotton adoption in developing countries using computable general equilibrium (CGE) models (Smale et al. 2008). For example, Anderson and Yao (2003) evaluate the introduction of GM rice and cotton in China based on general assumptions on the effects of the technology in any region, and simulate specific textile and cotton scenarios for China. Huang et al. (2004) also provide an assessment of the effects of the adoption of GM rice and cotton in China by using significant refinements in productivity assumptions and regulatory effects, but without explicitly accounting for GM crop adoption in any other country. Elbehri and

MacDonald (2004) measure the effects of Bt cotton introduction in Western and Central Africa (WCA) using region-specific productivity effects in this region. Finally, Anderson and Valenzuela (2007), and Anderson, Valenzuela, and Jackson (2008) provide simulations of Bt cotton introduction in the entire region of Sub-Saharan Africa with specific productivity assumptions that add the combination of GM cotton adoption to full trade liberalization.

Overall, these empirical studies show that adopters of Bt cotton will likely derive economic benefits and that Sub-Saharan Africa, will lose if they do not adopt Bt cotton. The results of the five cited studies (Anderson and Yao 2003, Anderson and Valenzuela 2007, Anderson et al. 2008, and Elbehri and Mac Donald 2004, and Huang et al. 2004) show that the introduction of Bt cotton would provide annual global gains of between $1.5 billion and $3.6 billion. More specifically, the adoption of Bt cotton in China results in welfare gains of between $100 million and $1 billion per year. The case of Sub-Saharan Africa is more difficult to synthesize due to different regional disaggregation across studies, but their simulation results suggest that the region would suffer losses from not adopting Bt cotton, and would gain by adopting this technology. In other words, these studies confirm that the technology implies a large opportunity cost for Sub-Saharan Africa.

Each of the abovementioned studies, however, is based on a set of specific modeling assumptions that may bias the value of their estimates. In particular, Hicks-neutral productivity shocks, or adapted factor biased shocks based on *ad hoc* Hicks-neutral assumptions that are used in these studies may not characterize the effect of Bt cotton in a realistic manner, as it is known that this technology has specific effects on labor, input use, and/or yields that vary across countries.[2] Secondly, although some countries have high Bt cotton adoption rates, there is no country with a 100% rate of adoption. Thus, without accounting for partial adoption, some of these studies may have overestimated the general effect of the technology.[3] Third, some of the studies do not consider adoption or productivity differences across countries. Fourth, most of the studies do not account for the over-aggregation of sectors and/or regions in the GTAP database, assuming, for example, that cotton can effectively represent all plant-based fibers globally. Lastly, none of the examined studies explicitly accounts for the effect of Bt cotton adoption on cottonseed production, even though it represents a significant share of oilseed production in some of the Bt cotton-adopting countries.

In this paper, we propose an improved modeling approach to address these limitations. We use a multi-country CGE model calibrated on a modified production function that allows for the partial adoption and introduction of region-specific factor-biased productivity shocks in the cotton and oilseed sectors. We also use proportional corrections to cope with the aggregation of sectors and regions in the GTAP database. The resulting model is used to simulate the adoption or non-adoption of Bt cotton in seven selected Sub-Saharan African countries.

Benin, Burkina-Faso, Mali, Senegal and Togo are part of a wider cotton producing region whose economies directly depend on cotton exports. In recent years the entire region has suffered losses in terms of trade, notably due to the relative decline in cotton prices, the increase in oil prices, the unfavorable Euro/U.S. Dollar exchange rate, and increased productivity in competing countries (Baffes 2005).

In Eastern Africa, the countries of Tanzania and Uganda, which used to be significant cotton producers, have maintained smaller cotton production levels with low productivity either because of tradition or the lack of alternatives. Pest management, seed quality, and soil fertility are considered to be some of the main constraints to cotton productivity in this region (Baffes 2009).

Among other solutions, these countries have been considering the adoption of Bt cotton as a way of reducing input costs and increasing yields, and thereby potentially providing a new competitive edge for the sector (Baffes 2005). The reported success of Bt cotton in Asian developing countries (e.g., Pray et al. 2002; Gruere, Mehta-Bhatt, and Sengupta 2008) may have played a role in encouraging this particular option. Yet of these countries, only Burkina Faso has taken steps to introduce this technology. After a few years of field trials between 2008-2009, that country has allowed the production of Bt cotton to be undertaken on a limited scale for seed multiplication, with the intent to expand it into commercial production the following season. None of the other six examined countries have followed its example. Instead, they remain unsure of whether they should adopt this controversial technology or adopt a more cautious position.[4]

In what follows, we first present our modeling approach and the scenarios to which it is applied. We then use the model to provide refined estimates of the economy-wide effects of Bt cotton adoption in the seven countries under study. We also run a sensitivity analysis on adoption and productivity assumptions to ensure the validity of our results, and provide an additional scenario to simulate the combined effects of Bt cotton adoption with full trade liberalization in the cotton and oilseed sectors of the respective countries.

2. Modeling approach

We use MIRAGE, a multi-sector, multi-country, CGE model[5] based on the GTAP database, which is modified to allow for the partial adoption of a productivity-enhancing technology in each selected region. In our case, the technology induces productivity shocks on three factors (land, labor, and pesticides) in two sectors (cotton and oilseeds). The novelty of our approach consists of: a) a better calibration of the adoption rates and productivity shocks in the three abovementioned factors, accounting for GTAP sector and region aggregation; b) a modification of the basic model to separate the relevant sector into GM and non-GM products; and c) a second modification of the model to allow for the use of factor-based productivity shocks differentiated by country/region in the GM product sector.

More specifically, based on assumptions taken from available data and the literature, we first derive a set of assumed adoption rates and productivity shocks. These estimates are then translated into usable inputs for the model by following a detailed procedure outlined in the appendix. To cope with the regional aggregation of the database (e.g., in WCA), we adjust the rate of adoption of Bt cotton in the region by accounting for the share of cotton from the relevant adopting countries in the total production of cotton for the whole region. Because the GTAP database aggregates cotton lint with other plant-based fibers (e.g., jute, flax, hemp or sisal), we also adjust the adoption rate by accounting for the weight of cotton production in total plant-based fiber production in each country adopting the technology (in our case, using FAOSTAT 2005 estimates). We follow the same procedure for cottonseed within the oilseed sector. Lastly, changes in uses of insecticides are adjusted to account for the fact that other chemicals (e.g., fertilizers and herbicides) are also used in cotton production. This adjustment is done by weighing the share of pesticide costs in total chemical costs used in cotton production based on a survey of national production budgets (International Cotton Advisory Committee 2004).

Policy simulations are run with the MIRAGE model, which includes an updated representation of trade policies and bilateral and multilateral trade preferential agreements (using MacMap-HS6, 2004 data). In this model, if value added and intermediate consumption are complementary (as per the Leontief hypothesis[6]), there exists some substitutability both between primary factors inside the value added, and between commodities consumed during the production process inside the intermediate consumption. The reference year of the model is 2004, but a pre-experiment is carried out in order to account for shocks that occurred in 2005, in particular the evolution of the U.S. Farm Bill and the end of the Multi-Fiber Arrangement[7]. For the sake of simplicity, we use a perfect competition hypothesis in all sectors. Further refinements of our simulations could include dynamic and imperfect competition modeling.

The model is modified by the introduction of two sectors for GM cotton (as a substitute for non-GM cotton) and GM oilseeds to account for the specific productivity shifts related to the use of GM cotton. First, in countries adopting GM technology, we split the cotton and oilseeds sectors into GM and non-GM product sub-sectors according to the desired rate of adoption. Second, we applied the derived productivity and input shocks into the model only in the GM sub-sectors.[8] Because of the reallocation of productive factors into the GM sub-sectors, this process implies larger adoption rates of GM technology than desired. Therefore, we re-started the entire process based on modified initial rates of adoption until final adoption rates reached the targeted levels. Convergence was rapid and usually obtained after four to six runs. The resulting representation of these sectorsreflects a modified production structure with GM and non-GM cotton and oilseeds sectors divided according to the initial adoption rates and input-differentiated productivity shocks.

3. Application: assumptions and simulation scenarios

Table 1. **Geographic decomposition**

Name	Countries and regions included
Ro Asia & Oc.	New Zealand, Rest of Oceania, Hong Kong, Japan, Korea, Taiwan, Rest of East Asia, Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia,, Sri Lanka, Rest of South Asia
Ro North Am.	Canada, Rest of North America
Ro Latin Am.	Bolivia, Ecuador, Peru, Venezuela, Chile, Uruguay, Rest of South America, Central America, Rest of Free Trade Area of the Americas, Rest of the Caribbean
EU	Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, Cyprus, Czech Republic, Hungary, Malta, Poland, Slovakia, Slovenia, Estonia, Latvia, Lithuania
Ro Europe	Switzerland, Rest of EFTA, Rest of Europe, Albania, Bulgaria, Croatia, Romania, Russian Federation, Turkey
Central Asia	Kazakhstan, Kyrgyzstan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgie
North Afr.-Mid. East	Iran, Islamic Republic of, Rest of Middle East, Morocco, Tunisia, Rest of North Africa
Ro Sub-Sah. Afr.	Botswana, Rest of South African Customs Union, Malawi, Mauritius, Mozambique, Zambia, Zimbabwe, Rest of Southern African Development Community, Madagascar
TU	Tanzania, Uganda
WCA	West and Central Africa (Senegal excluded), Nigeria

The Table provides the reference name of the region as found throughout the paper and a detailed explanation of this region.

Table 2. **Sector decomposition**

Number	GTAP Sectors
1	Raw milk, Meat: cattle,sheep,goats, horse , Meat products , Dairy products, Wearing apparel , Leather products
2	Cereal grains
3	Chemical, rubber, plastic products
4	Plant-based fibers
5	Forestry, Fishing, Wood products, Paper products. Publishing.
6	Food products, Beverages and tobacco products
7	Petroleum, coal products, Ferrous metals, Metals, Metal products, Motor vehicles and parts, Transport equipment, Electronic equipment, Machinery and equipment, Manufactures, Electricity, Gas manufacture and distribution
8	Cattle, sheep, goats, horses, Animal products
9	Oil seeds
10	Crops
11	Water,Construction, Communication, Financial services, Insurance, Business services, Recreation and other services, Public Administration/Defense/Health/Education,Dwellings
12	Coal, Oil, Gas, Minerals, Mineral products
13	Paddy rice, Processed rice
14	Sugarcane, Sugar beet, Sugar
15	Wool,silk, worm cocoons,Textiles
16	Trade, Transport ,Sea transport, Air transport
17	Vegetables, Fruits, andNuts
18	Vegetable oils and fats

19	Wheat

Note: The correspondence with the GTAP 7 database can be obtained upon request.

Our representation of the world includes 21 regions), including the most important players in the world cotton market: eleven countries (Argentina, Australia, Brazil, China, Colombia, India, Mexico, Pakistan, Senegal, South Africa, the United States) plus ten other aggregated regions (see Table 1; correspondence with the GTAP 7 database may requested from the authors). We disaggregate the economy into 19 sectors (see table 2), including plant-based fibers, which includes cotton, a separate sector for textiles, a sector for chemicals, including those going into agriculture, and the oilseeds sector for products derived from cottonseeds. Our region of study is composed of Senegal, four countries included within the WCA region of the GTAP 7 database (Narayanan and Walmsley 2008), which includes all countries in a wide band between Mauritania and Sudan in the North; Gabon, Congo and Kenya in the South; and a third region composed of Tanzania and Uganda (TU).

Table 3. **Assumed adoption rates under each scenario**

Scenario	Description	Countries adopting GM cotton and adoption rates
Base	Situation in 2004/05	Argentina (20%), Australia (60%), China (65%), India (5.3%), Mexico (61%), South Africa (95%), USA (78%).
1	Situation in 2008/09	Argentina (25%), Australia (90%), Brazil (40%), China (75%), Colombia (50%), India (70%), Mexico (64%), South Africa (90%)[1], USA (93%).
2	1 plus partial adoption in selected African countries	Argentina (25%), Australia (90%), Brazil (40%), China (75%), Colombia (50%), India (70%), Mexico (64%), Senegal (50%), South Africa (90%)[1], TU (50%), USA (93%), WCA (50%)[2].

Notes: [1] Personal communication with Marnus Gouse, University of Pretoria, for 2005/06. [2] Adoption only in Benin, Burkina Faso, Mali, and Togo within WCA.

Sources: Smale et al. (2008) for 2004/05, and data from the International Cotton Advisory Committee for 2008/09.

We propose three adoption scenarios to capture the dynamics of Bt cotton adoption, as shown in table 3. To model the effect of the technology globally, we first model its adoption from 2004/2005 in Argentina, Australia, China, India, Mexico, South Africa, and the United States as a basis of analysis (Base scenario), and then introduce scenario 1 with modified adoption rates in these and other countries (Brazil and Colombia) from 2008/2009. Lastly, we run a simulation where the seven selected African countries also adopt Bt cotton (scenario 2).

The assumed productivity effects associated with Bt cotton are derived from various farm level and industry or trade-level studies in each country, as shown in table 4. We use estimates of yield effects, insecticides and labor effects in each country. For our region of study we use average productivity assumptions from Falck-Zepeda, Horna and Smale (2008), and Vitale et al.(2008)[9]

Table 4. **Assumed productivity effects of GM cotton.**

Scenario	Countries	% Yield effects	% Input effects	
			Pesticides	Labor[1]
BASE	Argentina	33.1	-46	-5
	Australia[2]	0	-21	-2
	China	10	-67	-5.8
	India	26.5	-22	5
	Mexico	18	-77	-5
	South Africa	40	-49	-25
	USA[3]	11	-30	-2
Changes with 1	Brazil[4]	29.6	-18.9	-4
	China	7	-67	-6.7
	Colombia[5]	26	8.3	-3
	India	39.1	-38.8	5
Changes with 2	Selected African countries	20	-66	-10

[1]When unknown for 2005 adopters, the labor effect was assumed to be -5%. [2] Mostly herbicide tolerance, assumed to be similar to that in the United States. [3] Insect resistant and herbicide tolerant cotton. [4] Average for Argentina and Colombia. Sources: Authors' derivations, based on Edge et al. (2001); Elbehri and MacDonald (2004); Falck-Zepeda, Horna and Smale (2008); Gruere, Mehta-Bhatt and Sengupta (2008); Huang et al. (2004) ; Ismael, Bennett and Morse (2002); Klotz-Ingram et al. (1999); Marra et al. (2002); Pemsl, Waibel and Orphal (2004); Price et al. (2003); Purcell and Perlak (2004); Qaim and de Janvry (2003); Qaim and Matuschke (2005); Shankar and Thirtle (2003); Thirtle et al. (2003); Traxler et al. (2001); Traxler and Godoy-Avila (2004); Vitale et al.(2008); and Zambrano et al. (2009).

4. Simulation results

The results are expressed in relative terms compared to a scenario without GM products. The opportunity costs of not adopting Bt cotton for the seven examined Sub-Saharan countries is defined as the difference between these countries' real income under scenarios 2 and 1. The only difference between these two scenarios is that the countries under study also adopt Bt cotton in scenario 2. On the other hand, the difference between scenario 2 and the base scenario also includes higher rates of adoption in other countries.

Table 5. **Simulation results: welfare effects – ($ million/year) under different scenarios (Bt cotton adopters are in boldface)**

	Welfare changes from adoption			Relative changes		
	Base	1	2	1-base	2-base	2-1
Argentina	**-9**	**-15**	**-15**	-6	-6	0
Australia	**20**	**35**	**34**	15	14	-1
Brazil	-13	**33**	**33**	46	46	0
Central Asia	-5	-7	-7	-2	-2	-1
China	**205**	**258**	**263**	53	58	5
Colombia	4	**19**	**19**	15	16	0
EU	164	271	277	107	113	6
India	**100**	**1297**	**1297**	1197	1197	1
Mexico	**216**	**255**	**256**	39	40	1
North Afr.-Mid. East	22	51	55	29	33	4
Pakistan	8	12	13	4	5	1
Ro Asia & Oc.	203	275	288	72	85	13
Ro Europe	36	58	60	22	24	2
Ro Latin Am.	22	30	31	8	9	1
Ro North Am.	17	28	29	11	12	1
Ro Sub-Sah. Afr.	-5	-3	-2	2	3	1
Senegal	0	1	**5**	1	5	4
South Africa	**20**	**23**	**23**	2	3	1
TU	-1	-2	**5**	-1	6	7
United States	**657**	**876**	**881**	219	224	5
WCA	**-13**	**-16**	**14**	-3	27	30
World	**1646**	**3477**	**3557**	**1831**	**1911**	**80**

Source: Authors' simulations.

The global welfare results are presented in table 5, which shows that the overall global welfare effects associated with the introduction of Bt cotton range between $1.6 billion and $3.6 billion annually. The absolute welfare changes in the base scenario compared to the initial situation are positive in most adopting countries. China gains over $200 million, India gains $100 million, and the United States gains $657 million. Differences in gains reflect differences in production levels and adoption rates. On the other hand, Argentina suffers minor losses due to a reduction in its terms of trade (resulting from a decline in export prices) that exceed its technical gains in the oilseed sector (a typical example of "*immiserizing growth*").[10] As expected, non-adopting exporters lose market shares because of the productivity shift; in particular, Central Asia (Uzbekistan is one of the world's leading exporters of cotton) loses about $5 million, while Brazil and WCA lose about $13 million annually under the base scenario. Other textile or cotton consumers experience large gains due to the relative decrease in prices.

Scenario 1 represents the situation in 2008, with increased adoption of Bt cotton in all 2005 adopters, as well as the entry of Brazil and Colombia. Changes in welfare effects relative to the base scenario are shown in the fifth column of table 5 (column 1-base). With this increased adoption, the world doubles welfare gains compared to the base, which is mostly the result of the twelve-fold increase of adoption in India. India increases its gains by about $1.2 billion, the United States by $219 million, and China by $53 million.[11] Cotton (and/or textile) consuming countries of Europe and Asia also significantly benefit from increased adoption (through an improvement of their terms of trade). As expected, all other countries experience relatively small changes in welfare. WCA loses $16 million in absolute terms, or $3 million more than in the base scenario, and the changes in Senegal and TU are relatively small.

Scenario 2 adds the partial adoption (at the 50% level) of the seven examined countries. Under this scenario, WCA gains $14 million per year, Senegal gains $5 million/year, and TU gains $5 million/year, as shown in the fourth column of table 5. The Rest of Asia and Oceania (Ro Asia & Oc.) and the European Union (EU) are the two other regions that gain from this additional adoption as consumers of cotton or textile products derived from cotton. The global welfare change relative to scenario 1 reaches $80 million.

The total opportunity cost of the adoption of Bt cotton (shown in column 2-1 of table 5) amounts to $30 million/year for the four countries in WCA, $4 million/year for Senegal, and $7 million/year for TU. In relative terms, the total opportunity costs of non-adoption amounts to 0.02%, 0.06%, and 0.03% of the total welfare in WCA, Senegal, and TU, respectively. At the macroeconomic level, this is a minor shock. At the sectoral level, this is much more significant.

Table 6. **Changes (%) in production of plant-based fibers and oilseeds in adopting countries**

	Plant-based fiber sector						Oilseeds sector					
	Base	**1**	**2**	**1-Base**	**2-Base**	**2-1**	**Base**	**1**	**2**	**1-Base**	**2-Base**	**2-1**
Argentina	6.2	5.1	5.1	-1.1	-1.1	0	-0.5	-0.7	-0.7	-0.2	-0.2	0
Australia	2.2	3.4	3	1.2	0.8	-0.4	2.7	4.1	4.1	1.4	1.4	0
Brazil	-4.8	8.7	8.3	13.5	13.1	-0.4	-0.6	-0.2	-0.2	0.4	0.4	0
China	-2.3	-2.1	-2.5	0.2	-0.2	-0.4	5.2	5.7	5.7	0.5	0.5	0
Colombia	-5.2	24.1	23.7	29.3	28.9	-0.4	-0.2	0.7	0.7	0.9	0.9	0
India	0.6	21.4	21.2	20.8	20.6	-0.2	0.2	3.6	3.6	3.4	3.4	0
Mexico	4.1	2.9	2.8	-1.2	-1.3	-0.1	1.3	1.1	1.1	-0.2	-0.2	0
Senegal	-3.8	-6.9	55.7	-3.1	59.5	62.6	0	0	0.3	0	0.3	0.3
South Africa	29.4	24.4	23.7	-5	-5.7	-0.7	1.3	1	1	-0.3	-0.3	0
TU	-4.5	-10.9	13.4	-6.4	17.9	24.3	-0.1	-0.2	4.4	-0.1	4.5	4.6
USA	12.3	14	13.6	1.7	1.3	-0.4	0.9	0.9	0.9	0	0	0
WCA	-5.6	-8.8	17.5	-3.2	23.1	26.3	0	0	1.3	0	1.3	1.3

Source: Authors' simulations.

Table 7. **Changes (%) in exports of plant-based fibers and oilseeds in adopting countries**

	Plant-based fiber sector						Oilseeds sector					
	Base	**1**	**2**	**1-Base**	**2-Base**	**2-1**	**Base**	**1**	**2**	**1-Base**	**2-Base**	**2-1**
Argentina	2.1	0.8	0.4	-1.3	-1.7	-0.4	-1.9	-2.2	-2.2	-0.3	-0.3	0
Australia	1.2	2.1	1.1	0.9	-0.1	-1	2.9	4.4	4.4	1.5	1.5	0
Brazil	-7	10.4	9.5	17.4	16.5	-0.9	-1.3	-1.1	-1.1	0.2	0.2	0
China	-4.8	-5.9	-6.9	-1.1	-2.1	-1	6.3	6.5	6.5	0.2	0.2	0
Colombia	-6.3	39.5	39.8	45.8	46.1	0.3	-0.4	0.4	0.4	0.8	0.8	0
India	-5.1	51.9	50.5	57	55.6	-1.4	-0.2	9	9	9.2	9.2	0
Mexico	15.1	11.1	10.2	-4	-4.9	-0.9	1.3	0.9	0.9	-0.4	-0.4	0
Senegal	-4.9	-8.9	39.6	-4	44.5	48.5	-0.5	-0.8	-2	-0.3	-1.5	-1.2
South Africa	42.8	31.9	30.2	-10.9	-12.6	-1.7	0.2	-0.2	-0.2	-0.4	-0.4	0
TU	-6.4	-15.4	9.8	-9	16.2	25.2	-0.7	-1.1	3.1	-0.4	3.8	4.2
USA	24.7	28	27.1	3.3	2.4	-0.9	0.4	0.4	0.4	0	0	0
WCA	-5.8	-9.1	13.3	-3.3	19.1	22.4	-0.1	-0.2	-0.1	-0.1	0	0.1

Source: Authors' simulations.

Table 8. **Changes (%) in imports of plant-based fibers and oilseeds in adopting countries**

	Plant-based fiber sector						Oilseeds sector					
	Base	**1**	**2**	**1-Base**	**2-Base**	**2-1**	**Base**	**1**	**2**	**1-Base**	**2-Base**	**2-1**
Argentina	-5.9	5.4	5.5	11.3	11.4	0.1	-0.1	-0.3	-0.3	-0.2	-0.2	0
Australia	-2.2	-2.2	-2.3	0	-0.1	-0.1	-0.4	-0.1	-0.1	0.3	0.3	0
Brazil	-6.3	1.3	1.5	7.6	7.8	0.2	-1.3	-0.4	-0.4	0.9	0.9	0
China	12.3	14.4	16.5	2.1	4.2	2.1	-2.1	-2.2	-2.2	-0.1	-0.1	0
Colombia	-14.6	-0.7	0.6	13.9	15.2	1.3	-0.4	0	0	0.4	0.4	0
India	5.2	-25	-21.1	-30.2	-26.3	3.9	-0.4	-7.9	-7.8	-7.5	-7.4	0.1
Mexico	2	5.4	5.4	3.4	3.4	0	0.4	0.5	0.5	0.1	0.1	0
Senegal	0.1	-0.02	8.7	-0.12	8.6	8.72	-0.5	0.3	1.1	0.8	1.6	0.8
South Africa	-17.7	-16.3	-16.1	1.4	1.6	0.2	-0.6	-0.3	-0.2	0.3	0.4	0.1
TU	-0.1	-1.6	-6.7	-1.5	-6.6	-5.1	-0.1	-0.1	-2.9	0	-2.8	-2.8
USA	-17	-20.1	-20	-3.1	-3	0.1	-0.9	-0.4	-0.4	0.5	0.5	0
WCA	-3.9	-6.2	15.3	-2.3	19.2	21.5	-0.1	-0.1	0	0	0.1	0.1

Source: Authors' simulations.

Table 6 shows the relative change in production volume in plant-based fibers (including cotton) and oilseeds (which include cottonseeds) for the GM cotton-adopting countries under the different scenarios. In the first two scenarios (base and 1), all adopting countries increase their production of plant-based fibers except China, which reduces its production by two percent, in part because it loses competitiveness compared to other countries. Under the same scenarios, the largest increases in production of plant-based fibers with Bt cotton adoption are experienced by South Africa (29.4%, base scenario), Colombia (24.1%, scenario 1), and India (21.4%, scenario 1). Under scenario 2, the adoption of Bt cotton by the seven African countries also largely increases their production of plant-based fibers, with a rate of 17.5% for WCA, 13.4% for TU, and a leading rate of 55.7% in Senegal (a small cotton-producing country).

Tables 7 and 8 show the relative changes in exports and imports, respectively, in the two sectors being studied. Under the three scenarios, China reduces its exports between 5-7% and increases its imports between 12-16%. Yet overall, because it is the largest consumer of cotton, and partially because of terms of trade gains in the oilseed sector (increasing production and exports by 5-6%), China experiences significant welfare gains. In contrast, India largely expands its cotton production, increases its cotton exports by over 50% (scenario 1) and decreases cotton lint imports by up to 25%, while raising its competitiveness in the oilseeds market. WCA and Senegal experience a small decrease in exports of oilseeds under scenario 2; this region imports more oilseeds from countries adopting GM cotton.

5. Discussion

Overall, the seven African countries gain from adopting GM cotton technology, and since they are not large intermediate consumers of cotton, most of the gains can be attributed to the producing sectors in these countries.[12] This result may first appear to contradict the conclusions of other studies, like Kaye-Blake et al. (2008), which argue that GM technologies – if they only increase productivity – will always result in negative producer returns. But this apparent contradiction can be explained by modeling and assumption differences. Kaye-Blake et al. (2008) use a partial equilibrium model with the adoption of GM crops everywhere and with inelastic demand for all products. In our case, Bt cotton is adopted by certain countries, but not others (like Uzbekistan or Pakistan, which are major cotton producers), and adopters can gain market shares on these other countries. Furthermore, our model does incorporate cost-reducing factors that feed into the welfare effect and a relatively elastic supply. So, if producers in some countries lose from GM cotton adoption, others gain.

Figure 1 shows the distribution of opportunity costs of non-adoption for each examined country under the 50% adoption rate, using the production share in 2004/2005 as a proxy of the share of total benefits in each country of the WCA and TU regions. Of the seven countries, Benin, Burkina Faso, Mali, and Tanzania are bound to gain the most from adopting, and to lose the most from rejecting the technology, with opportunity costs ranging from just over $2 million to more than $10 million annually in Burkina Faso. This distribution may partially explain why Burkina Faso was the first to adopt this technology. Overall, these aggregate welfare gains may look limited, but even a small portion of these gains could have a significant effect in the livelihood of the tens of thousands of poor farming families living mainly from cotton revenues.

Table 9. **Comparison of the simulation results with those of other selected studies: welfare effects with adoption of Bt cotton in specific countries ($ million/year)**

Study	**Scenario**	**China**	**India**	**USA**	**SSA**	**Global**
Anderson and Yao (2003)	with China, 0% in SSA & India	340	-26	286[1]	-52	1,483
Anderson and Valenzuela (2007)	Without SSA	113	817	61	-13	2,018
	With SSA	100	822	57	199	2,323
Anderson et al. (2008)	Hicks neutral with SSA	100	970[2]	57	187	2,323
	Factor-biased with SSA	189	1,554[2]	62	214	3,594
Elbehri and McDonald (2004)	a) Without WCA	n/a	n/a	n/a	-$87[3]	n/a
	b) WCA adopts	563	710	37	82[3]	1,795
Huang et al. (2004)	China adopts without others	1,097	n/a	n/a	n/a	n/a
Results of authors' simulations	1) no SSA	258	1,296	876	-21[4]	3,477
	2) with 7 countries	264	1,297	881	20[4]	3,557

Note: n/a: not available, WCA: Western and Central Africa, SSA: Sub-Saharan Africa

[1] Estimate for North America. [2]Estimate for South Asia. [3] WCA. [4]SSA with shock applied only to seven study countries.
Source: Cited sources and authors' derivations.

Table 9 shows that the welfare results are within the range of published results for China, but much larger than previous results for India and the United States, as well as globally. These observed differences result directly from our productivity, data, and modeling assumptions. In particular, we assume large adoption rates, based on 2008 data, whereas Elbehri and MacDonald (2004), one of the only studies with partial adoption, used lower adoption rate for these countries (25% for India, 37% for the United States). In the case of India, we impose a larger productivity effect in specific factors (e.g., 26.5% yield gains) than Anderson and Valenzuela (2007) or Anderson, Valenzuela and Jackson (2008), who use a 15% shock, and we especially apply it to a much larger production base (based on 2004 data from GTAP 7) than they do (based on 2001 data from GTAP 6.1). We also include the impact on oilseeds, which affects the United States and other countries as well.

Still, the opportunity costs of non-adoption in Sub-Saharan Africa are lower than those suggested by the results of previous studies.[13] More specifically, we obtain slightly lower losses without Bt cotton and lower gains with Bt cotton than those studies that treat larger regions in Africa.

Anderson and Yao (2003) find that without adopting Bt cotton, Sub-Saharan Africa would lose \$52 million annually, while Elbehri and MacDonald (2004) find that WCA would lose \$87 million annually (accounting for the associated price decline). Anderson and Valenzuela find that Sub-Saharan Africa would lose about \$13 million annually, a total closer to ours; we find a loss of \$20 million for countries in Sub-Saharan Africa (see table 5, scenario 1).

On the other hand, the gains obtained by these studies range from \$82 million to \$214 million with adoption in countries of Sub-Saharan Africa, while our simulation results suggest that Sub-Saharan Africa would gain \$22 million if they adopt Bt cotton – see scenario 2 in table 5.

While we cannot elucidate every single factor accounting for these differences, it is clear that assumptions and scenarios especially related to the nature of productivity shocks and adoption rates do matter. We do focus on fewer countries in Sub-Saharan Africa; taken together they may explain why, with many new competitors, Sub-Saharan African countries do not in fact obtain as large a gain as found in previous studies.

6. Sensitivity analysis

Obviously, the assumptions on productivity shocks and adoption rates are critical to the simulation exercise. In this section, we propose a sensitivity analysis with respect to the magnitude of these parameters to gauge the importance of each assumption.

We implement a reduction and an augmentation of each assumed critical parameter in the seven countries under study. More specifically, we successively vary the adoption rates of GM cotton and oilseeds in the region, as well as the assumed yield effects, labor effects, and pesticide effects associated with Bt cotton. Each of these assumed parameters is first decreased by 50%, and then increased by 50% relative to the original (central) scenario. For example, in the case of the adoption rate, we compare the effect of 50% adoption in the central scenario to the case of a 25% and 75% adoption rate in the countries being studied.

Table 10. Sensitivity analysis: opportunity cost ($ million/year) of non-adoption of GM cotton in WCA, Senegal, and TU under various assumptions

	WCA			Senegal			TU		
Change in:	-50%	Central	+50%	-50%	Central	+50%	-50%	Central	+50%
Adoption	14	30	50	2	4	8	3	7	11
Yield effect	30	30	30	4	4	4	6	7	7
Pesticide effect	30	30	30	4	4	4	7	7	8
Labor effect	23	30	36	3	4	4	6	7	7

Source: Authors' derivations.

Table 10 presents the results of this sensitivity analysis in terms of net opportunity costs of non-adoption (i.e., the relative change in welfare between scenarios 1 and 2) for the four WCA countries, Senegal, and TU. The central column in each region indicates that under our original assumptions, the total opportunity costs are $30 million, $4 million and $7 million for WCA, Senegal, and TU, respectively. These results clearly show that the most critical assumption in the simulation is by far the adoption rate. The opportunity costs of non-adoption are divided by two with a 25% adoption rate, but it increases by more than 50% with a 75% adoption rate. On the contrary, the size of the shock on pesticides or yields has only a minor influence on the net welfare gains of these countries,[14] while the assumed shock on labor productivity is slightly more significant.

These differences can be largely explained by the structure of the shock and the characteristics of the affected countries. As noted above (see endnote 6), share parameters are used to apply productivity shocks. These parameters measure the share of each input in the total cost of production at initial prices. Concerning the countries under study, these shares fall between 2-21% for chemical inputs, 8-10% for land, and between 36-58% for labor. Thus, variations in the labor productivity shock have much more impact on welfare results than changes in yield and pesticide effects. At the same time, changes in the adoption rate translate into absolute changes in the three effects (yield, labor, and pesticide) and therefore induce larger variations in welfare effects.

At a time of multilateral trade negotiations under the aegis of the World Trade Organization, liberalization of the cotton sector is a key issue, in particular for the least developed countries of Sub-Saharan Africa. As pointed out by Anderson and Valenzuela (2007), full trade liberalization of the cotton sector may magnify the gains from GM adoption in this sector.

To test this hypothesis, we run a new scenario with full liberalization of the cotton and oilseeds sectors added to the shocks defined under each scenario in tables 3 and 4. The trade reform includes the worldwide elimination of all import duties, production and export subsidies in the cotton and oilseeds sectors.

We find that, under scenario 2, the world welfare gain is augmented by about 30%, up to $4.6 billion. The additional gain is particularly important for the three studied African regions:

trade reform increases gains from $14 million to $35 million in WCA, from $5 million to $6 million in Senegal, and from $5 million to $27 million in TU. However, the opportunity costs of Bt cotton are not significantly affected; they only increase in the case of TU from $7 million to $8 million.

While these results support the inclusion of cotton in trade negotiations, they suggest that the net gains from adoption are independent from the goal of full trade liberalization. This means that countries should look at this technology based on its own merit, as well as its own opportunity costs, regardless of the status of multilateral trade negotiations.

7. Conclusions

In this paper we propose a refined approach for measuring the total opportunity costs of non-adoption of Bt cotton. Our multi-country CGE model uniquely employs region-specific partial adoption rates and factor-biased productivity shocks decomposed into labor, chemical, and yield effects in the cotton and oilseed sectors in all Bt cotton-adopting regions. We then use this model to simulate the effects of the adoption or non-adoption of Bt cotton in Benin, Burkina Faso, Mali, Senegal, Togo, Tanzania, and Uganda – seven Sub-Saharan African countries that have expressed interest in the technology when other countries adopt it.

Our results show that the region under study stands to lose about $17 million annually if it does not adopt Bt cotton while others do, and that the region could gain about $24 million annually if it were to adopt Bt cotton at the 50% level. In other words, the opportunity costs of not adopting Bt cotton for these seven countries is approximately $41 million a year. Burkina Faso, which is the first country to have approved Bt cotton, has the most to gain. These results remain generally valid even if we augment or reduce our productivity assumptions by 50%, but they depend on the adoption rates applied in the countries under study. Higher adoption rates result in much higher opportunity costs. We also find that global trade liberalization of the sector brings real income gains for these countries, but does not substantially alter the net benefits derived from Bt cotton adoption.

The fact that these arguably more precise estimates of the opportunity costs of not adopting Bt cotton are lower than those of other studies raises the possibility that modeling and assumption simplifications inflate expectations around the economic effects of this technology. Our results do confirm that the technology is undeniably useful and costly to avoid for Sub-Saharan countries, but the relatively smaller gains we obtain suggest some possible past exaggerations. We also show that trade liberalization will have independent effects from technology, which somewhat contradicts the results of Anderson and Valenzuela (2007). While simulations using multi-country, multi-market CGE models will always be constrained by aggregated assumptions, our results suggest that refinements can make significant differences in results, and may even do so to the point of altering the conclusion. More effort should be made to assess the importance of critical modeling assumptions in ex-ante economic simulations.

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Endnotes

[1] Estimates from the International Cotton Advisory Committee (ICAC) for 2008/09, January 2009.

[2] In particular, some farm-level literature has shown that Bt cotton resulted in a significant reduction in pesticide use but generated moderate yield gains in China, while it had much larger yield effects and lower pesticide effects in neighboring India (Smale et al. 2008).

[3] Elbehri and MacDonald (2004) and Huang et al. (2004) do include partial adoption rates. Anderson et al. exclude non-cotton plant-based fibers, but do not model the partial adoption of cotton explicitly in their model.

[4] Uganda has approved confined field trials of Bt cotton, and Tanzania is conducting laboratory research, but it is still uncertain whether these efforts will ultimately lead towards commercialization.

[5] The MIRAGE model was developed at the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) in Paris. A full description of the model is available at the CEPII website (www.cepii.fr). MIRAGE was used in impact studies of the Doha Development Agenda (Bouet, Bureau, Decreux and Jean 2005; Bouet, Mevel and Orden 2007; Bouet and Laborde 2010), of regional trade agreements (Berisha-Krasniqi, Bouet and Mevel 2008) and more recently of increased domestic support of biofuels (Valin, Dimaranan and Bouet 2009).

[6] This "Leontief" hypothesis strictly means that production of an output demands a constant proportion in volume of value added and of intermediate consumption.

[7] The US Farm Policy has been updated as domestic support to US cotton producers is an important element of the international cotton sector – to see details on how this updating has been implemented see Bouet et al.(2005). Accounting for the end of the Multi-Fiber Arrangement was also important as under this arrangement the US, the EU and Canada in particular have been imposing quantitative restrictions on exports of textile and garments by developing countries from 1974 to the end of 2004.

[8] As noted above, the production function of cotton or oilseeds is defined as a Leontief combination of value added and total intermediate consumption. Value added is a Constant Elasticity of Substitution (CES) function of land, capital, unskilled and skilled labor, and intermediate consumption is modeled as a CES function of each intermediate goods. In our application, productivity shocks are applied on land, labor and chemical consumption based on the share of the total cost of production they represent.

[9] The results of the first production season in Burkina Faso had not been formally assessed when this paper went to press.

[10] As noted by Kaye-Blake, Saunders and Catagay (2008), negative producer returns are expected from a productivity enhancing GM technology if the demand is sufficiently inelastic. Argentina is a significant producer and exporter of oilseeds.

[11] Despite similar adoption rates, the total gains in China are not as large as in India, mostly because of differences in the countries' respective productivity shocks. In India, Bt cotton increases yields, which translates into production and exports increases with associated gains in the terms of trade, while in China the gains are mostly in the pesticide sector.

[12] The exact decomposition of consumer and producer surplus remains unavailable from the model, but the welfare gains and production and export increases, as well as the very limited cotton consumption in these countries, suggest the significant role of producer gains.

[13] Even if these studies do not directly evaluate the opportunity cost of not adopting this technology, it can be derived from their results by drawing the difference between the welfare effects with Bt cotton adoption and the welfare effects resulting from non-adoption.

[14] Differences are not zero; they are less than $0.4 million.