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IFPRI Discussion Paper 00718

September 2007

The Economic Impact and the Distribution of Benefits and Risk from the Adoption of Insect Resistant (Bt) Cotton in West Africa

Jose Falck-Zepeda
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and
Melinda Smale

Environment and Production Technology Division

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ABSTRACT

Cotton is the largest source of export receipts of several West African countries. Statistics however show a decreasing tendency in cotton yields and an increasing tendency in pesticide use. Under this circumstances there appear to be potential payoffs from the use of biotechnology products in the farming systems of the region. In this study we estimate different scenarios for the potential deployment of insect resistant cotton in selected countries in West Africa (WA).

We use an economic surplus model augmented with a more rigorous sensitivity analysis of model parameters. Hypothetical scenarios of Bt cotton adoption in WA are simulated and single point values of model parameters are substituted with probability distributions. The scenarios include: no adoption in WA; adoption of existing varieties; adoption of WA varieties backcrossed with private sector lines; and fluctuating adoption patterns.

According to the simulations, the total net benefits of adopting Bt seem to be small even after including the innovator surplus who accrues a larger share of the benefits. In contrast the WA countries included in the evaluation are worse off if they decide no to adopt Bt cotton. These results are in part explained by the conservative assumptions taken. The adoption pattern and the length of the adoption period affect the share of benefits earned by producers as compared to innovators. This study provides tools and information that can be used to build greater confidence in the process of setting agricultural research investment priorities.

Key Words: Bt cotton, West Africa, economic surplus, risk, probability distributions, impact assessment, net benefits

1. INTRODUCTION

Governments and producers in West Africa have expressed interest in the potential application of modern biotechnology products as one way to improve the economic and social returns to smallholder agriculture and to increase food security in the region. Potential applications of modern biotechnology innovations include improved crop resistance to pests, diseases, weeds and abiotic stresses, all of which could positively affect the rural poor in West Africa. The development of appropriate and sustainable bioinnovations in West Africa however needs to recognize the wide variability in bio-physical conditions, prevailing production systems, governance and institutional issues, as well as the different degrees to which each commodity will be affected by different production constraints.

Genetically modified insect resistant (Bt) cotton is currently considered for use in West Africa (see Appendix A for a description of the technology). This bioinnovation that was developed by the private sector has already been field tested in Burkina Faso. The potential adoption of Bt cotton in West Africa has generated significant controversies related to the potential socio-economic, institutional, political and environmental effects of technology adoption. Socio-economic concerns about the potential market effects of local adoption of Bt cotton include impacts on resource poor farmers, farmers dependence on a continuous flow of innovations, as well as external impacts that may affect local farmers such as the potentially adverse reaction in some European markets. Other important concerns raised by opponents of the technology are the potential environmental and ecological implications of transgenic technologies, all of which bring additional uncertainty to the likelihood of farmer adoption.

Despite these challenges and uncertainties, there does appear to be a significant potential for capturing large economic, social, and environmental payoffs from the use of biotechnology products in the farming systems of Africa (Cabanilla et al. 2004; Elbehri and MacDonald 2004). The potential payoffs must be weighed against the potential costs and risks to both society and the environment. Results presented here are an attempt to use best practices and methodologies to assess the potential impact of the adoption of insect resistant cotton in West Africa.

The primary purpose of this analysis was to illustrate the application of an augmented economic surplus model to estimate the potential impact of Bt cotton adoption in west Africa. The present scope of this study is not to generate definitive estimates of the level and social distribution of benefits, as this would require extensive field data collection. Nevertheless, we have used the best available information on constraints and productivity alleviation potential to showcase patterns of variables potentially affecting Bt cotton performance. Examination of these patterns lends insights into critical issues for designing biotechnology, advancing biosafety regulatory processes and making policy decisions.

For instance, we could illustrate the effects on economic benefits of changes in technology fees or regulatory delays that result from additional years of testing. Flexibility has been built into the design of the model so that modifications are easy to implement. Given the brief time period of this study, it was not feasible to work with national experts from the study countries in order to calibrate the model and validate the results. However, the results of this study, the methodological approach and the stochastic economic surplus simulation tools will be made accessible to our West African colleagues. Planned joint activities in the near future include collecting detailed field data.

The study is structured as follows. First, we briefly review the current context and issues surrounding cotton production, productivity constraints and biotechnology development and use in the West Africa region. Next we describe the methodological steps of the economic surplus assessment, augmented to take into account risk considerations. We then estimate the potential magnitude of the economic cost, benefits and risk from Bt cotton in West Africa, and indicate how these are likely to be distributed among innovators, farmers, and consumers within adopting nations in the West Africa region. This study provides tools and information that can be used by policy analysts, policy makers, those funding biotechnology, national research directors, and other stakeholders to build greater confidence in the process of setting investment priorities. There is a pressing need though to collect and assess field data on pests, control efforts, adoption behaviors, and other relevant parameters from individual countries, regions and producers in order to fine tune the estimates presented here.

Cotton in West Africa

Cotton production and productivity in West Africa

Cotton plays an important part in West Africa’s development, particularly through regional exports to world markets and as a source of hard currency. Cotton is relatively well suited for the agro-ecological conditions in West Africa and other areas where drought and rainfall variability limits planting alternative crops. Cotton represents the largest source of export receipts for several West and Central African countries. Africa accounts for approximately 10-15 percent of world cotton exports (Baffes 2004; UNCTAD 2006). Although Africa’s total share of world trade in cotton is relatively small, the crop is critical to the economies of numerous countries on the continent. Table 1 disaggregates the value of production and shares of exports by country for all of the cotton producing countries in the region.

Eight countries in West Africa (Benin, Burkina Faso, Cameroon, Chad, Cote d’Ivoire, Mali, Senegal and Togo) produce 99 percent of all cotton in the region. According to Baffes (2004) and UNCTAD (2006), all countries in West Africa cultivate a total of 2.9 million hectares. Areas have increased dramatically over the last 20-30 years in the region (Ton 2001; SWAC Secretariat/OECD 2005). Comparative advantage of the region in terms of lower production costs, the high quality of fiber, and existing institutional infrastructure that supports farmers accounted for these dramatic increases. In addition, all countries in West Africa export approximately 745 million dollars worth of cotton annually (a total regional production of 2.8 million tons of cotton lint per year). Mali, Côte d'Ivoire and Benin are the three largest exporters. The share of cotton in the total exports of Burkina Faso and Benin is above 35 percent. Furthermore, in Burkina Faso, Benin, Mali and Chad, the share of total agricultural exports is higher than 50 percent.

According to SWAC Secretariat / OECD (2005) a significant share of cotton is planted by smallholder farmers. This paper estimates that 1-2 million smallholder farmers produce the crop, largely with household labor. In addition, production on household farms engages an estimated 6 million persons directly and an estimated 16 million persons off-farm in the cotton industry. Cotton production is carried out in diversified farming systems that include crops such as cereals and vegetables. This mode of production serves the dual purpose of providing for household consumption and cash needs.

Cotton in West Africa tends to have significantly lower production costs compared to industrialized countries (SWAC Secretariat / OECD 2005; Estur 2005). This is the result of lower labor costs and the significantly lower use of productive inputs such as fertilizer and pesticides by West African farmers. Because cotton is hand picked, the quality also tends to be higher than in other countries. The level of contamination from foreign matter though has increased in hand picked cotton. This factor added to the stickiness induced by pest infestations has translated to penalties and in some cases refusals to buy the production (SWAC Secretariat /OECD 2005).

Cotton production in West Africa has been characterized by its vertically integrated production system (the Filière intégrée) from farm to gin. The system in most countries is still controlled –with some variations– by the State. In most countries the State continues to regulate and intervene in market operations, yet most governments are at the same time divesting themselves from the cotton sector. The lack of sustainability of a state support system and the pressure to liberalize important economic sectors has been main driving forces for African governments to take a sidestep on the cotton production and marketing chain. Monopsonistic structures however continue to exist in Cameroon, Chad, Mali, and Senegal, as there are approximately 25 ginning companies with 84 gins in the eight largest producing countries (Estur 2005) thus allowing exercise of market power. In contrast, ginning has been liberalized (partially or completely) in Benin, Burkina Faso, Côte d'Ivoire and Togo. The SWAC Secretariat / OECD, (2005) same reference cited before indicate that most of cotton producers in the region belong to more than 1,000 producer associations or cooperatives.

2. PRODUCTIVITY CONSTRAINTS OF COTTON IN WEST AFRICA

Insects and Diseases

Lepidopteran insects cost West African producers approximately 194 million dollars in insecticides annually (CAB International 2001). Table 2 lists the Lepidopteran insects reported as significant enough to require pesticide controls in West Africa. In the region yield losses due to these insects, with insecticidal control reach on average 23 and 34 percent without control.

Ajayi et al. (2002) have indicated that in recent years cotton yields have declined in West Africa with a concurrent increase in the use of pesticides. This pattern may be partially explained by increased resistance of pests to commonly used pesticides in the region. For example, Martin et al. (2002) reported resistance of cotton bollworm to pesticides. There have been some efforts to change the current system for managing insect pests in order to reduce costs and improve control by farmers (Ochourt et al. 1998). Use of control thresholds early in the season is one of these strategies, but as of 2001 this practice does not appear to have been widely adopted (Silvie et al. 2001).

Other productivity constraints on Cotton in West Africa

Apart from pests and diseases there are other biotic and abiotic constraints to cotton producers' productivity in West Africa. These include:

- Severe decreases of annual precipitation amounts coupled with an increase in rainfall variability, especially in the Sahelian countries such as Burkina Faso, Mali, Chad, and Senegal (Toulmin and Gueyè 2003). Although cotton resists drought to a higher degree than other crops, the decreases in annual precipitation are sufficient to affect cotton productivity.
- Severe decreases in soil fertility and severe increases in land degradation. These two factors have reduced soil productivity in the region.
- Poverty issues. On one hand, a study on poverty in Burkina Faso shows that poverty has decreased amongst the rural poor and amongst cotton producers from 1998 to 2003 (World Bank 2004a). On the other hand, cotton producers have become more vulnerable to risk as the terms of trade of cotton have been severely affected by low international prices (World Bank 2004b).
- Internal, regional and external macro policies that have an impact on agriculture. These policies include exchange rates, structural adjustments, liberalizations, and subsidies to cotton production in industrialized countries.

The introduction of the Bt cotton in West Africa will be greatly enhanced if it is part of a broader technological package that addresses other constraints listed above. Bt cotton is a knowledge intensive technology and addressing potential for institutional and environmental problems as early as possible in the technology diffusion process would help to ensure benefits. As we know the possibilities for alternative crop substitutions and cropping rotations are limited in the region. Thus, enhancing cotton production continues to be a necessary strategy for West African policy makers and national agricultural research systems, and now with an increasingly larger role- the private sector.

3. STAKEHOLDERS AND THE DEBATE WITH REGARD TO BT COTTON

Independently of the controversy generated and uncertainties of GM technologies, area planted to Bt cotton has increased significantly over the last years. Estimated adoption rates of Bt and other GM cotton have reached 50 percent in Mexico, 70 percent in China and 95 percent in South Africa (Appendix A). Area planted to cotton has doubled in India, and the expectation is that the share of GM cotton will increase significantly as the Government of India has introduced mandates reducing the price charged to farmers to almost half of the previous year's values. Price charged to farmers including the technology fee is one of the themes identified by Smale et al. (2006) as one of the cross-cutting issues defining the level of producer benefits across countries.

The technology might be very successful at controlling Lepidopteran insects, but it is the institutional and/or marketing conditions that may in the end determine whether farmers gain or lose from introduction of the technology (Smale et al. 2006). Another critical issue is the ability of the innovator and/or the technology transfer agent to transmit to farmers the necessary knowledge to manage the technology under field conditions. Furthermore, the need arises to re-think the Bt technology and other insect resistance technologies as part of a broad, integrated pest management or better yet, an integrated crop management strategy for implementation in West Africa. We argue then that the introduction of Bt cotton needs to be made considering the broader agricultural development and economic growth policies where proper incentives support the sustainability of the technology and of technology flows over time.

The potential production of Bt cotton in West Africa has been a very controversial issue over the last years. The debate in West Africa has been magnified by conflicting positions for and against taken by some civil society organizations, non-governmental actors, producer organizations and the private sector (including multi-national companies). Some NGOs and producer organizations have campaigned (and continue to do so) against the introduction of Bt cotton and other GM biotechnologies.[2]

Stakeholders opposing the introduction of Bt cotton and other technologies argue that genetic modifications will reduce biodiversity, harm ecosystems in West Africa, negatively affect organic and Fair Trade cotton production systems, and create even more dependency of farmers on productive inputs. In contrast, proponents of Bt cotton argue that it presents economic advantages, reduces dependence on international companies involved in the distribution of pesticide and fertilizer, and has a safe track record under field conditions in several countries. The safety recored has been validated by the accumulated

[2] Examples of the opposition to the introduction of Bt cotton arguments are contained in the publications by the Association des Organisations Paysannes Professionnelles in Mali (AOPP) "Manifeste: le Mali face à la menace des O.G.M." or the publication "GM cotton set to invade West Africa Time to act!" edited by GRAIN, OBEPAB: Organisation Béninoise pour la Promotion (Benin), REDAD: Réseau pour le Développement Durable (Benin), GIPD: Projet de Gestion Intégrée de la Production et des Déprédateurs (Mali) and the PAN Afrique: Pesticides Action Network (Senegal).

experience with previous use of Bt as a foliar insecticide, the environmental and food safety assessments in other countries, and the safe track record of the event used extensively under filed conditions. This technology has been approved for release into the environment by biosafety regulatory systems in countries such as South Africa, Argentina, Mexico, China, USA, Australia, India and others without any major negative biosafety outcomes to date.

The introduction of Bt cotton in West Africa will follow formal biosafety assessments and approval by biosafety regulatory agencies in individual country. West Africa has moved to advance regional efforts towards establishing a coherent biosafety and regulatory framework for biotechnology. However, these efforts have not materialized just yet in the region. In spite of these regional efforts for biosafety regulation, regulatory approval will be given by national governments (as the valid legal competent entity for effects of the Cartagena Protocol and Convention of Biological diversity) unless regional approaches for approval are negotiated within the region.

Other stakeholders involved with the decision making process include West African Governments, public sector institutions, the French government and public sector. The Ministries of Agriculture, Science and Technology, Trade and Finance, and Environment in West African countries may have different decision making approaches to these technologies as their mission, objectives and time frames, are typically different. In some cases, regulatory approaches supported by a specific ministry may be more precautionary, whereas in others technology development and deployment may be vital for some other ministries and public sector organizations.

From the standpoint of the private sector, West Africa may be an attractive market. Table 3 presents gross income estimates of the value of the technology fee under varying adoption assumptions. Assuming a constant 20 percent adoption rate across all countries in the region, the total market value of the Bt technology fee runs from 8.5 to 45 million dollars for fees of $15 and $80 per hectare, respectively. If the area planted to Bt cotton reaches 20 percent in the countries with the highest potential to adopt Bt cotton in the region including Burkina Faso, Benin, Mali, Côte d'Ivoire, and Togo; the total value of the technology fee ranges from 4.6 to 24.5 million dollars annually for these countries. In general, private sector innovators including Monsanto/Delta and Pineland and Syngenta will support bio-innovations within the scope of a business model, whereas NGOs and other Civil Society organizations may oppose the introduction of this technology. One cannot generalize as different.

4. REVIEW OF RESEARCH METHODS

Experiences with Bt Cotton

Bt cotton impact evaluation at the industry level have been more documented in industrialized countries, namely the U.S. Falck-Zepeda et al. (2000a, 2000b) analyzed the case of Bt cotton in the U.S. from 1996-1999 using Alston, Norton and Pardey (1999) approach to economic surplus and Moschini and Lapan (1997) framework to account for temporary monopolies derived from intellectual property. The Falck-Zepeda articles laid out a model that has since provided the foundation for economic surplus applications for the assessment of biotechnologies in developing economies.[3] This model has also served in further analysis of various crops biotechnologies in U.S. agriculture (e.g., Lin, et al. 2004).[4]

Ex-post impact evaluations have been conducted at the farm level in China, South Africa, India, Argentina and Mexico However, there is very limited literature that covers the *ex-post* impact at national (aggregated) level, of Bt cotton in non-industrialized countries For a complete discussion of the studies in these countries please refer to Smale et al. (2006). The number of *ex-ante* evaluation studies is even smaller. The following discussion will center on relevant issues for the study done in West Africa.

Pray et al. (2001) using a single year of data in China found that smallholder farmers gained substantial economic benefits from Bt cotton adoption, Consumers however did not benefit because the government bought almost all of the cotton at a fixed price. Moreover, because of weak intellectual property rights (IPR), farmers obtained the major share of the benefits, with very little accruing to Monsanto or the public research institutions that developed local Bt varieties. (Traxler et al. 2003; Traxler and Godoy-Avila 2004) found that Bt cotton reduced costs and raised revenues for farmers in the Comarca Lagunera in North-Central Mexico using small open economy model. In this area reduced insecticide use benefited producers, consumers and the environment. Over the two years of the study, the authors estimated that seed suppliers and innovators earned 15 percent of the economic benefits from adoption, while farmers earned the major portion of these benefits (85 percent). Consumers did not

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[3] The findings of studies conducted in the U.S. are of interest, though they are not fully reported in the text. Falck-Zepeda et al. found that, over the 3 years studied, farmers and the innovator-seed supplier (Monsanto-Delta and Pineland) shared almost equally in the benefits, despite the temporary monopoly in the seed market. Falck-Zepeda, et al. (2000) explain that the monopolist must provide farmers with an adoption incentive by setting a price that makes the new input more profitable than existing options—a principle that is well established in the economics literature. Consumers gained very little, which is expected to be the case for agronomic traits such as insect-resistance as compared to product quality attributes. Lin, et al. (2004) reported that US farmers captured a much larger share of benefits for Bt cotton than for herbicide-tolerant (HT) soybeans and HT cotton. In the case of HT cotton, U.S. consumers and the rest of the world (ROW) received the bulk of the benefits.

[4] Particularly in industrialized economies where supplementary databases can be consulted, numerous additions to the basic model have been proposed. Examples include adding spatial data on pest and disease incidence (Alston et al. 2002, for rootworm resistant maize in the U.S.), and a bio-economic model with stochastic simulation (Demont and Tollens, 2004). A remaining subset of this literature includes several articles that recommend and/or apply the real options approach to address the issue of irreversibility in costs and benefits of genetically engineered crop varieties.

receive economic benefits since there was no change in price and the region is assumed to be a price taker and thus dependent on the prevailing world price. Traxler et al. (2004) further assert that the risk of crop failure declined with the use of the Bt cotton technology in Comarca Lagunera.

Bt cotton Studies in West Africa

Few GM impact studies have been conducted in West Africa. These few studies have mostly focused on the evaluation of insect resistant cotton. Cabanilla et al. (2004) developed a linear-programming model to assess the potential cost to West Africa (in particular, Mali) of not adopting Bt cotton. The aggregate benefits per year to farmers were estimated at $68 million in Mali, $41 million in Burkina Faso, $53 million in Benin, $39 million in Côte d' Ivoire and $8 million in Senegal. The authors drew parameters from detailed farm-level studies already conducted in Mali, and combined these with published data from studies implemented in China, South Africa and Mexico. On their representative farm, they included groundnut and cereals cultivation to meet subsistence needs. The analysis was used to generate estimates of optimal land area allocations, output, farm profit, and whole farm income. They then aggregated their findings to the national level and conducted sensitivity analyses, introducing the effects of various technology fees. Their results indicate that even with a high technology fee, there are significant economic benefits that would be lost without the adoption of Bt cotton, including more stable farm incomes. Cabanilla et al. (2004) point to important institutional issues, such as whether the technology will be imported, adapted, or generally adopted, as likely to be significant determinants of the extent and social distribution of benefits.

Overall results presented in studies evaluating Bt cotton show the possibility of producer receiving net benefits caused by the use of Bt cotton. Economic surplus and other measurements of economic performance estimated in the literature evaluating Bt cotton vary over time, size and scale of production systems and location. Results of studies presented depend on pest population dynamics, crop management practices, availability of appropriate information to manage the crop, seed costs including the technology fee, and farmer and farm production attributes. In this sense, findings from one country or location are very hard to generalize.

Another important observation is that significant economic and environmental impacts have not been included in the studies done so far. Issues that include the positive or negative effects of reducing pesticide applications to the environment, loss of agricultural and wildlife biodiversity, potential effects on non-target organisms or changes in risk and vulnerability, have not been considered in most studies of Bt and other biotechnologies adoption.

Limitations and Opportunities of the Economic Surplus Approach

The assumptions used to derive standard applications of the economic surplus models, as well as their limitations, are well known (see Appendix B). Economic surplus models best depict an industry with commercially-oriented farmers who buy and sell in well-organized markets and who grow their crops under relatively homogeneous growing conditions. The economic surplus model nonetheless can be used judiciously in a developing country setting given that its limitations are fully understood. In particular it is important to understand that the quality of the underlying data is crucial to the validity of the results. In general, reliable cross-sectional time-series data are not yet available for these technologies in developing economies because they are too costly to collect. In contrast, in the U.S., extensive surveys have been conducted continually (e.g., the USDA Agriculture Resource Management Survey on which many of the detailed analyses are based), and cheaper methods are feasible (mail and phone interviews).

"Pure" ex ante analyses (in the sense that they have no data drawn directly from field observations) are even more limited than ex post analyses. In the case of these analyses, all parameters are projected based on expert interviews and existing secondary data. On the other hand, if carefully crafted and interpreted, ex ante analyses of this type can still provide information that is crucial for national decision-makers in a relative small period of time.

Economic surplus models are used to estimate aggregated outcomes for all producers in the unit of analysis. Although it is feasible to disaggregate producers by size, the economic surplus model is not intended for modeling individual farmer and/or household effects. Two points should be emphasized. First, adaptations to standard models via explicit modifications of the structural equations within the model are feasible to treat some of the methodological challenges described above. To construct the modified economic surplus systems of equations such as the ones derived in Appendix B for adaptation to local conditions, one needs to have a clear understanding of the internal organizational structure within the country. Secondly, this methodology provides the type of information that most national policy makers and investors in technology development consider to be fundamental to the decision-making process.

In order to obtain a significantly better diagnostic of the potential impact from the introduction of Bt cotton in West Africa and elsewhere, several complementary methodologies will need to be implemented in tandem or sequentially through a well thought-out triangulation of approaches and multi-disciplinary processes (Meinzen-Dick, et al. 2004) at farmer, household, industry and trade levels.

5. MODEL SPECIFICATION

We use an economic surplus model[5] augmented with a more rigorous sensitivity analysis of model parameters (Davis and Espinoza 1998; Falck-Zepeda et al. 2000; Zhao et al. 2000; Fisher et al. 2001). The economic surplus model consists of a set of equations that depict the cotton market in an economy. Based on the available data, a set of distributions are posited for the parameters subject to uncertainty, sparse data, or even discrepancies between experts with regard to magnitude or direction of effect. This approach to the economic surplus model addresses some of the data limitations mentioned above.

We used an add-in program for spreadsheets (@Risk™ software). This software allows for the substitution of single point values of model parameters with a probability distribution. The probability distribution may be created entirely by imposing the parameters of a particular distribution (such as the mean and standard deviation for the normal distribution). Alternatively, the @Risk™ program can be used to fit distributions to existing field data. This approach opens the possibility of performing advanced analysis of the risk associated with variation in: supply elasticities, adoption rates, technology transfer fees, per hectare cotton yields, and costs of production.

For this study, we generated sample values by drawing from a triangular distribution of each parameter using the @Risk™ program. The triangular distribution is a continuous probability distribution, described by the minimum, maximum, and mode (or "most likely") parameter values. The triangular distribution is the simplest approximation of a normal distribution that is often used in simulations to model potential outcomes with sparse sample data. The @Risk™ program then proceeds to calculate model results for designated output variables (e.g., producer surplus, consumer surplus, total surplus, net present value, internal rate of return). This step is called an "iteration." After each iteration, the program saves estimated values for each variable and statistics for the iteration. For example, after 10,000 iterations the program would save 10,000 values for each variable, accompanied by statistics such as means, variance, standard deviations, skewness and kurtosis. Convergence of parameter means to a stable state can also be monitored. Convergence to a stable state implies that additional iterations do not markedly change the shape of the sampled distribution. We chose a cut-off point of less than 1.5 percent change between iterations.

We applied this process for 5 scenarios: 1) No adoption of Bt cotton in West Africa (WA), but adoption in rest of the world; 2) WA adopts available private sector Bt cotton varieties; 3) WA uses West African varieties backcrossed with private sector lines; 4) WA uses West African varieties backcrossed with private sector lines, premium is negotiated; 5) WA uses West African varieties backcrossed with

[5] Appendix B describes how standard models are derived

private sector lines but adoption is irregular (For complete discussion of scenarios including assumptions see Tables 4a and 4b[6]). The number of iterations was set to 10,000 for Scenarios 1 - 4 and 25,000 for Scenario 5.

Producer, consumer, innovator and total surplus were estimated on a yearly basis for a total of 24-25 years depending on the scenario. The innovator surplus was defined as the additional benefit appropriated by the institution that delivered the gene and germplasm. We follow the convention of estimating innovator surplus by multiplying the area planted to Bt cotton times the technology fee or premium (Falck-Zepeda et al. 2000). This assumption considers the price of conventional seed as competitive. Thus, the difference between conventional and Bt cotton seed (defined as the technology fee or premium) is the monopoly rent generated by the innovation.[7] Based on the stream of yearly estimates, we calculated the Net Present Value (NPV) and when appropriate, the Internal Rate of Return (IRR) to society.

Assumptions

Our evaluation is based on a number of assumptions mostly based on the available literature on Bt cotton experiences in other countries. In this subsection we explain the assumptions and outline the variations considered in each of the five scenarios (Table 4a and 4b).

Adoption Curve

A critical parameter for simulating an adoption curve is the maximum level of adoption or adoption rate for the technology. Cabanilla et al. (2004) assume maximum Bt cotton adoption rates of 30, 50 and 100 percent in West Africa. In the paper, the authors indicate that due to the severity of the Lepidopteran problem (e.g., Mali); it is feasible that some countries could have adoption rates as high as 100 percent. These authors' estimates are based on adoption patterns in China, South Africa, USA and Australia, as reported by James (2001, 2002). For the purposes of this paper, we choose a constant 20 percent adoption rate in the rest of the world (ROW), that is, for cotton producers outside West Africa. For Scenarios 2 and 3 in West Africa, we used 30 percent as the maximum adoption rate in each adopting country (lower value used by Cabanilla et al. 2004), In Scenario 4 we allowed a larger adoption rate of 50 percent to accommodate a change in adoption induced by a lower Bt seed price. In Scenario 5, we allowed adoption,

[6] We estimated 3 additional scenarios including the possibility of Chinese varieties flowing into West Africa and other scenarios examining differences in technology fees and institutional diffusion patterns. Results of these scenarios will be mentioned briefly in the results section.

[7] Falck Zepeda, Traxler and Nelson (2000a, 2000b) also partitioned innovator surplus between the supplier of the gene and the supplier of the seed by examining licenses and royalties that Monsanto and Deltapine paid to each other. This information was available to the public through the respective companies' financial reports..

dis-adoption and re-adoption for Mali and Benin. This irregular shaped adoption pattern has been documented elsewhere in Africa (Smale et al. 1991; Morris et al. 1999). Scenario 5 is included in order to emphasize the importance of institutional and governance considerations. As documented by Gouse et al. (2005) for Bt cotton in South Africa, countries may find themselves in the position of having Bt cotton becoming a "technological triumph but an institutional failure."

Supply elasticity

The supply elasticity has a critical impact on the level of benefits estimated from an economic surplus model. In the conventional economic surplus approach proposed by Alston, Norton and Pardey (1995), yield increases (horizontal shifts of the supply curve) are converted to equivalent cost changes (vertical shifts of the supply curve) by dividing the percent yield change by the elasticity of supply. Clearly, the difference between an elasticity supply of 1 and 0.1 can be dramatic. In the absence of additional information, Alston, Norton and Pardey suggest using a unitary elasticity of supply, although this is considered to be a weakness of their approach. Other authors have suggested more sophisticated approaches (Oehmke and Crawford 2002; Qaim, et al. 2003, Moschini et al. 2000; Demont 2006; Demont and Tollens 2004). The dissertation by Demont (2006) and related peer-reviewed papers has valuable discussion on the relative merits and values of these approaches. In his conclusions, Demont (2006) suggests that the choice of approach will be dictated by data availability. Given the limited information we have about the supply elasticity of cotton in West Africa, we used an assumed unitary elasticity in this initial estimation as the most likely value. To set the range of the elasticity values, we consulted Minot and Daniels (2005), who employed a lower value of 0.5 and maximum of 1.5, with an intermediate value of 1.0. However, we chose a more conservative minimum value ($\varepsilon = 0.3$).

Yield advantage

The model uses relatively conservative estimates of yield differences between Bt and conventional cotton. These values are drawn from published findings (Falck-Zepeda et al. 2000; Huang et al. 2003 and 2004; Bennett et al. 2004). The mode (or most likely) value used in our estimations was a 20 percent yield difference between Bt and conventional cotton. In turn the maximum value assigned to this variable was 40 percent and the minimum value was 0 percent. The three values that describe the triangular probability distribution represent the range of values in the literature which are based on either experimental results (in the case of ex ante studies) and/or actual farmer data (ex-post studies).

A growing body of literature reminds us that genetic resistance to insects is an input abatement technology (Oude Lansink and Carpentier 2001; Pemsl et al. 2005; Qaim and de Janvry 2005). This implies that yield differences between conventional and Bt technologies are observed only when the target pest attacks the crop. In seasons when there is no pest infestation, any difference between a Bt variety and non-Bt variety would be related to differences in the yield performance of the genotypes rather than the trait.

As a partial solution within the scope of an ex-ante framework to the damage abatement consideration in this study we set the minimum value of the yield difference in the triangular distribution at zero, allowing for the possibility of no yield effect induced by the Bt trait. Whenever the simulation program samples a zero value for yield advantage, it will not have an effect on the displacement parameter of the supply curve ("the K") for that particular simulation. Note that we follow a similar rationale for the cost differences parameter below (i.e. introduce possibility of negative yield difference – conventional yields more than the Bt variety). It is possible that due to the random sampling procedure used in our simulations, a particular iteration may have both yield and cost differences equal to zero, and thus yield a negative outcome as farmers still have to pay the technology fee upfront.

We repeat the calculation of economic surplus for a large number of iterations (10,000-25,000) not only to achieve convergence to stable solutions but also to ensure that we obtain a fairly large number of iterations from which to draw a distribution of outcomes. The decision maker then needs to analyze these results against its risk aversion preferences to make a decision. A much better solution is to have data on the frequency of pest infestation, combined with the severity of the infestations in order to model specifically the damage abatement process and then continue with the risk simulations, but such data are rarely available, particularly at a broad geographical scale.

Cost advantage

The cost advantage is the per unit cost savings from reduced pesticide use. In other words the costs advantage is the net of the technology premium charged for the use of Bt seed as compared to conventional varieties with conventional control. We consulted the literature in order to set the values of the triangular distribution (as shown in Table 4b), emphasizing the lower range of values reported. We set the minimum cost difference at zero. The implication of this assumption is that in a worst case scenario the technology is not successful in controlling target insects and thus does not reduce the need for insecticide applications. Alternatively, the Bt technology might be indeed successful in controlling primary pests, but secondary pest populations could be high enough that control costs would have to increase off-setting benefits from reduced applications to control primary pests. The issues of secondary pest infestations that may become economically significant and other environmental impacts are not explicitly modeled in our study. These are two areas which we will work on in our work in West Africa.

Adaptive research and biosafety regulatory costs:

The process of drafting and finalizing biosafety regulations and implementation of guidelines is on-going in most West African countries. Among both scientists and regulators, there is insufficient clarity concerning the steps needed to assess the biosafety profile of GM biotechnologies. This is less so the case of Bt cotton in West African countries as there are multiple regional efforts to define appropriate biosafety systems in the region[8]. Consequently, obtaining accurate estimates for the cost of compliance with biosafety regulations for the West African region may not yet be feasible. It is important to point out that if such costs of compliance with biosafety regulations were excluded from our simulations, the benefit values generated would represent the present value of *gross* benefits to producers and consumers. In this paper we use estimates from other developing countries such as India and China to obtain preliminary data on the cost of the biosafety assessments. Since there are very few estimates in the literature, we also used estimates reported in conferences and publications for any Bt crop (for example Pray et al. 2005, Quemada 2003; Falck Zepeda and Cohen 2006). For Scenarios 2-4, we considered estimates of the cost of compliance with biosafety regulations and/or adaptive research and development (R&D). These costs may vary significantly between countries.

Technology fee or premium

The technology fee used in our model was based on literature review of fees charged to farmers in other Bt cotton adopting countries. Notice that West African countries are new markets for the innovators. We assumed a distribution with a minimum technology fee of US$15 per hectare, a most likely technology fee of US$ 32 per hectare and a maximum technology fee of US$ 56 per hectare. Furthermore, we arbitrarily reduced the technology fee for minimum, maximum and mode values in Scenario 4 by 40 percent to 9, 19 and 34 dollars per hectare respectively, to reflect the potential of the negotiating power by farmer and marketing associations in West Africa.

Scenarios

We consider five hypothetical scenarios for potential adopting countries in West Africa, which can be influenced through government policies. These scenarios are designed to illustrate how certain factors affect the total benefits generated and the distribution of the benefits. One factor is the time lag associated with research and development (R&D) and biosafety regulatory compliance, which may be concurrent or sequential. Even when there is no time lag for adaptive research, varieties may still enter regular

[8] Jaffe (2006) has a very good review of current biosafety systems in East Africa including a set of descriptors of a functional biosafety system and suggestions for a regional biosafety system framework.

performance trials or Plant Protection Quarantine processes while biosafety information is compiled. In each scenario, the time lag should be understood as the total time required for completing all of these processes when the processes are performed in the adopting country.

A second factor affecting the distribution of benefits is the way the technology diffuses among countries in the region. For all economic surplus scenarios described below, with the exception of the baseline scenario, we assume that Burkina Faso leads in promoting the Bt cotton technology, and is followed later by Benin, Mali, Senegal, and Togo.[9] We needed to assume then that a time lag between the initial adoption in Burkina Faso and the rest of the (potential) adopting countries listed in West Africa. One potential avenue for further analysis is to examine the possibility of reducing this time lag, taking advantage of the biosafety information generated in Burkina Faso.

A third factor is the technology fee that is charged to farmers. Here, technology fees are applied in all scenarios other than the baseline, Scenario 1. This implies that the Bt technology is developed or adapted via joint ventures between the gene and germplasm innovators and West African organizations. The model is constructed in such a way that scenarios can be easily modified. Scenarios are summarized next.

Scenario 1: Baseline

In the baseline scenario, there is no adoption of Bt cotton anywhere in West Africa, but adoption occurs in the Rest of the World (ROW). As a consequence, ROW countries are able to take advantage of the benefits of the technology. This evaluation is done over a period of 23 years. Adoption in ROW induces downward pressures on world cotton prices, benefiting consumers. Producer welfare in the ROW is adversely affected by lower prices, although this effect can be counterbalanced by the cost savings or damage reduction that result from successful use of the technology. Depending on the level of adoption and the relative value of these gains and losses, farmers in the ROW may benefit overall. In contrast, producer welfare in West Africa is negatively affected by the downward pressure on prices. The price effect on producers may be counterbalanced by gains to consumers, so that total surplus may still be positive.

Scenario 2: Direct transfer of existing varieties by gene/germplasm innovator with conventional adoption patterns

In this scenario, Burkina Faso, Benin, Mali, Senegal and Togo pursue the option of direct use of varieties that are available in international markets. While the strategy observed in Burkina Faso and elsewhere has

[9] This is a realistic assumption as there may be significant technology flows to neighboring countries as happened between Argentina and Brazil with herbicide tolerant soybeans (Qaim and de Janvry, 2003).

been to backcross their (private) varieties into local varieties as soon as possible, this scenario is used to showcase the effect of time lags. The research lag is shorter compared to either Scenarios 3 or 4 because existing varieties can be readily deployed in West Africa. This scenario also assumes a technology fee that varies between US$15- US$56 per hectare. Technology fees for Bt cotton have varied significantly across countries. The range reported in the literature has been between US$15 and US$80 per hectare (see Falck-Zepeda et al. 2000a and 2000b; Huang et al. 2003; Bennett et al. 2004; Huang et al. 2004). We use a lower upper bound, which could reflect either a strategy by the innovator to penetrate the West African market or is a consequence of the negotiating power of national stakeholders (i.e. farmer associations).

Scenario 3: West Africa adopts West African varieties backcrossed with private sector lines

Under scenario 3, studied countries use the Bt cotton gene technology after adapting West African varieties to enable gene expression. This condition delays the stream of benefits because of the longer research and biosafety process required. Note that for this scenario the 'most likely' and 'maximum' yield differences have been increased to 25 and 45 percent. This 25 percent increase in yield difference with respect to Scenario 2 values reflects better adapted varieties. This scenario implies then a longer time lag, which is 6 years for Burkina Faso. Other adoption countries adopt the technology 3 years after Burkina Faso, to permit their own regulatory process. In this case, if the data generated in Burkina Faso is accepted by other countries in the region, there may be an opportunity to reduce the overall time lag for adoption. Given the experience of countries that have already adopted Bt cotton, we consider that this to be an optimistically brief time lag. A more realistic time lag could be a decade. In the case of Burkina Faso the decision to explore use of Bt cotton occurred in 2001, and we have timed our simulations to begin on this date.

Scenario 4: West Africa adopts West African varieties backcrossed with private sector lines with reduced premiums compared to Scenario 3

In this scenario, we illustrate the effect of reducing the technology fee in all adopting countries through negotiations between the innovator, farmer unions and marketing associations. We chose an arbitrary 40 percent reduction to showcase the effect of a decrease in the overall level of potential technology fees charged to producers in West Africa. The maximum adoption rate is also increased to 50 percent, to reflect the response of farmers to the lower seed prices that result from a lower technology fee. The rest of the assumptions made in Scenario 3 are held constant.

Scenario 5: Fluctuating adoption in Mali and Benin

We use the example of Benin and Mali to illustrate how abrupt policy or institutional changes can affect the benefits that are generated through fluctuating adoption rates. Mali and Benin, in particular, have advanced in liberalizing and reforming their cotton marketing channel following different approaches (Figures 1, 2, and 3). Diffusion paths, expressed as the percentage of farmers using, or area planted to, the new technology may be irregular (Smale et al. 1991; Morris et al. 1999; Gouse, et al. 2005), although it is common to assume that they are smooth and sigmoid in shape (like an "S"). In general, farmers usually need to adapt new technologies to their own conditions and during this process they may decide to reject the technology. In sub-Saharan Africa and regions with developing economies, external shocks (extreme weather conditions, social and political turmoil) and institutional change also affect the supply and demand for technology.

Results

Scenario 1

When West Africa chooses not to adopt Bt cotton while the ROW does, the ROW (and particularly producers in the ROW) continue to benefit from cost savings and reduced yield damage. In contrast, producers in the West African countries endure the price decreases caused by adoption of Bt in the ROW, without the counterbalancing effect of earning benefits from use of the technology. Column 2 in Tables 5 and 6 presents the mean values of economic surplus from the 10,000 iterations estimated during the simulation of Scenario 1. Values in Table 5 are expressed as current values, whereas those in Table 6 are expressed in present values.

Although not reported in Table 5, producer surplus is negative across all the study countries in West Africa. The total economic surplus in Scenario 1 is also negative for each of the study countries because producer losses are not compensated by consumer gains, because the rate of domestic consumption of cotton in the study countries is relatively low.

The model output (of 10,000 iterations) provides the basis for estimating probability distributions. Examples of probability distributions for total economic surplus and producer and consumer surplus are shown in Figures 4-6 in present value terms.

In Scenario 1, there is a high probability (99.5 percent) that total economic surplus in the study countries in West Africa will be negative, and that producer surplus in Burkina Faso will be negative (92.6 percent). Similar results are obtained with respect to the other countries included in our study. On the other hand, benefits to consumers tend to be positive and even high depending on how much cotton they demand internally. Senegal for instance is a large domestic consumer of cotton (see Figure 6). The expected consumer surplus in Senegal is positive, with a small probability of a negative outcome.

Scenario 2

In this Scenario adopters in West Africa are able to earn benefits from the use of Bt cotton. Producer surplus increases relative to Scenario 1. Total economic surplus, expressed in present values, is also positive. Results of simulations made for Scenario 2 are shown in column 3 of Tables 5 and 6.

Probability distributions of total economic surplus are shown in Figure 7 and Figure 8 for the study countries in the region and Burkina Faso, respectively.

Not surprisingly, the probabilities of negative present values of total economic surplus and producer surplus are much lower than in Scenario 1, and fluctuate between 4 and 8 percent. Similar results are obtained for other adopting countries in the region. Figure 9 shows the probability distribution of consumer surplus in Senegal. Results are as expected.

We see a pattern emerging when we examine Scenarios 1 and 2. Although the numbers in Tables 5 and 6 indicate that economic surpluses are generally positive in scenario 2, they mask significant variability at the individual country level. Figures 4 through 8 (and some figures generated for other countries in the study that are not reproduced here) reveal that the probability that producer surplus is negative (downside risk) varies significantly between countries and scenarios. The simulations suggest, therefore, that Scenario 2 generates considerable financial risk for farmers. These risks may be greater than with the base scenario. It is worthwhile to point out that we have assumed a 100 percent probability of success of the research and biosafety approval processes. Lower probabilities of success, which imply a longer lag period (i.e. for biosafety assessments and adaptive R&D), would augment the financial risk indicated here.

Scenario 3

Scenario 3 introduces the possibility of backcrossing the Bt gene into West African varieties. The immediate consequence of backcrossing is an increase in the time lag relative to Scenario 2 due to additional adaptive research, and possibly, a longer biosafety approval process. Average economic surplus present values for Scenario 3 are shown in column 4 of Tables 6. We observe a slight increase in the overall level of benefits as well as the surplus earned by producers and consumers. The small increment in benefits with respect to Scenario 2 was 3 percent overall and 8 percent for producers in the five study countries of West Africa. In the case of Burkina Faso the increment was higher (10 percent overall and 20 percent for producers). We can interpret these findings in two ways. On one hand, the benefits of having appropriate varieties may compensate for the additional lag needed to develop them.

On the other hand, we can speculate that the benefits from this strategy could be higher if West Africa managed to improve the efficiency of the R&D and biosafety regulatory system, thus reducing the time lag.

Figure 10 presents the probability distribution of total economic surplus for West Africa under the conditions laid out in Scenario 3.

We observe a very small reduction in the probability of obtaining negative outcomes with respect to scenario 2. This observation is supported by Figure 11, showing the probability distribution for producer surplus in Burkina Faso. The probability of obtaining a negative outcome in Burkina Faso is reduced from 8.3 percent in Scenario 2 to 5.8 percent in Scenario 3.

Average benefits to the cotton sector are summarized by sector actor (producer, consumer, and innovator) and country in Table 7. The main conclusion is that there are significant differences among countries in terms of the overall magnitude of economic benefits. Between Scenarios 2 and 3, there is little change in terms of either average numbers or the risk profile for consumers in Senegal (Table 7 and Figure 12).

As this is a very important strategy for study countries in West Africa, we conducted a regression in @Risk to examine the sensitivity of these results to the assumptions that underlay the structural model. Results are shown in Figure 13 for the case of Burkina Faso. Not surprisingly, the levels of expected producer surplus are most heavily influenced in Scenario 3 by yield performance in the rest of the world and by price elasticities, followed by yield performance in Burkina Faso, cost and other parameters of the structural model.[10]

Scenario 4

Average benefits (over 10,000 iterations) are presented in Tables 5, 6, and 8 for Scenario 4. Overall, we observe an increase in the level of benefits earned by consumers and producers in West Africa, while innovators lose benefits.

This pattern results from the lower technology fees paid to the innovators, lower seed prices, and higher adoption levels. The lesson is that negotiating technology fees will have an impact on the overall level of benefits to the cotton sector, and not just to producers and innovators.

[10] An additional step, not presented here, was an advanced sensitivity analysis of the simulation results presented for scenario 3 and 4. In this advanced sensitivity analysis, we allowed positive and negative 10% change for four steps for key parameters. For each one of these steps we generated 10,000 iterations. There were a total of 56 simulations done. In general, results seem to be fairly robust to changes in distribution parameters.

A crucial finding expressed in Figures 14-16 is that the probability of obtaining a negative outcome has declined relative to other scenarios, reducing financial risk to the cotton sectors of study countries.

It is important to remember though that there are many types of risk to which cotton producers and consumers in the region are exposed, which are not considered in this model. These include risks associated with credit and marketing, for which institutional considerations such as the structure of the market channel are foremost. As explained in the methods section, such considerations are difficult to build into a model of this type.

Sensitivity analyses were also performed for this scenario. Figure 17 illustrates for the case of Burkina Faso the sensitivity of expected producer surplus to variation in the parameters of the structural model. Overall, findings are fairly consistent with Scenario 3, lending indirect support to the robustness of the analysis made for the different scenarios in Burkina Faso and West Africa. Results of the sensitivity analysis for consumer surplus in Senegal are shown in Figure 18.

While many factors appear to play a role, variable that have the greatest influence on economic benefits are: 1) yield advantage of Bt cotton in ROW, 2) price elasticity, and 3) cost differentials.

Scenario 5

Irregular adoption rates in Benin and Mali have a negative impact on producer surplus and total economic surplus in West Africa as compared to Scenarios 2, 3, and 4, (Column 6, Table 5). In comparison to Scenario 4 both, a reduction in consumer surplus and a increase in surplus earned by innovators are observed. Average results by country and actor are shown in Table 9.

Examination of the probability distributions of producer surplus confirms that in this model, the risk of negative producer surplus induced by external shocks that affect adoption can be as high as 40 percent in Mali and Benin. The probability of negative producer surplus is lower for Senegal (20 percent), but remains substantial. In the other countries, effects on producer surplus appear to be more of a consequence of time lags assumed in the simulations. In contrast, consumer surplus remains almost unaffected by irregularity of adoption, because consumers benefit from the adoption of Bt cotton in the ROW. Notice that consumers are mostly located in the ROW.

Rates of Return and Distribution of Benefits

Table 10 shows the Internal Rate of Return (IRR) for individual countries for Scenarios 3, 4 and 5. In most cases, although the IRR is higher than interest rates used in our simulations, it is relatively low compared to usual estimates of rates of return to technology adoption. This result is probably due to the conservative estimates employed for yield and cost advantages associated with the technology, combined with the relatively high technology fees assumed. Still, we had sound reasons for caution, given the experiences of other developing countries.   Benefits are partitioned by actors in the cotton sector in Table 11.

Our estimates show that, when the study countries are considered as a group, producers and innovators earn the largest share of the benefits from the adoption of Bt cotton, while consumers benefit little. Similar patterns have been documented in other studies of Bt cotton (Falck-Zepeda et al. 2000). Nonetheless, the situation is not uniform for either the individual countries included in our study, or between scenarios. In Scenario 3, where West African lines are backcrossed with private sector lines, innovators tend to earn a larger share of the predicted surplus than producers. In Scenario 4, with reduced premiums, the opposite is true. Again, we attribute the partitioning of benefits that is evident in Scenario 3 to the fairly conservative assumptions used in our simulations concerning the potential farm-level benefits of Bt cotton in West Africa.

Results from other simulations

We also estimated three additional scenarios. We present some qualitative results to support the conclusions already presented in the scenarios discussed previously. The first alternative scenario is the possibility of licensing Chinese varieties for use in West Africa. The Chinese national system has been working on Bt cotton for several years and has released Bt cotton varieties that could be adapted to West African conditions. This scenario contemplated the possibility of China becoming a major GM technology provider via the licensing of their varieties. The assumptions included a lower technology fee that ranges between US$ 15 and $30 per hectare and a different productivity potential (slightly lower) from that assumed in the direct transfer scenario. The main lesson from this scenario was that reduced technology fees can compensate for lowered productivity from the use of less-than-fully-adapted varieties.

The second and third scenarios were variations of Scenarios 2 and 3, assuming different regulatory lags and the absence of a technology fee due to release by the public sector. The crucial importance of negotiating the technology fee was reinforced in these scenarios. One additional conclusion was that holding other factors constant longer time lags associated with research, development and biosafety regulatory processes have a tendency to decrease net present gains for both producers and innovators.

Result Limitations and Opportunities for Further Research

In the results presented here, there are “winners” and “losers” from the adoption of the technology. All non-adopting farmers in the aggregate are assumed to lose from the use of the technology by adopting farmers. This a result of the decrease in the cotton lint price, keeping everything else constant, induced by the shift of the supply curve. It is worthwhile noting a positive producer surplus estimate really means that in the aggregate adopting farmers gained from using the technology. Individually farmers may still lose from using the technology even if the overall outcome (producer surplus) is positive.

In the economic model used in this paper, a decrease in cotton lint prices translates into a gain for consumers from the introduction of the technology. In some cases however yield and cost advantages may not be sufficiently large to compensate for the technology fee paid by farmers. Note furthermore that in the model, innovators gain if there is adoption by farmers. Our assumption of the technology fee being a proxy for the temporary monopolistic rents obtained by the innovator results then in gross margins. We have not adjusted these rents to account for costs of introducing the technology nor compliance with the biosafety regulation and legal fees in a particular country.

It is important to point out that the possibility that other minor pests may become economically important is high. This is especially relevant considering that the range of pests controlled by the Bt protein is limited to Lepidopteran insects. Often broad-spectrum insecticides are used to controls Lepidopteran insects. If these major pests are reduced then the use of broad spectrum insecticide would as well reduce and thus the population of minor pest would increase. This fact points to the need of using locally adapted varieties to insert the Bt gene. These varieties will have broader resistance to other pests and diseases endemic to the region. Incorporating these concepts into the estimation spreadsheet and model used in this study poses some challenges. The first is the paucity of methodological approaches to measure input abatement effects *ex ante*. The second, and most important, limitation is the need for production data that carefully compares Bt and conventional technologies, such as those based on comparison of an isogenic line with its GM counterpart, and careful productivity studies that seek to understand Bt and conventional technologies produced with and without binding constraints. This implies carefully measuring actual and potential yields estimates for Bt and conventional technologies in situ, identifying binding constraints to yield and characterizing cost comparisons between technologies.

6. CONSIDERATIONS FOR ECONOMICS RESEARCH IN WEST AFRICA

In this study we have estimated the potential impact of the deployment of insect resistant cotton in selected countries in West Africa using different scenarios. We have used the best available methodological approaches in order to overcome some of the limitations of the economic surplus model. The common approach was expanded in order to consider the effects of risk and the variability of outcomes and uncertainty on the values of key parameters due to data sparseness. The goal was to further develop the economic surplus model as part of a suite of proposed methodological elements that can be implemented with West African scientists and stakeholders in their countries. These methodologies can provide additional data and analysis to elucidate the relationship between innovation, technology progress and adoption and poverty issues in West Africa. In particular, the tools proposed here can help decision makers define their policy options and choose best development strategies for the cotton sector.

A range of potential issues may ultimately determine the level and distribution of economic benefits in those countries adopting (or not) Bt cotton in West Africa. On one hand, under the assumptions of the model, all countries included in the evaluation, except the ROW, are worse off by not adopting Bt cotton. On the other hand, the net benefits of adopting Bt for some scenarios seem to be small even after including the innovator surplus. The conservative assumptions used in our model and the downward effect on prices caused by adoption rates coupled with the high number of hectares planted in the rest of the world may account for these results.

Preliminary findings appear to reinforce the perceived need for decision-makers in West Africa to re-examine whether or not the technology needs to be adapted if only to "catch-up" technologically with other major cotton-producers of the world. The downward pressure on global prices of high adoption rates in the ROW creates a distinct possibility that West African countries will have to adopt the technology just to be able to compete in a global market. Thus, the issue of how and where to set the price (and particularly setting the level of technology premium for using the technology, as shown in Scenario 4) becomes crucial to the appropriate deployment of the technology. This fact cannot be overstated.

Burkina Faso seems to be the country closest to adopting Bt cotton in West Africa, having taken the lead in conducting confined field trials of Bt cotton which have been conducted already in 2004 and 2005. Because of this fact, Burkina Faso was assigned a leading (first mover) role in our simulations. A leader role translated into a greater potential to capture higher levels of producer surplus. In contrast, gains in consumer surplus are low because West Africa is largely a net exporter with low rates of internal consumption. The largest rate of consumption in-country is in Senegal (13 percent of the total produced), but in absolute numbers, the highest consumption of locally- produced cotton is in Benin, which benefits with the highest consumer surpluses in each of the scenarios.

Across all studies discussed around the world, a significant share of the expected economic benefits from the adoption of the technology is earned by producers. According to our simulation, however, this finding does not hold for the study countries of West Africa. Here, a larger share of the benefits often accrues to the innovator. We hypothesize that this result may also be a consequence of the conservative assumptions used in the model. Thus, this finding emphasizes the need for West African stakeholders to focus on the technology price-setting mechanism, and to consider the full range of technology transfer options.

Scenario 5 (irregular adoption) serves to illustrate the point that policy-makers need to begin to address the technical, biophysical and institutional issues that could cause fluctuating rates of adoption before -rather than after- the release of Bt cotton. In this scenario, potential producer benefits are lost during the period of dis-adoption. This affects not only total benefits but also the distribution of benefits, shifting a larger share to the innovator. The adoption pattern and the length of the adoption period both affect the share of benefits earned by producers as compared to innovators. A longer adoption period would probably translate into larger shares of benefits transmitted to producers. This result illustrates the importance of decision makers in West Africa addressing the stability of cotton market channels during the process of reform in the region. The results as well take into consideration the effect that ongoing reforms may have on the strength of seed demand and the vulnerability of farmers to fluctuations in seed and product prices and farm income.

An overarching concern was to identify the factors and determinants of benefits created by the potential use of Bt cotton technologies in West Africa at different levels. The objective was to support regulators, decision makers and national governments in identifying strategies and options and systematically assessing the Bt cotton innovation. This paper supports those efforts by providing a set of tools to do such work in a specific country at a finer degree of detail.

Do farmers in West Africa potentially gain from the introduction of the Bt cotton technology? Taking into consideration the limitation of this study and the caveats described in the paper of not including important environmental and economic effects in our calculation, there does appear to be real potential for some farmers to gain from the technology. The share of farmers that stand to gain from the introduction of Bt cotton technology will be largely influenced by whether or not national governments and technology innovator support appropriate incentives and address institutional and socio-economic issues that may limit benefits to be captured by poor smallholder farmers in West Africa. Therefore, knowledge and knowledge flows to and from farmers will play a critical role in the proper deployment of the technology.

TABLES AND FIGURES

Table 1. Basic cotton production data by country for West Africa

Global rank area	Country	Number of cotton farms (1000)	Cotton share of GDP (%)	Average value of exports (2000-2002, Million US$)	Cotton share of country's share of total exports	Cotton share of country's total agricultural exports	Average area planted to cotton 2000-2004 (000 ha)	Average cotton production 2000-2004 (000 tons)
14	Benin	-	8.8	128.0	37.6%	72.6%	369.9	412.7
11	Burkina Faso	250	6.9	68.0	51.4%	70.6%	395.4	414.4
26	Cameroon	200	1.3	93.5	5.4%	19.6%	205.7	202.3
17	Côte d'Ivoire	150	1.7	151.4	3.4%	6.0%	303.8	328.2
75	Gambia	-	-	0.1	1.3%	1.6%	1	0.4
48	Ghana	-	-	4.9	0.2%	0.5%	29.7	20.7
44	Guinea	-	-	2.0	0.3%	7.4%	41.9	50.3
65	Guinea-Bissau	-	-	2.5	4.4%	3.7%	3.5	4.4
10	Mali	400	5	172.4	25%	62.1%	459.8	497.8
67	Niger	-	-	-	0.2%	0.6%	2.8	10
8	Nigeria	-	-	13.3	0.2%	7.9%	582.2	400.8
47	Senegal	-	-	10.8	2.0%	8.6%	36.3	40.8
19	Chad	-	5.1	-	36.2%	58.7%	283.5	184.0
30	Togo	200	-	35.6	11.1%	41.1%	167.3	57.5
TOTAL				745.4	-	-	2900.3	2783.2

Source: FAOSTAT 2000-2004; WDI World Bank 2004; Coton et Development (1999)

Table 2. Lepidopteran cotton pests in West Africa

Country	Cotton Bollworm *(Helicoverpa armigera)*	Pink Bollworm *(Pectinophora gossypiela)*	Tobacco budworm *(Heliothis virescens)*	Other bollworm *(Earias spp Diparopsis spp)*	Armyworms *(Spodoptera spp)*	# Insect. sprays
Nigeria	X	X		X		3-4
Mali	X			X	X	5
Burkina Faso	X	X		X		7-8
Benin	X	X				6
Côte d'Ivoire	X	X		X		6
Chad	X			X		5
Cameroon	X	X	X	X		5

Source: Oerke, et al. 2004; Compiled by Patricia Zambrano.

Table 3. Annual gross income to gene/germplasm innovator from charging a per hectare technology fee assuming 100%, 60% and 20% adoption levels in West Africa

Country	Income from technology fee with 100% adoption		Income from technology fee with 60% adoption		Income from technology fee with 20% adoption	
	Tech fee= 15 ($/ha)	Tech fee= 80 ($/ha)	Tech fee= 15 ($/ha)	Tech fee= 80 ($/ha)	Tech fee= 15 ($/ha)	Tech fee= 80 ($/ha)
Benin	5,447,605	29,053,893	3,268,563	17,432,336	1,089,521	5,810,779
Burkina Faso	4,834,145	25,782,107	2,900,487	15,469,264	966,829	5,156,421
Cameroon	3,042,790	16,228,213	1,825,674	9,736,928	608,558	3,245,643
C. African Rep.	500,930	2,671,627	300,558	1,602,976	100,186	534,325
Chad	4,386,765	23,396,080	2,632,059	14,037,648	877,353	4,679,216
Congo, D.R.	1,040,000	5,546,667	624,000	3,328,000	208,000	1,109,333
Côte d'Ivoire	4,473,955	23,861,093	2,684,373	14,316,656	894,791	4,772,219
Gambia	10,920	58,240	6,552	34,944	2,184	11,648
Ghana	521,000	2,778,667	312,600	1,667,200	104,200	55,733
Guinea	697,500	3,720,000	418,500	2,232,000	139,500	744,000
Guinea-Bissau	51,500	274,667	30,900	164,800	10,300	54,933
Mali	6,045,665	32,243,547	3,627,399	19,346,128	1,209,133	6,448,709
Mauritania	40,000	213,333	24,000	128,000	8,000	42,667
Nigeria	8,455,000	45,093,333	5,073,000	27,056,000	1,691,000	9,018,667
Senegal	446,220	2,379,840	267,732	1,427,904	89,244	475,968
Togo	2,256,705	12,035,760	1,354,023	7,221,456	451,341	2,407,152
Total	42,250,715	225,337,147	25,350,435	135,202,320	8,450,155	45,067,493

Table 4a. Assumptions used in the estimation of economic surplus model for the adoption of Bt cotton in West Africa

Assumptions	Scenario 1 No adoption in West Africa-adoption rest of the world	Scenario 2 WA adopts available private sector varieties	Scenario 3 WA uses West African varieties backcrossed with private sector lines	Scenario 4 WA uses West African varieties backcrossed with private sector lines plus and negotiated premium	Scenario 5 WA uses West African varieties backcrossed with private sector lines and irregular adoption	Source(s) of assumptions
Maximum adoption rates (%)	0% in WA 20% in ROW	30% in WA 20% ROW	30% in WA 20% ROW	50% in WA 20% ROW	Fluctuating adoption in Benin and Mali, 30% in rest of WA, 20% ROW	Based on Cabanilla, et al. 2004. For fluctuating adoption patterns see Figure 3.
Total R&D & Biosafety lag (years)	0	5	6 Burkina Faso, 9 other WA countries	6 Burkina Faso, 9 other WA countries	6 Burkina Faso, 9 other WA countries	Own (subjective) assumption
Adoption lag (years)	0	5	5 Burkina Faso, and other WA countries	5 Burkina Faso, and other WA countries	5 Burkina Faso, and other WA countries	Own (subjective) Assumptions
Year at maximum adoption level	7	7	7	7	7	Own (subjective) Assumptions
Years to dis-adopt	0	5	5	5	5	Own (subjective) assumptions
Total years simulation	23	23	24	24	24	Sum of all components of adoption pattern

Notes: WA = West Africa, ROW=Rest of the World.

Table 4b. Continued

Assumptions	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Source(s) of assumptions
Technology fee (US$/ha)	Triangular (15, 32, 56) for ROW	Triangular (15, 32, 56) for WA and ROW	Triangular (15, 32, 56) for WA and ROW	Triangular (9,19,34) for WA and (15, 32, 56) for ROW	Triangular (15, 32, 56) for WA and ROW	Falck-Zepeda et al. 2000; Huang et al. 2003; Bennett et al. 2004; Huang et al. 2004
Supply elasticity (Units)		Triangular (0.3,1,1.5)	Triangular (0.3,1,1.5)	Triangular (0.3,1,1.5)	Triangular (0.3,1,1.5)	Minot and Daniels 2005; Dercon 1993, Delgado and Minot 2000, Alston, Norton and Pardey 1995
Yield advantage of Bt over conventional varieties (%)	Triangular (0, 0.2, 0.4) for ROW only	Triangular (0., 0.2, 0.4) for WA and ROW	Triangular (0,0.25,0.45) for Burkina Faso and WA for ROW(0., 0.2, 0.4)	Triangular (0,0.25,0.45) for Burkina Faso and WA for ROW (0., 0.2, 0.4)	Triangular (0,0.25,0.45) for Burkina Faso and WA (0., 0.2, 0.4) for ROW	Falck-Zepeda et al. 2000; Huang et al. 2003; Bennett et al. 2004; Huang et al. 2004
Cost advantage of Bt over conventional varieties (%, net of technology fee)	Triangular (0, 0.06, 0.12) equivalent to a reduction of 0, 7, 14 applications for ROW only	Triangular (0, 0.06, 0.12) for ROW and (0, 0.13, 0.26) for WA equivalent to a reduction of 0, 7, 14 applications	Triangular (0, 0.06, 0.12) for ROW and (0, 0.13, 0.26) for WA equivalent to a reduction of 0, 7, 14 applications	Triangular (0, 0.06, 0.12) for ROW and (0, 0.13, 0.26) for WA equivalent to a reduction of 0, 7, 14 applications	Triangular (0, 0.06, 0.12) for ROW and (0, 0.13, 0.26) for WA equivalent to a reduction of 0, 7, 14 applications	Cabanilla et al. 2004; Bennett et al. *2004*; Huang et al. 2004

Table 4b. Continued

Adaptive R&D / Biosafety regulatory costs (US$ total)	0	$120,000 distributed over 4 years in BF, $90,000 distributed over 3 years rest adopting countries ion WA	$120,000 distributed over 4 years in BF, $90,000 distributed over 3 years rest adopting countries ion WA	$120,000 distributed over 4 years in BF, $90,000 distributed over 3 years rest adopting countries ion WA	$120,000 distributed over 4 years in BF, $90,000 distributed over 3 years rest adopting countries ion WA	Pray et al. 2005, Quemada 2003 and Falck Zepeda and Cohen 2006

Note: The Triangular probability distributions used in the simulations are fully described by minimum, mode and maximum values. In the table above values for these three parameters are included in parentheses in each cell of this table, when appropriate.

Table 5. Level and distribution of economic surplus in West Africa and Burkina Faso by scenario (Millions US$)

	Scenario 1 No adoption in West Africa-adoption rest of the world	Scenario 2 WA adopts available private sector varieties	Scenario 3 WA adopts West African varieties backcrossed with private sector lines	Scenario 4 Scenario 3 with reduced technology premiums negotiated by farmers associations	Scenario 5 Scenario 3 with irregular adoption patters in Benin and Mali
West Africa					
Producers	-77.6	190.5	199.7	208.3	145.9
Consumers	1.4	1.5	1.56	1.7	1.5
Innovators	0	219.3	219.3	131.5	188.7
Total surplus	-76.2	410.9	420.1	341.1	335.7
Burkina Faso					
Producers	-19.3	47.4	56.7	58.6	51.2
Consumers	0.4	0.4	0.4	0.4	0.4
Innovator	0	54.9	54.9	32.9	54.9
Total Surplus	-19.0	102.6	111.9	91.9	106.5

Note: Data presented here are actual current values. Note that the values for producer, consumer and innovator surplus do not add to the value for total surplus shown in the table. Value for all the components of surplus presented in each cell of this table are the average of the 10,000-25 000 iterations for each scenario.

Table 6. Level and distribution of the present value of economic surplus in West Africa and Burkina Faso by Scenario (Millions US$)

	Scenario 1 No adoption in West Africa- Adoption rest of the world	Scenario 2 WA adopts available private sector Varieties	Scenario 3 WA adopts West African varieties Backcrossed with private sector lines	Scenario 4 Scenario 3 with reduced technology Premiums negotiated by farmers associations	Scenario 5 Scenario 3 with irregular adoption patters in Benin and Mali
West Africa					
Producers	-28.1	30.4	32.9	33.6	20
Consumers	0.5	0.5	0.6	0.6	0.5
Innovators	0	47.9	48.	28.8	37
Total Surplus	-27.7	78.7	81.1	62.8	58
Burkina Faso					
Producers	-7.0	10.9	13.4	13.8	13.5
Consumers	0.1	0.1	0.1	0.1	0.1
Innovators	0	14.8	14.7	8.9	14.7
Total Surplus	-6.9	25.7	28.3	22.7	28.3

Note: Data presented here are expressed in present values. Note that the values for producer, consumer and innovator surplus do not add to the value for total surplus shown in the table as the values presented in each cell of this table are the average of the 10,000-25,000 iterations for each scenario.

Table 7. Average present values of economic benefits to the cotton sector, by sector actor and country, Scenario 3 (Values in US$)

Country	Producer Surplus	Innovator Surplus	Consumer Surplus	Total Surplus Without Innovator	Total Surplus
Benin	7,397,656	11,381,600	203,629	18,931,930	7,550,328
Bf	13,452,700	14,778,650	139,729	28,303,260	13,524,610
Mali	8,416,729	15,339,090	102,146	23,811,640	8,472,551
Senegal	553,824	1,305,254	91,535	1,904,289	599,035
Togo	3,045,468	5,172,745	20,321	8,192,210	3,019,465
Row	4,073,093,000	2,794,727,000	1,477,385,000	8,345,204,000	5,550,478,000

Note*:* The values for producer, consumer and innovators surplus do not add to the value for total surplus and total surplus without innovator shown in the table. Value for all the components of surplus presented in each cell of this table are the average of the 10,000-25,000 iterations for each scenario.

Table 8. Average present values of economic benefits to the cotton sector, by sector actor and country, Scenario 4 (Values in US$)

Country	Producer Surplus	Innovator Surplus	Consumer Surplus	Total Surplus Without Innovator	Total Surplus
Benin	7,579,815	6,828,961	223,300	14,581,120	7,752,158
Bf	13,789,120	8,867,198	153,230	22,747,890	13,880,690
Mali	8,525,793	9,203,451	112,017	17,794,940	8,591,486
Senegal	560,684	783,151	100,379	1,397,890	614,739
Togo	3,167,267	3,103,650	22,284	6,246,877	3,143,227
Row	4,441,543,000	2,794,728,000	1,619,545,000	8,855,815,000	6,061,088,000

Note*:* The values for producer, consumer and innovators surplus do not add to the value for total surplus and total surplus without innovator shown in the table. Value for all the components of surplus presented in each cell of this table are the average of the 10,000-25,000 iterations for each scenario.

Table 9. Average present values of economic benefits to the cotton sector, by sector actor and country, Scenario 5 (Values in US$)

Country	Producer Surplus	Innovator Surplus	Consumer Surplus	Total Surplus Without Innovator	Total Surplus
Benin	2,307,335	7,415,446	202,151	9,873,975	2,458,529
Bf	13,499,500	14,778,660	138,715	28,349,060	13,570,390
Mali	848,027	9,085,328	101,405	9,988,436	903,108
Senegal	557,971	1,305,253	90,870	1,907,769	602,517
Togo	3,065,317	5,172,746	20,174	8,211,913	3,039,167
Total For 5 Wa Countries	20,278,150	37,757,433	553,314	58,331,153	20,573,710
Row	4,078,755,000	2,794,726,000	1,465,509,000	8,338,990,000	5,544,264,000

Note: The values for producer, consumer and innovators surplus do not add to the value for total surplus and total surplus without innovator shown in the table. Value for all the components of surplus presented in each cell of this table are the average of the 10,000-25,000 iterations for each scenario.

Table 10. Internal rate of return (IRR) Scenarios 3, 4 and 5 (%)

Country	Scenario 3		Scenario 4		Scenario 5	
	Ts	Tsi	Ts	Tsi	Ts	Tsi
Benin	28	21	25	20	14	20
Burkina Faso	44	32	38	31	32	44
Mali	27	19	24	18	12	18
Senegal	29	19	25	19	19	29
Togo	28	20	24	19	20	28

Note: 1) TS = Total Surplus without innovator surplus, TSi= Total Surplus including innovator surplus. 2) Shares have been rounded to next whole number.

Table 11. Percent (%) share of benefits to sector actors, by country, Scenarios 3, 4 and 5

Country	Scenario 3			Scenario 4			Scenario 5		
	Ps	Is	Cs	Ps	Is	Cs	Ps	Is	Cs
Benin	39	60	1	52	47	1	23	75	2
Burkina Faso	47	52	<1	60	39	<1	48	52	<1
Mali	35	64	<1	48	52	<1	8	91	1
Senegal	28	67	5	39	54	7	29	68	5
Togo	37	63	<1	50	49	<1	37	63	<1
5 Countries Wa	40	59	<1	53	46	1.0	35	65	<1

Note: Shares have been rounded to next whole number.

Figure 1. Historical cotton performance - Mali

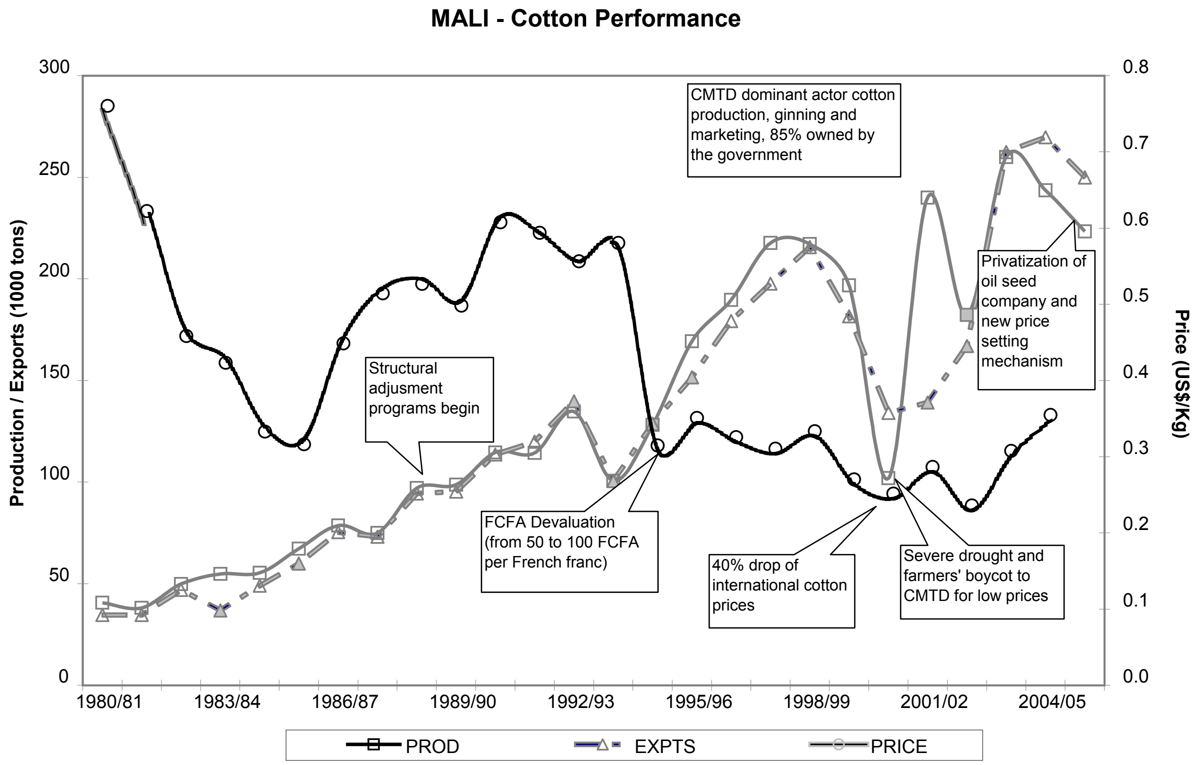


Figure 2. Historical cotton performance - Benin

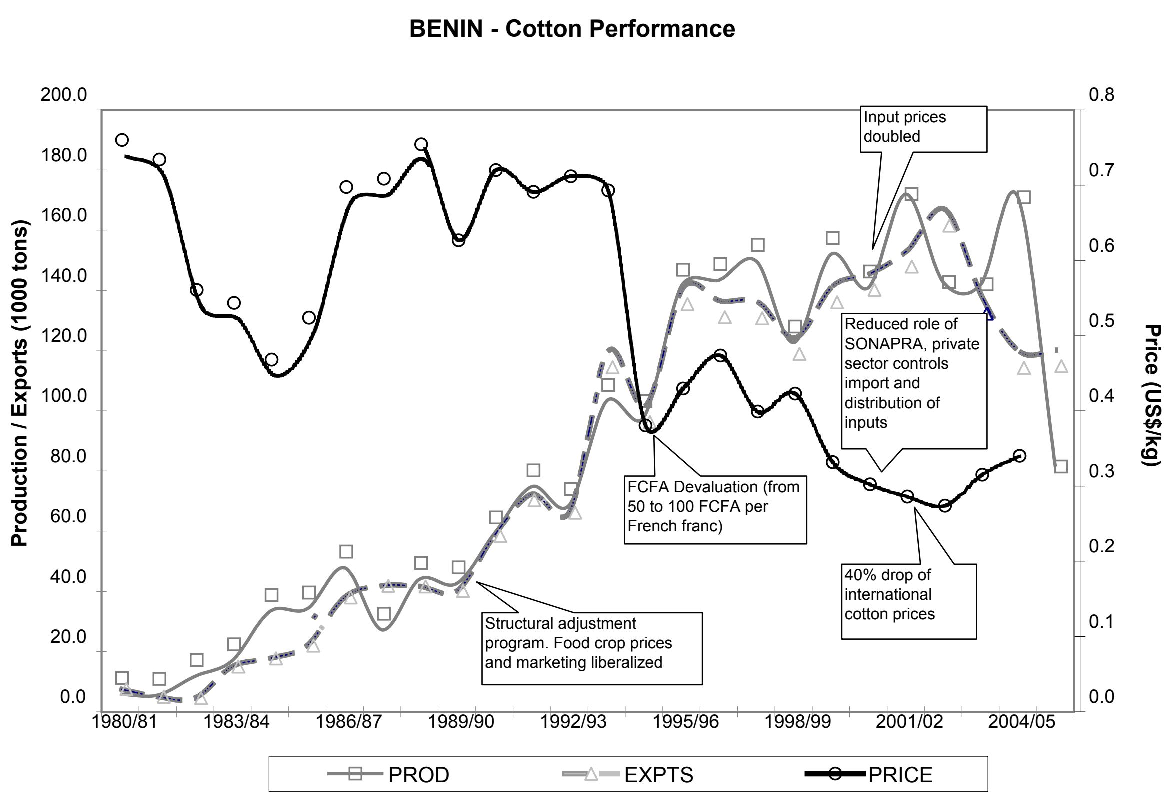


Figure 3. Stylized fluctuating adoption path due to endogenous characteristics and exogenous shocks in Benin and Mali

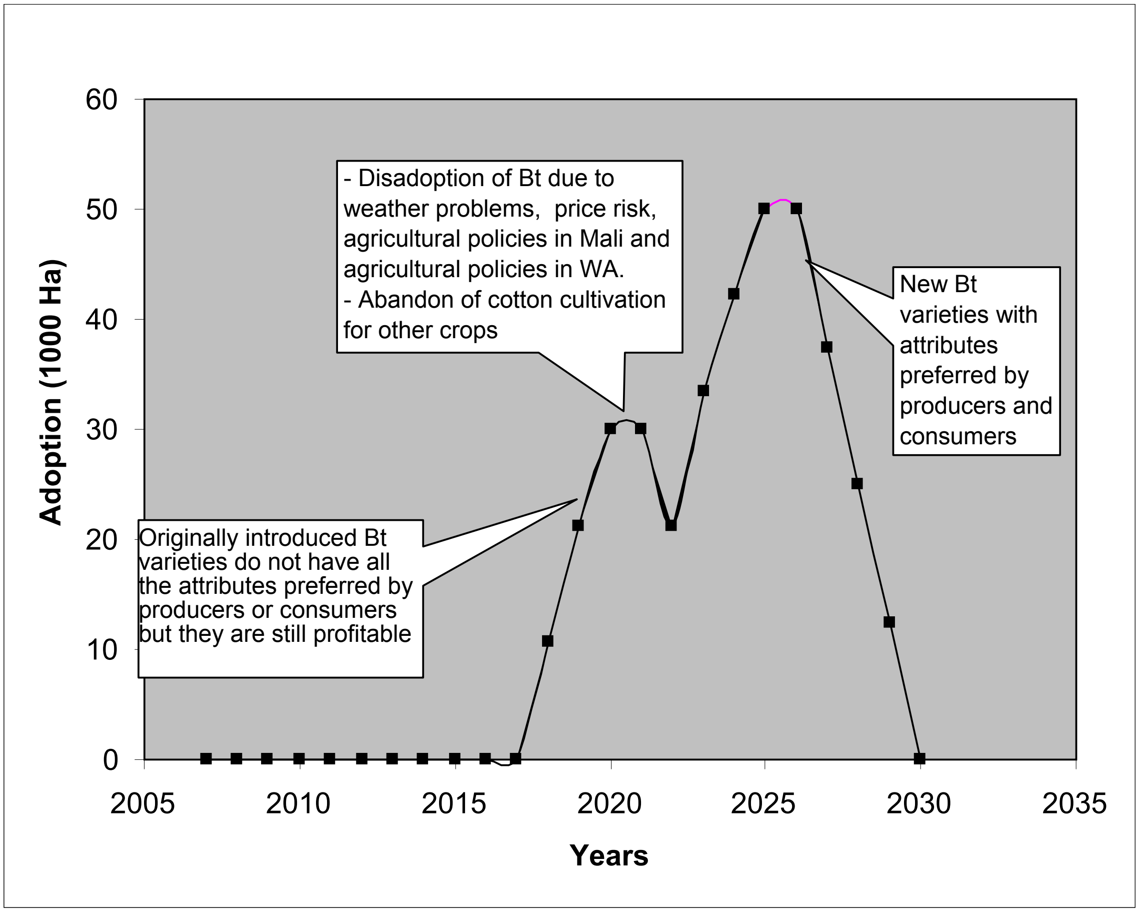


Figure 4. Distribution of present value of total surplus, Scenario 1, West Africa

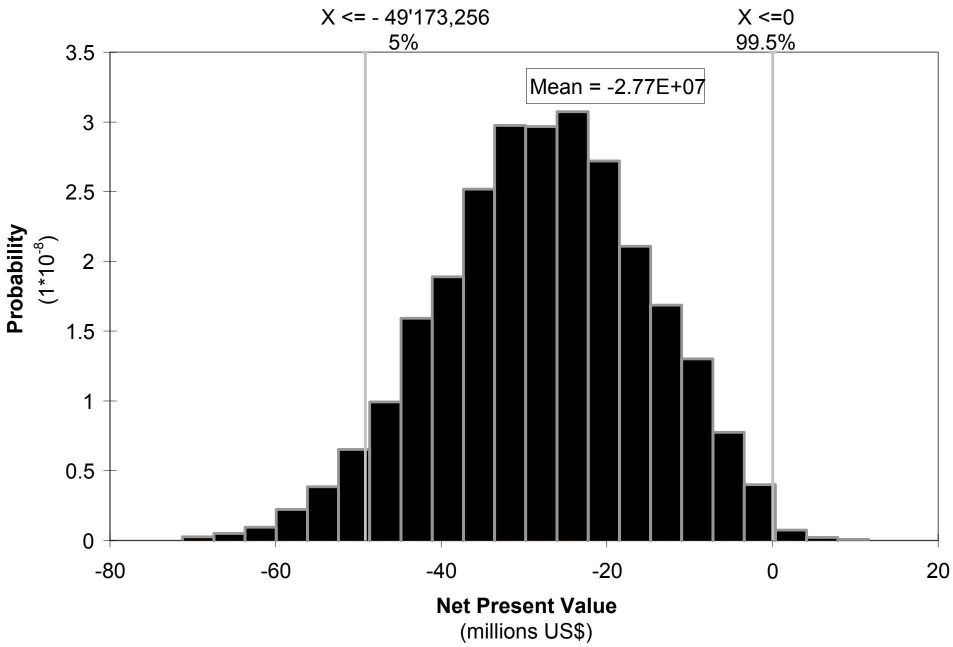


Figure 5. Distribution of present value of producer surplus, Scenario 1, Burkina Faso

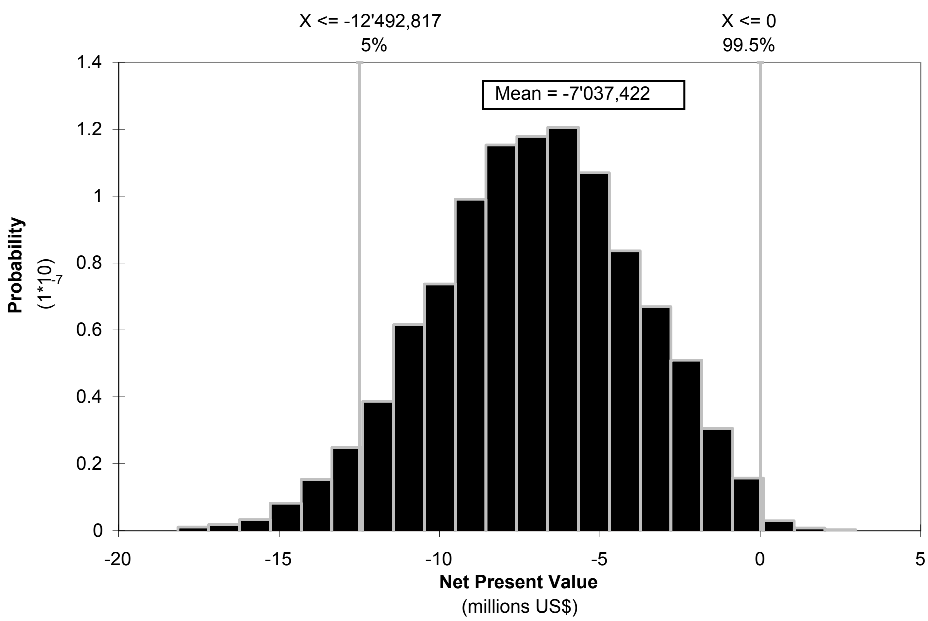


Figure 6. Distribution of present value of consumer surplus, Scenario 1, Senegal

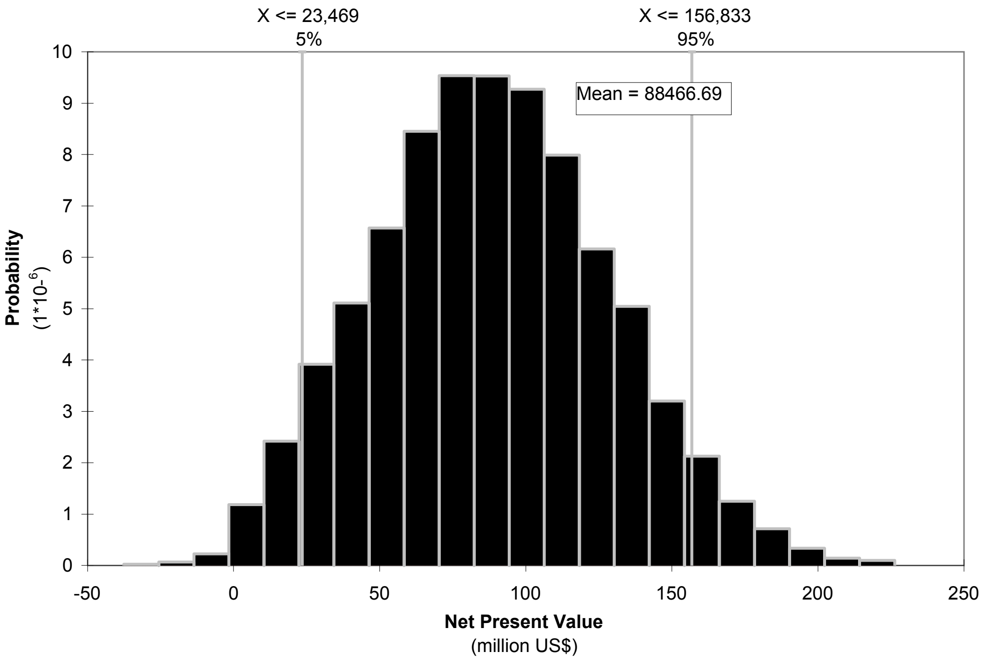


Figure 7. Distribution of present value of total surplus, Scenario 2, West Africa

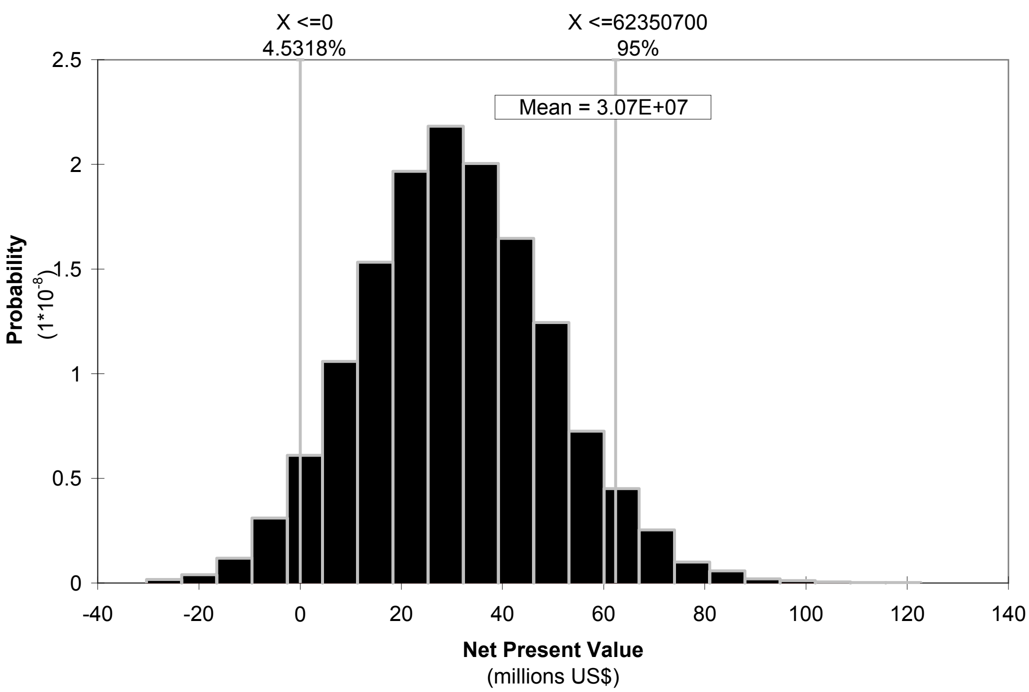


Figure 8. Distribution of present value of producer surplus, Scenario 2, Burkina Faso

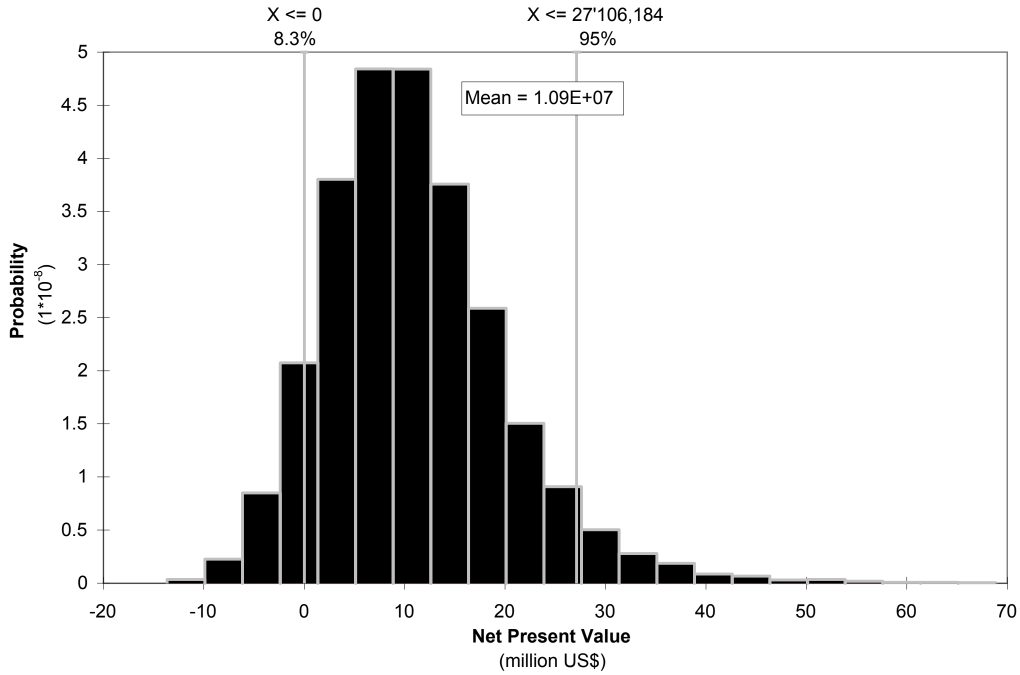


Figure 9. Distribution of present value of consumer surplus, Scenario 2, Senegal

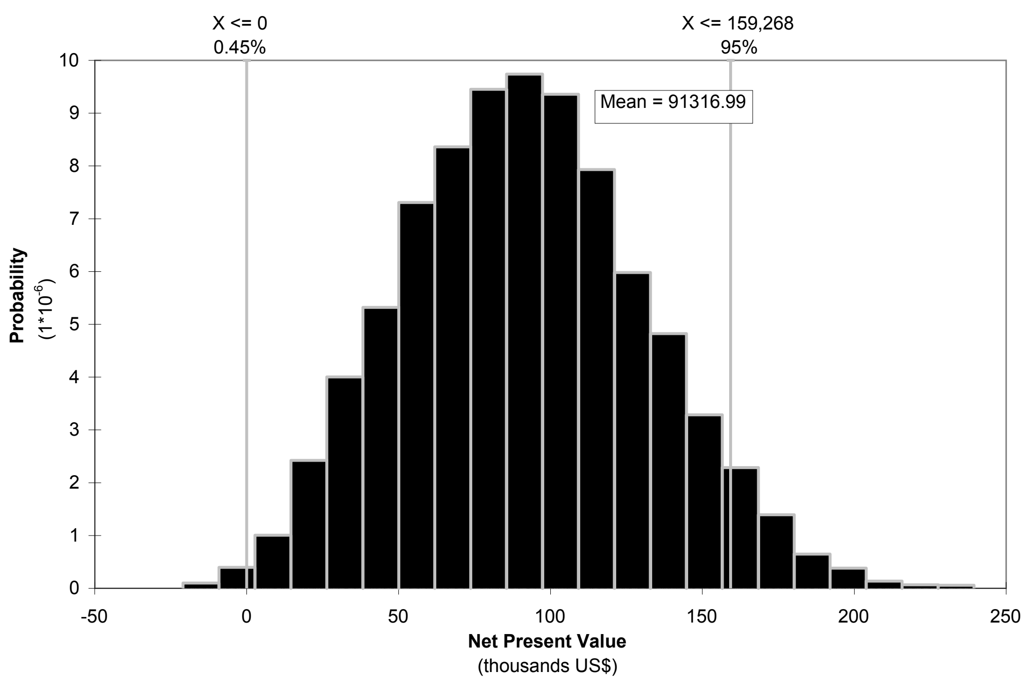


Figure 10. Distribution of present value of total surplus, Scenario 3, West Africa

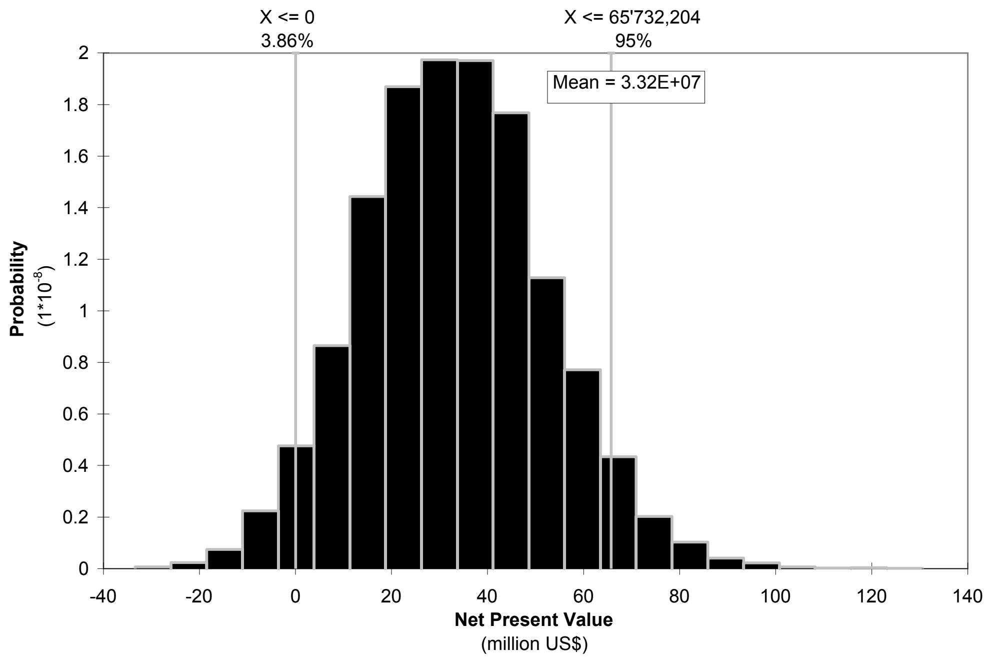


Figure 11. Distribution of present value of producer surplus, Scenario 3, Burkina Faso

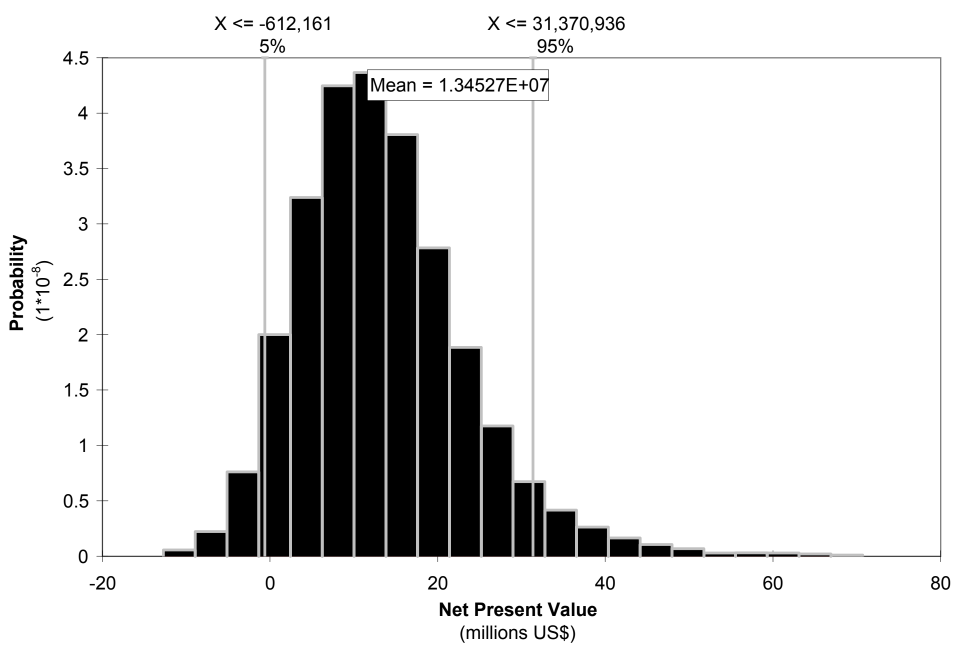


Figure 12. Distribution of present value of consumer surplus, Scenario 3, Senegal

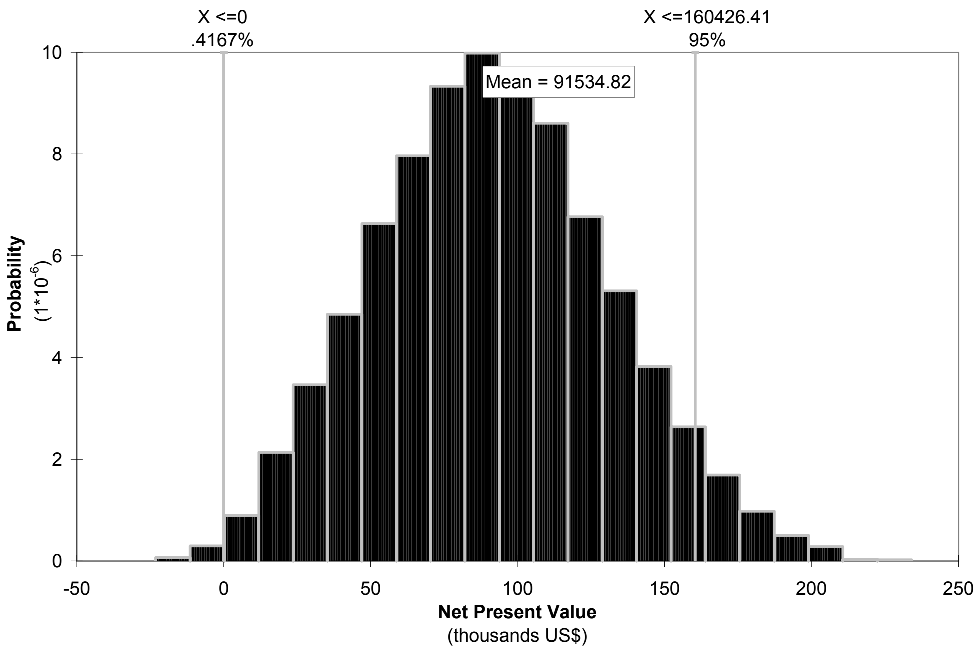


Figure 13. Sensitivity of the distribution of producer surplus, in present value, Scenario 3, Burkina Faso

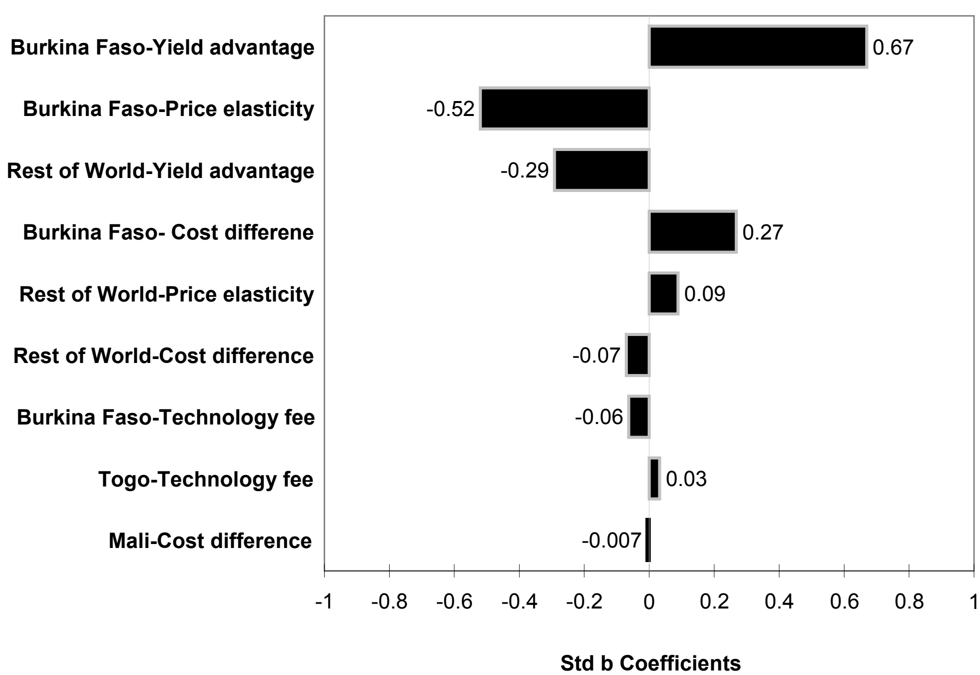


Figure 14. Distribution of total surplus in present value, Scenario 4, West Africa

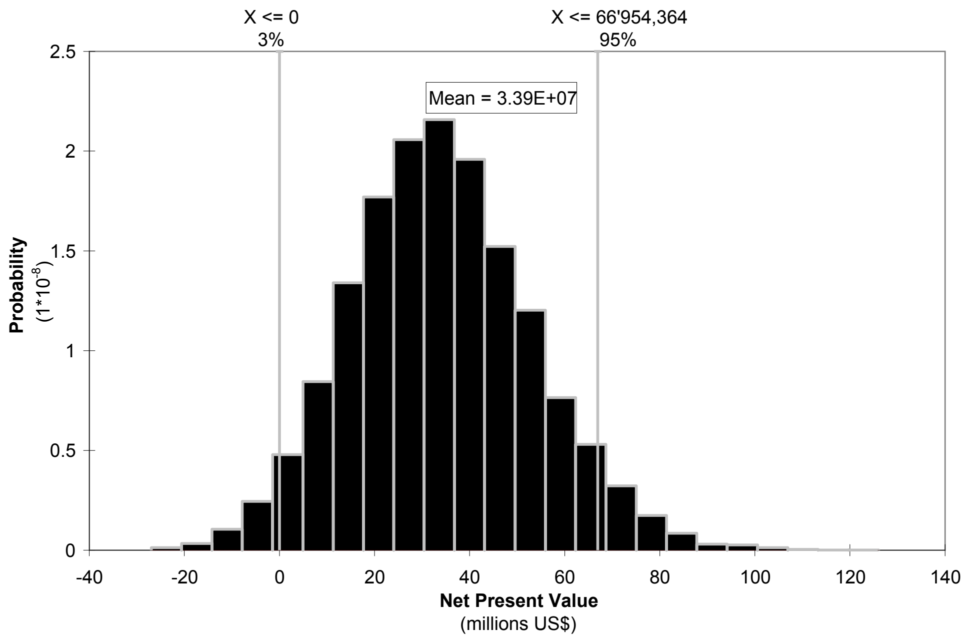


Figure 15. Distribution of producer surplus in present value, including innovators, Scenario 4, Burkina Faso

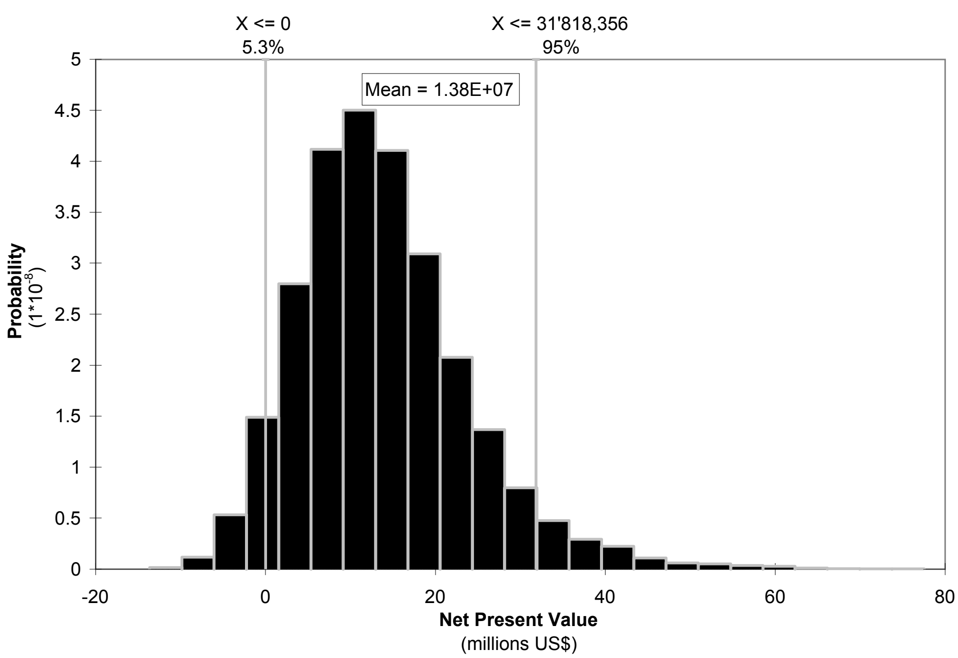


Figure 16. Distribution of consumer surplus in present value, including innovators, Scenario 4, Senegal

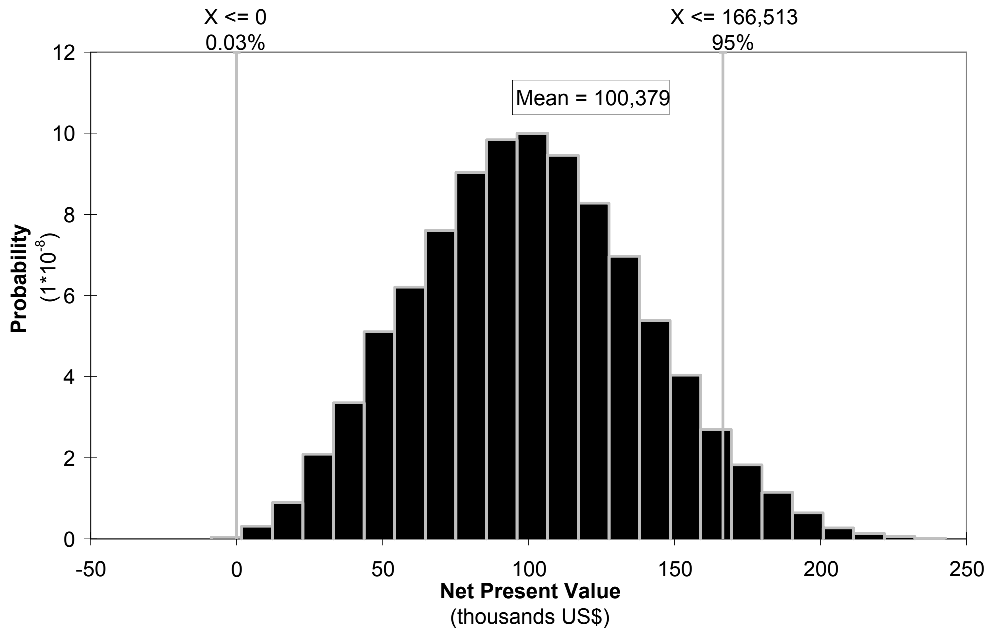


Figure 17. Sensitivity of the distribution of producer surplus, in present value, Scenario 4, Burkina Faso

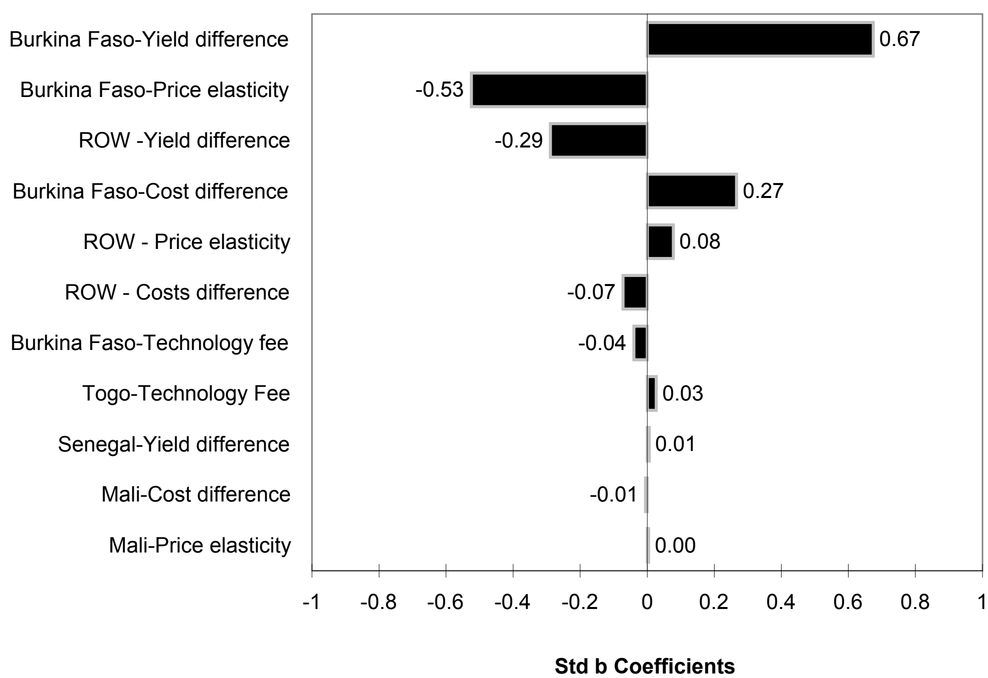
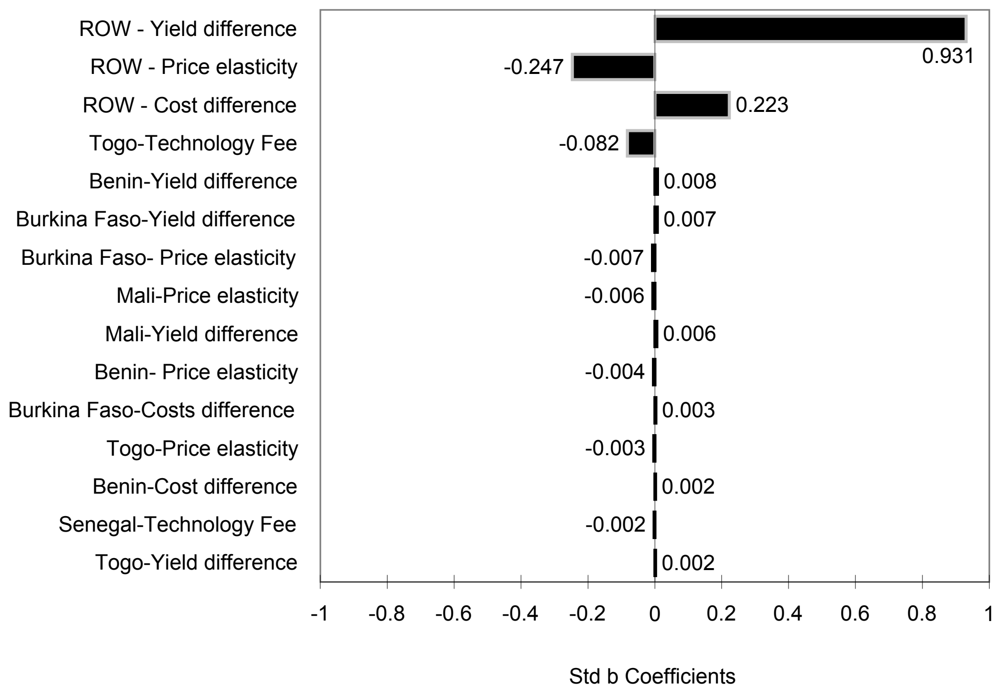


Figure 18. Sensitivity of the distribution of consumer surplus, in present value, Scenario 4, Senegal



APPENDIX A.

The Bt cotton technology and its global status

The first gene used in Bt cotton (commercial name BollgardTM), known as Cry1Ac, was developed by Monsanto in the 1980s from a soil microorganism, Bacillus thuringiensis kurstaki, long known to produce a protein that is toxic to a limited number of genus and species of Lepidopteran insects when ingested. Bt cotton was first sold in the United States in 1996 and was developed through a strategic alliance between Monsanto and the dominant U.S. seed cotton firm, Delta and Pineland (D&PL). Subsequent innovations included the stacking or insertion of two or more genes into the cotton germplasm. For example, Monsanto's Bollgard IITM uses Cry1Ac and Cry2Ab. The WidestrikeTM technology of Dow Agrosciences uses Cry1Ac and Cry1F. More recent Bt formulations, such as Syngenta's VIP cotton, carry the VIP 3A gene.

The primary targets of the original Bt cotton releases included the tobacco budworm (Heliothis virescens), pink bollworm (Pectinophora gossypiela) and cotton bollworm (Helicoverpa armigera and Helicoverpa zea) Lepidopterans. However, the original Bt cotton release demonstrated only limited activity against other pests such as beet armyworms (Spodoptera exigua Hubner), soybean loopers (Pseudoplusia Includens Walker) and other bollworms. The range of control has been extended through the introduction of BollgardII and Widestrike, or through the introduction of new chemistries such as VIP cotton.

If these pests are present at high densities or populations persist for an extended period, supplemental insecticide applications may be needed to prevent further yield losses. Furthermore, even when there is adequate control of the target pests, secondary pests that used to be controlled – albeit indirectly – when controlling the target pest may become economically significant. For example in the U.S., other bollworms and stink bugs have increased in importance after several years of using Bt cotton technologies (Bacheler and Mott, 2005). Recently, Wang et al. (2006) presented evidence of secondary pest evolution in China, though it is refuted by Huang et al. (2006). In any case, secondary pest evolution is a well known issue in breeding and managing plant genetic resistance, which needs to be addressed as early as possible through variety release plans and regulatory approval processes. Integrated Pest Management (IPM) practices, scouting techniques, and agronomic management practices must keep pace with a changing pest population.

Hence, one critical issue is the need to recommend insect resistance management practices along with the Bt cotton variety. Bt expression introduces selective pressures on a pest population. Eventually, individual pests that are resistant to the Bt protein will survive and thrive, rendering the technology obsolete. To lengthen the time until resistance is overcome, various strategies have been devised. One successful strategy to date has been setting aside areas planted with non Bt cotton varieties where resistant individuals mate with non-resistant individuals, thus diluting the proportion of resistant individuals. The set aside is called a refugia. There are different variations in terms of whether farmers are allowed to spray for non-target insects in the refugia and the relative area dedicated to the set aside. As indicated before, the refugia have been successful so far in delaying the appearance of resistance to the Bt gene under field conditions. Bt cotton was introduced back in 1996 and so far no case of resistance has been observed.

Another critical issue is the possibility of incidental gene transfer to wild cotton populations. Although this possibility is remote, some countries have chosen to limit the areas where Bt cotton is planted. In the U.S., Bt cotton varieties are not permitted for cultivation in the Southern part of Florida, Hawaii, U.S. Virgin Islands or Puerto Rico. In Mexico, Bt cotton varieties are not permitted for cultivation in the southern states as there are wild relatives of cotton in the region. Interestingly enough, the possibility that modern cotton varieties will be able to sexually cross with wild relatives is very low, as most modern varieties include.

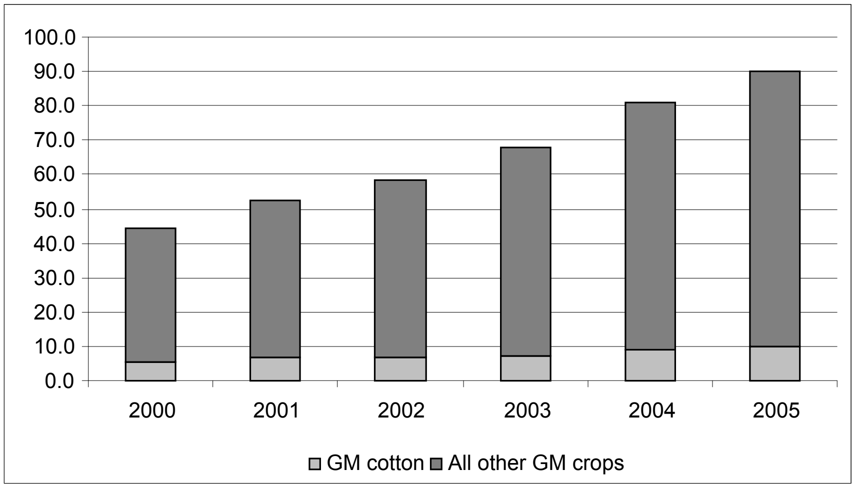
GM cotton areas and adoption rates

Patricia Zambrano[11]

The most widely used source for GM crop areas are the data reported in James' annual reviews (1996- 2005). The distribution between GM cotton and all other GM crops, expressed as a percent of total (worldwide area) is shown in Figure A-1. GM cotton share of total area planted to GM crops has remained fairly stable at 10 percent or less.

[11] Patricia Zambrano is a Senior Research Analyst at the International Food Policy Research Institute (IFPRI).

Figure A.1. Area under GM cotton as a proportion of total Worldwide GM area (mill Ha)



Source: James (2000, 2001, 2002, 2003, 2004, and 2005)

Table A.1. GM cotton areas by technology

Year	GM cotton areas					
	Total	Bt	Bt/HT	HT	Total cotton area	Cotton Adoption rate
			Million hectares			%
1996	0.8	0.8		<0.1		
1997	1.5	1.1	<0.1	0.4		
1998	2.5					
1999	3.7	1.3	0.8	1.6		
2000	5.3	1.5	1.7	2.1	25	16
2001	6.8	1.9	2.4	2.5	34	20
2002	6.8	2.4	2.2	2.2	34	20
2003	7.2	3.1	2.6	1.5	34	21
2004	9.0	4.5	3	1.5	32	28
2005	9.8				35	28

Source: James (1997,1998, 1999, 2000, 2001, 2002, 2003, 2004, and 2005)

In his reports, James does not report adoption by crop and by country, except for scattered data in the text. In addition, the data presented by James is for area planted to cotton, making it difficult to compare this information with other sources who usually report harvested area. It is a well known fact that planted and harvested areas can be substantially different due to losses between both events. Comparisons with other data sources is further complicated by the fact that cotton in many developing countries can be planted in one calendar year and harvested in the following year. Given these limitations of the data presented by James, we also present data collected by the International Cotton Advisory Committee (ICAC) data in Table A.2.

Table A.2. Area planted to GM cotton

Country	GM cotton areas					GM cotton adoption rates			
	2002/3	2003/4	2004/05	2005/06	*2006/07*	2002/3	2003/4	2004/05	2005/06
	Thousand hectares					*percentage*			
Argentina	7.31	15.29	37.46	61.00	*88.00*	5.0	6.0	10.0	20.0
Australia	66.15	117.90	188.40	293.40	*225.00*	30.0	60.0	60.0	90.0
Brazil				34.28	*150.00*				4.0
China	2,133.84	2,962.93	3,700.45	3,542.00	*3,817.43*	51.0	58.0	65.0	70.0
Colombia		5.49	11.33	28.92	*25.94*		10.0	14.0	50.0
India	38.34	97.88	465.66	1,242.22	*3,984.38*	0.5	1.3	5.3	14.0
Indonesia	0.09	0.10	0.12			1.0	1.0	1.0	
Mexico	20.75	23.71	64.26	74.66	*62.55*	50.0	38.0	61.0	59.0
South Africa	22.11	32.51	26.62	21.35	*21.35*	74.0	75.0	95.0	95.0
USA	3,869.20	3,740.44	4,121.59	4,524.53	*4,823.50*	77.0	77.0	78.0	81.0
WORLD	6,157.79	6,996.25	8,615.89	9,822.36	*13,198.15*	20.6	21.8	24.4	29.1

Source: ICAC, personal communication. Data for 2006/7 are initial estimations

Table A.3 illustrates the evolution of GM adoption over time, according to data presented by James. Countries in this table are listed chronologically, according to the first year of adoption. We notice that for the past four years non-industrialized countries, primarily from Latin America, have been added to the list of GM adopters. Interesting to note that after 1998, India and Colombia are the only two additional countries that have adopted GM cotton.

Table A.3. Area planted to GM crops planted 1997 – 2005 (Million hectares)

Country	Years									GM Crops planted
	1997	1998	1999	2000	2001	2002	2003	2004	2005	
USA	8.1	20.5	28.7	30.3	35.7	39.0	42.8	47.6	49.8	Soybean, Maize, **Cotton,** Canola, Squash, Papaya
China	1.8			0.5	1.5	2.1	2.8	3.7	3.3	**Cotton**
Argentina	1.4	4.3	6.7	10.0	11.8	13.5	13.9	16.2	17.1	Soybean, Maize, **Cotton**
Canada	1.3	2.8	4.0	3.0	3.2	3.5	4.4	5.4	5.8	Canola, Maize, Soybean
Australia	< 0.05	0.1	0.3	0.2	0.2	0.1	0.1	0.2	0.3	**Cotton**
Mexico	< 0.03	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	**Cotton,** Soybean
Spain	-	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	Maize
France	-	< 0.1	< 0.1	< 0.1					<0.1	
S. Africa	-	< 0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.5	Maize, Soybean, **Cotton**
Portugal	-	-	< 0.1						<0.1	Maize
Romania	-	-	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	Soybean
Ukraine	-	-	< 0.1							
Uruguay	-	-	-	< 0.1	< 0.1	< 0.1	< 0.1	0.3	0.3	Soybean, Maize
Germany	-	-	-	< 0.1	< 0.1	< 0.1	< 0.1	<0.1	<0.1	Maize
India	-	-	-	-	-	< 0.1	0.1	0.5	1.3	**Cotton**
Bulgaria	-	-	-	-	-	< 0.1	< 0.1			
Indonesia	-	-	-	-	-	< 0.1	< 0.1			
Colombia	-	-	-	-	-	< 0.1	< 0.1	<0.1	<0.1	**Cotton**
Honduras	-	-	-	-	-	< 0.1	< 0.1	<0.1	<0.1	Maize
Brazil	-	-	-	-	-	-	3.0	5.0	9.4	Soybean
Paraguay	-	-	-	-	-	-	-	1.2	1.8	Soybean
Iran	-	-	-	-	-	-	-	-	<0.1	Rice
Philippines	-	-	-	-	-	-	<0.1	0.1	0.1	Maize
Czech Rep									<0.1	
Total	11.0	27.8	39.9	44.2	52.6	58.5	67.7	81.1	90.0	

Source: James (1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, and 2005)

APPENDIX B.

The Economic Surplus Model

Jose Falck-Zepeda

Most ex post or ex ante analyses of the size and distribution of national economic benefits from adopting transgenic crops have been conducted with adaptations or versions of the economic surplus approach detailed by Alston and Pardey (1999). This approach is also termed a partial equilibrium displacement model because it considers only the effects of the technology change in the market where the technical change occurs. Effects in other markets, such as input markets, are disregarded.

In the standard model, the estimated magnitude and distribution of the economic benefits depend on many factors. These include: a) price elasticities of supply and demand for the crop; b) the volume of production (whether the country is a large or small producer, price setter or price taker); c) trade issues, if the country exports or imports the crop; d) nature of the innovative change induced by the technology; e) uniqueness of crop attributes; and, f) relevance of traits for genetic enhancement (agronomic traits, traits for resistance to extreme weather conditions and/or to pest infestations). Data are typically drawn from some combination of sources including sample surveys of farmers, trial data (field and greenhouse), and/or secondary data. The analysis can be conducted at the regional, national, or global level.

Several modifications of the basic economic surplus model have been proposed to deal with specific conditions encountered in either developed or developing countries. For example, when households are consumers as well as producers, and markets are incomplete, as is often the case for food crops in developing countries, supply of the product is difficult to separate from demand for the product. For example, Hayami and Herdt (1977) made an adjustment to the basic model for subsistence consumption in a country that does not trade the crop. The adjustment partitions the aggregate supply curve into partial supply curves in order to estimate differential effects on the income of farmers. This procedure allows for distinct rates of technical change and adoption among producer groups, particularly those that are classified by production size.

The Alston Norton and Pardey (ANP) Economic Surplus Model

A method to estimate economic surplus is proposed by Alston, Norton and Pardey. This model is based on the assumption that the adopting country markets and economy as well as the technological adoption pattern can be modeled by supply, demand and market equations as in the following system:

(1) Supply: $Q_S = \alpha + \beta(P + k) = (\alpha + \beta k) + \beta P$

(2) Demand: $Q_D = \gamma - \delta P$

(3) Market Clearing $Q_S = Q_D$

where Qs is quantity supplied, Q_D is the quantity demanded, *k* is the shift in supply due to the introduction of the technology, and P is the equilibrium price. A graphical representation of this model is presented in Figure 1. The Market Clearing identity $Q_S = Q_D$ allows us to estimate the equilibrium price P, by algebraic manipulation and by the areas identified as consumer and producer surplus in Figures 2a and 2b. The relative reduction in price (Z) is defined as

(4) $Z = \varepsilon K / [\varepsilon + \eta] = -(P_1 - P_0) / P_0$

In these formulas ε is the elasticity of supply, η is the absolute value of elasticity of demand, P_0 is the pre-innovation price, and P_1 is the post-innovation price. After setting $Q_S = Q_D = Q$, the formula to estimate world price is $P = (\gamma - \alpha - \beta k) / (\beta + \delta)$. If $k = 0$, $P_0 = (\gamma - \alpha) / (\beta + \delta)$. If $k = KP_0$, $P_1 = (\gamma - \alpha - \beta KP_0) / (\beta + \delta)$, therefore the change in price, $P_1 - P_0 = -\beta K P_0 / (\beta + \delta)$ and the absolute value of the relative change in price $Z = -(P_1 - P_0) / P_0 = \beta K P_0 / (\beta + \delta)$. Multiplying the numerator and the denominator by P_0 / Q_0, and manipulating algebraically, yields the elasticity equivalent formula (4) above. For the closed economy model, geometrical and algebraic formulas for producer, consumer and total surplus are then:

Changes in	Geometrical Formulas	Algebraic Formula
Consumer Surplus	Δ CS = Area P_0aeP_1 = Area Rectangle P_0abP_1 + Area Triangle abe	$\Delta CS = P_0 Q_0 Z (1 + 0.5 Z \eta)$
Producer Surplus	Δ PS = Area P_1bcd = Area rectangle P1ecd + Area Triangle bce	$\Delta PS = P_0 Q_0 (K - Z) (1 + 0.5 Z\eta)$
Total Surplus	Δ TS = P_0abcP_1 = Area Rectangle P0acd + Area Triangle abc	$\Delta TS = \Delta CS + \Delta PS = P_0 Q_0 Z (1 + 0.5 Z \eta)$

For the case of the small open economy we know that Δ CS=0 as the reference is the world price and thus consumers do not benefit from the price reduction from the adoption of the innovation. Therefore producer surplus equals total surplus ($\Delta PS = \Delta TS$). The formula for producer surplus can be estimated by taking the limit of the formula for change in producer surplus when the demand elasticity approaches infinity (Alston, Norton and Pardey). Formula for producer surplus is therefore:

(5) $\Delta PS = \Delta TS = P_W Q_0 K (1 + 0.5 Z\varepsilon)$

where Δ CS is the change in consumer surplus, Δ PS is the change in producer surplus, Δ TS is the change in total surplus, due to the introduction of an innovation. The estimate of *k,* the cost reduction estimate induced by the introduction of biotechnology varieties, is crucial to the estimation of economic surplus and it is often the hardest variable to measure accurately. To improve the estimate of *k*, the researcher can use estimates of output changes due to the technology from experimental fields and/or actual results in the farmer fields. Yield increases can be transformed into cost-reduction by dividing the industry or experimental yield increase by the elasticity of supply (Alston, Norton and Pardey). The advantage of using experiment station information is that the researcher is able to isolate other sources of yield increase and/or cost decrease. Conversely, farm data can be used in conjunction with adoption information to get a better estimate of how the varieties performed in field situations. There has been a gap between experiment station yield information and on-farm performance showing as much as 50 percent higher yield on experiment plots.

Alternatively the analyst may use information from surveys of farmers, on-farm experiment plots, and on-station experiment plots to refine the estimate of *k*. The procedure may be applied at the national, regional and even local level by appropriately weighting the shares of each sub-group to the overall *k*. Yield changes need to be transformed to equivalent cost change units. The equivalent cost change of yield is found by dividing yield change by the elasticity of supply. For pesticide savings, input cost change per ton is found by dividing input cost change per acre by (1 + percent change in yield). For technology fees, input cost change per ton is found by dividing input cost change by (1 + percent change in yield). Net cost change is found by adding yield equivalent cost change, pesticide input cost change, and technology fee input cost change. Overall, K is found by multiplying the net cost change by the adoption rate.

Limitations of the economic surplus approach

Alston et al. (1995) and other authors have pinpointed the advantages and limitations of the economic surplus approach. The major advantages are that these methods are parsimonious with respect to data and can be used to portray the effects on the benefits distribution of various institutional and market structures. The principal disadvantages are:

1. The surplus calculated is Marshallian, which accounts for price effects but not for changes in the income of farmers.
2. The approach ignores transactions costs, assuming that markets clear and function well.
3. As with any partial equilibrium model, prices and quantities of other commodities produced by farmers are fixed.
4. Effects on input markets are not investigated. In particular, the approach does not account explicitly for returns to land or labor, which are critical factors for measuring the impact of new technologies on the national and regional economy.
5. Furthermore, farmers are considered to be risk-neutral, price-takers who either maximize profits or minimize costs.

6. As we have seen in the farm-level studies, year-specific effects on productivity can be large but are not accounted for in single-year, ex post studies. Location-specific effects on the farm budget data that provide parameters of the models can also be large. Year-specific and location-specific effects are especially pronounced for farming systems in developing countries where crop management practices and conditions are highly heterogeneous.

Figure B.1. The closed economy model for economic surplus

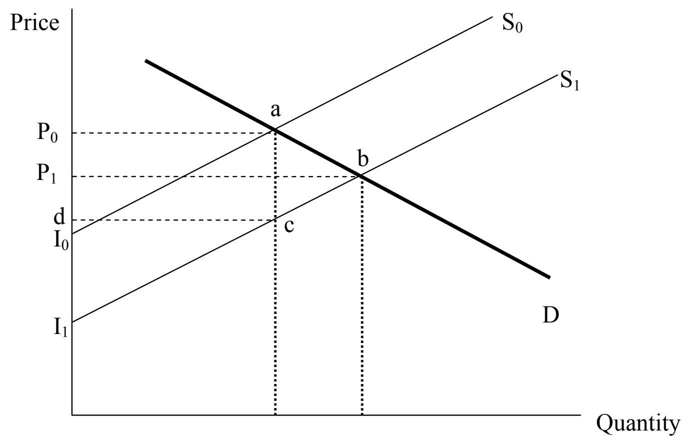
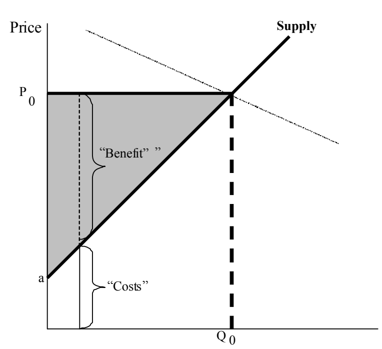
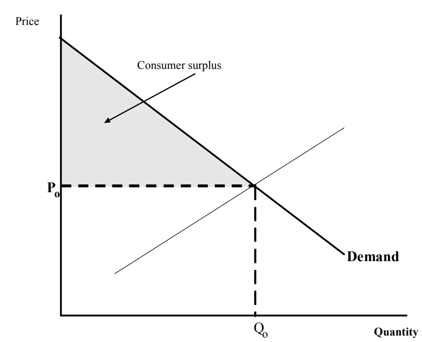


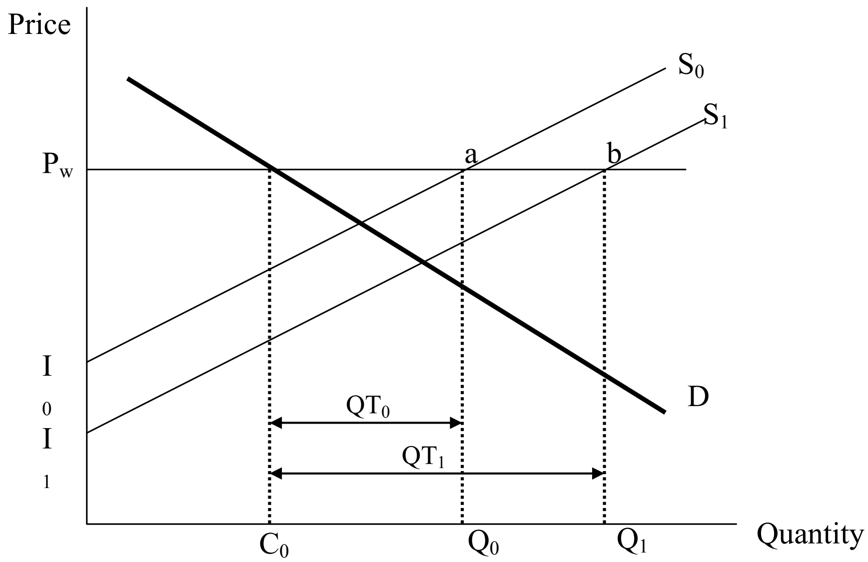
Figure B.2. Producer and consumer surplus





2a. Producer surplus **2b. Consumer surplus**

Figure B.3. Supply and demand for a small open economy: The case of the net exporter



Note: Pw = World Price, S_0 = quantity supply before innovation adoption, S_1 = supply after innovation adoption, D = Demand, C_0= Quantity consumed before innovation, Q_0 = Quantity produced before innovation adoption, Q_1 = Quantity produced after innovation adoption, QT_0 = Quantity traded before innovation adoption, QT_1= Quantity traded after innovation adoption.

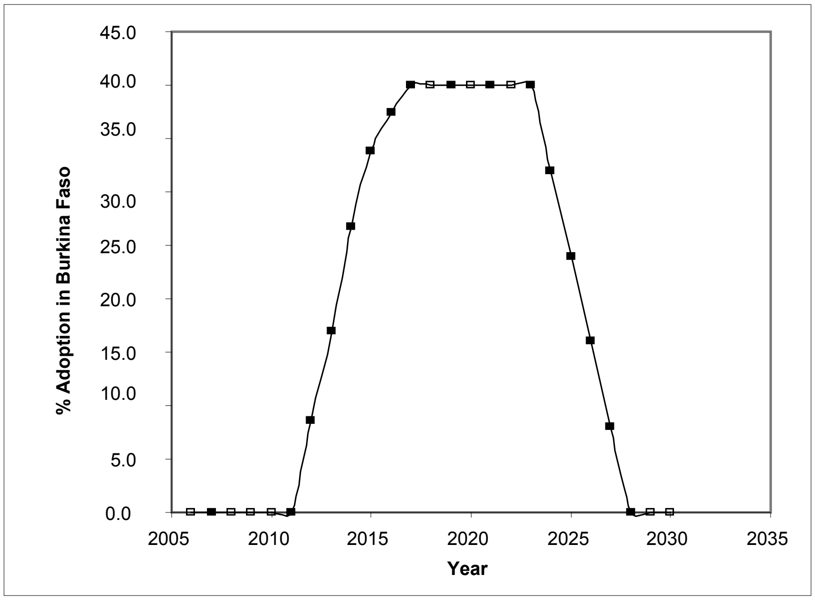
Economic Surplus Model for West Africa

The following estimates were made for the countries Benin, Burkina Faso, Mali, Senegal and Togo, each of which is represented with a subscript i in formulas below. The rest of the cotton producing countries in West Africa were grouped with other countries named Rest of the World (ROW).

Global and National Adoption

We assumed that each scenario would start in 2006. The adaptive R&D and biosafety regulatory assessment would last until 2011. Adoption starts in 2012 in Burkina Faso, followed by other adopting countries 3 years later, after their own assessments. The initial adoption phase was modeled using a logistic curve with a maximum adoption rate that varied according to country and scenario (See Table 4a).

Figure B.4. Adoption profile for Burkina Faso



Estimation of K

Estimation of the K value for each one of the countries in the study is as follows:

Total Cost Change (ΔC_i) = (Δ Yield$_i$ / ε_i) + {Δ Cost$_i$ / (1 + ε_i)] – {T_i / TC_i)
Potential K_i (K_{poti}) = ΔC_i * A_i
Effective Ki ($_{Keffi}$) = K_{poti} * R_i
K_{fi}= Kpoti * Si_{Bt}

where Total Cost Change due to the innovation is ΔC_i , Δ Yield$_i$ is the yield difference between Bt cotton and conventional cotton , ε_i is the elasticity of supply in country i, Δ Cost$_i$ is the cost difference between Bt cotton and conventional cotton in country i, , T_i is the technology fee, and TC_i is the Total costs of production in country i. A_i is the adoption rate in country i, R_i is the probability of R&D success (assumed in this exercise to be 100 percent), S_{iBt} is the share of the hectares of Bt planted in country i with respect to total global area planted.

The overall (global) K (K_w) is estimated by adding the individual countries in West Africa and the ROW.

$K_w = K_{fBenin} + K_{fBurkina} + K_{fMali} + K_{fSenegal} + K_{fTogo} + K_{fROW}$

Estimation of prices and quantities

The Kw is used to estimate the global market clearing price P1w with the technology adoption based on the observed price (P0w). Pow is the Cotllook A reference price. We calculated P1w with the formula:

$$P_{1w} = \frac{P_{0w}}{\left[1 - \frac{(\varepsilon - K)}{(\varepsilon + Sa\,\eta + (1 - Sa\,\eta_b^e)} \right]}$$

The observed price is the global market clearing price P_{1w} is weighted by the difference in global price with and without the technology so that in the end, all prices in individual countries have the absolute equivalent departure from the estimated world price.

Weighted P_{1i} (WP_{1i}) = $P_{1i} - (P_{1w} - P_{0w})$

Formula for Z_i

$Z_i = (P_{1i} - P_{0i}) / P_{0i}$

Producer, Consumer and Innovator Surplus

Formula for producer surplus estimated for each one of the countries in West Africa is as follows

$\Delta PS_i = \Delta TS_i = P0_i\, Q_{0i}\, (K_i - Z_i)\, (1 + 0.5\, Z_i\, \varepsilon_i)$

Formula for Innovator Surplus:

Δ PS = Tech fee$_i$ * Area Planted *A_i

Formula for Producer Surplus Rest of the World

$\Delta PS_{ROW} = \Delta TS_i = P0_i\, Q_{0i}\, (K_i - Z_i)\, (1 + 0.5\, Z_i\, \varepsilon_i)$

APPENDIX C.

Questions that need a more detailed answer for the assessment of the potential economic benefits in West Africa

Status of cotton production

1) What are the major and minor (secondary) insect pests that attack cotton in West Africa? What are the dynamics of pest populations in West Africa? What are the levels of damage by Lepidopteran and other insects?
2) What are the levels of damage by other productivity constraints such as diseases, drought, management practices problems, etc.
3) What are actual and potential (feasible) cotton yields?
4) What are the most binding productivity constraints?
5) How many pesticide applications are farmers applying for target pests? For non-target pests?
6) Are there Integrate Crop and Pest Management (ICPM) practices being used in West Africa? How does Bt cotton fit within the scope of an ICPM managed system?
7) Need carefully collected data of partial and full budget for farm households that produce cotton in the region.

Performance of the technology

1) Will Bt cotton reduce insecticide use and reduce damage due to Lepidopteran insects?
2) Will Bt cotton increase income to farmers?
3) Will there be a need to establish insect resistant management strategies (IRM) in West Africa?
4) Are IRM strategies feasible for implementation in West Africa?
5) Will Bt cotton reduce biodiversity in the region? Need information on wild relatives, sexual compatibility with relatives, pollen flow, rate of successful introgression into population, potential damage to wild relative populations and a full risk assessment of all these components.

Institutional

1) Is there the necessary institutional framework to support the transfer of knowledge to farmers to empower them to manage the technology?
2) What will the technology diffusion pathway be like? Private or public sector led effort?
3) What is the technology fee that innovators will charge in West Africa?
4) Will there be a contractual agreement between the innovator and producers? What are the conditions by which farmers will get access to the technology?
5) Who will negotiate on behalf of farmers? Farmer associations and cooperatives?
6) Will companies share the benefits of the technology with farmers as in other parts of the world?
7) Will farmer associations and cooperative have the power to negotiate a technology fee that allows benefit sharing generated by the use of the technology? As demonstrated elsewhere, even in the presence of a monopolistic innovator, benefits may need to be shared with producers, particularly in the early stages of adoption, where other alternatives exist (conventional production with pesticides or other crops) and/or where there have been limits to the innovators' ability to align the technology fee towards a competitive level.

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