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Introducing a Genetically Modified Banana in Uganda

Social Benefits, Costs, and Consumer Perceptions

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ABSTRACT

Banana is a staple crop consumed by Ugandan households. The Uganda National Agricultural Research Organization has implemented conventional and biotechnology programs that seek improving bananas and address the crop's most important pest and disease problems. A major thrust is the development of genetically modified (GM) bananas.

The purpose of this paper is to examine potential social welfare impacts of adopting a GM banana in Uganda. The study has three objectives. First, suggest and apply an approach to calculate reversible and irreversible benefits and costs of introducing a GM banana. The study applies a real option approach to estimate, ex ante, the maximum incremental social tolerable irreversible costs (MISTICs) that would justify immediate introduction of the technology. Second, suggest an approach for assessing producer/consumer preferences and willingness to pay (WTP) for introducing a GM banana. Finally, the paper discusses main implications for biosafety decision making for GM crops in Uganda.

Results of MISTICs estimation for different scenarios indicate that in delaying the approval of a GM banana, Uganda foregoes potential annual benefits ranging approximately from US$179 million to US$365 million. Average annual MISTICs per household vary between US$34 and US$ 69. Results indicate that only if the average household is willing to give up at least US$38 per year to avoid introduction of a GM banana, should postponing an immediate release be considered. Results imply that although GM bananas promise vast benefits, realization of those benefits depends on consumers' perceptions and attitudes and the willingness to pay for the GM technology.

Keywords: GM banana, real option, choice experiment, biosafety, MISTICs, Uganda.

ABBREVIATIONS AND ACRONYMS

IBC	Institutional Biosafety Committee
MISTIC	Maximum Incremental Social tolerable Irreversible Costs
NARO	National Agricultural Research Organization
NBAC	National Biotechnology Advisory Committee
NBC	National Biosafety Committee
SIRB	Social Incremental Reversible Benefit
UNCST	Uganda National Council of Science and Technology

1. INTRODUCTION

Banana is a staple crop in Uganda. Ugandans have the highest per capita consumption of cooking banana in the world (Clarke, 2003). However, banana production in Uganda is limited by several productivity constraints such as pests, diseases, soil depletion, and poor agronomic practices. To address those constraints, the country has invested significant resources in research and development and other publicly funded programs, pursuing approaches over both the short and long term. Uganda formally initiated its short-term approach in the early 1990s; it involves the collection of both local and foreign germ plasms for the evaluation and selection of cultivars tolerant to the productivity constraints. The long-term approach, launched in 1995, includes breeding for resistance to the productivity constraints using conventional breeding methods and genetic engineering. Genetic engineering projects in Uganda target the most popular and infertile cultivars that cannot be improved through conventional (cross) breeding. The main objective of genetic engineering in Uganda is to develop genetically modified (GM) cultivars that are resistant to local pests and diseases, have improved agronomic attributes, and are acceptable to consumers (Kikulwe et al., 2007).

The introduction of a GM banana in Uganda is not without controversy. In Uganda, where the technology of genetic engineering is still in its infancy, it is likely to generate a wide portfolio of concerns, as it has in other African countries. According to the Uganda National Council of Science and Technology (UNCST) (2006), the main public concern is the safety of the technology for the environment and human health.

Several countries have designed and implemented policies to address the safety concerns of consumers and producers (Beckmann, Soregaroli, and Wesseler, 2006a, 2006b). Such policies include assessment, management, and communication of the biosafety profiles of genetically modified organisms (GMOs) (Falck-Zepeda, 2006). As a consequence of its international obligations and the need to guarantee a socially accepted level of safety to its citizens, Uganda has taken significant steps to ensure the safety of GM biotechnology applications. GM banana varieties will need to undergo biosafety assessments[1] and receive the regulatory approval of the country's National Biosafety Committee before being approved for research, confined field trials, and release into the environment for commercialization.[2]

The biosafety regulatory process, however, has several economic consequences as biosafety regulations are not costless endeavors. Kalaitzandonakes, Alston, and Bradford (2007) calculate the compliance costs for regulatory approval of herbicide-tolerant and insect-resistant maize to be on the order of about US$7 to 50 million. They note that the approval costs for similar types of GM crops will be similar. In addition, biosafety-testing requirements can consume significant amounts of time—from a few months to several years. A delay in the approval of a new variety forestalls access to the potential benefits generated by farmer adoption of the technology, and one can expect such costs to be substantially higher than the regulatory compliance costs. Wesseler, Scatasta, and Nillesen (2007), for example, estimated that the average annual benefits of Bt corn for the European Union amount to about 155 million euros per year. On the other hand, regulatory processes create additional information about the technology and can help to improve the selection and regulation of appropriate technologies.

Jaffe (2006) has noted that existing drafts of Uganda's biotechnology and biosafety policy stress the importance of the socioeconomic implications of the technology for biosafety regulation, but that author also observes a lack of precision in identifying the socioeconomic aspects and how they should be

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[1] The original scope of biosafety as described in the Cartagena Protocol on Biosafety was environmental safety. However, over time the original scope has been expanded to include food and feed safety in terms of toxicity or allergenicity. In this paper, it is therefore understood that the label biosafety includes both environmental and food/feed safety.

2 As of the final draft of this paper, three technologies have been approved for confined field trial testing in Uganda, including a virus-resistant cassava, an insect-resistant and herbicide-tolerant cotton, and a fungus-resistant banana. The cotton and banana confined field trials are being proposed by NARO. Unlike the confined cotton field trial, the banana confined field trial including 200 plantlets has been established on 30th November 2007.

considered. Each country decides independently whether to include socioeconomic considerations as part of the process of deciding which technology may be approved for commercialization after being deemed safe by the biosafety authority. In fact, Article 26.1 of the Cartagena Protocol gives countries the choice of whether to include socioeconomic considerations in the biosafety assessment process consistent with other international treaties although limited to the context of biodiversity (Jaffe, 2006). Article 26.1's "may take into account" clause has been applied strictly in some countries, such as India, where the socioeconomic consideration is mandatory for biosafety applications.

Many countries, including Uganda, have not determined whether and how to include socioeconomic considerations, at what stage of the regulatory process to include them, and what the scope and decision-making process within biosafety regulations should be. In fact, some biosafety experts (and some countries) have resisted including such considerations in the biosafety decision-making process, as in their view, such issues may cloud that process and distract regulators from the scientific/technical issues related directly to biosafety. It is worthwhile to note that inclusion of socioeconomic considerations for biosafety regulatory approval at the laboratory/greenhouse or confined field trial stages contributes very little to the decision-making process, as the material will not enter the food chain and thus will not be commercialized until it is given regulatory approval further along in the process. Therefore, a major objective of this discussion paper is to illustrate the relevance of socioeconomic analyses for supporting biotechnology decision making but also for contributing to the development and implementation of biosafety regulations. We present a general approach using GM banana as an example.

In the following sections we discuss the benefits that a GM banana could provide to producers and consumers in Uganda and the role of biosafety regulations in governing the introduction of a GM banana. A real option model is presented that shows how concerns about environmental risks can be considered within a cost-benefit analysis as a first step toward a socioeconomic assessment of introducing a GM banana in Uganda. We explicitly show how the underlying trade-offs between potential irreversible and reversible benefits and costs that accompany a GM banana can be assessed, building on previous research on banana production in Uganda by Bagamba (2007) and Edmeades and Smale (2006). We calculate the maximum incremental social tolerable irreversible costs (MISTICs). The application of the MISTICs approach pays closer attention to the application of the precautionary principle within the assessment of GM crops (Just, Alston, and Zilberman, 2006). It is important to note here that this is the first application of the MISTICs approach in a developing-country setting.

In addition, we show how the results of the economic analysis can be combined with the consumers' willingness to pay (WTP) for a GM banana using a choice experiment model. We explicitly demonstrate how one can use a latent segment model to capture and account for heterogeneity among consumer preferences given a tangible economic benefit of the GM banana.[3] The latent segment model complements and extends the dimensions of previous research (Li et al., 2003; Loureiro and Bugbee, 2005; Knight et al., 2007) on consumers' WTP for GM food by, first, incorporating the foregone economic benefits of a delay in release and, second, incorporating producers as consumers in the sample. The approach is unique in its application to banana varieties in a developing-country context.

The paper is structured as follows. The second section discusses in more detail the relevance of a GM banana for Uganda. Section 3 introduces an overview of biosafety regulations in Uganda. Section 4 presents the MISTICs approach and explains its application. Section 5 reports and discusses the preliminary results. Section 6 introduces the theoretical framework of the choice experiment and its application. The final section draws conclusions and discusses implications for decision making regarding biotechnology and biosafety regulations for a GM banana in Uganda.

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[3] A *tangible economic benefit* refers to a benefit foregone if the GM banana is not introduced immediately.

2. THE RELEVANCE OF A GM BANANA FOR UGANDA

Banana is one of the most important crops in Uganda with approximately 7 million people, or 26% of the population, depending on the plant as a source of food and income. Bananas are estimated to occupy 1.5 million hectares of the total arable land, or 38% of the cultivated land, in the country (Rubaihayo and Gold, 1993; Rubaihayo, 1991). The plant is grown primarily as a subsistence crop in rural areas, although consumption is not limited to rural areas as approximately 65% of urban consumers in Uganda have a meal of the cooking variety of banana at least once a day. Ugandans have the highest per capita consumption of cooking banana in the world (Clarke, 2003).

Most of the banana varieties grown in Uganda are endemic to the East African highlands—a region recognized as a secondary center of banana diversity (Stover and Simmonds, 1987; Swennen and Vuylsteke, 1988; Smale and Tushemereirwe, 2007). The endemic banana varieties (AAA–EA genomic group) consist of two use-determined types: cooking bananas (matooke) and beer bananas (mbidde). Karamura (1998) recognized 238 names of East African highland banana varieties in Uganda, with 84 clones grouped into five clone sets. The nonendemic clones include dessert bananas (varieties that are consumed raw), some beer bananas (varieties suitable for beer and juice making), and roasting bananas (or plantains).

Banana yields in Uganda are severely reduced by several pests and diseases. Among the pests that cause the most yield damage are weevils (*Cosmopolites sordidus*) and nematodes (*Radopholus similis, Pratylenchus goodeyi, and Helicotylenchus multicinctus*). The diseases that contribute to the worst yield losses in Uganda are the soil-borne fungal Panama disease, or *Fusarium* wilt (*Fusarium oxysporum*), bacterial wilts including the banana *Xanthomonus* wilt (*Xanthomonus campestris* pv. *musacearum*), and the air-borne fungal black leaf spot disease or "black Sigatoka" (*Mycosphaerella fijiensis* Morelet) (Gold, 1998; 2000; Gold et al., 1998, ; 2001; Tushemereirwe et al., 2003).

Consequently, the National Banana Research Program of the National Agricultural Research Organization (NARO) in Uganda has developed a breeding program that employs a range of traditional crop breeding methods and a portfolio of biotechnologies to address the crop's most debilitating problems caused by pests and diseases (Kikulwe et al., 2007). The short-term breeding strategy includes the assembly of local and foreign germ plasms for evaluation and selection of varieties resistant or tolerant to existing productivity constraints. Resistance to a limited set of pests and diseases (e.g., black Sigatoka) was identified in hybrid banana varieties. Though characterized by bigger bunches, the hybrid varieties are not widely grown in Uganda (Nowakunda, 2001; Smale and Tushemereirwe, 2007). Producers and consumers prefer the East African highland cooking bananas, but these are also highly susceptible to black Sigatoka (Nowakunda et al., 2000; Nowakunda, 2001) and bacterial wilts (Tushemereirwe et al., 2003). Susceptibility to diseases prompted the national researchers to adopt a long-term breeding strategy that includes the generation of new genotypes and other new approaches to introduce resistance.

The highest-yielding highland cooking bananas proved to be sterile, which slows down their improvement through conventional breeding (Ssebuliba, 2001; Ssebuliba et al., 2006). With major biotic constraints not easily addressed through conventional breeding and management practices, recent efforts have been made to employ genetic engineering for the insertion of resistance traits into selected banana background planting material. Unlike crossbreeding, genetic engineering allows for improving the agronomic traits (e.g., disease and pest resistance) as genes are inserted into potential host varieties (cultivars) while not changing other production and product attributes (e.g., cooking quality). The genetic modification approach has shown potential for the improvement of the crop (Tripathi, 2003). At the University of Leuven, Belgium, GM bananas with resistance against black Sigatoka have been developed. Yet the performance of the new varieties and/or traits inserted into local host varieties cultivated under local conditions is not known as the field trials have just begun.

Edmeades and Smale (2006) argue that the choice of a host variety for a genetic transformation largely determines its acceptability by producers and consumers. In those regions strongly affected by biotic constraints, it is likely that GM banana cultivars will be more beneficial to poorer and subsistenceoriented farmers. In addition, the insertion of multiple traits into East African highland bananas, although associated with additional research and development costs (e.g., transformation costs, regulatory costs), could further increase the benefits generated by the adoption of the technology in Uganda. Multiple traits may also increase adoption rates, as farmers may not immediately notice the beneficial effect of a single trait.

Although GM bananas look promising for large-scale (mass clonal) multiplication and dissemination, empirical evidence of the success of such organisms is still limited. Long-term multiplication of micropropagated (tissue-cultured) plants, for example, may lead to epigenetic[4] (somaclonal) variations. Additionally, genetic uniformity in a trait intensifies the probability of mutations in the targeted pest or disease that overcome resistance and increase epidemic vulnerability. These two aspects raise questions about the clonal fidelity of offspring plants and their genetic stability, both affecting economic benefits of GM banana varieties. In this context biosafety measures to monitor, evaluate, and mitigate effects of such occurrences become critical for the appropriate deployment of the technology in Uganda.

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[4] *Epigenetic changes* are changes that do not affect the DNA sequence of genes but change the gene in other ways. These changes may be induced spontaneously in response to environmental factors or in response to the presence of a particular allele, even if it is absent from subsequent generations. Modgil et al. (2005) note that the in vitro process, length of in vitro culture, and in vitro stress due to unnatural and nutritional conditions are some of the factors believed to induce epigenetic changes.

3. BIOSAFETY REGULATIONS IN UGANDA

Uganda is among the few African countries that have invested in agricultural GM crop research and development and have initiated procedures for confined field trials to evaluate GM technologies (Atanassov et al., 2004).[5] The country has taken significant steps to ensure safety in biotechnology application (Nampala, Mugoya, and Sengooba, 2005). Biosafety regulations and, to a degree, biotechnology developments in Uganda are governed in the context of the Cartagena Protocol on Biosafety (GOU, 2002b; 2004). The country signed the protocol in May 2000 and ratified it in November 2001 (GOU, 2004; Wafula and Clark, 2005). UNCST is the institution responsible for the implementation of the biosafety protocol and the protocol's designated competent authority. UNCST established the National Biosafety Committee (NBC), a technical evaluation arm, in 1996. NBC is responsible for reviewing applications and implementing general biosafety guidelines and regulations (GOU, 2004; Wafula and Clark, 2005).

Currently, the basis for the development and application of biotechnology is the National Science and Technology Policy of 2001 (GOU, 2004). The National Science and Technology Policy provides general reference to biotechnology within the broader context of the role of science and technology in national development. The responsibilities of the various institutions and agencies involved in the approval process for biotechnology products have been outlined in the Biosafety Framework of 2000. The National Biosafety Framework, which was developed by UNCST, is based on the United Nations Environment Programme's International Technical Guidelines on Safety in Biotechnology (2001). Those guidelines provide terms of reference for NBC and the institutional biosafety committees (IBCs)—detailed information on risk assessment and management procedures for microbes, inspection, and approval (Traynor, 2003).

Under the National Biosafety Framework, UNCST has the mandate of approving genetically modified organisms for research purposes, confined release into the environment, and commercial planting in Uganda. UNCST receives all applications for research on or the deliberate introduction of GMOs, conducts a screening for completeness, and enters the applications into the national public records as submitted, before forwarding them to NBC for review and risk assessment evaluation. The complete risk assessment is done by the applicant. NBC is obliged to review the risk assessment dossiers submitted by the applicant after the application has been assessed by the IBCs and finally advises UNCST.

The members of NBC are stakeholders, such as representatives from regulatory agencies, the scientific community, universities, the private sector, and civil society. (Nampala, Mugoya, and Sengooba, 2005). NBC is also responsible for writing the draft National Biotechnology and Biosafety Policy, the draft National Biosafety Regulations (GOU, 2004), and the Guidelines on Biosafety in Biotechnology for Uganda (GOU, 2002a), and for developing draft manuals addressing specific issues surrounding biosafety regulations, such as confidential business information. These documents make up the biosafety regulatory framework for Uganda. At this point in time, the documents still need to be approved by the government (Jaffe, 2006). The implementation of the finally agreed upon biosafety regulations for a specific GM crop will be managed by UNCST. UNCST is advised by the National Biotechnology Advisory Committee (NBAC), which is an interministerial committee including representatives from key institutions in biotechnology development and NBC (GOU, 2004).

Applications for the import and export of GMOs are also approved by NBC. The government of Uganda (2005, p. 6) stipulates that "any person, prior to intentionally introducing a GMO shall apply to the Competent Authority for authorization. In case of imports, the exporter or the Competent Authority in the country of export may submit an application on behalf of an applicant, and may designate in the application with whom the Competent Authority shall communicate regarding the application." In the

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[5] The GM banana field trials were approved by the National Biosafety Committee and have been established at Kawanda by NARO. Note that Uganda is now among the other five African countries that have conducted confined field trials of GM crops namely: South Africa, Egypt, Burkina Faso, Zimbabwe, and Kenya. Of those, only South Africa has approved crops for commercialization.

case of field testing, the Ugandan government (2005, p. 7) continues to specify that "the applicant shall document to the Competent Authority that participating personnel will have appropriate training that the field test will be overseen by an individual possessing appropriate technical expertise." The competent authority has to reply within 90 days. Within a period of not more than 270 days after the scientific risk assessment, the competent authority will make a final decision on whether to approve or deny the applicant the authority to introduce the GMO. This implies that if all the required documents are submitted and complete, the approval will take about one year. In the case of a denial of a request, the applicant is given 30 days to appeal with genuine reasons and/or additional relevant information, and the competent authority has 30 days within which to render a final decision. The competent authority will finally avail to the public any proposal about the intentional introduction of GMOs. The public is given not more than 60 days to submit comments, which the competent authority shall take into consideration before the final decision is made.

According to Wafula and Clark (2005), NARO submitted applications to UNCST in 2000 to introduce Bt cotton and Bt maize, but they were not approved for confined field trials. One of the reasons UNCST gave was that Uganda was unprepared to handle GM crops because it lacked a national biotechnology and biosafety policy. In addition, Uganda lacked confinement and containment facilities for GMO field trials. Recently, the government selected biotechnology as one of the priority areas in its plan for the modernization of agriculture (Oxford Policy Management (OPM), 2005). Consequently, substantial investments have been made in institutional development and capacity building for agricultural biotechnology and biosafety.

Jaffe (2006) analyzed and compared biosafety regulatory systems in Uganda, Kenya, and Tanzania using the African Model Law, which is one of the documents given consideration throughout Africa when a country begins drafting laws and regulations to address biosafety. Jaffe's assessment considered key issues such as comprehensiveness, transparency, participation, and efficiency of the regulatory systems. In the context of Uganda's existing biosafety regulatory framework, despite all the efforts that have been made, the author notes some shortcomings, particularly in the areas of transparency and clarity regarding the process to be followed such that all interested stakeholders are able to understand and meet the requirements of the regulatory process. Those shortcomings include, first, no clear indications of how the assessment of the potential food safety risks that might arise from the GMOs will be handled. Second, even though UNCST is involved in the formulation of the biosafety regulation policy, the statute authorizing its creation does not provide legal authority to regulate GMOs. Neither the biosafety policy nor the government regulations establish a clear safety standard for approving a GMO. Third, within the documents, there are no elaborations on how and what socioeconomic considerations will be considered, how they will be analyzed, by whom, and how they will be considered in the decision-making process. These shortcomings will need to be addressed to ensure a robust, efficient, cost-effective, and socially acceptable biosafety regulatory process in Uganda.

4. TOWARD CONSIDERING THE SOCIOECONOMIC ASPECTS OF A GM BANANA

The economic net benefits of introducing a GM banana depend on the reversible and irreversible benefits and costs the technology will generate. Reversible benefits and costs can be defined as those benefits and costs that can be reversed after the planting of the crop and do not result in additional ex post (after stopping production) benefits and costs. An illustrative example is the purchase of inorganic fertilizer. If the producer finds that producing a GM banana crop is no longer worthwhile, the purchased fertilizer can be used for other crops. Similarly, other variable costs can be considered as being reversible as well.

On the other hand, irreversible benefits and costs refer to those benefits and costs that will continue to occur even if GM bananas are no longer produced or those that cannot be fully reversed. Examples are sunk costs or chronic health damages from pesticide use. The reversible and irreversible benefits and costs can be further differentiated into private and nonprivate benefits and costs. This differentiation is useful for understanding the distribution of benefits and costs between, for example, farmers (private) and society at large (nonprivate). The private and nonprivate costs include effects on nontarget species; for instance, the introduced genes in nematode-resistant GM banana may affect beneficial nontarget nematodes. Others include effects on human health such as antibiotic resistance and allergies, evolution of pests and disease resistant to the inserted genes (Kendall et al., 1995), and loss of genetic diversity (FAO, 2001). Certainly, a net reduction in the use of insecticides and nematicides on GM banana will have positive impacts on human health, the environment, and biodiversity, and those can be considered as being irreversible benefits (Wesseler, 2003). Demont, Wesseler, and Tollens (2004) provide a number of examples illustrating the difference between reversibility and irreversibility.

The different types of benefits and costs are summarized in Table 1. Table 1 shows a two-dimensional matrix differentiating between reversible and irreversible and private and nonprivate benefits and costs for an ex ante economic analysis of GM crops. The sum of quadrants one and two gives the value of the net social reversible benefits and that of quadrants three and four the net social irreversible costs. The irreversible costs are of critical importance for biosafety decision making. They are the major argument supporting biosafety regulations under the Cartagena Protocol on Biosafety (Secretariat of the Convention on Biological Diversity, 2000). However, it is not irreversibility itself that has been used exclusively to justify specific biosafety regulations for GM crops as well as to justify a delay in release (flexibility) to obtain additional knowledge and information on the new technology; rather, uncertainty about irreversible costs in combination with uncertainty about the economic benefits of GM crops has been put forward in the Cartagena Protocol and other regulatory processes to justify such interventions.

Table 1. The two dimensions of an ex ante analysis of social benefits and costs of GM crops

Scope **Reversibility**	**Private**	**Nonprivate**
Reversible	Quadrant 1 Private reversible benefits Private reversible costs	Quadrant 2 External reversible benefits External reversible costs
Irreversible	Quadrant 3 Private irreversible benefits Private irreversible costs	Quadrant 4 External irreversible benefits External irreversible costs

Source: Demont, Wesseler, and Tollens (2004).

In the context of the Cartagena Protocol, the introduction of a new GM crop becomes a decision-making process under uncertainty, irreversibility, and flexibility. Analyzing decision making under uncertainty, irreversibility, and flexibility is not new to economists and has a tradition in environmental economics that originated in the early 1970s with papers published by Arrow and Fisher (1974) and

Henry (1974), while in economics it can even be traced back to Louis Bachelier (1900) (Bernstein, 1992). Irreversible benefits and costs in combination with uncertainty and flexibility can be considered within a real option approach for the assessment of the adoption impacts of a GM crop. Examples are provided by Demont, Wesseler, and Tollens (2004) and Scatasta, Wesseler, and Demont (2006) for the introduction of GM strains of sugar beet and corn in the European Union.

Maximum Incremental Social Tolerable Irreversible Costs

We begin with the assumption that incremental reversible net benefits follow a continuous-time, continuous-state process with trend, where GM crops may be released at a point in time. In this approach, the social incremental reversible benefits W* (the sign * indicates optimal timing) need to be greater than the difference between the social incremental irreversible costs (I) and the social incremental irreversible benefits (*R*), weighted by the size of the uncertainty and flexibility (or hurdle rate) associated with the introduction of the new technology. The hurdle rate is commonly expressed in the form $\frac{\beta}{\beta-1}$, where $\beta > 1$ captures the uncertainty and flexibility effect and is a result of identifying the profit-maximizing decision rule under irreversibility, uncertainty, and flexibility, if benefits do follow a geometric Brownian motion.[6] The interpretation of the decision rule for the case of the GM banana is that, as long as $W - \frac{\beta}{\beta-1}(I - R) \leq 0$, Uganda should delay adoption of a GM banana until more information about the new technology is available.

In the context of GM crops, where people are more concerned about the not-so-well-known irreversible costs of the technology, it is feasible to estimate threshold values that indicate the maximum incremental social irreversible costs that an individual or society in general is willing to tolerate as compensation for the benefits of the technology. Scatasta, Wesseler, and Demont (2006) have called this threshold value the *maximum incremental social tolerable irreversible costs, I*,* or *MISTICs* for short. In the specific case of Uganda, the estimated MISTICs can be interpreted as the maximum willingness to pay (WTP) for having the GM banana approved for planting in the country. Actual incremental irreversible social costs, *I,* are to be no greater than the sum of incremental irreversible social benefits and incremental reversible social net benefits for introducing a GM banana, such that

$$I < I^* = \frac{W}{\beta/(\beta-1)} + R. \tag{1}$$

Using Equation 1 with parameter values generated for the case of GM banana can provide threshold values for the irreversible costs. The values can be compared with information from secondary sources to identify whether the threshold value will be met in Uganda.

In practice, estimation of the maximum incremental social tolerable irreversible costs (MISTICs, or *I**) requires quantification of three factors:

social incremental reversible benefits from GM crops (SIRBs, or *W*);
social incremental irreversible benefits (SIIBs, or *R*) rate; and
hurdle rate, $\beta/(\beta-1)$.

All these factors can be estimated or calculated using econometric and mathematical modeling techniques following Demont, Wesseler, and Tollens (2004).

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[6] The geometric Brownian motion is a Wiener process with a geometric trend for which changes expressed as natural logarithms are normally distributed. The Wiener process is a continuous-time, continuous-state stochastic Markov process with three properties: (a) probability distributions of future values depend on the current value only; (b) the Wiener process grows at independent increments; and (c) changes are normally distributed. The assumption that the adoption of this technology follows a geometric Brownian motion accounts for the uncertainty of the technology (Cox and Miller, 1965).

5. DATA SOURCES, DATA, AND PRELIMINARY RESULTS

Secondary data have been used for the estimations of parameters for the real option model. Data are taken from the database of a NARO/IFPRI project conducted between 2003 and 2004 in Uganda. The data set is complemented by data from the Uganda Bureau of Statistics (UBOS) and the Food and Agriculture Organization. Table 2 lists the private and nonprivate reversible and irreversible benefits and costs directly and indirectly considered.

Table 2. Social benefits and costs for GM banana considered

Scope Reversibility	Private	Nonprivate
Reversible	Quadrant 1 Benefits - Higher yields Costs - Labor costs	Quadrant 2 Benefits - Zero Costs - Zero
Irreversible	Quadrant 3 Benefits - Negligible Costs - Planting material	Quadrant 4 Benefits - Indirect: improved food safety and decreased vulnerability Costs - Indirect: possible health and environmental effects

Source: Authors

The social incremental reversible benefits (SIRBs) were estimated based on private net benefits. Private incremental reversible benefits can be defined as the difference between the gross margin from GM and non-GM bananas, excluding planting material. Table 3 shows preliminary results for the incremental benefits estimations for a GM banana in Uganda. The starting point for these estimations is the gross margin for a non-GM banana crop as reported by Bagamba (2007, p. 31). The annual variable costs for a non-GM banana crop include hired labor used mainly for weeding and crop sanitation. The use of other inputs such as fertilizer and pesticides is, according to Bagamba, negligible. The average output in metric tons per year is about 10.6 per hectare with an average price about 149,600 Uganda shillings (USh) per metric ton. Under the current production practices, most farmers do not incur costs for planting materials. Most of the planting materials are exchanged for free between farmers (Kikulwe et al., 2007).

The average annual gross margin from producing one hectare of non-GM banana (traditional) is approximately USh 1,411,200 (US$800) excluding labor costs for planting. The main benefit of introducing a GM banana is an increase in banana yield through reduced biotic pressure. Assuming that planting a GM banana with a gene resistant to black Sigatoka[7] increases yield by 20% and labor costs by about 10% and that the average annual costs for planting material are USh 151,700, the gross margin per

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[7] In Uganda and in other countries, black Sigatoka may damage production, reducing yields up to 50% (Tushemereirwe et al., 2000; Craenen, 1998).

hectare would increase from about USh 1,411,200 to about USh 1,650,500, or by about USh 239,300. If the irreversible planting costs are deducted, the expected average private incremental reversible benefits are about USh 389,200 per hectare (about US$222 per hectare).

Table 3. Incremental gross margin of cultivating one hectare of GM matooke

Variable	Non-GM banana (matooke)*	GM banana (matooke)**
Output (metric tons/year)	10.6	12.7
Price per ton (K)	149.6	149.6
Value of output (K)	1,504.4	1,902.9
Hired labor (hours)	232.8	256.1
Family labor (hours)	2,295.8	2,525.4
Total labor (hours)	2,528.6	2,781.5
Wage rate (USh/hour)	400.1	400.1
Cost of hired labor (K)	93.2	102.5
Cost of planting materials (K)[a]	0	151.7
Gross margin (K)	1,411.2	1,648.7
Return to family labor (USh/hour)	614.7	652.9
Expected average incremental gross margin (K)		237.5
Expected average private incremental reversible benefits (K)		389.2
Incremental average return per family labor (USh/hour)		38.2
Total incremental labor income per hectare (K)		96.4

* Source: Bagamba (2007).

** Source: Calculated by authors.

Note: Benefits and costs are valued in Uganda shillings (USh 1,750 ≈ US$1); return to fixed resources (e.g., land) is not deducted from the gross margin in the computation of return to family labor.

[a] Tushemereirwe, Kashaija et al. (2003) recommend an average of about 1,100 plantlets per hectare. Currently, the cost of one no-GM tissue cultured plantlet is USh 1,000. Due to biosafety requirements, the cost of a GM banana plantlet may at least increase by 30% (USh 1,300).

The introduction of a GM banana will trigger an additional cost for planting materials. The total planting costs for about 1,100 plantlets at a price of USh 1,300 per plantlet are about USh 1,430,000 per hectare (about US$817). In our computations, we calculated the average annual cost of planting materials using a capital recovery factor for a 10% interest rate and an expected GM banana plant life cycle of 30 years. Furthermore, we assumed no price discount for the GM banana at the farm gate and no other costs of adoption.

The private incremental reversible benefits per hectare were used as the initial value for calculating the SIRBs. To obtain conservative estimates of SIRBs for Uganda, we assume that GM banana adoption follows a logistic function.[8] We used this function to predict what the incremental benefits would be if the GM banana were adopted according to the logistic adoption function. We used an adoption ceiling rate of about 50% as a proxy for adopting any GM banana cultivar. This rate is based on

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[8] Following Griliches (1957) and Feder, Just, and Zilberman (1985), the adoption curve of a new technology is defined as $P = {}^{K}\!\big/_{1 + ae^{-bt}}$, where p is the percentage planted with GM banana in a given year, K is the ceiling rate (the long-term upper bound of adoption), a is the constant, related to the time when adoption starts, b is the speed of adoption, and t is the time variable. Parameters a and b were estimated using linear regression.

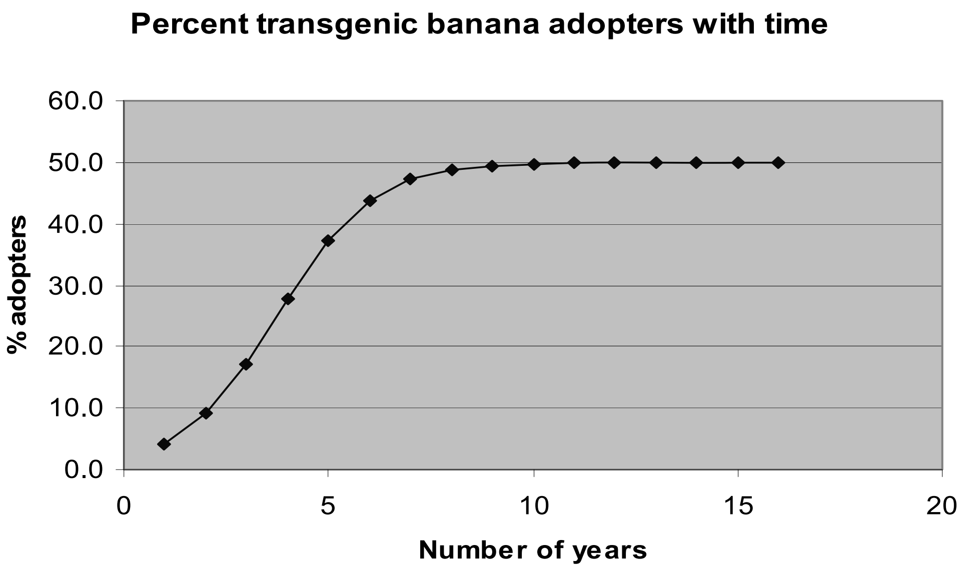
the predicted demand for nakitembe (a commonly grown cultivar) after effective insertion of genes with 60% resistance to both black Sigatoka and weevils, with supporting public investments in education, extension, and market-related infrastructure as estimated by Edmeades and Smale (2006). The adoption curve for an adoption ceiling of 50% and an estimated speed of adoption of 0.86 in linear form is $p(t) = 3.2 - 0.86t$. Figure 1 shows the assumed adoption curve.

We computed the SIRBs at time *t* (*SIRB (t)*), as the SIRBs at complete adoption times the adoption rate at time *t, P(t),* times the expected growth (or drift) at rate *α*: $SIRB(t) = SIRB \cdot P(t) \cdot e^{\alpha t}$. The discounted sum of SIRBs, $SIRB_{PV}$, for Uganda over time is calculated as:

$$SIRB_{PV} = \int_0^{\infty} SIRB(t) \cdot e^{-(\mu - \alpha)t} dt\ , \tag{2}$$

where μ is the risk-adjusted discount rate and *α* the drift rate of the geometric Brownian motion, explained in more detail below. The initial value for the calculation of the area for banana production is 1,670,000 hectares at full adoption.

Figure 1. GM banana adoption rate over time



Source: Authors' own elaboration

In our analysis, we limit ourselves to the private incremental reversible benefits at the farm level, assuming all the rents from the new technology are captured by farmers. In the longer run, the rents will be distributed among farmers, the agents within the banana supply chain, and banana consumers. Additional secondary benefits such as improved food security and reduced vulnerability to external shocks may be generated through higher farm income among banana growers. Assessing such benefits would require the use of a general equilibrium model for Uganda and be beyond the scope of this study. Thus, the computed SIRBs are equal to the private incremental reversible benefits (PIRBs).

We also tried to identify the social incremental irreversible benefits (SIIBs) on a per hectare basis using information provided by Bagamba (2007). Most banana producers in Uganda do not use pesticides or fungicides to manage pests and diseases, as mentioned earlier. A small proportion (less than a quarter) of banana producers applies small amounts of pesticides.

In the literature on banana production, no shock has been reported as a result of epidemics of banana pests and diseases. If an epidemic did result as a consequence of introducing the GM banana, that would result in an irreversible social cost, even if the possibility existed for reversing the epidemic (Demont, Wesseler, and Tollens, 2005). Epidemics can be considered among irreversible costs. An epidemic is both a private and public irreversible cost. This is indirectly accounted for in the computed MISTICs—see Table 2, quadrants 3 and 4.

The hurdle rate, $\beta/(\beta-1)$, depends on the uncertainty related to the expected SIRBs. Secondary time series data on banana yield per hectare (UBOS, 2006b) were used to estimate the drift and variance of the geometric Brownian motion as a proxy for the drift and variance rate from gross margin time series data. The geometric Brownian motion $U=(U_k(t), t\geq 0)$ is a continuous-time, continuous-state stochastic process in which the logarithm of the randomly varying quantity follows a Brownian motion: $U_k(t)=U_0\exp\left[\left(\lambda-\frac{\sigma^2}{2}\right)t+\sigma W(t)\right]$; where *W(t)* is a Wiener process, U_0 is the initial real random number, *t* is the length of equally spaced intervals for all $t\in[0,T]$, and parameters λ and σ are constants.

The random variables $\log(U_k/U_0)\equiv g_k(t)$ are independently and identically distributed with mean $(\lambda-\sigma^2/2)t\equiv \alpha t$ (α is the expected growth rate or drift) and variance $\sigma^2 t$, where $k=0,1,.....,n$. The maximum likelihood estimators for α and σ^2 were estimated as follows (see Campbell, Lo, and MacKinlay, 1997):

$$\alpha=\frac{1}{nt}\sum_{k=1}^{n}g_k(t), \tag{3}$$

$$\alpha=\frac{1}{nt}\sum_{k=1}^{n}g_k(t), \sigma^2=\frac{1}{nt}\sum_{k=1}^{n}(g_k(t)-\alpha t)^2, \tag{4}$$

where *t*, the length of intervals, was one year (t = 1), and n = 24 years (1980 through 2004). The estimated parameter values were ultimately used to derive hurdle rates for Uganda.

The different hurdle rates, $\beta/(\beta-1)$, were calculated as follows (see Dixit and Pindyck, 1994, pp. 147–52):

$$\beta=\frac{1}{2}-\frac{r-\delta}{\sigma^2}+\sqrt{\left[\frac{r-\delta}{\sigma^2}-\frac{1}{2}\right]+\frac{2r}{\sigma^2}}>1, \tag{5}$$

where *r* is the risk-free rate of return and δ is the convenience yield defined as the difference between the risk-adjusted discount rate μ and the drift rate α; i.e., α, $\mu\geq r$, and α and σ^2 variance rate as before. From the Uganda Bureau of Statistics' data on total area and production of all types of bananas, we estimated the average yield per hectare. Since cooking bananas contribute 80% of total banana production in Uganda, this is a fairly good proxy for the yield of cooking bananas. We estimated a variance rate (σ) of 0.0328 and a drift rate (α) of 0.0083 for the yearly difference change for all years from 1980 to 2004. Information about the risk-free rate of return and the risk-adjusted rate of return for farm household investments is rarely available and is difficult to calculate. Therefore, hurdle rates were calculated for different risk-free rates of return and risk-adjusted rates of return (0.04, 0.06, 0.08, 0.10, 0.12, and 0.14). Table 4 shows the computed annual SIRBs and MISTICs for a GM banana. The MISTICs are presented in total, on a per hectare, per household level, assuming 5,186,558 households as of November 2002 (UBOS, 2006a), and per banana-growing farmer, assuming 1,500,000 banana-planting farm households (Kalyebara et al., 2006).

Table 4. Hurdle rates, average annual SIRBs and MISTICs per hectare of GM banana, per household, and per banana-growing farm household at different risk-free rates of return (*r*) and risk-adjusted rates of return (*μ*)

			Risk-adjusted discount rates μ					
			0.04	0.06	0.08	0.10	0.12	0.14
		SIRB (million $)	365	304	260	226	200	179
		SIRB ($/ha)	459	399	356	326	303	287
risk free interest rate	0.00	Hurdle rate	1.0169	1.0104	1.0075	1.0059	1.0048	1.0041
		MISTIC (million $)	359	301	258	225	199	178
		MISTIC ($/ha)	451	394	353	324	302	285
		MISTIC ($/household)	69	58	50	43	38	34
		MISTIC ($/farmer)	239	201	172	150	133	119
	0.04	Hurdle rate	1.3298	1.0405	1.0166	1.0103	1.0075	1.0058
		MISTIC (million $)	274	293	256	224	198	178
		MISTIC ($/ha)	345	383	350	322	301	285
		MISTIC ($/household)	53	56	49	43	38	34
		MISTIC ($/farmer)	183	195	170	149	132	119
	0.10	Hurdle rate				1.1386	1.0355	1.0161
		MISTIC (million $)				199	193	176
		MISTIC ($/ha)				286	293	282
		MISTIC ($/household)				38	37	34
		MISTIC ($/farmer)				132	129	118

Source: Authors' computation.
Exchange rate $1 = USh 1,750.

The results in Table 4 show that the SIRBs, as expected, decrease with an increase in the risk-adjusted rate of return. The estimated SIRBs range between US$365 million and US$179 million per year, or US$459 and US$287 per hectare per year, for the range of risk-adjusted discount rates that varied from 4% to 14%. The hurdle rates differ as the risk-free rate of return and risk-adjusted rate of return vary. For instance, at $\mu = 0.1$ and r=0.04, the hurdle rate is about 1.01. This means that on average every US$1 of incremental social irreversible cost has to match with about 1.01 SIRBs to justify the immediate introduction of the GM banana. In general, the hurdle rates estimated in this paper are very low compared with other estimates in the literature. This indicates that the irreversibility effect (Henry, 1974) is relatively small and much less important in comparison to other cases studies, where the hurdle rates range between 1.04 and 3.69 (Demont, Wesseler, and Tollens, 2004) and 1.03 and 5.6 (Wesseler, Scatasta, and Nillesen, 2007). We speculate that a potential explanation for the small value of irreversibility is that the statistical data from which we derived the MISTICs are not capturing production variability. Uganda's production data used to estimate the MISTICs are fairly smooth, in spite of observed biotic shocks in the 1990s and other years. Damage in a particular year may have been localized, yet heavy in those localized areas, so that national averages smooth out variations. Nevertheless, a smaller hurdle rate for Uganda implies that a delay in the introduction of a GM banana, for biosafety assessments or other reasons, affects benefits negatively.

The annual MISTICs decrease as well with an increase in the risk-adjusted rate of return and with an increase in the risk-free rate of return. At $\mu = 0.10$ and $r = 0.04$, MISTICs are about US$322 per hectare per year, or about US$224 million per year. The MISTICs per banana-growing farm household and those per household indicate a large difference between the two groups. The MISTICs per farm household are more than three times larger than the MISTICs per household. As indicated previously, the MISTICs can be interpreted as the maximum willingness to pay for having a GM banana approved for planting in Uganda. Therefore, the difference in the MISTIC values between farm households and non-banana-producing households—both urban and rural—shows that in general the average banana-growing farm household may have a much larger interest than an average Ugandan household in having access to a GM banana even if the banana-growing household is concerned about the irreversible costs.

Non-banana-producing households in Uganda outnumber banana-producing households by about three to one. Therefore, the numbers presented here underscore the large magnitude of benefits foregone by Uganda, and thus reducing as much as possible the time needed to complete biosafety assessments becomes critical for the country. This statement supports scientists' opinion to not delay the introduction of disease-resistant bananas as the biological characteristics of the banana plant point to a lower risk as compared with other crops. As the banana plant is female sterile, an insignificant quantity of seed is produced, which is mainly sterile, and thus the probability of sexual reproduction or gene flow is insignificant. Therefore, the GM banana has a relatively safe environmental biosafety profile. An approach to assess whether benefit valuation is different between producer and consumer households is presented in the following section.

The specific GM banana that is going to undergo a confined field trial and posterior biosafety assessments is intended to control the fungal disease black Sigatoka. That disease affects mainly yield, but it also reduces bunch size. Consumers are able to observe the smaller bunch size but may not be able to associate the smaller size with the disease. The latter statement may also be true for other pests and diseases that primarily affect yield, such as nematodes, banana weevils, and other diseases. In contrast, the damage of diseases such as banana bacterial wilt is not readily apparent to consumers until after they purchase and consume the banana. In such a case, the consumer may be able to more readily associate damage with a disease. Thus, the value to consumers of a GM banana that is resistant to bacterial wilt may be higher. Consumers, in the case of bacterial wilt, may have a higher demand for a specific resistant variety. The increased demand may be high enough that consumers will pay a premium for a variety that guarantees an undamaged product. The latter statements, of course, become testable hypotheses for future work, and thus proposing methodologies to finely measure consumer willingness to pay for a GM banana becomes critical. We introduce one alternative methodology in the next section.

6. WILLINGNESS TO PAY FOR A GM BANANA

GM bananas are still currently a nontradable good in Uganda. A non-market valuation method (i.e., stated preference) can be used to determine the willingness to pay for a GM banana. Stated preference techniques involve asking respondents about their economic behavior, given a well-described artificial market scenario. Such techniques avoid some difficulties associated with revealed preference studies: they can assess demand for products that have poorly developed markets; they avoid issues of colinearity and low variability in explanatory variables; they are less demanding of research resources; and they can be experimentally designed to provide clear and easily interpretable results (Louviere, Hensher, and Swait, 2000).

Stated preferences are commonly elicited by using choice experiments. A choice experiment normally provides four pieces of information about a non-market good: (1) which attributes are significant determinants of the product value; (2) the relative rank of attributes among relevant populations; (3) the value of changing more than one attribute at once; and (4) the total economic value of the good (Bateman et al., 2003). A choice experiment is a highly structured method of data generation that relies on carefully designed tasks or experiments to reveal the factors that influence choice, but requires large sample sizes. The good is defined in terms of its attributes and the levels these attributes would take under different management scenarios. One of the attributes is the price, which enables estimation of the welfare measure, or value. Experimental design theory is used to construct profiles of such a good in terms of its attributes and attribute levels. Often, two or three alternative profiles are assembled in choice sets and presented to respondents, who are asked to state their preferred profile in each choice set (Louviere, Hensher, and Swait, 2000; Bennett and Blamey, 2001; Bateman et al., 2003).

The choice experiment method is one of the various choice models derived from random utility theory (e.g., McFadden, 1974; Ben-Akiva and Lerman, 1985). Lancaster (1966) proposed that consumers derive their satisfaction not from goods themselves but from the attributes they provide. Consumers try to maximize their utility by choosing the goods they think suit them best, all else equal. Chosen goods include products, services, and policies. The choice is subject to consumers' knowledge about competing options and individual constraints, such as income (Adamowicz et al., 1999; Bennett and Blamey, 2001; Bateman et al., 2003). The consumer *n* will choose option *i* over alternative *j* if $U_{ni} > U_{nj}$. Due to the random component, predictions cannot be made with certainty. Thus, the analysis becomes one of probabilistic choice. The probability that any particular respondent prefers a given option in the choice set to any other option can be expressed as the probability that the utility associated with a given option exceeds that associated with all other options:

$$P_{ni|C} = prob(U_{ni} \geq U_{nj}); i \neq j, \forall j \in C, \tag{6}$$

where the probability that individual *n* chooses alternative *i* in the choice set *C* ($P_{ni|C}$) is proportionate with the probability that the utility U_{ni} is greater than the other alternatives U_{nj} in *C*. The equivalent indirect utility function, following Hanley, Wright, and Adamowicz (1998) and Adamowicz et al. (1999), can be stated as

$$U_{ni} = V_{ni}(X_{ni}) + e_{ni}, \tag{7}$$

where U_{ni} is the total utility that individual *n* acquires from alternative *i*, which is decomposed into a deterministic component (V_{ni}) and an error component (e_{ni}). The deterministic component is a function of a vector X_{ni}, consisting of attributes of a selected option and personal characteristics of the respondent *n*. The error e_i accounts for the entire unknown attributes and characteristics (Adamowicz et al., 1999) and is assumed to be independent of X_{ni} and to follow some predetermined distribution.

U_{ni} is a conditional indirect utility function (Adamowicz, Louviere, and Williams, 1994; Rolfe, Bennett, Louviere, 2002). Assuming the e_{ni} disturbances are Gumbel and are independently and identically distributed (IID) with type-I extreme-value (Gumbel) distribution, the standard multinomial logit (MNL) model (McFadden, 1974) can be derived to estimate the parameters of U_{ni}, which takes the form

$$P_{in} = \frac{e^{\mu \beta X_{in}}}{\sum_{j \in C} e^{\mu \beta X_{jn}}}. \qquad (8)$$

The scale parameter μ is usually assumed to be equal to 1 (implying constant error variance) for the standard MNL model. This model is usually simple in constructing and analyzing data but imposes stringent behavioral restrictions on the data such as homogeneity with respect to individual preferences. This can lead to biased utility parameter estimates in cases where there is heterogeneity in preferences (Greene, 1977. Heterogeneity in preferences is a reasonable assumption for producers and consumers of GM crops.

Farmers have heterogeneous preferences regarding crop choices that depend on economic and socioeconomic factors and are well documented in the literature. Those preferences are likely to affect the willingness to pay (WTP) as well as the likelihood of adoption. The WTP of consumers in urban areas as well can be expected to differ and to depend on such differences as income, education, and occupation. Urban consumers may assign higher utility values to expensive, good quality, and more nutritious bananas. On the other hand, they may be more concerned about the future health risks of foods. Urban consumers have different sources of information and may differ in their capacity to utilize information. With genetic engineering remaining controversial, information on GM crops may influence consumers' willingness to pay for a GM banana. Difference in demand implies that homogeneity in tastes is unlikely to be the case for a GM banana.

To account for this heterogeneity a number of alternative models have been suggested. The commonly used ones are the heteroscedastic extreme value (HEV)[9] models, random parameter models,[10] mixed logit models (Greene and Hensher, 2003; Rigby and Burton, 2005), and latent class models (Swait, 1994; Louviere, Hensher, and Swait, 2000). The latent class models are suitable for capturing heterogeneity, while the basic multinomial logit models assume homogeneity in tastes and preferences. The random parameter logit model allows choice parameters to vary across individuals, but the latent segment (LS) approach assumes that choice parameters vary across segments of individuals. The LS approaches have been quite successful at identifying the sources of heterogeneity (Fredman and Emmelin, 2001; Kontoleon, 2003; Hu et al., 2004; Kontoleon and Yabe, 2006) at the segment level that are policy relevant. Kontoleon (2003) notes that unlike all other models that capture heterogeneity in consumer preferences, the LS model was found to be superior on policy grounds because it provides information on the viability of creating segregated food production, distribution networks, and markets, as well as an understanding of the welfare distributional impacts of alternative GM food policies.

In this study we apply an LS model similar to that of Swait (1994) to capture and account for heterogeneity among consumers (both farmers and urban consumers). The proposed model can generate the required parameters estimating respondents' willingness to pay to avoid or seek a level of an attribute or an alternative among members of the population. The use of the LS model developed by Swait (1994)

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[9] HEV models parameterize μ with individual sociodemographic characteristics and relax the independent alternative assumption (IAA) property (see Louviere, Hensher, and Swait, 2000; Johnson, Banzhaf, and Desvousges, 2000). These models capture differences in respondent coherence, decision making, or interest in the activity (Breffle and Morey, 2000), but the approach does not examine how choice attributes differ across individuals with varying characteristics.

[10] Random parameter logit models allow all choice-specific parameters to vary across individuals but assume that the functional form and utility arguments are common. The models are not subject to the IAA property and perform better than conditional logit approaches (e.g., Breffle and Morey, 2000; Brownstone and Train, 1999; Revelt and Train, 1998). Some studies (e.g., Boxall and Adamowicz, 1999; Adamowicz et al., 1998) have raised concern that random parameter models are not appropriate for explaining the sources of heterogeneity.

and Boxall and Adamowicz (2002) allows one to identify the factors that drive consumers' willingness to pay and in particular the willingness (if any) to give up social benefits. The LS model identifies the sources of unobserved preference heterogeneity across individuals by revealing a finite number of latent segments of consumers that comprise individuals with tastes $\beta_s, (s = 1, \ldots, S)$ unique to that segment or that have different underlying variances (Swait, 1994; Louviere, Hensher, and Swait, 2000). The model postulates an indirect utility function of the form

$$U_{ni/s} = \beta_s X_{ni} + e_{ni/s}, \tag{9}$$

where *i* is the alternative chosen by individual *n* belonging to segment *s*, in which $e_{ni/s}$ are IID and of extreme-value type-I (or Gumbel) distribution.

The probability of choosing alternative *i* by the *n*th individual in segment *s* is then given by

$$P_{in/s} = \frac{e^{\mu_s(\beta_s X_{in})}}{\sum_{j \in C} e^{\mu_s(\beta_s X_{jn})}}, \tag{10}$$

where μ is a scale factor that captures difference in variances, and the probability of an individual *n* being in segment *s* is

$$W_{ns} = \frac{e^{\lambda(\alpha_s Z_n)}}{\sum_{s=1}^{S} e^{\lambda(\alpha_s Z_n)}}, \tag{11}$$

where Z_n is a column vector of observed and unobserved characteristics of the individual and α_s is the row vector of the corresponding parameters. Bringing equations 10 and 11 together, we construct an unconditional probability of individual *n* belonging to segment *s* choosing alternative *i*:

$$P_{isn} = \sum_{s=1}^{S} P_{in/s} W_{ns} = \sum_{s=1}^{S} \left[\frac{e^{\mu_s(\beta_s X_{in})}}{\sum_{j \in C} e^{\mu_s(\beta_s X_{jn})}} \right] \cdot \left[\frac{e^{\lambda(\alpha_s Z_n)}}{\sum_{s=1}^{S} e^{\lambda(\alpha_s Z_n)}} \right]. \tag{12}$$

The number of segments in the LS model can be endogenously determined with the utility coefficients using various information criteria (Boxall and Adamowicz, 2002; Andrews and Currim, 2003). Thus, instead of arbitrarily dividing consumers into different segments based on observable similarities (e.g., sociodemographic characteristics) and estimating respective preferences for each individual class, the LS model uses the information derived from individual choices.

The WTP Welfare Measures in the Latent Segment Model

Once models have been developed and the required parameters generated, respondents' willingness to pay to give up social benefits of a GM banana can be estimated. The LS model allows us to calculate WTP welfare measures for each respondent within a segment. Deriving welfare measures under the LS models is done in two steps. First, policy impacts at the segment level are identified by calculating WTP welfare measures for each segment. Second, the standard aggregate procedure (that assumes homogeneous preference) is corrected for heterogeneity. That is done by computing the weighted sum of segment-specific welfare measures. The weights are the estimated individual segment membership probabilities (Boxall and Adamowicz, 2002). The individual segment WTP can finally be aggregated to estimate WTP welfare measures for the whole population.

Following Hanemann (1983, 1984), the general WTP welfare measure can be calculated as

$$CV_n = \frac{1}{\theta}\left[\ln\left(\sum_{i\in C} e^{\beta X_i{}^0}\right) - \ln\left(\sum_{i\in C} e^{\beta X_i^1}\right)\right], \tag{13}$$

where the compensating variation CV_n is the amount of money that one would have to give the individual n after the change has occurred in order to remain as well off as before; θ is the marginal utility of money and is the coefficient of the price attribute; βX_i^0 represents the individual's utility at the initial level (i.e., prechange state); and βX_i^1 is the utility of the alternative level (i.e., postchange state) following changes in attributes in X.

The final marginal WTP welfare measure can be derived by, first, integrating the welfare effects across the different segments,

$$CV_{n|s} = \frac{1}{\theta_s}\left[\ln\left(\sum_{I\in C} e^{\beta_s X_I{}^0}\right) - \ln\left(\sum_{I\in C} e^{\beta_s X_I^1}\right)\right], \tag{14}$$

and, second, by calculating the weighted sum of the segment membership:

$$CV_{n|s}^t = \sum_{s=1}^{S} W_{ns}\left\{\frac{1}{\theta_s}\left[\ln\left(\sum_{I\in C} e^{\beta_s X_I{}^0}\right) - \ln\left(\sum_{I\in C} e^{\beta_s X_I^1}\right)\right]\right\}, \tag{15}$$

where W_{ns} is the probability of an individual n being in segment s.

Suggested Sampling Procedures and Data Collection for a GM Banana in Uganda

The WTP study can be conducted in different regions in Uganda where cooking bananas (matooke) are produced and consumed, including urban areas that are net consumers of bananas. Implementation of this procedure allows for the capture of heterogeneity in preferences across different population segments. The survey sample can be drawn using a multistage sampling procedure from the major banana-producing regions in eastern, central, and southwestern Uganda. The 2002 Uganda census indicates that only 12.3% of the population resides in urban areas. Those areas include cities, municipalities, and town councils (UBOS, 2006a). Every day, 65% of urban consumers in Uganda have a meal of matooke (Clarke, 2003). More than three-quarters of bananas produced are consumed on the farm (NARO, 2001), implying that a large proportion of matooke production is for subsistence. Respondents should therefore be stratified into rural consumers (producers and consumers) and urban consumers of matooke and receive extra information about the GM banana.

Studies have revealed that willingness to purchase GM food products increases especially for GM foods with tangible consumer benefits (Loureiro and Hine, 2002; Li et al., 2003; Loureiro and Bugbee, 2005; Onyango and Govindasamy, 2005). All choice sets should therefore incorporate several attributes of the GM banana, including the incremental social benefits. In addition, respondents will be asked about their awareness of, perceptions of, and attitudes toward biotechnology and the biosafety of genetically modified products. Socio-demographic characteristics will also be captured. This allows one to identify the factors that influence the willingness to pay and, in particular, the willingness (if any) to give up social benefits.

The primary sampling unit (PSU) should be the subcounty for rural areas and the municipality/town council for urban areas. A total number of 12 PSUs will be selected—three-quarters in rural areas, and a quarter in urban areas. This is based on the distribution of the Ugandan population[11] as reported in the 2002 census. The secondary sampling unit is defined at the village level, including 20 randomly selected households with 40 households per PSU. A sample size of about 480 households is needed for the suggested attributes and attribute levels. Table 5 shows attributes (consumption and production) and levels for choice sets for the GM banana.[12] Tables 6 and 7 show examples of possible choice scenarios.

Table 5. Attributes, their definitions, and levels for choice sets

Attribute[a]	**Definition**	**Attribute level**
Bunch size	The average weight in kilograms of a banana bunch at harvest, categorized into small, medium, and large	5 to 15 (small) 16 to 25 (medium) 26+ (large)
Extra benefit	The estimated extra monetary benefit per hectare in Ugandan shillings that would result if a gene were inserted in cooking banana (matooke) planting materials in order to improve resistance to pests and disease (e.g., banana bacterial wilt or black Sigatoka)	USh 0 USh 60,000 USh 120,000
Technology	The technology used to produce the banana planting material	Tissue culture only Tissue culture + GM
Price	Hypothetical percent change in price of a bunch of bananas	-30 -15, 0, +15, +30 +40

Source: [a] Attributes were derived from focus group interviews with farmers, as well as from previous work on banana attributes in Uganda. For more information, several studies can be consulted: Smale and Tushemereirwe (2007); Edmeades (2003); Nowakunda et al. (2000); Karamura et al. (1998); Gold et al. (1998).

Table 6. Example of a choice scenario with a benefit presented

Attribute	**Option A**	**Option B**	**Option C**
Bunch size (Kg)	5–15	26+	I would not buy any of those mentioned banana
Extra benefit to farmer per hectare (USh)	0	120,000	
Technology	Tissue culture only	Tissue culture + GM	
Price (% change)	15	0	
Indicate your choice by a tick in any one box	☐	☐	☐

Source: Author's own elaboration

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[11] Less than a quarter of the population is in urban areas, but the selected regions contribute over 90%.

[12] The perceived consumption (cooking) quality of the GM banana (matooke) is expected to be akin to that of non-GM matooke—that is, with good taste, soft texture, and yellow color.

Table 7. Example of a choice scenario with no benefit presented

Attribute	Option A	Option B	Option C
Bunch size (Kg)	16-25	5-15	I would not buy any of those mentioned banana
Extra benefit to farmer per hectare (USh)	0	0	
Technology	Tissue culture +GM	Tissue culture only	
Price (% change)	40	0	
Indicate your choice by a tick in any one box	☐	☐	☐

Source: Author's own elaboration

Integrating MISTICs and WTP

The MISTICs associated with the immediate introduction of a GM banana can be compared with the estimated WTP values for the GM banana for different scenarios. The MISTICs provide a threshold value for the immediate release of a GM banana. The WTP shows how much money consumers are willing to pay to accept or avoid the introduction of a GM banana. Therefore, if the WTP for not having a GM banana introduced is greater than the MISTICs, then arguments can be advanced for delaying the introduction of the GM banana. If the WTP for not having a GM banana is positive but below the MISTICs, then very good economic arguments exist for not further delaying the introduction of the GM banana. An advantage of estimating the WTP is that the results of the study will allow identification of the differences between segments of producers and consumers that can help to formulate national policies. We expect that the parallel (joint) estimation of the MISTICs, the SIRBs, and the WTP will become an invaluable technique in the socioeconomic impact assessment of genetically modified biotechnologies and other technologies.

7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In this study we have presented an approach for considering concerns about genetically modified crops within a socioeconomic analysis of GM crops. The study proposes a framework for the GM banana. The approach presented relates the economic benefits to consumers' concerns. We propose to compare the maximum incremental social tolerable irreversible costs (MISTICs) with the willingness to pay for the technology. The suggested procedure considers not only the possible long-term effects but also the short-term benefits and costs of the technology. The comparison provides information on whether the introduction of a GM banana poses a socioeconomic problem from the consumer's point of view.

We calculated the MISTICs associated with the adoption of a GM banana in Uganda. The MISTICs were presented for different risk-free and risk-adjusted rates of return. The preliminary results show the MISTICs to be between approximately US$176 million and US$359 million per year, or between US$282 and US$451 per hectare per year. In the scenario with a risk-adjusted rate of return of 12% and a risk-free rate of interest of 4%, which we consider to be a reasonable scenario, the annual MISTICs per household are about US$38. This result can be interpreted as follows: the immediate release of the GM banana should be postponed or abandoned only if the average household is willing to give up more than US$38 per year for not having such a banana introduced.

In the case where approval of the GM banana is delayed due to missing regulatory procedures and protocols, Uganda will forego potential benefits (social incremental reversible benefits, or SIRBs) in the approximate range of US$179 million to US$365 million per year. This foregone benefit can be an indicator of how much Uganda can pay to compensate for potential damages. Additionally, the SIRBs provide a clue about the maximum costs farmers would endure in order to comply with biosafety regulations, including the cost of implementing coexistence policies and after deducting planting costs of US$101 per hectare. In a reasonable scenario, for instance, the average SIRBs total about US$303 per hectare. Adopters of the GM banana would not be willing to pay more than US$200 per hectare per year in transaction costs—i.e., costs to comply with biosafety regulations, R&D costs, and technology transfer costs. If the average WTP per hectare of a banana-growing household is below the MISTICs but biosafety regulators are inclined to implement biosafety regulations to address concerns of consumers with a high WTP for not having the GM banana, those additional costs should not exceed US$200 on average per year per hectare of GM banana. Assuming a maximum of 541,530 hectares that may be planted in GM banana in Uganda, this implies that the maximum total costs to bring the GM banana to Ugandan producers cannot exceed US$108 million. Otherwise, the GM banana is not a viable alternative.

One of the limitations of this analysis, however, is that we have not included the transaction costs that might be involved between the technology developers and the end users, including R&D costs, compliance with biosafety regulatory costs, and technology fees.[13] Such costs can be substantial and are one of the major obstacles to technology dissemination in developing countries such as Uganda (Brenner, 2004). The problem is not limited to GM technology but to embodied technologies in general. Adding such costs will reduce the SIRBs. Again, they should on average not be more than the SIRBs per hectare, and should be even less if biosafety regulatory costs at the farm level are added.

The approach for assessing the WTP contributes to the knowledge of understanding the extent of concerns (e.g., consumer attitudes toward biosafety risk) about GMOs in a heterogeneous banana industry. The approach used in this study illustrates a framework that can be used to identify the different consumer segments within the population—their size, their characteristics, and how they differ. In this regard, the biosafety regulators can, first, know what would be the impact of introducing a GM banana to consumers with heterogeneous preferences and, second, have a rough estimate of how much would be required to compensate a given population segment if a GM banana were introduced. Finally, policymakers would have explicit information about the risk margins for introducing a GM banana (or other crop), which contributes to better-informed debates and a more transparent policymaking process.

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[13] As technology fees charged by innovators are used to recover R&D costs and biosafety costs, it is imperative to include such costs as net costs to society to avoid double-counting.

Implications for Decision Making on Biotechnology and Biosafety Regulations

The analyses in this paper demonstrate the economic value and the effect of the foregone benefits as a result of waiting to release a GM banana. The results illustrate several implications to numerous stakeholders. First, the calculation of the MISTICs considers explicitly possible long-term effects of GM banana. The results indicate that with each year of delay in the introduction of a GM banana, Uganda loses about US$179 million to US$365 million to all households in Uganda. The MISTICs are on the order of about US$176 million or more. Only if the real average annual irreversible costs of planting a GM banana would be as high, or higher than, the irreversible benefits, should the release be delayed. We have found no evidence yet that this will be the case. Given the potential and significant economic benefits from the introduction of a GM banana, NARO has to work harder to push the GM banana through the biosafety protocols as promptly and efficiently as possible.

Second, the results may not convince all stakeholders. There is an urgent need for NARO and other R&D institutions to conduct research to understand how consumers feel about GM banana biosafety risks and the potential challenges for marketing the product. We have illustrated how one could implement such a study of consumer perception. Further research on implementing the assessment procedure that this paper describes has been initiated by the authors in Uganda. The experience gathered from the field research in Uganda can serve to establish a feasible and practical system for consumer assessments as part of the approval process for GM crops if indeed socioeconomics become part of the decision-making process for approval before commercialization.

Third, our findings indicate that a banana-growing household may have a much (three times) larger interest in having access to a GM banana than an average Ugandan household. This can be explained by the great losses experienced by farm households due to the prevailing banana constraints. The losses caused by banana constraints, therefore, make the opportunity cost to farmers of not using the GM banana technology extremely high. This implies that a farm household would naturally benefit disproportionately from a GM banana technology that is likely to ensure a return to sustainable production.

The challenge decision makers (regulators) face is to develop a regulatory process that will ensure a high degree of safety without imposing stringent biosafety regulations on the development and accessibility of the technology. Unfortunately, such a process may mean substantial time will pass before the product can be accessed by farm households. The reasons for that may be, first, that approval of the GM banana in Uganda has followed a sequential protocol of biosafety regulation where each stage demands an application to and approval by the National Biosafety Committee, and second, that a fungus- (or bacteria-) resistant banana is a novel crop in terms of the gene, the transformation process, and the crop. There is very little regulatory experience elsewhere with any of these components. There may be additional delays in terms of regulatory time for approval as a result of the likely regulatory procedures and protocols to prove the safety of the gene, the transformation protocol, and the final novel product. The implication of this extended procedure will be a (likely) higher cost of compliance with the biosafety assessments. A longer time, a greater effort, and thus a greater cost than is necessary to prove safety in the biosafety regulatory analysis of a GM banana may presumably result in failure to access the expected benefits of the GM banana.

Biosafety regulatory assessment, and its posterior analysis, has to overcome the observed tendency of most regulatory processes globally of avoiding committing regulatory errors during decision making and particularly stacking the odds in favor of not approving technologies that are safe against approving a technology that is not safe. In essence, decisions made by most regulatory bodies tend to be more precautionary than warranted. To ensure a more balanced approach to decision making, the literature suggests consideration of all benefits and costs—including opportunity and irreversible—supporting regulatory decision making. This paper proposes one alternative in this line of reasoning.

Lastly, the approach used here highlights how one can evaluate the socioeconomic aspects of GM crops in general. To those stakeholders who are pessimistic about such technologies, it shows how much benefits are foregone as a result of a delayed release of a given technology. We have also indicated how one can consider long-term irreversible effects and how one might assess consumer attitudes toward GM crops. The approach can therefore be adapted to new GM crops requiring biosafety assessments prior to commercialization and can help to overcome one of the problems of establishing a biosafety system for Uganda. In particular, NARO may want to institutionalize the approach suggested in this paper and build a system that allows for conducting similar analyses of other GM crops. Banana is one of the staple crops in Uganda and is integral to ensuring the livelihood of households in the country. Addressing and resolving the binding constraints on banana production in Uganda therefore will contribute to ongoing poverty alleviation efforts and compliance with the Millennium Development Goals and overall sustainable social and economic development.

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