Assessing Agricultural Biotechnology: Applications of *Ex-ante* and *Ex-post* Methods to Genetically Modified Crops

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Introduction

Generating, promoting, and adopting agricultural biotechnology are on the agricultural development agendas of developing countries, but knowledge about the economic impact of agricultural biotechnology is inadequate. Policymakers, non-government organizations (NGOs), and researchers are questioning the potential and actual benefits and costs associated with adopting genetically modified (GM) crops. Therefore, accepting genetically modified food for aid or growing genetically modified crops for export or even local consumption is a contentious issue. To inform the debate, more impact assessment regarding the benefits and costs of agricultural biotechnology adoption is needed, but for this assessment to occur, researchers need to know and understand how and when the various impact assessment methods should be used.

Ex-ante and *ex-post* economic assessment studies using various methodologies have been conducted, but this information is scattered amongst

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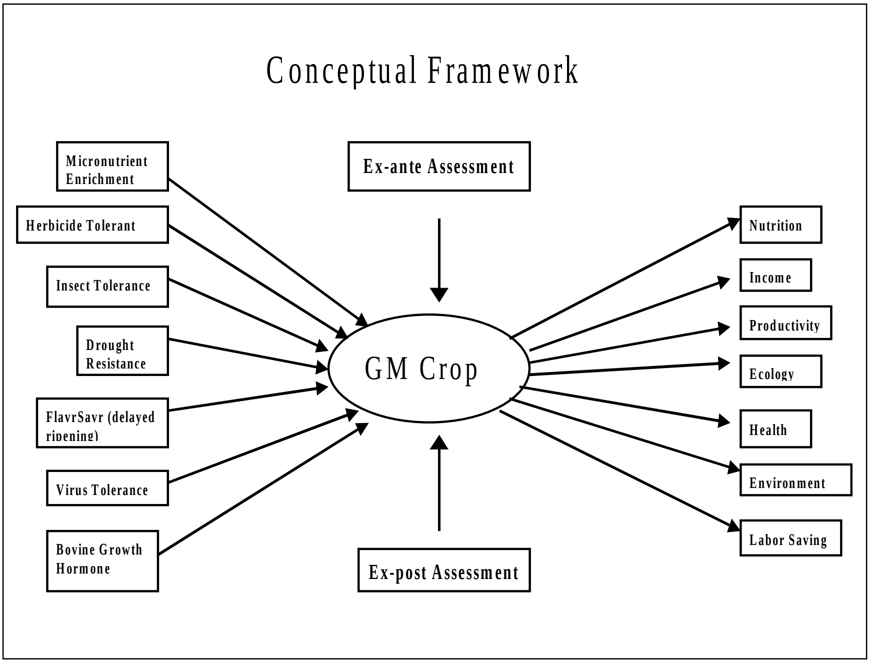
various journal articles, conference presentations, and other unpublished work. This paper attempts to compile different *ex-ante* and *ex-post* economic impact assessment methodologies that are applicable to adopting agricultural biotechnology. Whenever possible, this paper takes it one step further by giving an example of the method being applied to a genetically modified crop. Before delving into the different methodologies, a conceptual framework for assessing the economic impact of crop biotechnology is presented. The importance of assessing the economic impact of adopting this technology is then explored. After understanding why economic assessment is essential, the various *ex-ante* and *ex-post* assessment methods are reviewed. Each methodology description explains how the assessment can be adapted to biotechnology products and what data is needed to undertake such an assessment. If an agricultural biotechnology case study is available, it is included with the explanation. Learning the different methods is only the first step in analyzing the economic impact of adopting genetically modified organisms. There are several challenges that restrict the use of these methods, which are discussed in the following paragraphs.

Conceptual Framework

Technology assessment of potential costs and benefits serves as a bridge between the generation of technology in the laboratory and its adoption. Figure 1 places technology assessment at the center of identifying the benefits and the cost of adopting technology. Biotechnology traits that decrease cost or increase output are listed on the left side of the conceptual framework. They include, but are not limited, to micronutrient enrichment, herbicide tolerance, insect-tolerant, virus tolerance, FlavrSavr, and Bovine Growth Hormone. The potential productivity, nutritional, and environmental gains from adopting these technologies include but are not limited to improved nutrient content of crops, increased yields, higher income resulting from increased output, and improved ecology, health, and environment, which are listed on the right side of the conceptual diagram.

The two major approaches to technology assessment are *ex-ante* and *ex-post*, which are identified at the center. These two approaches are elaborated in the following sections.



What Methodology To Use?

Researchers can assess GM crops for economic impact before and/or after it is commercially adopted. Thus, the method used for this assessment depends on when it will be conducted. *Ex-ante* methodologies are used for crops not commercially adopted and *ex-post* methods for after their adoption. However, choosing a technology assessment method is not as simple as choosing between *ex-ante* or *ex-post* approaches. There are several different methodologies within the two broad categories, which are described below.

Ex-ante Technology Assessment

Ex-ante methodologies help set priorities and allocate financial and human resources for technology development that addresses specific needs of targeted users such as enhanced income or food security in a sustainable way. Table 1 lists *ex-ante* methodologies and case studies of their application if available.

Table 1: *Ex-ante* Methods of Economic Assessment

Method	Examples
Partial Budget Approach	Alston, Hyde, and Marra. 2002
Cost-Benefit Analysis	Araji and Guenthner, 2002
Consumer/Producer Surplus	Falck-Zepeda, Traxler, and Robert, 2000
Dynamic Research Evaluation and Management Model	Pachico, Escobar, Rivas, Gottret, and Perez, 2001
Computer General Equilibrium/ Simulation Model	Nielsen, Thierfelder, and Robinson, 2001
	Demont and Tollens, 2001
	Moschini, Lapan, and Sobolevsky, 2000
	Barkley, 2002
Multi-Market Model	Yet to be applied

Partial Budget Approach

The partial budget approach compares costs and returns of alternative farm plans and evaluates the economic effect of minor adjustments and changes in fix resource (Dalsted and Gutierrez, 2001). It estimates changes in profits or losses, measures changes in income and returns to limited-resources, provides limited assessment of risk, and suggests a range of prices or costs at which a technology becomes profitable.

The approach requires an adoption model to be used to determine the estimated adoption rate of a particular crop, which is based on the next-best alternative. The method only includes budget components that are expected to change with the adoption of the new technology. Therefore, the data will vary according to what is expected to change, but the basic data requirement are input and output quantities, input prices, productivity levels of alternative technologies, and output prices. Adding farm and non-farm benefits will determine the national benefits (USDA/ERS, 1999-2000).

Case Study: An Ex Ante Analysis of the Benefits from the Adoption of Monsanto's Corn Rootworm Resistant Varietal Technology — YieldGard Rootworm

This study estimates the likely economic impact of commercial adoption of Monsanto's YieldGard Rootworm in the United States. The first step involves evaluating the farm-level economic impacts of adopting YieldGard Rootworm varieties. The second step is to translate those farm-level impacts into an estimated economy-wide impact. Alston *et al.* (2002) used data from 11 districts and assumed the adoption that all farmers in a particular agroecology will adopt the technology in year if it is expected to be more profitable than the next-best alternative subject to a risk non-pecuniary aspects. To begin the analysis, a base yield and price for untreated crops was determined (USDA/ERS, 1999-2000). Then the base yield was adjusted upward by the average yield increase associated with the type of control – genetically modified or chemical applications. The net benefits of YieldGard Rootworm relative to chemical applications was calculated by setting each yield increase to the average level associated with a given root rating. They computed the total annual regional benefits by multiplying the region-specific benefits per acre by the relevant number of acres in the region. To determine the non-farm benefits, they multiplied the seed premium by the number of applicable acres. In calculating the total benefits, Alston *et al.* (2002) summed information on per acre benefits from adoption, the number of profitable adopted acres, and profits of seed companies.

The results from this method vary according to the scenario and the region, but overall there were benefits. The total annual regional benefits, under the moderate scenario and based on the regional prices of corn in 2000 ($1.85/bushel) was $16.49 per acre treated. Between the "low" and "high" scenarios, the estimates of total benefits ranged from $8 to $29 per acre. If the regional price of corn was based on the ten-year average the US price ($2.32/bushel), the total annual benefits would be $23 per acre treated. The annual national benefits in 2000 (using 2000 prices) would have been $402 million.

Cost/Benefit Analysis

The cost/benefit analysis considers gains and losses that are measurable. This method is useful for estimating annual gross benefits and projecting the present value of the flow of annual gross benefits from a technology adoption in the future. The data needed to estimate the benefits are the expected total acreage affected by the technology, the expected percentage change in net production per tonne, net reduction in price discount, pesticide cost, net decrease in storage loss, expected price per tonne of the genetically modified crop, and price per unit of crop.

Case Study: Genetically Modified Foods: Consumers and Producers Perceptions and the Economic and Environmental Benefits

Araji and Guenthner (2002) used this method to estimate the economic and environmental benefits of genetically modified potatoes. The data needed were total hectares of potatoes, percentage of planting currently susceptible to late blight, percentage of plants susceptible to late blight that require fungicide spray, fungicide application rate, and percentage of active toxic materials in each fungicide. Gross benefits included summing yield increase, storage loss reduction, improved quality, and reduced fungicide cost. Adopting GM potatoes is estimated to increase yields by 5 per cent, reduce storage loss by 1.2 per cent, and improve revenue by 3.2 per cent. This model also estimated the annual world gross benefit to exceed $4.3 billion. The present value of GM potatoes over 25 years with a 6 per cent discount rate is $27 billion dollars for producers. In addition, an estimated 37 million kilograms of active toxic ingredients will not enter the global environment.

Consumer/ Producer Surplus

The consumer /producer surplus approach uses a partial equilibrium single market analysis to determine how benefits are distributed amongst consumers and producers. The benefits received by each group will depend on the behaviour of farmers and consumers.

Case Study: Surplus Distribution from the Introduction of a Biotechnology Innovation

Falck-Zepeda *et al.* (2000) analyze the distribution of transgenic cotton benefits in the United States among various populations under a monopolistic regime as a result of IPR regulations. To undertake this analysis, Falck-Zepeda *et al.* (2000) estimated the technology-induce supply shift for each region, calculated world and regional prices resulting from this shift, estimated the Marshallian surplus distribution in domestic and international markets, and estimated monopoly profits. The data needed to undertake this study were yields, input prices, adoption rates, and world price. This study showed that US farmers received $140.8 million, Monsanto received $49.8 million, and D&PL received $13.2 million in surplus. The consumer surplus for the US was $21.6 million. The consumer surplus for the rest of the world was $36.5 million, while the ROW producer loss $21.6 million.

Dynamic Research Evaluation for Management Model (DREAM)
DREAM simulates and compares the benefits with and without the technology in single and multiple markets. Its system of linear supply and demand equations consists of production quantities, production cost per hectare under current technology and alternative technologies, and changes in production. This approach generates results for geographical locations as well as social groups within the area and changes in production patterns. It also takes into consideration spillovers and the technology's adaptability.

Case Study: Income and Employment Effects of Transgenic Herbicide Resistant Cassava in Colombia: A Preliminary Simulation
Pachico *et al.* (2001) assessed the income and employment effects of herbicide resistance Cassava in Columbia using DREAM. It compared equilibrium outputs, prices, and consumer and producer benefits under three technologies: transgenic herbicide-resistance, conventional breeding mechanization, and current technology. This assessment found that herbicide resistant cassava reduced the per hectare costs from $592 to $429. Adopting this technology reduces manual weed control, which in turns reduced labour per hectare by 46 days. These reductions lowered per tonne production cost by 34.1 per cent. With a 5 per cent discount rate, herbicide-resistant cassava total benefits would be $508 million with consumers receiving approximately 40 per cent and non-adopting farmers becoming net losers.

Computable General Equilibrium (CGE)/ Simulation Model
A CGE model considers the entire economic system when simultaneously determining prices and quantities in an economy while assuming perfect competition. In order to undertake a computable general equilibrium *ex-ante* study, three conditions need to be met:

A representative case study in terms of production, exports, and preferences of the agricultural commodity is needed; commercialization or near commercialization of the commodity in another representative country; and minimum acceptance of the new technology in the study area. In addition to these three conditions, information regarding the following variables, conditioned on the objectives of the study is needed for solving the system of simultaneous linear equations: cost reduction, adoption rate, markup price, supply and demand elasticity, world price, per unit cost reduction in crop production, trade restrictions (quotas), and production quantities of GM and non-GM goods are needed (Demont and Tollens, 2001).

A CGE model can be adapted for assessing agricultural biotechnology on a national economy and international trade by segregating the markets (Nielsen, Thierfelder, and Robinson, 2001; Demont and Tollens, 2001; Moschini, Lapan, and Sobolevsky, 2000; Barkley, 2002).

While undertaking a CGE study, two scenarios regarding consumer preferences must be analyzed: indifference and non-preference of GM food. This analysis will shed light on four outcomes of adopting genetically modified crops: GM product market; changes in the cost-drive price of the non-GM product market; changes in the competition for primary production factors and inputs; changes in consumption pattern based on new relative prices; and changes in import pattern due to relative world price.

Case Study: Genetically Modified Foods, Trade, and Developing Countries
Nielsen *et al.* (2001) adapted the CGE model to incorporate GMOs by segregating the markets into a GMO and non-GMO market. They assume that there is complete segregation of the markets; therefore, GM livestock and GM food processing industries will only use GM inputs and non-GM

livestock and non-GM food processing industries will only use non-GM inputs. Another initial assumptions are that regions in the model initially produce both GM and non-GM varieties of the crop, intermediate inputs are identical for both markets, and destination structures of exports are identical.

This study shows that with segmented markets, traded patterns adjust according to consumer preferences. Also, countries that prefer not to import GM goods, will actually export more non-GM goods, which will impact trade relations. The results also suggest that there are large welfare gains for developing countries if productivity benefits outweigh GM seed costs. However, the assumption of segmented markets raises a signal for caution.

Multi-Market Approach

A multi-market approach simultaneously assesses the impact of a change in one market on another market, and it links markets vertically as well as horizontally (Goletti and Wolff, 1998). It involves defining a system of demand equations for a set of food and non-food commodities and a system of supply equations of these commodities. In an *ex-ante* sense, this model is useful when non-GMO model parameters are available, which can be modified to take into consideration the introduction of GM crops. Although a multi-market model considers spillover effects, it still only captures part of the economy. It is yet to be applied in an *ex-ante* context for assessing the GM technology.

Ex-post Methodology

An ideal situation when assessing economic impact using *ex-post* method is to have information regarding output, costs, and inputs before introducing the technology. After adopting the technology, information regarding changes in inputs, outputs, and costs are collected. Although this process is ideal, it seldom occurs because baseline date is rarely collected. To compensate, researchers can use a comparable area within the region that has not adopted the technology to compare the technology's impact. *Ex-post* assessments are important for justifying the use of funds. Table 2 lists *ex-post* methodologies and agricultural biotechnology case studies if available.

Table 2: *Ex-post* Methods of Economic Assessment

Ex-post Methods	Case Studies
Partial Budget Analysis	Ismael, Bennett, and Morse, 2002a, 2002b
	Ismael, Bennett, and Morse, and Buthelezi, 2002c
	Huang, Hu, Pray, Qiao, and Rozelle, 2002
Multivariate Analysis	Huang, Hu, Pray, Qiao, and Rozelle, 2002
Production Function Method	Huang, Hu, Rozelle, Qiao, and Pray. 2002
	Lu, Pray, Hossain, Huang, Fan, Hu, not published
	Qaim and Zilberman, 2003
Profit Function Approach	Qaim and Traxler, 2002
	Fernandez-Cornejo, Klotz-Ingram, and Jans, 2000
Partial Equilibrium Approach	Qaim and Traxler, 2002
Technical Efficiency	Yet to be applied
Stochastic Dominance Approach	Yet to be applied
Index Method	Yet to be applied
Cost Function Approach	Yet to be applied

Partial Budget Analysis Approach

Partial budget analysis compares farm budgets for adopters and non-adopters. It is useful in determining differences in yields, pesticide use, herbicide use, and seed costs. When collecting the data, researchers need to interview adopters and non-adopters in the same region. The data will vary with the study's goals, but some basic data are farm characteristics such as farm size; age, gender, and education level of household head; seed and input costs; and yields. Other information that may be useful include perceptions of transgenic crops, rational for adoption, farming practices, pesticide knowledge, and pesticides use (Ismael *et al*. 2002b)

Case Study: Benefits from Bt Cotton Use by Smallholder Farmers in South Africa

In 1998, an estimated 12 per cent of smallholder cotton farmers were using Bt cotton. In 1999/2000, the adoption rate grew to 40 per cent and then to

60 per cent in 2000/2001 (Green, 2001; Matlou, 2001). To examine the impact of adopting Bt cotton in South Africa on yields, gross margins, and technical efficiency Ismael *et al.* (2002b) surveyed 100 randomly selected smallholder farmers, who were Bt cotton adopters as well as non-adopters in the Makhathini Flats region in 2000. Data collected included farm characteristics, farmer's age and gender, input use, input costs, cotton output, cotton revenue, and other sources of income.

During the second year of this two-year study, South Africa experienced high levels of rain. With that in mind, the study showed that cotton yields fell for both Bt adopters and non-adopters during the second year of the survey. However, adopters only experienced an 18 per cent decrease in production while non-adopters experienced a 40 per cent decline. The survey showed that Bt cottonseeds cost twice as much as non-Bt cottonseeds, but pesticide costs for Bt adopters fell on average 13 per cent during the first season under survey and 38 per cent during the second season with the unit price of pesticides remaining the same both years. The combination of yields, pesticide cost, and seed cost resulted in a higher average gross margin per hectare for Bt adopters than non-Bt adopters.

Production Function Method

A production function illustrates the relationship between the inputs needed for producing a good and the quantity produced. In assessing impact, this method estimates the contribution of the technology on production efficiency and marginal rates of return (Araji and Guenthner, 2001).

This approach, which has been used widely in assessing yield increases from biotechnologies such as biofertilizers, can be adapted to measure the impact of genetically modified agricultural goods by undertaking a comparison of production functions (Babu *et al.* 1998). One production function incorporates only tradition inputs such as fertilizer, another production function incorporates genetically modified inputs, and another production function incorporates other methods of combating the problem that the transgenic component is tackling. Input and output data such as farm size; area sown; targeted crop share in total crop sown; age and education of household head; yield; ratio of crop-specific fertilizers; fertilizer use;

applications of treatment to combat the problem; amount of combating agent; cost of combating agent; combating agent price; labour use, and any addition input variable associated with production of the crop is needed for a production function analysis. A benefit to this approach is that it does not need price information.

Case Study: Biotechnology as an Alternative to Chemical Pesticides: A Case Study of Bt Cotton in China

During the 1990s, the bollworm played havoc on cotton production as well as led to increase in production cost due to increased pesticide applications. In 1997, the Chinese Ministry of Agriculture approved Bt cotton for commercial use. With this adoption, information regarding its impact on pesticide use was needed (Huang *et al.* 2002). Huang *et al.* calculated two production functions. One including variables only associated with traditional inputs such as fertilizer and labour and one including abatement inputs such as pesticides or Bt. To undertake this analysis, a damage abatement function was incorporated into the production function, which calculated the yield recovered through abatement inputs. Another unique addition to this study is the incorporation of host plant resistant varieties into the analysis. The analysis could have solely looked at non-Bt crops with no pesticide use, non-Bt crops with pesticide use and Bt crops. However, this study went one step further to look at what happens to productivity when Bt cotton interacts with pesticides. To circumvent endogeneity of pesticides use, Huang *et al.* used an Instrumental Variable approach to develop a pesticide use model. A three-stage, iterative least squares estimation procedure was used to estimate this two-equation system model.

This study informed policymakers that pesticide use fell by 58 per cent for farmers that adopted Bt cotton. Although pesticide use results were highly reliable, the impact on cotton production varied according to the model's specifications. With the inclusion of other inputs and human capital, cotton production rose by 15 per cent.

Profit Function Approach

A profit function is the maximum profits that can be made from net outputs. When undertaking a profit function assessment information regarding output prices and output generated is needed. To estimate the impact of agricultural biotechnology using a profit function, first determine profit under the current technologies. Then determine profit using the price of genetically modified output and the quantity of the genetically modified output. The difference between these two estimates will highlight the cost or benefit from technology adoption.

Case Study: Farm-level Effects of Adopting Genetically Engineered Crops in the USA

Fernandez-Cornejo *et al*. (2000) used a profit function for examining the impact of herbicide-tolerant cotton and soybean and insect-resistant cotton on yields, farm profits, and pesticides. The simultaneous equation system included three demand functions, one supply function, and a profit function. They gathered information on input and output prices, pest infestation levels, probability of adopting the GMO, and the probability of adopting pest management practices. The study found that yields, profits, and pesticide use vary according to the crop and technology used. Adoption of herbicide-tolerant cotton increased yields and variable profits, but herbicide use did not change significantly. Herbicide-resistant soybeans only slightly increased yields and variable profits, but herbicide use decreased significantly, while Bt cotton resulted in yields and profits increasing significantly and insecticide use decreasing significantly.

Partial Equilibrium Model

A partial equilibrium model analyzes a commodity market given that the prices of all other commodities and inputs do not change. For an analysis of economic impact in a large, open economy with other countries producing the same crop, a multi-region model with international technology spillovers should be used (Alston *et al.* 1995). Time series data in crop production, consumption, and world market price is needed to calculate the consumer and producer surplus, share of technology adoption, relative yield difference, relative variable production cost difference, and price elasticity of supply. Information on the counterfactual crop price, supply, and demand is needed for isolating the technology-induced supply shift. When taking into consideration intellectual property rights, monopoly rents accruing to the firms must be included to have a holistic picture of the benefits.

Case Study: Roundup Ready Soybean in Argentina: Farm Level, Environmental, and Welfare Effects

Qaim and Traxler (2002) use a partial equilibrium model to estimate the farm level, environmental, and welfare effects of roundup ready soybeans in Argentina. This model assumes that that the processing sector is competitive, trade equilibrium exists, and a single world market price exists. The analysis shows large and steadily increasing aggregate welfare gains. Its economic surplus was $1.2 billion globally in 2001. The soybean consumers received 53 per cent of total surplus, producers received 13 per cent, and biotechnology and seed firms received 34 per cent.

By 2001, Argentine farmers received 90 per cent or $300 million in economic surplus. The US producer experienced a fall in surplus from 45 per cent in 1996 to 21percent in 2001. Non-adopting US soybean growers faced welfare losses, while monopoly rents increased from 42 per cent in 1996 to 57 per cent in 2001. In Argentina, technology revenues were only 8 per cent because of weak intellectual property rights. In addition to economic surplus, this model found that small-scale farmers realized that much of the economic surplus came through cost savings and higher gains in gross margins.

Multivariate Analysis

A multivariate analysis involves more than two variables in its equations. It is useful for determining the technology's impact on a particular input. The data needed includes the average price of the input that is analyzed for a particular technology adoption, an estimation of the loss due to the problem that the input controls, and the education and age of the household head.

Case Study: Biotechnology as an Alternative to Chemical Pesticides: A Case Study of Bt Cotton in China

Huang *et al.* (2002) used a multivariate analysis in determining the impact of Bt cotton on pesticide use. In addition to the general variables, Huang *et al.* included a variable representing advice from local extension service and dummy variables for counties and Bt cotton. The number of pesticide sprays, quantity, and cost of pesticide were the dependent variables. The results from the ordinary least squares (OLS) estimation show that pesticide expenditures declined to $94 per hectare when BT cotton was adopted.

Technical Efficiency

Technical efficiency is defined in two ways: producing maximum output with given inputs or producing a given amount of output with minimum inputs. A technical efficiency index is calculated by either the ratio of observed output level to the potential level, given inputs is the output-based index or the ratio of potential inputs to input levels observed; given the output level is the input-based index. To measure technical efficiency information on total crop production, the number of cultivated hectares, kilograms of seed per farm, kilograms of fertilizer, number of irrigations per year, and labour in worker equivalents is needed (Bakhshoodeh and Thomson, 2001). This information can be obtained through farm input-output surveys.

To adapt this approach for assessing the technical efficiency of agricultural biotechnology some additional data is needed. For example, Bt cotton replaces pesticides use. This change will need to be captured in the technical efficiency model.

Stochastic Dominance Approach

Adoption of crop biotechnology as in any other technology may involve yield risks caused by uncertain weather conditions. A frequently raised question among biotechnology critics is whether biotechnological innovations would help farmers in drought-prone areas to reduce the level of production uncertainty by making crops tolerant to drought. In order to address this issue, it is useful to compare the distribution of crop yields under biotechnology and traditional varieties grown under the same weather conditions. Such comparison requires studying the distribution of yields produced from genetically modified crops and traditional varieties over time. Stochastic dominance analysis helps to compare variable distributions to see which one dominants the other in yielding better overall results. Andersen *et al.* (1977) provide a good introduction to this approach, and Harris and Mapp (1986), Kramer and Pope (1981), and Richardson and Nixon (1982) provide examples of applying stochastic dominance to agricultural production problems. This approach is yet to be applied to genetically modified crops.

Index Number Method

The index number method estimates the average rates of return to consumer and producer surpluses. The data needed are price and quantity of crop with and without the technology, and elasticity coefficients for supply and demand (Araji and Guenthner, 2001). The index number method has not been applied to assesing the economic impact of GM technology.

Cost Function Approach

The cost function approach is used to measure the minimum cost for producing a given level of output; therefore, production decisions are based on costs. To determine the benefits, the quantity and costs of inputs needed to produce the same yield for adopters and non-adopters is needed. In addition to quantity changes of inputs, different inputs may be needed for the technology. This interplay of inputs will determine if the new technology is more or less costly.

Issues in Assessing Agricultural Biotechnology

In assessing agricultural biotechnology's impact on economic welfare a number of issues need to be taken into consideration: research and development lags, data availability, validity of assumptions, assessment, effects of trade, market distortions, and externalities.

There is a lag between the time that a technology change has occurred and when that technology change effects welfare. If genetically modified seeds are planted, the true impact of those crops on producers and consumers will not be know for some time. An initial welfare effect can be seen in cost reductions or increase cost for inputs, but production levels will not be known until at least harvest season. However, there are many factors that effect production levels so information from several harvests are needed. Also, to maximize the benefits of this new technology, knowledge on how to appropriately use it is needed. However, transferring knowledge to farmers will take time; therefore, the true benefits will not be know until the technology is used appropriately. Even after the technology is used appropriately over time, the economic impact cannot be assessed if data is not available.

The availability of data may be limited. For *ex-ante* assessment, some methods require data from pilot studies that are from a different, but representative area. Problems could arise if what was thought to be representative data was not representative of the area being assessed. Using the data to assess the technology's impact in a different part of the world could result in the research results being different from the actual results. Also, having sufficient data as well as the right data to assess the impact of adopting genetically modified crops in an *ex-post* study is critical. The adoption of genetically modified crops is very limited and has occurred only over the past few years; therefore, the data being collected can basically illustrate short run impacts on welfare, but not long-run impacts on welfare.

In addition to have available appropriate data, the methods used to undertake the assessment may be biased depending on the assessor. The organizations undertaking the analysis will select methods that will assess the impact of what it wants to assess; therefore, other impacts may be neglected. What steps are needed to eliminate this problem? Should external agencies undertake impact assessment or can organizations themselves undertake their own impact assessment? The selection of the assessor also plays a crucial role in the validity of the assumptions. Could choosing to assume something cause research results to differ from actual results?

Economic policy can also influence the economic impact of adopting agricultural biotechnology seeds and goods. The controversy over the risk associated with agricultural biotechnology goods is impacting trade. Only a few countries – Argentina, China, South Africa, and the United States – have openly accepted agricultural biotechnology products. Since European markets are not importing genetically modified food, this constrains the actions that developing country decisionmakers can take. Fears of not being able to export to European markets have halted governments from accepting genetically modified food for food aid, commercializing agricultural biotechnology products, and undertaking agricultural biotechnology research; therefore, the real impact is unknown. Understanding how agricultural biotechnology products impacts the economy, health, and environment will help relieve this constraint.

In addition to trade policy, market interventions could limit the economic impact felt by producers and consumers. With governments procuring yields and setting prices, will produce more food and reduce food insecurity? How will subsidies by developed countries impact the benefits from agricultural biotechnology products? Will US subsidies continue to undercut world market prices, hindering developing countries in trading their agricultural products? When assessing the economic impact of agricultural biotechnology, market distortions need to be considered to truly measure the economic impact. Also, measurable and non-measurable externalities need to be considered. These methods only analyze the measurable externalities. The question remains how the cost and benefits would change if non-measurable externalities were considered.

Challenges

Assessing biotechnology impacts faces several challenges in regulatory mechanisms such as institutions and policy, but also in capacity. Government expenditures on agricultural research (Pardey *et al.* 1998) and application have been declining over the past several decades; therefore funding may be a challenge for assessing the impact of agricultural biotechnology. Governments can increase funding by establishing linkages with private industry, which will use the comparative advantage of each sector. The private sector has been the major developer of genetically modified seeds; however, the private sector needs the public sector to approve the commercialization of the seeds. Therefore, funding to the public sector for impact assessment will assist in the genetically modified seeds being assessed, but problems could arise if the cost of public sector undertaking the impact assessment study is being paid by the private sector. This could influence the outcome of the impact assessment. Therefore, a general fund could be set up so that each genetically modified seed that is seeking approval contributes a certain amount of funds.

To be able to assess the impact of genetically modified crops, pilot studies need to be done; however, the approval process for a pilot study is often bureaucratic. For example, in India approval for a genetically modified crop to be commercialized must go through several departments and programmes. The Review Committee of Genetic Manipulation (RCGM) can either approve or disapprove genetically modified inputs for research and small-scale projects. The Biotech Research Promotion Committee of the Department of Biotechnology (DBT) must approve large-scale projects before it gets approval from the RCGM. Then the Genetic Engineering Approval Committee (GEAC) of the Ministry of Environment and Forest must approve field tests for large-scale projects and the importation of genetically modified crops for commercialization. Once field trials have been approved, GEAC and the Monitoring and Evaluation Committee (MEC) observe them. Finally, the Indian Council of Agricultural Research needs to approve the crop before it is commercialized (Rhoe *et al.* 2002).

In addition to bureaucratic approval systems, trade policies also influence the ability to undertake genetically modified crop studies. For example, Brazil has industrial policies that promote biotechnology, but their trade policy restricts importation of biotechnology inputs (Acharya, 1999). Therefore, industrial policy and trade policy need to be consistent for effective biotechnology transfer and use. Once the inputs are permitted and pilot studies occur, *ex-post* assessment is able to happen.

To improve assessment of agricultural biotechnology, capacity in assessment methods are needed. Until recently, many developing countries did not have biotechnology courses as a component of their national curricula. Also, for appropriate policies to be established decisionmakers and policy advisors need to understand the cost and benefits of adopting this technology. Government policy is needed to create this capacity within its country; therefore, government policy should include funding for training in agricultural biotechnology. Capacity can be created by establishing state university, encouraging study abroad, and developing information networks (Rhoe *et al*. 2002; Acharya, 1999; Knorr, 1995).

In addition to training policymakers and researchers, farmers need to be trained in appropriate application of the new technology. Studies have shown that pesticide use remains high even when Bt cotton is planted. Is this excess use of pesticides due to lack of information? Until farmers grow genetically modified crops correctly, assessment of the total benefits and costs will not be accurate.

Conclusion

Assessing the economic impact of agricultural biotechnology is essential for decisionmakers to decide if they want to adopt genetically modified crops as a strategy to rid food insecurity and malnutrition. For developing countries to reap the benefits of genetically modified crops, regulatory mechanisms for institutions, policy, and capacity are needed. Government needs to increase expenditures on agricultural research, pilot studies need to be carried out, industrial policy and trade policy need to be consistent, and capacity in assessment methods and application of agricultural biotechnology products should be strengthened.

The methods discussed above will assess a new technology's economic impact, but to ensure that the impact assessment of agricultural biotechnology captures the entire welfare effect, appropriate data needs to be collected. Also, trade restrictions and market distortion need to be considered as well as the nature of assumptions. Sufficient time for the impact to occur needs to be allotted. Also, a social scientist should be involved in undertaking the impact assessment. Furthermore, immeasurable externalities need to be included in the discussion. Including these constraints into the impact assessment will enhance the quality of the assessment and better guide policy in reducing poverty and food insecurity.

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