Economic Valuation of GM Technology : A Literature Review

** Parul Jain*

Abstract

Genetically modified (GM) technology has been part of the agricultural landscape for more than 20 years and has now been adopted on more than 181 million hectares (ha) in both developed countries (47%) and developing countries (53%). This paper is a review of existing literature on economic valuation of GM technology, focusing on the first generation GM varieties. Valuations at the micro and aggregate level are discussed with respect to specific parameter values, and other aspects such as environmental and regulation concerns were identified that can be included in further research so as to ensure more comprehensive results of the economic valuation of the GM technology .

Keywords : **economic benefits, genetically modified technology**

JEL Classification : O13, O33, Q16

Paper Submission Date : December 20, 2015 ; Paper sent back for Revision : March 29 , 2016 ; Paper Acceptance Date : June 5 , 2016

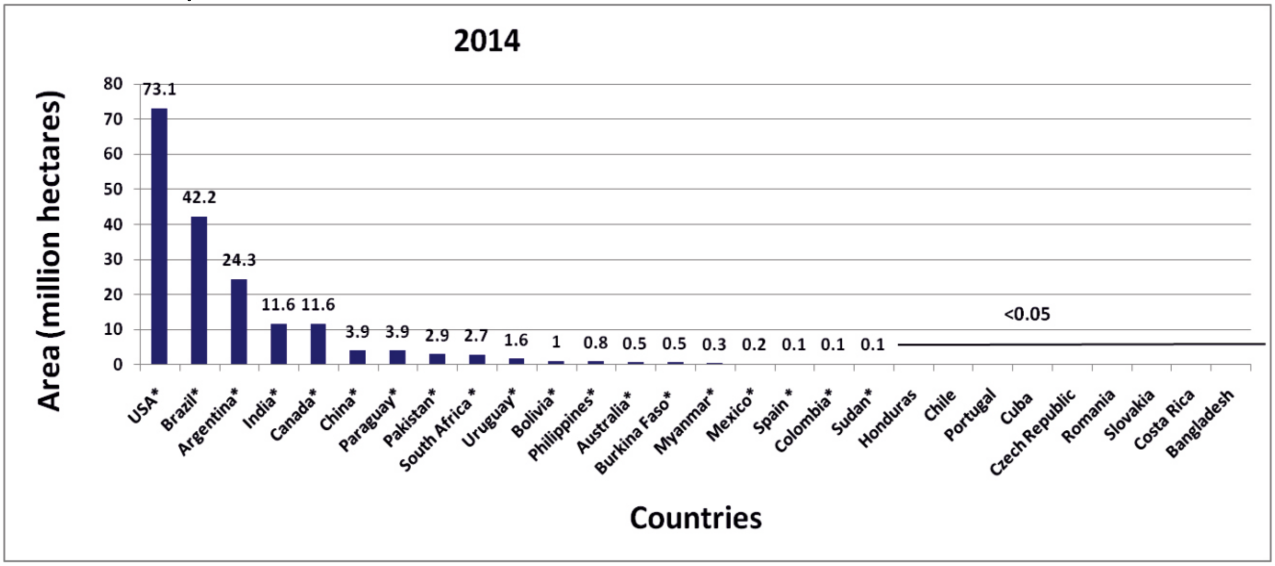
In today's modern times, advancement in technology is judged on the basis of its net benefits and not on the basis of the claim that it is dangerous. Countries are not adopting new technologies just because they want to remain on the safe side and avoid risks that a technology poses, but because of the perception that digital media has created against the benefits of a technology. The introduction of GM (genetic modification) technology is a step towards increasing the efficiency in the agricultural production system. GM technology has introduced new crops known as GM crops, which are genetically modified. According to International Seed Federation, genetically modified (GM) crops are those that have been genetically enhanced using modern biotechnology to carry one or more beneficial new trait. The basic techniques of plant genetic engineering were developed in the early 1980s, and the first GM crops became commercially available in the mid-1990s (Qaim, 2009).

The first genetically modified crop was tomato, which was planted in the United States in the year 1994 (James, 2014). Since then, other crops such as soybean, cotton, maize, potato, sugar beet, eggplant, and so forth have been genetically modified and widely adopted both in developed and developing countries. However, even after 20 years of the introduction of GM technology, there is still a blurred image in the minds of farmers about the potential benefits of this technology. In these 20 years, three generations of GM crops have been introduced. The first-generation GM crops involved improvements in agronomic traits, such as better resistance to pests and diseases; the second-generation GM crops involved enhanced quality traits, such as higher nutrient contents of food products ; and the third-generation crops are plants designed to produce special substances for pharmaceutical or industrial purposes (Qaim, 2009).

If we look at the adoption rate of GM technology, in the year 2014, about 18 million farmers in 28 countries (20 developing and eight developed countries) cultivated more than 181 million hectares of land with GM crops. The developing countries cultivated about 96 million hectares (53%), while the developed countries cultivated 85

**M. Phil Scholar,* Centre for International Trade and Development, School of International Studies, Jawaharlal Nehru University (JNU), New Delhi - 110 067. Email : itsparuljain@gmail.com

Figure 1. Global Area of Biotech Crops, 2014: Industrial and Developing Countries (Million Hectares)



Source : Reproduced from C. James (2014). *Global status of commercialized biotech/GM crops: 2014.* ISAAA Brief No. 49, ISAAA: Ithaca, NY. Retrieved from http://www.isaaa.org/resources/publications/briefs/49

million hectares (47%). The Figure 1 shows the relative area of genetically modified crops in industrial and developing countries for the year 2014. As can be inferred from the Figure 1, the U.S. had the highest cultivated area of 73.1 million hectares followed by the three developing countries Brazil, Argentina, and India (James, 2014).

Despite the widespread adoption of GM crops, there has been an ongoing debate on the economic impacts of these crops at the farm level, risk that they pose to the environment and health, and other social implications. Economic valuation of GM technology assesses the impact on cost and yields, the distributions toward various economic agents in the market, environmental effects, and issues of policy and regulation. In general economic theory, farmers will choose this technology only when their profits are maximized. The profit function for an individual farmer in presence of this technology becomes :

$$\Delta \pi = (p.\Delta y) + (q.\Delta x) - \Delta s$$

where,

$\Delta y = Ygm - Y con$ is the difference in effective yields between GM and conventional crop; $\Delta x = X con - X gm$ is the reduction in pesticide use due to the adoption of this technology ; p is the output price net of harvesting costs ; q is the pesticide input price, including spraying costs ; and $\Delta s = Sgm - Scon$ is the difference in the cost of seeds (Qaim, Subramanian, Naik, & Zilberman, 2006). If the change is large enough, then farmers will adopt this technology. However, profitability also depends on other factors, which are examined in this paper.

This paper reviews the available research on the economic valuation of GM technology. A major focus has been placed on the first generation GM varieties which are commercially available in both developed and developing countries. The first generation GM varieties are further classified into herbicide tolerance (HT) and insect resistance (IR) or Bt *(Bacillus thuringiensis)* varieties. The HT variety enables farmers to spray wide spectrum herbicides on their fields, killing all plants except GM plants as they are resistant to herbicides ; whereas, the IR variety has a Bt gene inserted in it, which allows them to produce their own insecticides, thereby making plants pest resistant, leading to a reduction in pesticide use (Roederer, Nugent, & Wilson, 2000). Thus, the adoption of GM technology allows farmers to reap benefits in terms of higher yields and reduce pesticide/herbicide use.

Micro- Level Valuation

The simplest approach for economic valuation of GM technology at the farm level is estimated by looking at the gross margins which assess the impacts on yields and costs. The gross margin is defined as the difference between revenue (value of output) and production costs. The value of output is calculated in terms of yield and production costs, which includes the reduction in pesticide use and the price of seeds. This approach is based on random sample surveys, and a comparison between adopters and non-adopters is done on the basis of their performance. This approach is based on the assumption that farmers are attempting to maximize profitability, so they will adopt this technology as long as the value of benefits is greater than the costs. There exists a vast literature that assesses the economic impact of GM technology at the farm level. It has been found that in general, the gross margin effects of GM technology are higher for developing countries in comparison to developed countries owing to the fact that the price of GM seeds are lower in developing countries due to weak Intellectual Property Rights (IPRs) and government interventions in the market (Basu & Qaim, 2007).

Ismael, Bennett, and Morse (2003) conducted a randomized sample study of hundred small farm holders in South Africa for 2 years (1998-2000) to determine the impact of Bt Cotton. They compared the performance of adopters with those of non-adopters. Though the cost of Bt seeds was higher than that of conventional seeds, it was offset by the reduction in pesticide cost. Their findings suggested that, on an average, gross margin per hectare was higher for Bt adopters than for non-Bt adopters. In the first season, it was 11% higher, but in the second season, it increased to 77% ; thus, indicating that gross margins vary over time.

On the other hand, farmers who adopted HT technology received benefits in terms of lower herbicide expenditures. However, various studies (Duffy, 2001; Marra, Piggott, & Sydorovych, 2004 ; Qaim & Traxler, 2005) showed that there were no significant yield differences between HT and conventional crops. The research in the North Carolina region supports this conclusion for HT maize, cotton, and soybeans (Marra et al., 2004). The survey of 293 farmers in this region by the authors suggested no statistically significant difference between the herbicide application costs for HT and non-HT varieties in any of these crops, but the seed cost per acre of HT varieties were higher than their conventional counterparts. In Argentina, the introduction of Roundup Ready (RR) soybeans (HT variety) led to a significant increase in application of herbicide on adopting fields as farmers substituted herbicide use for tillage (Qaim & Traxler, 2005). However, the region experienced tremendous gains in yields, which led to average gross margin of more than $20 per hectare. Whereas, Duffy (2001) compared the costs and returns for HT versus non- HT soybeans in his cross-sectional survey of Iowa soybean fields in the United States for the year 2000 and observed that the average yield of HT soybeans was 43.4 bushels per acre, while the non-HT soybeans was 45.0 bushels per acre. The difference in seed cost for HT soybeans over non-HT ones was around $5.69 per acre, and herbicide cost for non-HT fields were higher by about $6.17. Even after the inclusion of other costs, there was no significant difference in costs between the tolerant and non-tolerant fields. The main reason given by all the studies for the rapid adoption of HT technology by farmers was 'convenience' in terms of reduced tillage and effective control of weeds.

In all these studies, the problem of the selectivity bias arises as in the process of selection of the sample, it might happen that the farmers who have adopted the technology are more skillful and resourceful than their non-adopting counterparts. This will lead to overestimation of the technological impact as these farmers will outperform even without GM technology. There might be a downward bias in the estimation of the economic impact when the technology is adopted in those areas where pest infestation is very high. The effect of technology will vary under different climatic conditions (Qaim, 2009). Also, this approach assumes that there exists a perfectly elastic demand in the market, and the supply function is highly inelastic. The gross margin approach does not take into account how the increase in yield affects the price of the crop in the market and its consequent effects on the producer surplus.

As reviewed, most of the evidence is based on field trials of the technology for a short duration of 2 to 3 years. The implication is that over a longer time, there arises a possibility that pest populations might build up resistance, which might lower the benefits arising from the adoption of GM technology. In this regard, Kathage and Qaim (2012) analyzed the long-term development of Bt cotton in India by using panel data for the period from 2002-2008. The study was divided into two periods: 2002-2004 and 2006-2008. Their findings suggested that there was a 24% increase in Bt cotton yield per acre over conventional variety. They also estimated the impact of Bt cotton on farmers' profit through changes in yield and cost, and found a 50% gain over conventional cotton. The benefits were stable, though there was an increase in total cotton profit as adoption rate increased.

The other approach often used for valuation of GM technology is to assess the benefit of reduction in pesticide on yields through the 'damage control framework'. The framework takes into account the historic application of pesticides on fields. This approach is mainly used for insect-resistant varieties. In general, when farmers used small volume of pesticides on their conventional crop fields despite high pressure of pests, they realized a significant affect on yield with the adoption of GM technology ; whereas, high application of pesticides in low infested areas resulted in a drastic reduction in pesticides use when GM technology was introduced. Using Lichtenberg and Zilberman's (1986) study, the damage control framework can be expressed as:

$$Y = F(x)\,[1 - D\,(z, \mathrm{Bt}\,; N)]$$

where, Y is the effective crop yield and is equal to the product of a potential yield [F (.)] and loss due to damaging pests. The potential yield depends on land and traditional inputs such as fertilizer, water, and seeds. The pest damage [D (.)] is a function of the pest pressure ; N, application of chemicals ; z, and adoption of GM traits. This framework provides a conceptual model that determines the impact of GM technology and the conditions under which it will be adopted. The decision to adopt the technology, as well as the outcome, depends on both agro-ecological and economic conditions.

Using the damage control framework, Qaim and De Janvry (2005) determined how effectively Bt variety can be used as a substitute for chemical pesticides. The study examined the technological impacts of pesticide use and productivity based on farm survey of both Bt and non-Bt plots for the period from 1999- 2001 in Argentina. The authors used stratified random sampling procedure to differentiate between adopters and non-adopters of the GM technology. Their results suggested that if there were no pest control inputs (pesticides and Bt seeds), then crop damage would have been around 56%. The actual crop damage was around 29% on conventional plots and less than 5% for Bt plots when pest control inputs were used. The increase in effective yield was around 33%, which strongly supported the authors' hypothesis that Bt yield effects are higher in situations where crop damage is not effectively controlled through chemical pesticides by conventional farmers. In China, using the same approach, Huang, Hu, Rozelle, Qiao, and Pray (2002) estimated the effects of Bt cotton for the period from 1999-2001 and found that there was around 65% reduction in insecticide use and yield effects were 24%.

In contrast, Fernandez- Cornejo and Li (2005) provided estimates for Bt corn in the United States from a nationwide farm survey for the year 2001. The authors used a model that corrected for self-selection and simultaneity and was consistent with profit maximization. In the model, insecticide demand functions, the seed demand function, the supply function, and the profit function were specified as a simultaneous system. Their results showed a moderate insecticide reduction of 4.11% and a small yield increase of 0.39, which was associated with a 10% adoption of Bt corn relative to conventional corn varieties.

In many developing countries such as India, the domestic seed manufacturers incorporated Bt gene in a locally available seed variety. This led to a variation in the results as the seed in which this technology is contained behaves differently in given climatic conditions. Thus, to take account of this fact, Qaim et al. (2006) introduced the 'germplasm effect'. They presented a model that decomposes the yield effect into 'gene effect' and 'germplasm effect'.

$$\Delta y = \Delta d + \Delta v$$

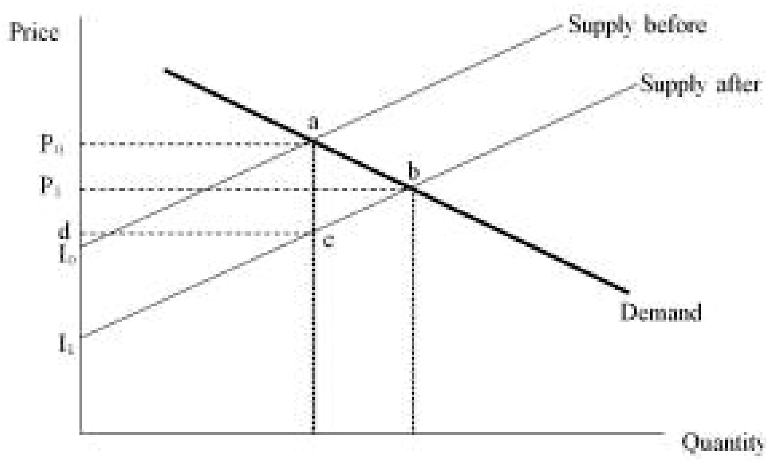
where, the gene effect (Δd) is the reduction in pest damage caused by Bt technology, and the germplasm effect (Δv) is the difference in the yield potential between the variety that carries the Bt gene and the conventional variety grown by farmers in a particular location. Germplasm effect is important because given market imperfections, the Bt gene can be incorporated into any variety, and farmers may use these hybrids which can affect cotton quality and yields. The germplasm effect can be negative if the Bt variety is not well adapted to local conditions. In their study of four states of India for the year 2003, except for Andhra Pradesh (that witnessed negative germplasm effect), the yield effect for other states increased to 42%.

Valuation at the Aggregate Level

The GM technology that is available to farmers globally has been commercialized by private companies which enables them to charge a technology fee for their innovation from farmers. This provides the motivation to estimate the aggregate impact and distribution of benefits from the introduction of GM technology to producers, consumers, and the industry. Studies estimating the benefits at the aggregate level use the farm level cost savings and model world supply and demand within an economic framework (Figure 2). This framework takes account of the fact that, as the new technology is introduced, it reduces the cost of production, thereby enabling farmers to expand the supply which results in a fall in prices leading to increased demand from consumers (Traxler, 2006).

Given this framework, the innovating firm will only be able to extract a part of the economic benefits as there

Figure 2. Effect of the Technology on the Supply Curve



Source : Reproduced from J. B. Falck-Zepeda, G. Traxler, & R.G. Nelson (2000). Rent creation and distribution from biotechnology innovations: The case of Bt cotton and herbicide-tolerant soybeans in 1997. *Agribusiness, 16*(1), 21–32. doi: 10.1002/(SICI)1520-6297(200024)16:1<21::AID-AGR3>3.0.CO;2-F will be spillover benefits, which will be enjoyed by other economic agents in the market. Algebraic manipulation is done in order to derive formulae to estimate the producer and consumer surplus. Various empirical studies have found that the benefits from GM technology have been widely shared among consumers, producers, and the industry. Some studies have used the partial equilibrium model to estimate the aggregate effects.

Falck- Zepeda, Traxler, and Nelson (2000) considered a large economy model with technology spillovers and IPR rents and assessed the distribution of economic benefits accruing to different agents of the economy. They considered the case of Bt cotton in the United States (large open-economy with no technical spillovers) for the period of 1996, where the innovating firm behaved as a monopolist. They assumed a linear supply and demand function and with the introduction of GM technology, the shift in the supply curve was estimated. The shift in the supply curve (K) is calculated as :

$$K_T = [(\Delta Q/ \varepsilon Q) - (\Delta C/ C) / (1+\Delta Q/Q)]\ p\ \theta_T\ (1 - \delta_T)$$

where, $\Delta C/ C$ is the change in cost per hectare and $\Delta Q/Q$ is the change in yield due to adoption of GM technology, p is the probability of success of biotechnology, where Θ is the adoption rate, e is the elasticity of supply, and δ is the annual rate of depreciation of technology. The monopoly rent or the IPR rent is computed by the quantity of GM seeds sold multiplied by the difference between price of GM seeds and marginal cost of producing those seeds (both conventional and GM seeds are produced at constant marginal cost). The authors estimated that there was an increase in total world surplus of $240.3 million of which the largest share went to the U.S. farmers (about 59%), the innovating firms received 27%, and the consumers received the rest.

In contrast, Demont and Tollens (2004) used the same approach that was adopted by Falck –Zepeda et al. (2000), but the difference lies in their computation of the shift-factor as a result of the introduction of new technology. In the earlier approach, the K-shift parameter was very sensitive to the value of elasticity of supply; hence, the author calculated the value of K-shift factor as :

$$K_T = \Theta_T \Delta \dot{C} / \dot{C}$$

where,

$$\Delta \dot{C}/ \dot{C} = -(C_1/Q_1 - C_0/Q_0) / C_0/ Q_0$$

is the proportionate per-unit cost reduction as a result of shift from insecticide use to Bt seeds and Θ is the adoption rate of the GM. They investigated the economic impact of Bt maize in Spain for the period from 1998-2003 and found that the total welfare gain was $1.49 million, where 65% went to farmers and 35% to innovating firms. Since Spain is assumed to be a small open economy with net importer of maize, the elasticity of demand is infinitely elastic and thus, there is no impact on consumer welfare. In case of China, Pray, Ma, Huang, and Qiao (2001), using the same model of Demont and Tollens (2004), found a positive impact of Bt cotton on total welfare, where 86% was shared by farmers and 14% by innovating firms. However, there was no impact on consumer surplus as the Chinese government administers a minimum support price.

In all of the above studies, the authors assumed that the marginal costs of producing GM seeds are the same as those for conventional seeds and any increase in price of GM seeds above the price of conventional seeds contributed to monopoly profits (or rents) from IPRs. This assumption will not result in correct estimation as it can happen that marginal costs of producing GM seeds may be higher or lower than for conventional seeds (Scatasta, Wesseler, & Demont, 2006). Also, the returns accrued to innovating firms in different countries will depend on the stringency of the enforcement of IPRs.

Environmental Costs of GM Technology

It is often seen that when economic valuation of a technology is done, the externalities that the technology creates on the environment is never taken into consideration. Studies that have assessed the economic benefits of GM technology have determined the environmental benefits associated with GM technology, but these effects have never been quantified in economic terms so as to calculate the net economic benefit of GM technology.

Since the first generation GM traits were focused on improved herbicide or pesticide management, most of the farm level studies have limited their analysis of environmental impact of GM technology on herbicide /pesticide use. The adoption of HT crops does not lead to reductions in herbicide quantities in most cases, but selective herbicides, which are often relatively toxic to the environment, are substituted by much less toxic broad-spectrum herbicides (Qaim, 2009). In order to evaluate the impact of GM technology on pesticide use, the environmental impact quotient (EIQ) indicator is often used. The indicator estimates the pesticide's risk on human health and on environment based on a ranking and draws on key toxicity and environmental exposure data related to individual products (Kovach, Petzoldt, Degni, & Tette, 1992). It is a widely used indicator and provides a better measure to evaluate the environmental impact of reducing pesticide/ herbicide volume as well as the impact of replacing one pesticide with another. Brookes and Barfoot (2014) used the Environmental Impact Quotient (EIQ) indicator to assess the impact on environment for both developed and developing countries. The most significant impact on pesticide use was seen in the case of GM insect resistant (IR) technology. The results of the study suggested that adoption of GM IR cotton led to 25.6% reduction in the volume of active ingredients used and a 28.2% reduction in the EIQ indicator (1996-2012). Similarly, the use of GM IR technology in maize led to 80% reduction in pesticide use in U.S. and 38% associated reduction in EIQ. However, the effects of GM crops on herbicide use is less straightforward. Benbrook (2012) concluded that GM HT technology contributed to a 239 million kg increase in herbicide use between 1996 and 2011 in U.S. The reason the author gave for the observed discrepancy was the changes in weed communities and development of resistance in crops.

GM technology has also contributed to reduction in greenhouse gas (CHG) emissions. The reduction in fuel use due to less frequent herbicide or insecticide applications and the increased adoption of no-tillage practices enabled by GM HT varieties has led to a decline in carbon dioxide emissions, which contribute to greenhouse gases (Brookes & Barfoot, 2014). In the United States, for the period from 1996-2012, the cultivation of GM HT soybeans led to an increase in no-till farming system, which subsequently led to a reduction in the average tillage fuel consumption by tractors on the GM HT planted area by 33.5 litres/ha compared to 41.3 litres/ha for conventional crops. Similar impacts in reducing GHG emissions were also estimated for soybean production in Argentina, Paraguay, and Uruguay (Brookes & Barfoot, 2014).

Other environmental impacts such as impact on water quality, genetic diversity, the extent to which GM crops hybridize with local crops, and so forth are not taken into consideration in any of the economic studies. Despite the fact that GM technology contributes significantly to the environment, its impact has never been taken into consideration by any economic valuation study. The effect on the environment is always treated as a separate study and never included in any production function framework or regression analysis to determine the economic benefits of GM technology.

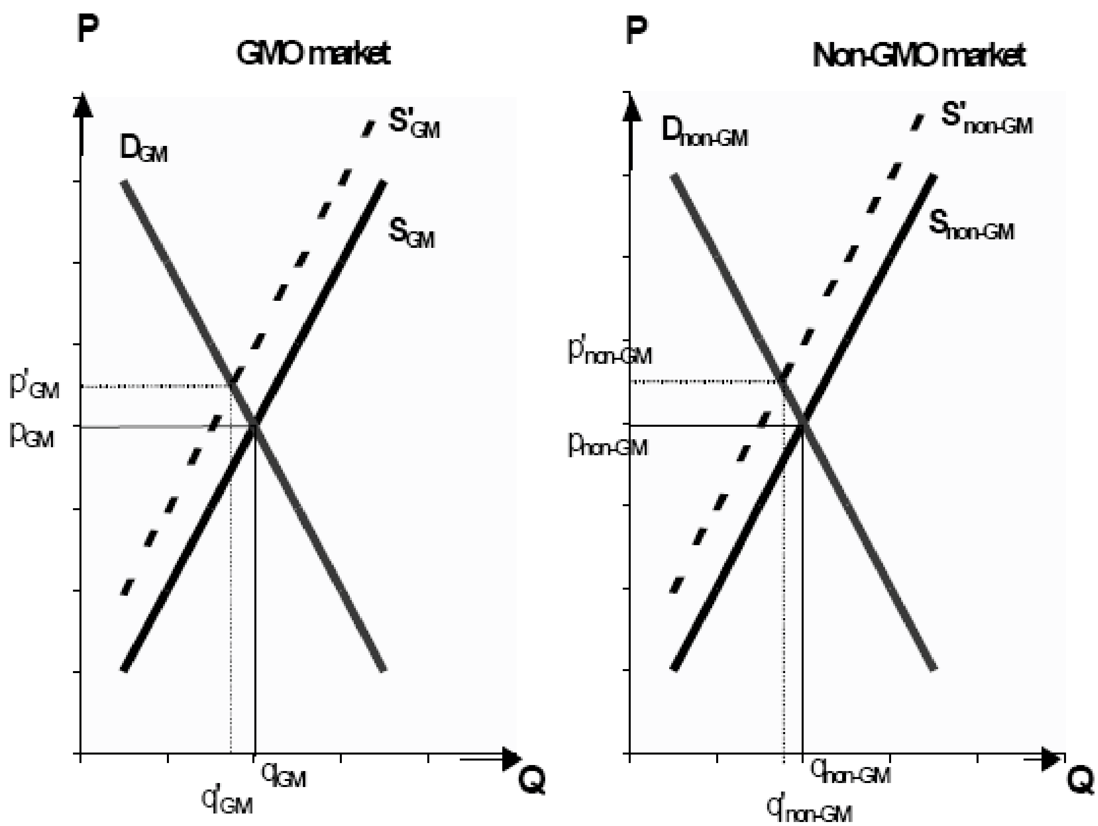
Regulation of GM Technology

The adoption and use of GM technology in recent years has aroused significant concerns related to health and the environment, which has led governments to introduce a regulatory framework that can address these issues (Qaim, 2009). Since regulation is associated with certain costs and disruptions in trade, they should be included in the economic valuation of GM technology (Scatasta et al., 2006). Several countries have introduced mandatory/ voluntary food-labelling requirements so as to enable consumers to distinguish between GM and non-GM food.

The process of labelling requires segregation and identity- preservation method. According to the European Commission (2003), segregation refers to a process in which one crop is separated from another. It implies that specific crops and products are kept apart, but does not necessarily require traceability along the production chain. Whereas, identity preservation (IP) is a system in which the source and content or composition of the food/crop is identified. IP requires a set of actions to allow traceability and is usually communicated to the consumer by a label. Each country generally sets a threshold limit under which genetic modification in food is considered to be fit for human consumption. Thus, the labelling process requires additional cost to be incurred at all stages of the food chain. The regulation system attempts to create a separate market for GM and non-GM products, which leads to disaggregation of supply and demand curves (Roederer et al., 2000).

Consider an aggregate supply curve of a crop which is sub-divided equally between GM variety and non-GM variety (see Figure 3). Assuming same demand and price for both the varieties, the introduction of labelling requirement will shift the supply curve in both the markets leftwards. In case of non-GM market, the producer has to incur the identity preservation cost, while the producers of the GM market will bear the cost for labelling of foods that contain some specific GM traits. This will reduce the quantity in both the markets, and prices will rise and there will be a loss to total welfare (Roederer et al., 2000).

Figure 3. Segregation of GM and Non-GM Markets



Source : Reproduced from C. Roederer, R.Nugent, & P. Wilson (2000). *Economic impacts of genetically modified crops on the agri-food sector: A synthesis.* Working document, Directorate-General for Agriculture. [EU Commission - Working Document]. Retrieved from: https://ec.europa.eu/agriculture/publi/gmo/gmo.pdf

Whenever the regulation is enforced, there is always a debate on who will bear these costs. In the economic theory, the regulation costs can be shifted to different economic agents under certain conditions. Buckwell, Bradley, and Brookes (1998) described the four conditions under which these costs can be shared :

(i) Price Responsiveness : The costs are generally shifted on the basis of the responsiveness of demand and supply to price. If demand is less responsive to price, then consumers bear these costs ; whereas, if supply is less price- responsive, then farmers have to pay for these costs.

(ii) Availability of Substitutes : If substitutes are easily available in the market, then in that case, price will be more responsive and the entire cost will be borne by farmers or food processing firms. On the other hand, if there are no substitutes available, then consumers have to bear the entire cost.

(iii) Market Structure : The concentration of market power also determines the sharing of the cost. If the market is concentrated at the food processing or retail agents, then the costs are passed either to farmers or consumers.

(iv) Government Pricing Policy : In countries where government administers minimum support pricing policies, these costs are borne by the food processing companies. In addition, the government pricing policy also creates disincentive against adopting new technologies.

The introduction of this regulation also creates the co-existence problem. The European Commission (2003) defined co-existence as ability of the farmers to make a practical choice between conventional, organic, and GE crop production while complying with the legal obligations for labeling and/or purity standards. The problem of coexistence arises because of the economic incentives associated with the regulation which includes GM gains associated with adoption of GM crops and IP gains that are generated by price premiums on non-GM crops (Demont & Davos, 2008). The need for coexistence measures arises so as to maintain the balance between GM and IP gains in a given region, which will allow both GM and non-GM crops to coexist in the market. If one of the incentives is absent, the coexistence problem will disappear, and either GM or non-GM crops will be cultivated. The choice will depend on the benefits and market demand conditions. If the benefits of cultivating GM crops exceed the costs related to technology and the costs of the implementation of coexistence measures, then farmers will adopt GM crops. Whereas, if the price premiums of identity-preserved non-GM crops are high, the farmers will adopt non-GM crops in that case and will implement the coexistence measures.

From the innovating firm's point of view, the widespread use of IPRs on genes, processes, and technologies has led to freedom-to-operate problems within the biotechnology industry (Qaim, 2009). Since the genetic modification of any crop may require the use of many patented intermediate technologies; licenses have to be negotiated with multiple parties, which ultimately lead to high transaction costs (Santaniello, Evenson, Zilberman, & Carlson, 2000). In that case, the profit of the innovating firms will be greatly affected and in order to cover these costs, the firms might pass on these to farmers in the absence of government support measures.

Different regulatory framework across countries has also led to problems in international trade, for example, Europe has mandatory labelling requirements, while United States allows for voluntary labeling. Thus, producers of non-GM food items have to incur IP cost if they want to sell their product in Europe while they can save on these costs if these products are sold in the domestic market. In economics literature, segregation and IP costs have been ascertained for various crops, but the impact of these costs on total welfare has been discussed in theoretical models. There are no empirical studies that estimate the trade-offs associated with this regulation system.

Policy Implications

Genetically-modified crops have the potential to solve the prevailing hunger and malnutrition problems, and to help, protect, and preserve the environment by increasing yield and reducing reliance upon chemical pesticides and herbicides. However, in the Indian case, the delay in clearance of certain Bt crops owing to political pressure and religious beliefs has led to non-adoption of many genetically modified crops (Bt Brinjal and Bt Rice) which could have resulted in increased agricultural production in the country. Thus, we should learn from the experience of other nations about the benefits of adoption of GM crops.

Conclusion

GM technology has been commercially adopted for the past 20 years. In these 20 years, three generations of GM crops have been introduced. However, only the first-generation GM crops have been adopted widely. The other two generations have not yet been commercialized owing to the delay in government clearance. During these years, various methods have been developed to assess the economic valuation of GM technology, both at the micro and macro level.

The empirical evidence of the different methods of economic valuation of GM technology at the micro and macro level with few exceptions suggests that there are positive gains to producers, farmers, and consumers. However, farmers in developing countries have gained more in comparison to farmers in developed countries owing to differences in IPR laws, government pricing policy, agronomic and climate conditions. Despite these benefits, there is still an ongoing debate on the total welfare gains from the adoption of this technology. The latest issue that has surfaced is that the widespread adoption of GM HT crops has led to the development of weed resistance, which has reduced the benefits of adopting this GM variety. In the U.S., the area affected by the adoption of GM HT crops is currently within the range of 15%-40% of the total area (Brookes & Barfoot, 2014). Taking account of this issue will lead to further variation in results.

Limitations of the Study and Scope for Further Research

The available literature does not take into account the externalities that GM technology has created in the environment. Most of the farm level studies have limited their analysis of the environmental impact of GM technology to herbicide /pesticide use. Other environmental impacts such as impact on water quality, genetic diversity, the extent to which GM crops hybridize with local crops, and so forth has not been taken into consideration in any economic study. At the same time, the governments of developed and developing countries have imposed various bio-safety and labeling regulations. These regulatory requirements are associated with certain costs, which have undermined the economic benefits associated with the technology. These costs have not been quantified in economic terms and have been totally left out from the valuation methods. Therefore, further research can be done to incorporate the indirect effects of GM technology on the environment, and the costs associated with the regulation of this technology in order to achieve more comprehensive results of the economic valuation of GM technology.

References

Basu, A.K., & Qaim, M. (2007). On the adoption of genetically modified seeds in developing countries and the optimal types of government intervention. *American Journal of Agriculture Economics, 89* (3), 784 - 804. doi: http://dx.doi.org/10.1111/j.1467-8276.2007.01005.x

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. – the first sixteen years. *Environmental Sciences Europe, 24* (24), 2190-4715. doi: 10.1186/2190-4715-24-24

Brookes, G., & Barfoot, P. (2014). *GM crops: Global socioeconomic and environmental impacts 1996 - 2012*. Dorchester : PG Economics Limited.

Buckwell, A., Bradley, D., & Brookes, G. (1998). *Economics of identity preservation for genetically modified crops : Final Report of a Study of the Food Biotechnology Communication Initiative.* Wye College and CEAS Consultants. London, U.K. Retrieved from http://www.ceasc.com/Images/Content/Final%20FBCI%20report%201745.pdf

Demont, M., & Devos, Y. (2008). Regulating coexistence of GM and non-GM crops without jeopardizing economic incentives. *Trends in Biotechnology, 26* (7), 353 - 358. doi: doi: 10.1016/j.tibtech.2008.03.006

Demont, M., & Tollens, E. (2004). First impact of biotechnology in the EU: Bt maize adoption in Spain. *Annals of Applied Biology, 145* (2), 197 - 207. DOI: 10.1111/j.1744-7348.2004.tb00376.x

Duffy, M. (2001, December). Who benefits from biotechnology? *Paper presented at the American Seed Trade Association Meet*, Chicago, Illinois, December 5-7, 2001. Retrieved from http://www.econ.iastate.edu/faculty/duffy/Pages/biotechpaper.pdf

European Commission. (2003). *Guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming* (Report No. L189). Retrieved from http://europa.eu.int/eurlex/lex/LexUriServ/LexUriServ.do?uri=CELEX:32003H0556:EN:HTML

Falck-Zepeda, J.B., Traxler, G., & Nelson, R.G. (2000). Rent creation and distribution from biotechnology innovations: The case of Bt cotton and herbicide-tolerant soybeans in 1997. *Agribusiness, 16* (1), 21–32. doi: 10.1002/(SICI)1520-6297(200024)16:1<21::AID-AGR3>3.0.CO;2-F

Fernandez-Cornejo, J., & Li, J. (2005, July). The impacts of adopting genetically engineered crops in the USA: the case of Bt corn. *Paper presented at American Agriculture Economic Association Annual Meet,* Providence, RI, July 24-27, 2005 Retrieved from: http://www.ageconsearch.umn.edu/bitstream/19318/1/sp05fe01.pdf

Huang, J., Hu, R., Rozelle, S., Qiao, F., & Pray, C.E. (2002). Transgenic varieties and productivity of smallholder cotton farmers in China. *Australian Journal of Agricultural and Resource Economics, 46* (3), 367 - 387. doi: 10.1111/1467-8489.00184

Ismaël, Y., Bennett, R., & Morse, S. (2003). Benefits of Bt cotton use by smallholders farmers in South Africa. *AgBioForum, 5* (1), 1-5.

James, C. (2014). *Global Status of commercialized biotech/GM crops: 2014.* ISAAA Brief No. 49, ISAAA: Ithaca, NY. Retrieved from http://www.isaaa.org/resources/publications/briefs/49

Kathage, J., & Qaim, M. (2012). Economic impacts and impact dynamics of Bt (Bacillus thuringiensis) cotton in India. *Proceedings of the National Academy of Sciences of the United States of America, 109* (29), 11652-11656. doi: 10.1073/pnas.1203647109

Kovach, J., Petzoldt, C., Degni, J., Tette, J. (1992). A method to measure the environmental impact of pesticides. *New York's Food and Life Sciences Bulletin, 139,* 1-8. Retrieved from http://ucbiotech.org/biotech_info/PDFs/Kovach_2003.pdf

Lichtenberg, E., & Zilberman, D. (1986). The economics of damage control: Why specification matters. *American Journal of Agriculture Economics, 68* (2), 261– 273. doi: 10.2307/1241427

Marra, M. C., Piggott, N. E., & Sydorovych, O. (2004). *The impact of herbicide tolerant crops on North Carolina's farmers* (Working Paper). Department of Agricultural and Resource Economics, North Carolina State University, Raleigh NC. Retrieved from: https://ag-econ.ncsu.edu/wp-content/uploads/2015/12/marapr05.pdf

Pray, C.E., Ma, D., Huang, J., & Qiao, F. (2001). Impact of Bt cotton in China. *World Development Review, 29* (5), 813 - 825.

Qaim, M. (2009). The economics of genetically modified crops. *Annual Review of Resource Economics, 1,* 665 - 693. DOI: 10.1146/annurev.resource.050708.144203

Qaim, M., & De Janvry, A. (2005). Bt cotton and pesticide use in Argentina: Economic and environmental effects. *Environment and Development Economics, 10,* 179 - 200. doi: 10.1017/S1355770X04001883

Qaim, M., & Traxler, G. (2005). Roundup ready soybeans in Argentina : Farm level and aggregate welfare effects. *Agriculture Economics, 32* (1), 73 - 86. doi: 10.1111/j.0169-5150.2005.00006.x

Qaim, M., Subramanian, A., Naik, G., & Zilberman, D. (2006). Adoption of Bt cotton and impact variability: Insights from India. *Applied Economic Perspective Policy, 28* (1), 48 - 58. DOI:10.1111/j.1467-9353.2006.00272.x

Roederer, C., Nugent, R., & Wilson, P. (2000). *Economic impacts of genetically modified crops on the agri-food sector: A synthesis.* Working document, Directorate-General for Agriculture. [EU Commission - Working Document]. Retrieved from: https://ec.europa.eu/agriculture/publi/gmo/gmo.pdf

Santaniello, V., Evenson, R., Zilberman, D., & Carlson, G.A. (2000). *Agriculture and intellectual property rights : Economic, institutional and implementation issues in biotechnology.* Oxfordshire, UK: CABI Publications.

Scatasta, S., Wesseler, J.H.H, & Demont, M. (2006). *A critical assessment of methods for analysis of social welfare impacts of genetically modified crops : A literature survey* (Mansholt Working Paper, 27). Wageningen, the Netherlands : Mansholt Graduate School of Social Sciences.

Traxler, G. (2006) The GMO experience in North and South America. *International Journal of Technology and Globalization, 2* (1/2), 46 - 64.