Explaining Public Resistance to Genetically Modified Corn: An Analysis of the Distribution of Benefits and Risks

Felicia Wu

Genetically modified (GM) crops have met with widespread approval among scientists and policy makers in the United States, but public approval of GM crops, both domestically and abroad, is progressing much more slowly. An underlying cause of public wariness may be that both nations and individual consumers do not perceive significant benefits to themselves from GM crops, while fearing the risks they may incur. In this study, an economic analysis is conducted to determine whether the benefits of one type of GM corn, Bt corn (genetically modified to resist damage from the ECB and Southwestern corn borer), outweigh the potential risks; and who the “winners” and “losers” are among stakeholder groups that may be affected by Bt corn. It is found that Bt corn growers, consumers, and industry all benefit from Bt corn adoption, though the purported health and environmental benefits of reducing chemical pesticide usage through Bt corn are negligible. Though the aggregated public benefit is large, the welfare gain to individual consumers is small and may not make up for perceived risks. While environmental and health risks of Bt corn are unlikely, the potential market risks—impacting both the organic corn market and total U.S. corn exports—are found to be significant. Currently, distributional analysis is not a part of regulatory decision making of Bt corn in the United States; yet it may help to explain why decision makers at both the government and individual-consumer levels have failed to embrace Bt corn and other GM crops.

KEY WORDS: Bt corn; distributional analysis; economic impacts; genetically modified crops

1. INTRODUCTION

In the summer of 2002, worldwide public wariness of genetically modified (GM) corn reached a prominence that the United States could not ignore. Between the months of May and October, several sub-Saharan African nations—in particular, Zambia, Zimbabwe, and Mozambique—repeatedly rejected U.S. food donations that contained GM corn, in spite of massive regional famines that threatened the lives of over 14 million people. While officials in those nations defended their decision on the grounds of wishing to avoid environmental and health risks, economic risks likely played a more significant role in their rejection of GM corn. First, these officials feared that African farmers would not be able to export their food commodities if they were found to be contaminated by genetically modified varieties. Second, they feared that if they accepted U.S. corn that was not guaranteed to be “GM-free,” European donor organizations would halt financial aid due to the European Union’s (EU) precautionary stance against GM crops. Thus, economic risks imposed from the outside may have been more salient in these officials’ decisions than any risks intrinsic to GM corn.

It is not only those African nations that are concerned with the economic impacts of GM corn. Worldwide, particularly in the EU and now increasingly in Asia, government officials and citizens worry that the benefits of GM corn do not outweigh the potential market and environmental risks. Furthermore,
the distribution of the benefits and the risks among different stakeholders in society is a cause of concern. It is feared that while individual farmers who adopt the new GM seed and industries that sell the seed will reap profits, society at large will gain virtually no benefit while incurring potentially large losses in the event of unforeseen risks.\(^5\)

This article analyzes the economic impacts of one type of genetically modified corn, Bt field corn, on social welfare in the United States. It is the first study to incorporate environmental and health externalities of Bt corn into an economic analysis. Two questions are posed regarding Bt corn’s economic impacts. The first addresses overall economic efficiency: whether the benefits of Bt corn outweigh the potential risks. The second question addresses distributional impacts: who wins, who loses, and who remains unaffected among the different stakeholders that could be impacted by Bt corn adoption. The answers to these questions may help to explain public attitudes, both in the United States and abroad, toward Bt corn and other genetically modified crops.

2. BT CORN: BACKGROUND, BENEFITS, AND RISKS

Bt corn is one of the most prominent genetically modified crops grown in the world today. GM crops contain genes that are artificially inserted instead of the organism acquiring them through sexual means. Bt corn is modified to produce its own pesticide; the transgene (inserted gene) that confers this trait is derived from a soil bacterium \textit{Bacillus thuringiensis}, with pest-protective properties against lepidopteran insects. The varieties of Bt corn analyzed in this study are those that control European corn rootworm (ECB) and Southwestern corn borer (SWCB).\(^1\) This pest-protected corn provides a marked yield improvement over previous pest management strategies, as its target pests typically burrow so deeply into the corn that conventional pesticide sprays are useless against them. Another benefit is that the toxin produced by Bt corn, unlike many conventional pesticides, is harmless to mammals, fish, birds, and reptiles.

In 2002, Bt field corn was estimated to constitute about 20\% of total U.S. field corn acres.\(^6\) It is assumed to have leveled off its expected adoption ceiling to those areas of the United States that would most benefit from the specific type of pest control it offers (namely, regions that normally experience the greatest infestation of ECB or SWCB).\(^6\)

The benefits of Bt corn fall into three main categories: increased yield, decreased use of conventional pesticides, and decreased mycotoxin contamination in corn. Yield increase occurs because Bt corn is nearly 100\% effective against certain corn pests that were previously difficult to control.\(^7,8\) Even with the technology fee, or price premium, on Bt corn seed, farmers in certain areas of the United States where pest infestation is heavy will experience a significant increase in revenue. Part of this benefit is transferred to consumers through reduced price of corn. (In other areas of the United States, where pest infestation is lower, the economic benefit that Bt corn would provide to the grower from increased yield would not justify the technology fee.\(^9\))

Farmers who adopt the new Bt technology will also be able to forego spraying pesticides that control for lepidopteran pests. Hence, the overall use of four pesticides—methyl parathion, chlorpyrifos, lambda-cyhalothrin, and permethrin—is expected to decrease as a result of Bt corn planting.\(^9,10\) Thus, not only does Bt corn adoption provide material, time, equipment, and labor savings, it also has potential beneficial impacts on the environment and on human health.

Finally, Bt corn has been shown in several field experiments to have significantly lower levels of \textit{mycotoxins}: chemicals produced by fungi that can be toxic and carcinogenic to animals and humans.\(^11,12\) Corn that suffers insect damage is more prone to mycotoxin contamination because of the ease with which fungal spores germinate on open kernel wounds.\(^11\) \textit{Fumonisins} are one common class of mycotoxins that develop on corn in the United States. The protection that Bt corn offers against pests effectively lowers fumonisin contamination, which can lead in turn to increased market acceptance of farmers’ corn and improved livestock and human health.\(^12,13\) The evidence for lower levels of other mycotoxins in Bt corn, such as aflatoxin, deoxynivalenol, and zearalenone, is more variable and being researched currently.\(^14-17\)

However, Bt corn is not without its potential risks also. When Bt corn was first approved in the United States in 1995, the full suite of potential risks to human health, the environment, and the U.S. agricultural market had not yet been fully discovered and assessed. In the last seven years, more information has emerged to shed light on new potential risks and, in some cases, to repudiate those risks. Among the most notable potential risks of Bt corn that have since been

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\(^1\) A new variety of Bt corn has recently been registered with the EPA (February 2003) that protects against the corn rootworm. This type of Bt corn is not analyzed in this study.
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repudiated by extensive scientific and governmental risk assessments are those of food allergenicity, horizontal gene transfer, and adverse impacts on nontarget species. Consumers, however, may not be aware that these risks to the environment and human health have since been disproven as popular media more often emphasize the potential risk rather than repudiation of the risk.

The remaining risks, including impacts of gene out-crossing to organic corn growers and agricultural market risks, are important to the overall economic impact of Bt corn in the United States. First, organic farmers are concerned that Bt corn pollen, through wind pollination, will contaminate their non-Bt corn, rendering their crops unfit in the organic market. All organic certification agencies worldwide prohibit the use of genetic engineering in organic production and processing; the Codex Commission on Food Labeling’s Guidelines for the Production, Processing Labeling and Marketing of Organically Produced Foods states: “All materials and/or the products produced from genetically engineered/modified organisms (GEO/GMO) are not compatible with the principles of organic production (either the growing, manufacturing, or processing) and therefore are not accepted under these guidelines.” Hence, even if an organic grower plants no Bt corn, his or her corn may be rejected in the organic market if it is found to contain trace amounts of transgenic material through cross-pollination with Bt corn.

A second important economic risk pertains to the international market’s wariness of GM crops. Since commercialization of Bt corn began in the United States in 1996, total corn exports to the EU have dropped significantly. So far, however, this has not had a significant effect on net U.S. exports, for two main reasons. The first is that even in the years prior to Bt corn planting in the United States (the early 1990s), exports to the EU represented only about 5% of total U.S. corn exports. The second is that when the EU shifted its corn purchases away from the United States after 1996, U.S. corn sales increased in some other markets; this ability to reroute trade meant that total volume of corn trade was little affected. This may change in the future, however, particularly as EU Directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms came into effect fully in April 2004. The Directive’s requirements for GM food traceability and labeling, practices that are now being supported in other parts of the world, may make the process of growing and marketing Bt corn in the United States (and elsewhere in the world) onerous. To be able to trace and label GM food requires grain segregation at the farmer and elevator level. Not only would farmers and grain elevator operators need to keep GM and non-GM corn separate, they must also prevent commingling during harvest, transport, and storage, which would significantly slow the rate of turnover in a high-volume business. Currently, elevators operate with very thin margins, and their profits depend on moving large volumes of product quickly. Furthermore, the impact of labels on consumer preferences is unknown.

The extent to which these benefits and risks apportion themselves among different stakeholders in society is likely to have a profound impact on overall public acceptance of Bt corn.

3. LITERATURE REVIEW

The relevant body of literature concerns the impacts of new agricultural technologies on welfare change and distribution of surplus, and specifically on the economic impacts of genetically modified crops. Alston et al. assessed extensively the economics of agricultural research, addressing issues such as the appropriate amount to spend for this type of research, how it should be financed, and how it should be allocated among different programs and regions. The economic surplus approach they present, by which research-induced surplus is partitioned between producers and consumers, is well established in the agricultural economics literature.

This approach was used by Falck-Zepeda et al. to examine the welfare distribution worldwide from the introduction of Bt cotton in the United States, with a focus on yield improvement and reduction in pesticide costs. They found that Bt cotton provided a large increase in world surplus, over half of which went to U.S. farmers that adopted the new technology. Monsanto Company, U.S. consumers, the rest of the world, and Delta and Pine Land (the germplasm supplier) also experienced net welfare increase.

The literature also contains several studies of the net economic value of Bt corn yield protection to growers. Marra, Pardey, and Alston estimated profit from yield improvement in different states across the United States for a variety of GM crops, including Bt corn. They found that in most years across the Corn Belt, Bt corn would provide a small but significant yield increase; and in some regions, that increase would be significant. A study done by Carpenter of the National Center for Food and Agricultural Policy (NCFAP) calculated the net
benefits from yield increase depending on the pest-infestation level for three different years in Illinois, based on the prices of corn and average Bt yield advantage in those years. This analysis found that while Bt corn afforded a net benefit to growers in 1997, Bt corn growers actually suffered a net loss in 1998 and 1999, because the relatively low pest-infestation levels in those years led to a marginal improvement in Bt corn yield that did not make up for the technology fee. Hyde et al.\(^{(29)}\) constructed a matrix of scenarios for expected revenues and probability of high infestation, and calculated for each scenario whether Bt corn would be economical considering the technology fee. It was found that Bt corn was economical only in those scenarios in which pest infestation was high (defined as greater than a 20% chance of one pest per stalk or more) and expected revenue large (defined as over $250 per acre).

This study takes the research described above further in several important ways. First, it examines the economic impacts not just of yield increase, but also of health and environmental externalities such as pesticide reduction and mycotoxin reduction. Second, it considers the economic impacts of two noteworthy risks of Bt corn: market risks to organic corn growers and agricultural export risk. Finally, it does not limit its analysis to the impacts to producers of Bt corn, but to a wider range of stakeholders in U.S. society.

4. ECONOMIC ANALYSIS
4.1. Static Economic Core of Bt Corn
Economic analysis of a project or technology typically consists of two components: analysis of efficiency and analysis of distribution. Efficiency, the primary component, is a measure of whether the project or technology produces an overall benefit to society, but is indifferent to the recipients of benefits and losses. This may omit important considerations that have emerged from the public debate regarding GM crops. As Laget and Cantley\(^{(5)}\) stated, people will support the commercialization of GM crops only if they perceive a clear benefit to themselves.

Whom in fact does Bt corn benefit? The driving commercial purpose for the economic analysis at hand is that Bt corn provides protection against the ECB and several other corn pests.\(^{(30)}\) Hence, planting Bt corn is a form of technological change that increases overall corn yield. This purportedly results in benefits to both the producers and consumers.

The economic surplus approach presented by Alston et al.\(^{(26)}\) is used to calculate Marshallian surplus in this study. Depending on the nature of supply and demand of corn, overall producer surplus could actually be negative, meaning an overall net loss to producers (keeping in mind that the broad category of producers includes both Bt and non-Bt corn growers). Controlling for other factors, adoption of a technology that increases corn supply in the market will lead to a reduced overall price of corn. Therefore, even if Bt corn growers benefit through their increased corn yields, non-Bt corn growers will lose through a decrease in corn price generated by the increase of corn supply. On the other hand, consumer surplus increases from the reduced corn price.

A simple model can predict the price change resulting from increased corn yield that will determine the overall producer surplus for corn. It assumes that short-run demand can be represented by a constant elasticity function\(^{(31,32)}\) given by:

\[
Q_D = aP^b, \quad (1a)
\]

where \(Q_D\) is the quantity of corn demanded, \(P\) is the price per unit, \(b\) is the price elasticity of demand of corn, and \(a\) is a constant that shifts the demand curve. Similarly, short-run supply can be represented by

\[
Q_S = cP^d, \quad (1b)
\]

where \(Q_S\) is the quantity of corn supplied by growers, \(d\) is the price elasticity of supply, and \(c\) shifts the supply curve. In a market equilibrium, the quantity of corn demanded is equal to the quantity of corn supplied, such that \(Q_D = Q_S:\)

\[
aP^b = cP^d \rightarrow P = \left( \frac{a}{c} \right)^{\frac{1}{b-d}}. \quad (1c)
\]

Thus, the percent change in the price \(P\) can be calculated as

\[
\%P = \frac{\%\Delta a - \%\Delta c}{d - b}, \quad (1d)
\]

where \(\%\Delta a - \%\Delta c\) is the percent change in demand minus the percent change in supply. This is the relationship that will be used to calculate the consumer and producer surpluses that result from an increase of corn supply in the market.

The change in price is measured using estimates of a 20% adoption of Bt field corn in the United States\(^{(6)}\) and an 8% increase in yield per Bt corn acre.\(^{(33,34)}\) Price elasticity of demand was estimated as a triangular probability distribution with a most likely value of \(-0.43\) (\(-0.30\) to \(-0.90\)),\(^{(31)}\) and price elasticity of supply with a most likely value of 0.29.\(^{(31)}\) Average corn price was assumed to be $2.29 per bushel.\(^{(35)}\)
4.2. Calculation of the Value of Bt Corn to Society

Many factors, not just the economic drivers of supply and demand discussed in the above framework, affect the positive and negative impacts of Bt corn on U.S. society. These economic and external effects are examined by creating an empirical model that incorporates the following factors: (1) direct profits from increased yield in Bt cornfields (discussed in the previous section), (2) indirect environmental and health benefits of planting Bt corn, (3) potential risks to organic growers from Bt corn, and (4) market risks related to international standards and trade.

The total monetized benefit of corn $B$ may be expressed as the sum of benefits from yield increase, benefits related to reduction in conventional pesticide use, and benefits related to reduction in mycotoxin contamination. Hence

$$B = B_{\text{yield}} + B_{\text{pesticide}} + B_{\text{mycotoxin}},$$

where

$$B_{\text{yield}} = \text{benefits from yield increase and subsequent price reduction},$$

$$B_{\text{pesticide}} = \text{benefits from reduction in conventional pesticide use},$$

$$B_{\text{mycotoxin}} = \text{benefits from reduction in mycotoxin contamination}.$$  

The benefits from “yield increase” are, to be precise, not a result of the Bt corn hybrids being bred to produce greater yield, but because Bt offers protection against the pest damage that prevents farmers from achieving maximum possible yield with the hybrid they use. Thus, the Bt corn grower’s profit may be measured by

$$B_{\text{yield}} = P_{c}DL - P_{s},$$

where

$$P_{c} = \text{price of field corn},$$

$$D = \text{pest damage caused to cornfield, per pest per stalk},$$

$$L = \text{level of pests on plant},$$

$$P_{s} = \text{technology fee for Bt corn}.$$  

That is, the profits from improvement in yield that Bt corn offers are directly related to the pest damage that would otherwise have been done. The profit is offset by the technology fee $P_{s}$ that growers pay to use the Bt seed.

The benefit accrued to growers and to the larger society from Bt corn being used in lieu of conventional pesticides is threefold: economic savings to growers, ecological benefits, and human health benefits:

$$B_{\text{pesticide}} = G_{p} + E + H,$$

where

$$G_{p} = \text{reduced costs of pesticide use to growers},$$

$$E = \text{ecological benefits},$$

$$H = \text{human health benefits}.$$  

The reduced cost of pesticide use to growers $G_{p}$ is attributed to reductions in actual pesticide costs, labor, and equipment. Ecological benefits $E$ are measured by impacts to aquatic life, honeybees, and birds and mammals. The pesticides typically used to treat ECB and SWCB have primarily toxic impacts to wildlife, and do not accumulate in soil and water. Finally, human health benefits $H$ from using Bt corn in lieu of conventional pesticides are based on number and type of illnesses that would otherwise have occurred from using those pesticides:

$$G_{p} = A(P_{p} + P_{l} + P_{c}),$$

$$E = A(T + Y + M),$$

$$H = AI_{i}C_{i}.$$  

where

$$A = \% \text{ decrease in acres sprayed due to Bt corn planting},$$

$$P_{p} = \text{price of pesticides},$$

$$P_{l} = \text{price of labor},$$

$$P_{c} = \text{price of pesticide application equipment},$$

$$T = \text{aquatic life loss value},$$

$$Y = \text{honeybee life loss value},$$

$$M = \text{mammal/bird life loss value},$$

$$I = \text{number of human illnesses caused by ECB pesticides},$$

$$C_{i} = \text{cost per illness}.$$  

Values used for the last two variables apply specifically to the four pesticides used to control ECB and SWCB in the absence of Bt, listed in Section 2. It is assumed that the pesticide industries that created these specific pesticides can use their real resources elsewhere, so any drop in pesticide usage through Bt corn adoption should not be included as a welfare loss to them.

Reduction in mycotoxin (specifically, fumonisins) contamination in Bt corn benefits farmers in two ways. First, higher-quality corn has a higher market value. That is, corn with the lowest levels of fumonisins and other mycotoxins can be sold for food-grade corn at
the highest price; corn with mid-levels of these mycotoxins can be sold for feed at a lower price; and corn with high levels of mycotoxins is either sold for non-food/nonfeed uses at an even lower price or rejected outright.\textsuperscript{(13)} Second, while significantly contaminated corn rarely finds its way into the U.S. food supply, it can be fairly common in livestock feed, hence endangering the lives of animals and posing an economic risk to farmers. Fumonisin has been implicated in the livestock diseases of equine leukoencephalomalacia and porcine pulmonary edema,\textsuperscript{(40–43)} as well as reducing growth rates in livestock. Aflatoxins cause a variety of adverse effects in different animal species, especially poultry. The benefits of mycotoxin reduction are calculated as

\[ B_{\text{mycotoxin}} = G_m + F, \] (5)

where

\[ G_m = \text{market benefits to Bt corn growers from improved grain quality}, \]
\[ F = \text{market benefits to farmers from improved livestock health}. \]

To the extent that Bt corn has been shown in field studies to have mycotoxin levels that are almost consistently below the most stringent guidelines for food, \( G_m \) represents the amount that would have otherwise been lost if conventional corn had been planted instead. It is a function of the percentage of corn that otherwise would have fumonisin levels too high for a particular grade of corn, the amount of corn intended for that particular grade, and the price differentials among the different grades of corn. The market benefit of improved livestock health \( F \) is calculated as a function of horse and swine lives saved and their respective market prices (the calculation does not include the cost of pain and suffering that the animals endure from these diseases):

\[ G_m = dP_{\text{food}} Q_{\text{food}} R_{\text{food}} + dP_{\text{feed}} Q_{\text{feed}} R_{\text{feed}}, \] (5a)

\[ F = P_h Q_h + P_s Q_s, \] (5b)

where

\[ dP_{\text{food}} = \text{price difference between food-grade and feed-grade corn}, \]
\[ dP_{\text{feed}} = \text{price difference between feed-grade and lowest-grade corn}, \]
\[ Q_{\text{food}}, Q_{\text{feed}} = \text{quantities intended for food and feed-grade corn, respectively}, \]
\[ R_{\text{food}}, R_{\text{feed}} = \text{proportions of corn found to be above fumonisin guidelines}, \]

\[ P_h, P_s = \text{market prices of horses and swine, respectively}, \]
\[ Q_h, Q_s = \text{horse and swine lives saved through fumonisin reduction}. \]

A more complete analysis of the economic impacts of mycotoxin reduction through Bt corn can be found in Wu et al.\textsuperscript{(45)} There are also costs associated with potential risks (economic, health, and environmental) to consider when analyzing economic impacts of Bt corn. As stated earlier, a wide body of scientific research indicates that the loss to society through potential risks such as food allergenicity, horizontal gene transfer of antibiotic resistance, and harm to nontarget species is expected to be zero. Hence, the expected economic loss through these potential risks is zero.

Two potential market risks associated with Bt corn adoption are monetized, however. The magnitude of the potential cost of Bt gene out-crossing to organic growers \( C_{\text{org}} \) is estimated by first determining the extent of organic corn planting and production and the likelihood of cross-pollination with Bt corn, then multiplying by the price premium lost by organic corn growers in the event of Bt contamination. It is necessary to know the total number of organic corn acres grown in the United States, where they are planted with respect to Bt corn, the probability of cross-pollination, the tolerance level of transgenic material in organic corn, and the price premium for organic corn:

\[ C_{\text{org}} = A_{\text{org}} R_{\text{cross}} dP_{\text{org}} Q_{\text{org}}, \] (6)

where

\[ A_{\text{org}} = \text{total U.S. organic corn acreage}, \]
\[ R_{\text{cross}} = \text{probability of cross-contamination with Bt corn}, \]
\[ dP_{\text{org}} = \text{price difference between organic corn and conventionally planted corn}, \]
\[ Q_{\text{org}} = \text{yield per organic corn acre}. \]

The potential cost \( C_{\text{export}} \) of the second significant market risk, that of GM/non-GM corn segregation in order to meet international standards, is estimated by the costs of five different parameters that must be changed for successful segregation:

\[ C_{\text{export}} = C_m + C_{\text{rm}} + C_s + C_{\text{at}} + C_h, \] (7)

where

\[ C_m = \text{cost of marketing}, \]
\[ C_{\text{rm}} = \text{cost of general risk management}, \]
\[ C_s = \text{cost of segregated storage}, \]

\[ C_{\text{at}} = \text{cost of segregation}. \]
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Table I. Key Model Parameters, Descriptions, Values, and References for Empirical Model of Bt Corn

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>Number of larvae per corn stalk across U.S. corn acreage; this has a direct impact on overall yield loss</td>
<td>Log-normal[0.98,2]</td>
<td>6, 22, 23</td>
</tr>
<tr>
<td>$P_c$</td>
<td>Price received by farmers per bushel of field corn, in U.S. dollars</td>
<td>Normal[2.29,0.43]</td>
<td>24</td>
</tr>
<tr>
<td>$A$</td>
<td>Percentage of corn acres across the United States that have reduced pesticide usage due to adoption of Bt corn</td>
<td>Beta[14,86]</td>
<td>9, 46</td>
</tr>
<tr>
<td>$C_i$</td>
<td>Cost per illness caused by accidental inhalation or ingestion of pesticides typically used on corn</td>
<td>Log-normal[400,2]</td>
<td>47</td>
</tr>
<tr>
<td>$I$</td>
<td>Total number of illnesses annually in the United States caused by pesticides used on field corn</td>
<td>Log-normal[4500,2.5]</td>
<td>48, 49</td>
</tr>
<tr>
<td>$dP_{feed}$</td>
<td>Cost to grower (dollars per bushel) of reduced value of feed corn with high fumonisin contamination</td>
<td>Log-normal[1.50,1.4]</td>
<td>13</td>
</tr>
<tr>
<td>$Q_h$</td>
<td>Estimated number of horses saved annually in the United States through reduced fumonisins in corn feed</td>
<td>Gamma[2,10]</td>
<td>40, 41, 42</td>
</tr>
<tr>
<td>$Q_s$</td>
<td>Estimated number of swine saved annually in the United States through reduced fumonisins in corn feed</td>
<td>Gamma[2,7]</td>
<td>40, 43</td>
</tr>
<tr>
<td>$A_{org}$</td>
<td>Total number of organic corn acres in the U.S.</td>
<td>Normal[80K, 15K]</td>
<td>50</td>
</tr>
<tr>
<td>$dP_{org}$</td>
<td>Price premium (dollars per bushel) organic corn growers receive over conventional field corn</td>
<td>Log-normal[0.70,1.5]</td>
<td>50</td>
</tr>
<tr>
<td>$C_s$</td>
<td>Cost to segregate Bt from non-Bt corn, dollars per bushel</td>
<td>Log-normal[0.02,2]</td>
<td>25</td>
</tr>
</tbody>
</table>

$C_{at} = $ cost of analysis and testing for GM content,

$C_{h} = $ cost of handling segregated crops.

The parameter estimations are based on data over the last six years of agricultural conditions and Bt, organic, and conventional corn planting over all regions of the United States. A subset of key model parameters, descriptions, and references are summarized in Table I.

4.3. Treatment of Uncertainty and Variability

There are many natural sources of uncertainty and variability in the case of Bt corn, such as weather conditions that would lead to changes in pest infestation or overall corn yield. There are also economic uncertainties, such as the price of corn in a given year or the acceptability of genetically modified corn in various parts of the world. There are also dynamic-scale uncertainties, such as the long-term impact of ingestion of Bt pollen to monarch butterflies. Quality of data is yet another source of uncertainty and variability.

In this study, uncertainties are estimated by reviewing the literature available on the particular benefit or risk parameter (see Table I), giving weight to the quality of the work, and fitting a distribution to the available data based on its quality and measurements of uncertainty. The model is implemented in Analytica™, a software tool in which model parameters can be specified as probability distributions, and values from these distributions are sampled using Monte Carlo techniques in each model run. Uncertainty is propagated through the model, and results are reported probabilistically.

5. RESULTS

5.1. Value of Benefits Provided by Bt Corn in the United States

For each benefit category, the total benefits of Bt corn, and benefits per acre, are shown in Table II.

Of these four categories of benefits, the benefits from yield increase contribute the largest portion, with a mean value of $13.59 (−$3.67 to $48.76) per Bt corn acre. The total welfare gain from yield increase in the United States is valued at $217 million annually (−$59 to $780 million). At the 95% confidence level, the benefit of increased yield may be negative, reflecting the conventional wisdom that in some years and in some regions of the United States the profit from planting Bt corn is not worth its technology fee because of low pest infestation.

The second largest benefit is to industry and its shareholders at $8 per Bt corn acre ($6−$10)[8,10] or $128 million across the United States ($96−$160 million), through the technology fee received for Bt corn seed. Details of the real cost of seed production are not known, but it is assumed that the marginal cost of seed production of Bt corn seed is identical.
Table II. Welfare Gain Provided by Each Benefit Category for Bt Corn Planting in the United States

<table>
<thead>
<tr>
<th>Benefit Category</th>
<th>Per Acre Benefit ($)</th>
<th>Total U.S. Benefit ($ Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield increase</td>
<td>13.59 (−3.67 to 48.76)</td>
<td>217 (−59 to 780)</td>
</tr>
<tr>
<td>Industry profit</td>
<td>8 (6 to 10)</td>
<td>128 (96 to 160)</td>
</tr>
<tr>
<td>Pesticide reduction</td>
<td>1.99 (1.00 to 2.98)</td>
<td>32 (16 to 48)</td>
</tr>
<tr>
<td>Economic savings to farmers</td>
<td>1.96 (0.85 to 2.68)</td>
<td>31.4 (13.6 to 42.9)</td>
</tr>
<tr>
<td>Health benefits to farmers</td>
<td>(0 to 0.02)</td>
<td>0.16 (0 to 0.32)</td>
</tr>
<tr>
<td>Environmental improvement</td>
<td>0.02 (0.01 to 0.03)</td>
<td>0.32 (0.16 to 0.48)</td>
</tr>
<tr>
<td>Mycotoxin reduction</td>
<td>1.98 (0.52 to 7.12)</td>
<td>32 (8.3 to 114)</td>
</tr>
<tr>
<td>Improved corn market value</td>
<td>1.97 (0.30 to 6.98)</td>
<td>31 (4.8 to 112)</td>
</tr>
<tr>
<td>Improved livestock health</td>
<td>0.01 (0 to 0.02)</td>
<td>0.16 (0 to 0.32)</td>
</tr>
</tbody>
</table>

The third largest portion of the benefit is contributed by the decrease in pesticide use, at $1.99 ($1.00 to $2.98) per Bt corn acre. Across the United States, the welfare gain from pesticide reduction is about $32 million annually ($16–$48 million). The reduced input costs to growers (including cost of the pesticidal ingredients and labor) contribute the bulk of this benefit: $1.96 ($0.85–$3.68) per acre. The health benefits per acre of Bt corn in lieu of using conventional pesticides is roughly $0.01 ($0–$0.02) per acre, while the ecological benefits are $0.02 ($0.01–$0.03) per acre. Hence, for this health benefit, the bulk of the value goes to Bt corn growers and not to society at large.

The benefit from reducing fumonisin levels in corn has an expected value of $1.98 ($0.52–$7.12) per Bt corn acre, or $32 million across the United States annually ($8.3–$114 million). The welfare change through improved animal health makes up only about 1 cent per Bt corn acre; the welfare gain experienced through fumonisin reduction is almost entirely through improved market value of corn. Welfare gains from reducing other mycotoxins are not calculated because more evidence is needed that Bt corn consistently and effectively reduces other mycotoxins to the level at which economic or health impacts can be observed.

5.2. Distributional Analysis: Who Wins and Who Loses from Bt Corn

The impacts on four stakeholder groups are summarized here: U.S. consumers of corn, the Bt corn seed-producing industry, Bt corn growers, and non-Bt corn growers. The welfare impacts to various stakeholder groups are listed in Table III.

The decrease in corn price and the external benefit of improved environmental quality through pesticide reduction translate to a welfare gain for consumers of about $530 million annually ($0–$1.2 billion). Divided across the roughly 280 million people living in the United States, the benefit is about $1.90 per person per year ($0–$3.00).

Table III. Benefits and Losses for Different Stakeholders in U.S. Society

<table>
<thead>
<tr>
<th>Stakeholder Group</th>
<th>Benefits of Bt Corn</th>
<th>Total Expected Gain or Loss ($ Millions)</th>
<th>Impact on Welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bt corn growers</td>
<td>Profit from increased yield</td>
<td>190 (−33.3–822)</td>
<td>12% increase in revenue</td>
</tr>
<tr>
<td></td>
<td>Reduced pesticide costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced farm worker illnesses from pesticides</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved corn quality for market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Bt corn growers</td>
<td>Negative benefit (net loss) from reduced corn price</td>
<td>−416 (0–960)</td>
<td>6.7% loss in revenue</td>
</tr>
<tr>
<td>Society at large</td>
<td>Reduced corn price</td>
<td>530 (0–1,200)</td>
<td>$1.90/person per year</td>
</tr>
<tr>
<td>Agricultural biotechnology</td>
<td>Improved environmental quality</td>
<td>128 (96–160)</td>
<td>Owners of firm benefit</td>
</tr>
<tr>
<td>industry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total welfare gain</td>
<td>Bt technology fee on seed</td>
<td>432 (63–1290)</td>
<td></td>
</tr>
</tbody>
</table>
Explaining Public Resistance to Genetically Modified Corn

As mentioned above, the total gross welfare gain to the Bt corn seed industry from the technology fee is about $128 million ($96–$160 million), or roughly $8 per acre.

Bt corn growers across the United States experience a total welfare gain of about $190 million (−$33.3 to $822 million). The gain from yield increase constitutes the highest portion at $126 million ($64.8–$432 million), or $7.90 (−$4.05 to $27) per acre. This value is the difference between their expected profit with a yield increase and a lower overall price, and the profit they would have made without Bt corn’s yield increase but with a higher overall price. The remainder constitutes the welfare gains through decreased pesticide costs and pesticide-related illnesses, and decreased mycotoxin contamination, as described in the previous section.

Non-Bt corn growers, however, lose on average $6.50 ($0–$15.60) per corn acre as a result of the downward price pressure from additional supply of corn. Across the United States, this loss sums to $416 million ($0–$960 million), or a 6.7% decrease in revenue for non-Bt growers.

The total expected welfare gain provided by Bt corn, summing across these four stakeholder groups, is thus $432 million. The apportionment of the benefits to various stakeholder groups is shown in Fig. 1. Consumer surplus amounts to about 63% of the total welfare gain; thus, consumers are by a significant margin the largest beneficiaries of Bt corn adoption. The benefits to Bt corn growers make up 22% of the total welfare gain, and industry profits are the remaining 15%.

5.3. Risks of Bt Corn and Their Costs

The first risk is that of Bt gene outcrossing to organic corn growers, in which the loss to that stakeholder group could be as high as $1 million annually ($0–$7.13 million). These costs accrue through the need for organic growers to test for potential cross-pollination with Bt corn, as well as for the potential loss of their price premium if such cross-pollination is found.

Economic concerns regarding potential international standards on traceability and labeling of GM crops could have a serious impact on agricultural practices in the United States. If all grain elevators across the United States were required to adopt segregation of Bt/non-Bt corn due to international pressures, the total cost to U.S. agriculture would be roughly $416 million ($220–$695 million). Though there is considerable uncertainty in this figure, it demonstrates that the total costs of Bt corn in this scenario—namely, the risk that international standards will require traceability and labeling of GM foods—could easily cancel the total welfare gain calculated above.

6. DISCUSSION

In a competitive industry such as agribusiness in the United States, technological changes tend to increase supply such that in the longer run, almost all the gains are passed on to consumers. In the last century, this has been borne out through continually falling prices for food. From the point of view of the farmers, it is often the case that they must adopt the new technology or “go broke.”(52) The industries that create the new technologies can benefit by continually innovating and earning quasi-rents before mass adoption drives the product price down.

Bt corn is an example of a new agricultural technology that increases supply, driving the cost of corn down and benefiting the consumer, as shown in this study. However, because both real and perceived risks have stigmatized Bt corn in the eyes of both government decision makers and individual consumers, it becomes important to consider what the benefits of Bt corn adoption really are, and who is winning and who is losing as a result. If distributional analysis were ignored when assessing the economic impacts of Bt corn, one might simply evaluate the revenue gain of Bt corn’s immediate technological benefit of yield

![Fig. 1. Apportionment of Bt corn’s total benefits to different stakeholder groups in the United States.](image-url)
increase, and conclude that it does in fact provide a net benefit to at least some members of society. However, this approach leaves out many important considerations; for example, whether the benefit is really significant considering the overall U.S. corn market; the impacts of environmental and health externalities; the nature of potential risks and their impacts on different stakeholder groups; and the large uncertainties that exist in evaluating Bt corn’s overall impact on society.

The net benefit that Bt corn provides to U.S. society, at $432 million, is a small but significant percentage of the total value of the U.S. corn market. Most of this benefit comes from yield increase and from profit to industry through the Bt technology fee. In each of these cases (except for the technology fee), the main beneficiaries on a per acre basis are the Bt corn growers; they gain through increased revenue, decreased input costs (of pesticides), and decreased risk of having moldy corn rejected at the grain elevator. Non-Bt corn growers are expected to lose a small fraction of their revenue, about 6.7%, due to the price decrease in corn.

The market savings that Bt corn growers experience through reduced pesticide use and reduced mycotoxin contamination are also significant. However, the environmental and health benefits of Bt corn through reduced pesticides and reduced mycotoxins, which would impact a larger portion of society, are negligible: on the order of several cents per Bt corn acre. Hence, the positive externalities in the case of Bt corn have no significant impact on its overall societal value.

Grossing the total benefits, consumer surplus is the largest component of the welfare increase afforded by Bt corn, at $520 million. On a per person basis, this amounts to roughly $2 per person per year. Although consumers are indeed price responsive and genetically modified corn can lower prices, the savings so far (as shown above) are small enough that the perceived risks to the individual consumers do not have to be large for them to reject the new agricultural biotechnology altogether. This finding has actually been suggested in a study done by Wu,(53) in which it was shown that though consumers understood the benefits GM crops could provide, the risks they feared often trumped any benefits they perceived to themselves.

What are the truly relevant risks, however? The risk to organic corn growers through Bt gene outcrossing could cost them about $1 million annually. This seems insignificant if considered only in comparison with the overall benefit of hundreds of millions of dollars that Bt corn provides. However, that economic loss is concentrated within the one small stakeholder group of organic corn growers, who state that their loss should be compensated because Bt corn growers are not able to control Bt pollen flow. In the words of one organic corn grower: “It’s extremely frustrating when you have to pay those kinds of costs, through no fault of your own, because somebody’s introduced technology they can’t manage.” Such complaints are important, as U.S. society values the organic market as evidenced by its growing popularity within the last decade,(55) though no federal statutes currently protect organic growers against GM gene contamination.

The market risk concerning new worldwide regulations is also significant. The recent regulatory changes in the EU concerning traceability and labeling of GM foods could have a significant impact on Bt corn’s value in the United States. If all grain elevators across the United States were to segregate Bt from non-Bt corn, the total added cost is estimated at about $416 million—roughly equivalent to the total benefits that Bt corn is estimated to provide (an expected $432 million). Although this cost would be borne immediately by the grain elevators, it would certainly be passed down to all levels of society through increased price of food and food processing. Hence, in such a scenario, society as a whole stands to lose as a result of any Bt corn planting in the United States. There is, however, great uncertainty in how this situation may change in the future, and what impact such standards may have.

The uncertainty in this latter regard also explains the wariness of African nations to accept any food aid from the United States that could contain genetically modified material. If it is difficult within the U.S. agricultural infrastructure to implement GM/non-GM grain segregation, it is even more difficult in developing nations that lack such an infrastructure. If growers in those nations were to hoard and plant (unmilled) Bt corn kernels, and this corn were to spread throughout the food system, then those nations could potentially lose their export market to the European Union, depending on the stringency of EU regulations. Since so much uncertainty exists regarding how the EU and other areas of the world will regulate and accept GM crops in the near future, it is understandable that developing nations do not want to take any risk of accepting Bt corn from the United States. Unfortunately, the result may be continued widespread hunger of millions of people.
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It is important for developing nations to consider, however, not just the risks associated with GM crops, but also potential benefits. For example, the fumonisin reduction exhibited by Bt corn could have a far greater impact in the developing world, where fumonisin contamination is a significant health problem. The risks and benefits of these different potential impacts should be weighed when making a decision about adoption of GM crops.

This study shows how a distributional analysis can inform regulatory decision makers in the much contested area of genetically modified crops. By considering the benefits and risks to all potential stakeholders, and not just economic efficiency, the findings help explain why large portions of the domestic and international public are wary of Bt corn and other GM crops.

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