WELFARE IMPACTS OF GMO ADOPTION ALONG THE MARKETING CHAIN

by

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M.S., Ecole Supérieure d'Agriculture de Purpan, 1999
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AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

ABSTRACT

Technological changes have always been subject to numerous debates and studies to establish if and how much they benefit society. Glyphosate resistant soybean can be seen as such a technological improvement that has generated numerous studies attempting to measure the welfare gains. There are obvious gains from adopting the technology from a production efficiency standpoint, as it significantly decreases production cost and simplifies weed control management. However, with some consumers being reluctant to embrace such a change, especially in Europe, it is not obvious that overall welfare gains are positive. This study attempts to address some shortcomings perceived in recent economic literature, namely the disregard of consumers' demand responses and the lack of analysis over time.

A partial equilibrium model is created where supply and demand functions are estimated based on observed prices and quantities, the adoption rate of the new technology, and production information such as yield and harvested areas. The model developed considers 6 different regions, namely the U.S., Europe, China, Argentina, Brazil and the rest of the world, and develops for each one of them a supply function and three demand functions for soybean grain, meal and oil. Once those are calibrated, the gains for the different players in the industry are computed.

The findings are that the gains are proportionally allocated to the different consumers based on the share of the demand for the specific country. Price supports in the U.S. in the early years provide, proportionally to the adoption rate, more gains to the consumers. Producers gain or lose from the technology depending on whether they have

adopted it or not. Countries like the U.S. or Argentina, who were the earlier adopters, definitely see an increase in their producer surplus from the adoption of the technology. Countries such as Brazil, which have delayed adopting the technology for political reasons, have faced a significant loss due to lower prices without the benefits of enjoying a cost-saving production technology. The innovator's gain increases over time as the adoption rate rises.

From a country perspective, the U.S. is without doubt the country that has benefited the most from the technology. The main reasons are that the U.S. has the largest acreage of soybean that is grown using the Glyphosate resistant technology. The U.S. consumer base for soybean products is the largest and the monopoly is a U.S.-based company. Therefore some of the gain captured abroad by the monopoly funnels into the U.S.

This study finds that, from 2002 to 2005, even if the European consumer completely stopped purchasing soybean, the U.S. as a whole would still benefit from the technology. For the earlier period 1998-2005, the study finds that if Europe had decreased its demand from 35% to 48%, there would have been a possibility for the U.S. as a whole to have been made worse off by the technology.

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Acknowledgments

I would like to express my gratitude to all those who have made it possible for me to reach this very important goal. First and foremost, I would like to thank the Department of Agricultural Economics, which has brought me so much and made so many things possible. Without its assistance, this would not have been possible. Everybody in the department has been so willing to help and a true pleasure to work with.

I would also like to thank my major professor, Dr. Jeffrey Peterson, for his assistance throughout my time in the graduate program and in writing this dissertation. In addition, I want to express my appreciation for my committee members Dr. William Blankenau, Dr. John Crespi, and Dr. Terry Kastens for their valuable comments and helpful assistance throughout this research. Though not on my committee, Dr. Kevin Dhuyvetter has been invaluable for his helpful comments and help throughout the process of this research.

On a more personal note, I would also like to thank all my family and friends who have always been there to provide support throughout my time in this program. Throughout this very demanding process, having my wife, Kira, by my side has made it much easier and, at times, even fun. I want to thank her for her constant energy and support, as well as the periodic (and needed) reality checks.

Enfin, je voudrai remercier mon oncle Philippe pour m'avoir communiqué sa passion pour l'agriculture. Sans lui je n'aurai surement jamais découvert la persévérance et le dur labeur nécessaires à la production de notre nourriture de tous les jours trop souvent dénigrée. Je voudrai aussi remercier mes parents Alain et Noëlle pour leur support et leurs encouragements tout au long de mes études académiques. Sans leur support financier, et moral, rien de tout cela ne serait arrivé.

CHAPTER 1 - Problem Identification & Explanation

Since their introduction in 1996, Genetically Modified Organisms (GMOs) have been the fuel of much controversy. In Europe, strong opponents of the technology regularly perform illegal actions, from swathing experimental fields to trespassing into warehouses containing genetically modified seeds. Citizens in Europe are starting to become concerned as reflected in numerous polls. Media coverage is often used as a proxy to gauge how much interest a subject has in public opinion. In the written press, the coverage has been somewhat moderate in the United States, with only 383 articles addressing biotechnology in 2001-2002 in the *Washington Post*, the *New York Times* and the *Wall Street Journal* (Thomson and Dininni, 2005). In Europe, GMOs have taken a more prominent position in the media with, 385 articles related to GMOs being published within the same period by the European newspaper, *Le Monde,* alone. This shows that biotechnology is an important topic in the minds of European consumers. It also shows that policy makers have complex decisions to make regarding the development of Genetically Modified (GM) crops.

As Hebden *et al.* (2005) described, the United States, in allowing the production of GM crops, has been facing mixed responses from its trading partners. Exports to South Korea dropped significantly and other countries such as, Australia, New Zealand, China, Japan, and members of the European Union (E.U.) have imposed restrictions on imports and implemented mandatory GM labeling systems (Hebden *et al.,* 2005). The E.U. and other countries have been opposing the U.S. and other adopters of the technology in the

World Trade Organization (WTO) framework for some time and a resolution does not appear to be in sight. European consumers want to see a labeling of the product they consume if it contains genetically modified material. Consequently, grocery stores have started to move in that direction and label the products to address consumers' concerns (Lapan and Moschini, 2004).

While a WTO judgment made the E.U. moratorium on GM approval illegal (Bloomberg, 2006), it does not directly incriminate labeling. Indeed, Europe had been very slow to approve GM products to be sold or produced in its territory. In 1998 the approval process slowed down significantly; therefore, a large number of GM products have never been approved since then. While the WTO resolution appears to force Europe to start to more effectively approve GM products, it does not seem to condemn labeling. This means that the European consumers should have enough information to make an educated choice regarding GM food versus non-GM food consumption.

It is, therefore, important to identify what gains are really to be achieved by producers who adopt this new technology in the U.S. If the gains from improved production efficiency outweigh the loss in markets then it would be in producers' best interest to continue to move toward adoption. On the other hand, if the efficiency benefits from the technology are smaller than the lost markets, or if the efficiency gains are captured primarily by seed companies exercising market power, then it might not be in the farmers' best interest to move in the GM direction. Many studies have considered GM crops from a theoretical standpoint (Falck-Zepeda, 2000; Moschini *et al.*, 2000; Sobolevsky *et al.*, 2005) but many empirical questions remain.

This research will focus on the economic effect of the introduction of genetically modified soybean, specifically the variety modified for Glyphosate resistance.[1] With almost 10 years of background information, it is possible to estimate how the supply of soybean has shifted due to the introduction of the GM technology. Since GM technology is under intellectual property protection, innovator firms have market power and therefore the methodology developed by Moschini and Lapan (1997) will be used to estimate the repartition of welfare among the different sectors of the soybean industry and soybean consumers. A sensitivity analysis will then be elaborated and will demonstrate whether it is possible that the changes are immiserizing (if, because of trade distortions, the overall gains from innovation are not positive) and, if they are not, what kind of trade distortion would be necessary to annihilate the technological gains. These are important issues due to the increased usage of genetically modified crops in the United States and the reluctance of some major importers such, as Europe, to let those products come into their markets without specific labeling.

The genetically modified soybean is widely adopted in the United States and represents almost 90% of the planted soybean acres in 2005 (Figure 1).

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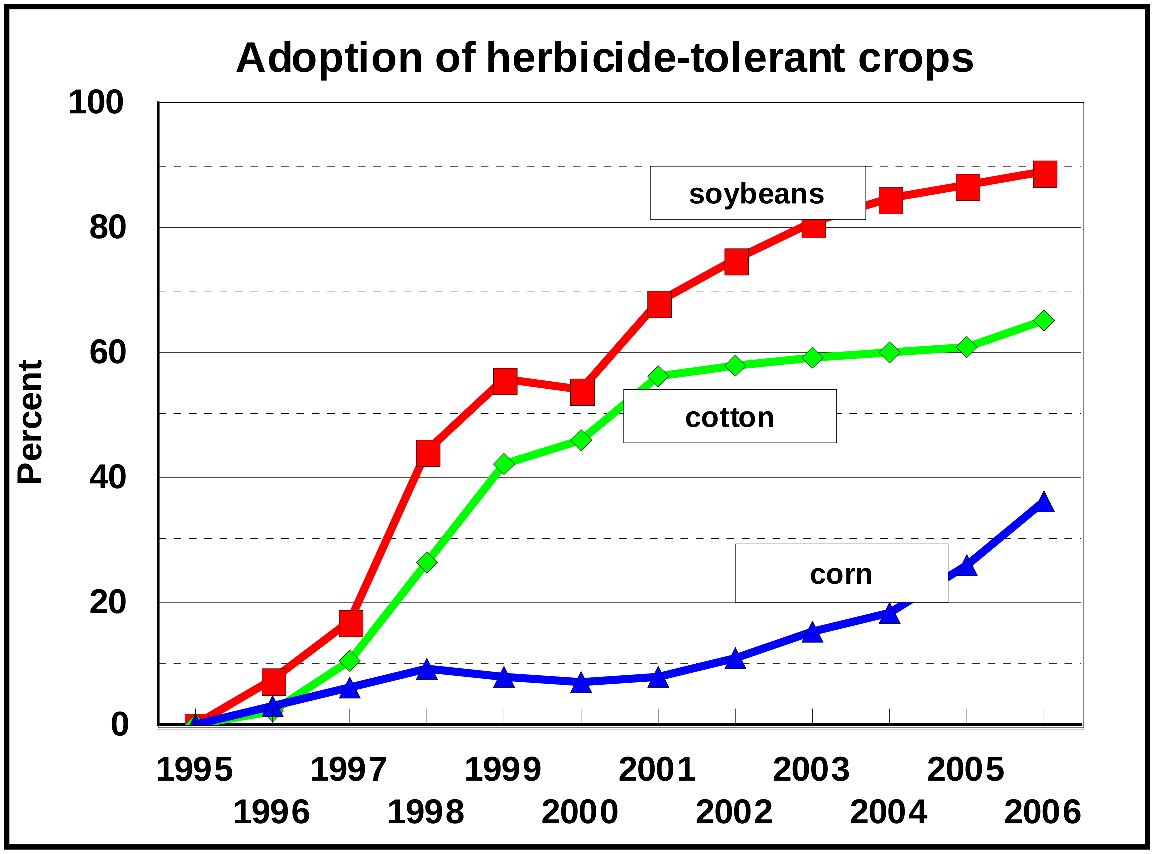
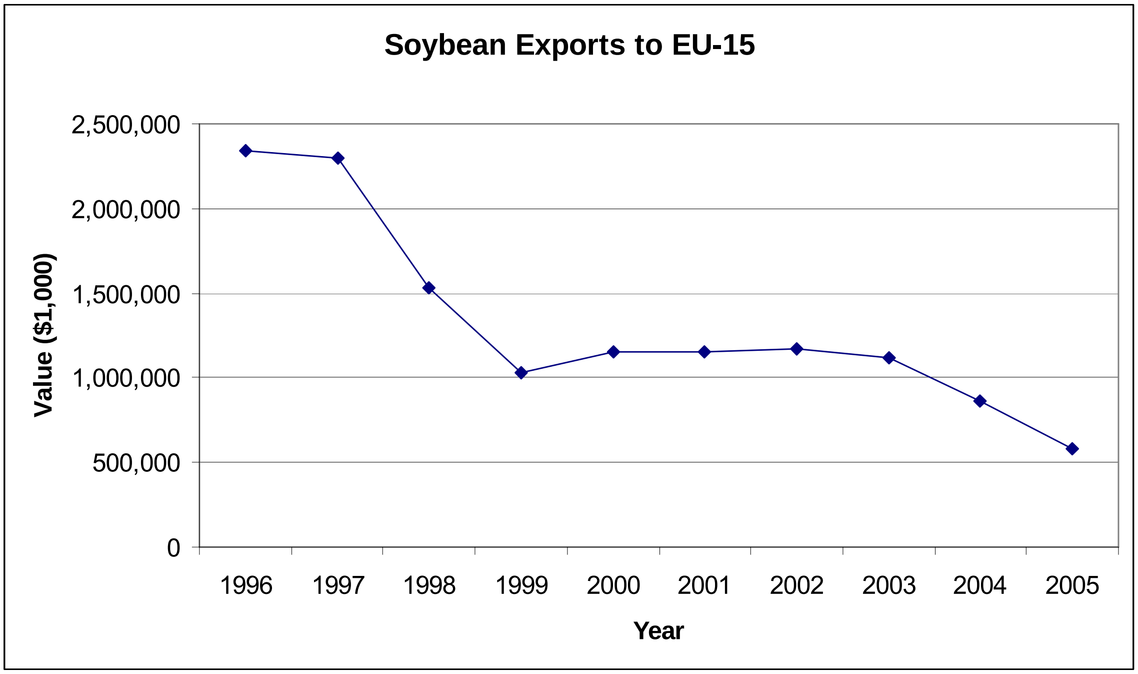
[1] Glyphosate is a herbicide that was sold under the brand name Roundup by Monsanto, who was the sole seller up to the end of 2000. Also note that Monsanto was the developer of the Glyphosate resistant soybean, which it sells under the brand name "Roundup Ready soybean". The patent given to Monsanto for that product will expire in August 2007.



Source: http://www.ers.usda.gov/Data/BiotechCrops/

Figure 1: Adoption of genetically engineered crops grown in the U.S.

Figure 2 shows how the export value of U.S. soybean to the E.U. varied over time. E.U. imports of U.S. soybean significantly decreased since 1997, from $2.3 billion in 1997 to $585 million in 2005.



Source: USDA Foreign Agricultural Service

Figure 2: Value of U.S. soybean exports to Europe over time

The primary objective of this study is to estimate the repartition of welfare gains due to the introduction of Glyphosate resistant soybean. In order to do so, the supply shift and demand shift will have to be calculated to measure producer as well as consumer welfare gains. There are also welfare consequences for seed producers and innovating companies that will need to be assessed. Indeed, because of the patenting of the technology, the innovator is allowed to act as a monopoly for a period of time. Finally, the model to be utilized in this study will assess the effect of potential customer resistance on the current level of welfare and, in particular, the reduction in demand from international markets needed that would make soybean producers in the U.S. worse off because of the introduction of the new technology. This study also will consider the welfare impacts of the technology adoption over time. It will not limit itself to one single year but will look at the entire period 1998-2005. When analyzing the soybean industry, it is important to consider the overall soybean complex, which is made of soybean grain, soybean oil and soybean meal. The welfare consequences on the soybean complex will be measured for different parts of the world, namely the U.S., the E.U., China, Argentina, Brazil and all the other countries combined under Rest of the World (ROW). In a context where countries have adopted different policies concerning biotechnology adoption or consumption, it is important to treat those countries individually. The tasks that will be accomplished through this study are as follows:

- Development of an economic model that is flexible enough to capture changes in soybean supply and demand.
- Calibration of the model to determine parameter values in the demand and supply functions.
- Estimation of monopoly profit from the Glyphosate resistant technology.
- Calculation of welfare change for the following groups: U.S. producers and consumers, South American producers and consumers, rest of the world producers and consumers.

CHAPTER 2 - Literature Review

The literature concerning GM food and its economic implications is quite abundant because it presents numerous challenges for economists due to the complexity of the subject. For clarity, this literature review will be organized along different themes. First, GM grains' acceptance by consumers has generated several studies, for which the main findings will be summarized. Second, the review will focus on studies that deal with producer adoption of this new technique as well as the factors that encourage or discourage adoption. Third, several research projects that have focused on welfare gains due to this innovation, as well as the distribution of the gains, will be explored. Fourth, because producers' welfare gains are linked to the supply shift, research on previous supply shifts due to technological improvements will also be addressed. Emphasis will be placed on the effect of assumptions concerning supply shifts and their consequences on producer surplus calculations. Finally, this review will consider studies on the welfare effects of innovation in the presence of distortionary policies – specifically the conditions under which a technological shift can have negative effects due to trade distortion. Of particular interest is the research concerning GM crops and trade distortions.

Consumer Attitudes Toward GMOs

GM foods have been a focus of numerous consumer studies over the last decade. Studies vary from trying to model consumers' aversion to GMOs (Springer *et al.* 2005) to labeling issues of products susceptible to containing GM material (Crespi and Marette, 2003).

Yearley (2001) explained the difference in consumers' acceptance of GM products as a result of the uncertainty associated with those products. He stated that the difficulty in analyzing consumer behavior resides in the fact that "the nature or the extent of the underlying uncertainties are themselves unknown" (p.151). For instance, when a risk is known and well documented, consumers can make judgments based on statistical evidence and therefore have a statistical basis to refer to. In the case of Bovine Spongiform Encephalopathy, for instance, because there was so much unknown about prions at the time, there was no statistical foundation to analyze the new technology (which consisted of feeding protein from dead animals to cows). Yearley's suggestion toward risk analysis is to develop a multi-criteria mapping that will, contrary to the usual techniques, not boil down risk perceptions to a few opinions but maintain the diversity of the risk approaches by evaluating different options and therefore making values and judgments explicit. This method functions as follows: "Representatives of key groups or key individuals are invited to formulate the options, the criteria and the weightings; the options are then scored against the criteria by experts, and the weightings applied. The most popular or least unpopular options can then be identified, and it is hard for the participants to disaffiliate themselves from the process since they are held to have been constitutive in setting up the options and in attaching the relative weights in the first place" (p.156).

Gaskell *et al.* (1999) attempted to answer the question of why European consumers seemed to exhibit different preferences toward GMOs than American consumers. They showed that consumers have different preferences when it comes to GM crops or GM food versus GM testing or GM medicines. They showed that American consumers are not necessarily more favorable to GM food than European consumers but overall there is a higher resistance level in Europe than in the U.S. While their study tried to explain consumer resistance based on the level of information proxy by media coverage, trust in institutions, and knowledge about biotechnology, they could not come up with a single explanation "for the greater resistance to food biotechnology in Europe" (p.386). Indeed, media coverage, while more abundant in Europe in 1996, was more positive than in the U.S. but the population was more reluctant towards GM food. While it is commonly accepted that scientific knowledge supports technology and innovation, this does not hold in the case of GM organisms. Only 4 out of 17 European countries had a lower population scientific knowledge than the U.S. but still GM organisms were not more favored than in the U.S. Finally, the third factor presented by Gaskell *et al.* is the trust in institutions: "Trust in the regulatory authorities is higher in the United States than in Europe" (p.386).

Terawaki (2005) used a similar approach to estimate the effects of the scientific information provided by the Japanese government on consumers' acceptance of GM corn oil in the form of their willingness to pay. He found that, while information seemed to reduce the variance component of the willingness to pay for GM corn oil, the level of information did not seem to reduce the mean component. This implies that no matter the level of information, it does not change intrinsically how much the average consumer is willing to pay for such a good.

Huffman (2003) also studied the effect of information on consumers' behavior concerning GM foods. He found that third party information from sources between the extremes of biotechnology companies and environmental groups might be perceived as a more objective information source. This would lead to less resistance to GM foods and might help "greatly improve future social welfare" (p.1117).

Springer *et al.* (2005) noted that, despite the numerous studies attempting to explain acceptance of GM food based on socio-economic factors or the way consumers are educated and the information that is distilled to them, there were still many unknown factors that seemed to be involved in consumer acceptance of GM products. They argued that the type of values present in a society and the correlation between these values and GM acceptance would be an important explanatory factor. The values in their survey were: self-direction, achievement, benevolence, conformity, stimulation, tradition, and universalism. These values were assessed by quantifying the importance each value had to each respondent. By looking at Greece and Germany, two European countries that have relatively different societal values, the researchers concluded that in a society where social norms are important, people will mainly rely on "beliefs and perceptions, which carry on family norms and traditions" (Springer *et al.,* 2005). The implication of this for GM food is that in a society that emphasizes self-direction and stimulation as opposed to tradition, security and conformity, people will have a more scientific outlook in the formation of attitudes, primarily by using a cost-benefit approach. Conversely, in other societies, acceptance will take longer as it will be based upon the perception of others' attitudes toward the new technology.

In a study attempting to measure consumers' willingness to pay for non-GM foods, Gifford *et al.* (2005) showed that there was a portion of the U.S. population that was willing to pay a 20 to 30% premium for food that will be certified non-GM. However, they pointed out that this share might be a hard target to reach for marketers as the researchers were not able to isolate particular socioeconomic characteristics that would significantly and consistently lead to a higher willingness to pay for non-GM foods.

Despite all the resistance that seems to exist around the world towards GM crops, Aldrich and Blisard (1998) asserted that we should look at the rbST experience as an example and take it into consideration when studying GM food acceptance. rbST is a laboratory-produced growth hormone that increases milk production. Similar to GM foods, its introduction generated significant resistance among consumers, with studies forecasting a drop in milk demand of 4% to 20%. With the passage of time since the introduction of rbST, none of the predicted negative reactions actually occurred. Therefore, from consumers' perspective, the market did not appear to have been affected despite the fact that consumers were concerned about this technique. The authors believe that the results should be similar with GM foods and that despite concerns, GM foods will still be consumed as long as there is an absence of reported harm.

Fulton and Giannakas (2004) and Crespi and Marette (2003) show the importance of consumer preferences while looking at the effect of GMOs on consumer welfare. Those studies focus primarily on labeling issues and show the complexity involved in the process of informing the consumer. Indeed, depending on the consumer sensibilities toward GM foods, mandatory labeling of GM products may be beneficial in the case where a large number of the population is concerned about the food they eat. Conversely, if the number of people concerned about food is low, then voluntarily labeling GM-free food might be the welfare-maximizing solution (Crespi and Marette, 2003). Fulton and Giannakas (2004) add to the labeling issue the fact that the market power of "life science companies" is important when determining consumers' preferences for different labeling options.

The studies presented have demonstrated that because there is some uncertainty associated with GM crops that cannot be quantified, and because risk levels are unknown, consumers have different acceptance levels of GM foods. Several studies have attempted to characterize the factors that would lead to such a difference. Those factors become difficult to pinpoint; beside the classical socioeconomic factors or sources of information, a part of consumer acceptance appears to be characterized by consumers' cultural values. Researchers have not yet been able to specifically isolate the consumer characteristics that would make an individual against or in favor of GM food.

Producers' Attitudes Toward GMOs

GM crops provide various benefits based on farm location as well as weed or pest infestation (Fernandez-Cornejo *et al.*, 2000). Apparently these benefits were sufficiently large to overcome producers' concerns about environmental and food safety impacts, as demonstrated by a rapid adoption rate. The main reason found in Fernandez-Cornejo *et* *al.*'s study on the adoption of GM crops in the U.S. was the small but statistically significant increase in yield as well as lower herbicide costs provided by this new technology. Fernandez-Cornejo *et al.*'s (2002) analysis looked also at GM adoption characteristics but this specific study is based on a larger database with the availability of two additional years of data compared to the 2000 study. Herbicide resistant crops have been widely accepted by producer populations in the U.S., with adoption rates up to 68%, at the time of their study, for Glyphosate resistant soybean. On the other hand, Bt resistant crops (crop resistant to corn-borer) have been less attractive for farmers as their adoption rates have leveled off and may even be decreasing in places in the U.S. The study concluded that adoption of herbicide resistant corn or cotton translates into a positive, statistically significant impact on financial performance. However, herbicide resistant soybean did not seem to have the same positive impact on financial performance. Finally, they concluded by showing that the adoption of herbicide resistant crops translated to a slight reduction in aggregate pesticide use.

Characteristics that affect farmers' decisions to plant GM crops have been the focus of numerous studies. Chimmiry *et al.*, in their study of Illinois farmers, found that operations for which the manager has a positive attitude toward GM food have a tendency to plant more acres to GM crops. On the other hand, farmers that have a more negative perception of GM organisms have a smaller probability of planting GM crops. Finally, if GM crops are viewed as providing microeconomic benefits (such as yield or profit improvements) to farmers then it increases the probability that they will plant genetically enhanced crops.

Saak and Hennessy (2002) looked at producer behavior from a different perspective and analyzed how the uncertainty associated with GM food markets affected planting decisions. If at planting time there is some uncertainty concerning the market price of the crop following harvest, and price discounts may occur because certain markets are resistant to GM foods, fewer acres of GM crops are planted than otherwise. Kalaitzandonakes (2002) similarly notes that “short term market realities and institutions … will have a significant impact on the rate and the direction of agribiotechnology research and product development” (p-1232). He also foresees the United States as keeping its strategic position and its leadership emphasizing the fact that industries are always fairly reactive to market signaling. For instance, if there is a premium to be made from non-GM soybean, the private sector will organize itself in such a way that it can capture that extra premium.

Supply shifts have occurred frequently in agriculture and have attracted the interest of many economists. Lemieux and Wohlgenant (1989), Schutz (1956) and Qaim (1999) studied production shifts in U.S. hogs, U.S. oranges and Mexican potatoes, respectively. Lemieux and Wohlgenant showed that the introduction of PST (pork growth hormone, porcine somatotropin) could produce benefits to producers and that its adoption was very sensitive to lagged adjustments in production as well as changes in product quality. Schutz explained that the introduction of a new technology that allows processing of oranges into concentrates may have had mixed effects on orange growers. Indeed, the period following the introduction of the process showed increased price volatility despite the constant increases in production. Qaim presented the tremendous impacts that viral resistant potatoes could have on the Mexican potato industry. He also showed how poorer countries could benefit from biotechnology research by investing in international research in order to have access to the genetic technology that would allow them to be able to develop their own domestic technology.

By looking at the few research findings presented above, GM crops present numerous advantages for farmers and that is the main reason they are so widely adopted. GM crops with lower adoption rates appear to have fairly localized benefits and do not seem to generate widespread improvements. Generally most technological improvements are capable of improving producers' situations. However, care needs to be taken as uncertainty on the demand side may offset these benefits.

Effects of Technological Improvements on Welfare

Technological changes are bound to happen over time. Very likely they will be resisted by part of the population as they can have adverse effects on certain groups. Just *et al.*(1979) explain that because of technological changes, some people will gain and some people will lose. In the case of perfect competition without market distortions and externalities, the overall welfare of the world should increase because of those changes. Technological changes that have the largest welfare effects usually improve the productivity of a scarce factor, which generally allows for an increase in output. However, one of the side-effects, sometimes unwanted, is that technological innovation may change the location of production.

In 1982 Freebairn *et al.* showed that the welfare gains from research are distributed along the production and supply chain from producers to consumers. They applied their theoretical model to the hog industry and showed that research at different levels of the supply chain benefits all players as well as the consumer. The model they developed assumes perfect competition but they extended their result to a situation where perfect competition would not be the case. The monopoly or firm with market power would then reap more of the benefits from research than the other players, but there still should be an overall gain to each of the players. Alston and Scobie commented that the strong assumptions made by Freebairn *et al*. (such as a zero elasticity of substitution between inputs, linear supply and demand functions and a parallel shift due to technology improvements) resulted in a loss of the benefits that marketing stages have had on production.

As early as 1972, Bieri *et al.* suggested that, when looking at how research affects the distribution of gains, studies often failed to take into account the structure of the sectors involved: i.e., input suppliers to agriculture, the agricultural production sector, and the food distributing and consuming sector. Because each technological innovation is specific and will affect each sector differently, care should be taken when analyzing the welfare gains generated by different technological improvements. Specifically, each sector should be looked at individually.

Edwards and Freebairn (1984) looked also at the repartition of welfare gains by taking into account the different sectors involved. They also accounted for the effects on the rest of the world's consumers and producers. They concluded that for a country that wants to maximize the social benefits from research, resources should be invested in research that affects imported commodities. By doing so, production costs of these commodities would decrease and therefore generate welfare gains in the rest of the world as well, which in turn would increase the demand for exported goods.

Gallagher (1998) presented a story with different nuances. He looked at a hypothetical GM soybean that would have different properties, namely higher oil content but less yield per acre. According to his model, this would result in no welfare gains, mainly due to the substitution effects toward other oil sources. In order to reach welfare gains, both yield and quality need to increase. Nevertheless, the yield effect should be pursued more aggressively as it ends up dominating the quality characteristics of the grains.

When talking about technological improvements, it is important to consider whether those improvements are input sensitive. Indeed, as Offutt *et al.* (1987) pointed out, technological improvements would be sensitive to land quality, as was the case in their study of Illinois corn. They recommend that, while trying to evaluate new technology, the researcher must be sensitive to regional differences as gains would likely be different from one region to another.

Carmen Fernandez Dias (2005), in a welfare study of the GM situation in Europe, argued that without mandatory labeling consumers in Europe would have been made worse off. Her theoretical model attempted to represent the real organization of the market. First the seed market, because of concentration and patent, was assumed to be monopolistically competitive. The production market, represented by farmers, and the transformation market, where raw grain products were transformed into food, were both assumed to be competitive. The study, solely theoretical, assumed a shift in the demand of food due to the introduction of GM products. This allowed for the assumption that consumers would have a positive Willingness To Pay (WTP) for non GM products and therefore part of the productivity gains from GM crops may be lost due to a weaker demand. She explains that if there is no labeling, there would be a welfare loss, because of higher prices due to the European market intervention that prevents prices within the E.U. from falling below a certain level, and also because of the "monopolist power of seed suppliers that prevents the transmission of cost savings" (p.15). Because of consumers being so sensitive to GM food, the presence of information, such as labeling, allows both GM food and non GM food consumers to be better off in her model.

Wilson *et al* (2005) did a thorough empirical study of the welfare consequences of introducing GM wheat. Their research took into account the supply shift due to the introduction of the new technology. They also took into account market acceptance nationally and internationally. They allowed for market segmentation and included the extra costs due to the requirements of segregating the different products. Based on the scenario they accepted as being the most likely, they showed a producer annual surplus gain of $301 million and a consumer surplus increase of $252 million in the U.S.

When computing producer or consumer surplus, Lindner and Jarett (1978) emphasized the importance of knowing the kind of supply shift that occurs. A parallel shift versus a convergent or a divergent supply shift will generate different results. Wise and Fell (1980) in their comments pointed out a mathematical flaw in the previous study but agreed on the fact that special care should be given when choosing the elasticities of demand and of supply.

Alston *et al.* (1983) noticed that, very often when welfare gains were calculated, perfect competition was assumed and may lead researchers to erroneous answers. They developed a conceptual framework, based on conjectural variations, that allowed for imperfect competition and therefore were able to account for oligopsony, oligopoly, or even both. By using conjectural variations theory, they were able to introduce model parameters that represented the level of market power exhibited on the supply or on the demand side. Those parameters had the convenient properties of being bounded between 0 and 1, with the extremes representing no market power and full monopoly/monopsony, respectively. Using their model in an imperfect competition situation allowed them to draw conclusions regarding the benefit distribution due to innovation.

First they explained that, as shown in previous literature, a parallel shift of the supply curve would provide the same gains as the perfectly competitive market minus the increase in dead weight loss due to the presence of market power. The innovation benefits in that case are strictly dependent on the two elasticities, the market power coefficients in the two sectors, and the producers' share of the price of the final good.

Second, they showed that a pivotal shift of supply has the potential of decreasing the dead weight loss. This does not mean that the market is less distorted, but it means that more gains are captured. Their main finding was that, by increasing the oligopsony or oligopoly power, the gains would tend to migrate toward the sector that had the most market power. This suggests that research investments may not always achieve the desired goal.

Zhao *et al.* (1997) also brought up some interesting points to take into consideration when attempting to measure welfare changes. They used an equilibrium displacement model and looked at how much the choice of functional form affected the results of welfare gains or losses. They found that, when supply and demand were locally linear, estimates were exact. If the supply and demand were locally log linear functions then the percentage change needed to be estimated as a difference of logs to be able to obtain exact results. If parallel shifts were assumed, then the errors would be small as long as the exogenous shift was small. However, the errors could be significant in the case of constant elasticity functional forms.

Although innovation generally leads to welfare improvements, previously presented studies provide interesting perspectives on technological changes and welfare relationships. Indeed, most agree that technological changes lead to welfare improvements. However, measuring those changes is not always an easy task as different factors need to be taken into consideration, such as functional form, effect on inputs use, type of supply shift, and the presence of market power.

Intellectual Property Right Effect on Economic Welfare

GM technology has introduced a new concept in agriculture, intellectual property rights. Indeed, users of GM seeds cannot replant the seeds from one year to another as they used to do for non hybrid crops. This is prevented due to the fact that innovator companies like Monsanto have obtained a patent on a genetic technology that confers to the plant certain properties. This is important to take into account while measuring welfare changes as it puts the holder of the intellectual property rights in a monopoly situation. Falck-Zepeda *et al.* (1997), Moschini and Lapan (1997), Langford (1997), Lence *et al.* (2005) and Graff *et al.* (2003) all studied the implication of intellectual property rights on rent creation and welfare distribution as well as technology transfers.

Regarding genetic material Intellectual Property Rights (IPR), Langford (1997) suggested that, while IPR are a necessary condition in order to attract private funding, a system needs to be put in place (eventually publicly financed) to maintain biodiversity and genetic patrimony. He concluded by saying that intellectual property rights give an incentive to investors to have more money invested in research. But he also said that, potentially, the interest of Third World countries would be to invest at the international level to guide and lead to discoveries from which they could benefit. Research findings then could be transportable and applicable to those countries. Once transformed and rationally sound for the population, this technology would improve national welfare.

Graff *et al.* (2003) explained that biotechnology is transforming the world of research in agriculture, especially the interaction between publicly and privately funded research. They discussed that, while intellectual property rights allow start-up companies to develop and to bear the risk of developing a new technology, such rights may also constrain future innovation in the private and in the public sector. IPR might also lead to new types of complementarities between private and public research.

Lence *et al.* (2005) looked at intellectual property rights and their effects over time. They started from the postulate that grain farmers would buy those improved inputs as long as they were cheaper than the profit premium farmers could expect from them. This would influence the cost structure of production and therefore affect the grain market itself. Taking into account the length of time the intellectual property rights are in effect before competition will take place, they showed that the optimal duration of intellectual property right protection is not really sensitive to the parameters but more to the productivity of the research and development sector. For a longer period of intellectual property right protection, consumer and producer welfare were not as high as for a shorter period. They concluded by saying that reducing the intellectual property period would bring more welfare to other sectors besides the seed industry.

Moschini and Lapan (1997) explain that traditional methods for calculating consumer and producer surplus cannot be applied in the case of GM crops, because the input market for producers is not competitive. Much of the research in the U.S. received public funds in the past and therefore the issue of proprietary information did not arise. As more research was privatized, more of the findings become the property of a firm that is given intellectual property rights to protect its discovery. Pricing for the new input is then bounded by, on the one hand, a price so high that producers would use a substitute, and on the other hand, the (low) price of the regular product where the monopoly would not make any profits from their innovation.

The model they developed assumes a competitive market on the output side and market power on the input side. In this framework, total welfare gain can be computed by aggregating the traditional Marshallian surplus measured on the output market and the monopoly profit generated in the input market. From simulations, Moschini and Lapan found that, while classical methods may not be too inaccurate for measuring the overall welfare gain from technology, they might fail to accurately allocate the welfare gains across market sectors. “What is conventionally measured as benefits to consumers and agricultural producers could in fact be largely captured by the innovating firms” (Moschini and Lapan, 1997, p.1241).

Falck-Zepeda *et al.*(2000) studied the welfare distribution due to Bt technology on cotton and generated preliminary estimates for Glyphosate resistant soybean for 1997.

They used the model first developed by Moschini and Lapan in 1997 to attribute the distribution of the rent due to GM technology. The model used is based on linear supply and demand, and they assumed a parallel shift of supply due to the introduction of the new technology. By invoking the Law of One Price, they assumed that prices in different regions differ only by transportation costs. This allowed them to convert the counterfactual world price (world price that would have been observed without the introduction of GMOs) to a percentage change in price. This permits regional price diversity and differences in regional production characteristics - i.e. local yields as well as cost savings induced by the new technology. Production data used are from the 1997 ARMS survey and elasticities are taken from previous literature. The model is calibrated to the year 1997. They found that, for Bt cotton, farmers captured 42% of additional rents, Monsanto through the licensing fee captured 35%, Delta and Pine Land Company (the seed company) 9%, consumers 7%, and the rest of the world 6%. Concerning soybean, the results were very sensitive to the elasticity chosen for the U.S. supply. Using Taylor's (1993) elasticity, they found 76% for US farmers, 4% for U.S. consumers, 9% for the rest of the world, and 10% for the innovator. Using Williams' (1998) elasticity they found that U.S. farmers captured 29%, U.S. consumers 17%, rest of the world 28%, with 25% of the total rent going to the innovator.

Moschini *et al.* (2000) used the model developed by Moschini and Lapan (1997) as the basis for their evaluation of the welfare effects in the soybean complex due to Glyphosate resistant soybean. The model was different in that it represented more accurately the reality of planting decisions made by farmers so that the choice variable was not the seed rate, but the number of soybean acres planted. The innovation could therefore affect overall supply of soybean either by increasing the planted acreage of soybean or by increasing yield.

They also introduced regional characteristics to represent the production differences between regions of the world as well as varying abilities to enforce IPR in different growing regions. They identified three regions defined as the U.S., South America and the Rest of the World (ROW). They noted that South America produces about as much oil and meal as the United States, but had a larger share of export markets. Europe mainly imports soybean meal, but is a net oil exporter. They also pointed out that, while China was the largest oil importer, its market was geographically separated from the other regions.

The model was constructed by assuming that farmers were profit maximizers, so that any increase in yield due to the new technology is converted to a cost saving. Once this assumption was made and the profit function established, the supply function for soybean can be derived. This soybean supply function faced three demand functions, the demand of soybean grain, oil and meal. Holding transportation and crushing costs constant, they were able to write the spatial market equilibrium conditions so that quantity produced and imported in one region minus quantity exported was equal to the quantity demanded for the specific region. The model was calibrated using price and quantities for the 1997-1998 year.

Other parameters such as the price differential between soybean products, as well as cost savings due to the technology, were calculated either using previous literature or Extension-based information. Imposing no change in stocks, they looked at different adoption rate scenarios in each of the three regions defined previously. They concluded that the gains generated by Glyphosate resistant soybean were important. Those gains decreased, for the United States the more the technology was transferred abroad. Indeed, U.S. farmers lost some of their competitive edge versus the rest of the world producers. Gains could be lessened even more if IPR enforcements were weak overseas.

Price *et al.* (2003) presented a compelling study as they acknowledged and summarized the previous work that has been done on welfare gains generated by GM technology for soybean. They used Falck-Zepeda *et al.*'s (2000) model as their framework but adapted it "to better reflect commodity flows and trade patterns" (p.20). They used a linear equilibrium model and estimated a supply shift by estimating the cost saving per acre of soybean planted. Once the shift was estimated, they used demand and supply elasticities for the U.S. and the rest of the world to generate the net welfare effect to producers, consumers, innovator for the U.S. and the rest of the world. They found that the gain to the world in 1997 from the adoption of Glyphosate resistant soybean was $307.5 million. The total share recouped by the U.S. was estimated at 94%, with U.S. producers capturing 20% of the total benefits. They explained the small share of the benefit compared to the total production of soybean by the fact that the cost savings as well as the yield increases were small. On the other side of the spectrum, gains for seed suppliers as well as innovator were estimated to be 68% of the total gains from the technology.

Qaim and Traxler (2005) developed a model based on a three-region model (U.S., Argentina and Rest Of the World) with international spill-overs to measure welfare effects of the introduction of Glyphosate resistant soybean. The model was based on linear supply and demand curves as well as a parallel supply shift due to the new technology. The main contributions of this study are that it is a more intensive study of Argentina's supply shift and also that it considers the period 1996-2001 instead of only one year like most of the studies previously mentioned. They showed that consumers, producers, as well as private firms, benefited from the Glyphosate resistant soybean technology. Important differences could be noticed regarding the welfare gain distribution related to the adoption of the technology between the U.S. and Argentina. While in the U.S., a large part of the gain was captured by the innovating firms, in Argentina farmers were the main beneficiaries due to the larger adoption rate as well as weaker IP regulations. Technology spillovers from the U.S. brought an estimated welfare gain of U.S. $300 million to Argentina in 2001. At the other end of the spectrum, farmers in countries that have not adopted the technology faced a welfare loss because they faced lower prices without being able to benefit from the technological improvement. However, if, as some have speculated, some consumers are willing to pay a premium for non-GM foods, the European labeling rule implementation may allow producers of those non-adopting countries to recoup some of their welfare loss. The authors concluded by explaining that developing countries can be the main beneficiaries from adopting GM technologies. However, the IP issue needs to be dealt with very carefully, as on one hand strong IP laws can reduce social welfare, while on the other hand laws that are too relaxed will not give an incentive to the private sector to develop the technology for the demanding country.

Sobolevsky *et al.* (2005) used the Moschini *et al.* (2000) model as a starting point for their study. They modified it by introducing two important concepts. First, they made the assumption that GM soybean was a weakly inferior substitute for GM free soybean in

Europe. And second, they introduced the concept that because of the agricultural policy in the U.S., producers made production decisions based not on soybean prices alone, but on the larger of the soybean loan rate and soybean price. Most of the assumptions necessary to calibrate the model were similar to the ones made by Moschini *et al*. The differentiated demand system was calibrated by assuming that 50% of the population in Europe was sensitive to GM/GM free characteristic of soybean and that the total demand would rise by 5% if the two products were to be priced at the same price. They found that, if there was no U.S. price support, the U.S. producers would be worse off in all cases except in the case where there was no segregation cost.[2] In the (real) situation where there was a price support, U.S. producer gain was $429 million, while the welfare effects on Brazilian producers range from a loss of $51 million to a gain of $15 million, depending on the cost of segregation. The effects for Argentinean producers ranged from a loss of $27 million to a gain of $9 million. The most beneficial outcomes were in the case of no segregation cost. Overall world welfare, according to their study, would have risen between $1,538 million and $1,668 million depending on the level of segregation cost chosen.

The previous studies have shown that calculating the effect of the introduction of a new technology on welfare is a complex task. The proprietary aspect of the biotechnology applied to agriculture has an effect on the welfare distribution. Besides the market power potential given to the innovator due to the acquisition of a patent, the welfare distribution is also very sensitive to the assumptions made concerning the supply shift. A study conducted by Moschini and Lapan in 1997 directly related to Glyphosate

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[2] Cost associated with keeping non-GM soybean from any contamination from GM soybean

resistant soybean estimated that producers earn 42% to 76% of the welfare gain in 1997, but another one in 2003 by Price *et al.* calculated the gains as being only 20% for producers.

Literature Discussion

This literature review has emphasized how important GM organisms are in the consumer's mind. Numerous studies have looked at consumer behavior toward GM food. Some of them elaborated on market mechanisms that could be potentially welfare enhancing such as mandatory versus voluntarily labeling of GM food. European consumers appear to be the most resistant to the new technology according to most of the studies.

Producers' attitudes towards GM crops have been to widely accept them in the U.S., with herbicide resistant soybean occupying 90% of U.S. soybean acreage in 2005. Farmers' attitudes were somewhat ambiguous at first because of the uncertainty that was attached to European consumers' concerns about the new product. But, as soon as they saw the cost savings associated with the production of GM crops as well as the relatively good acceptance of domestic consumers, they widely adopted the technology.

In order to calculate welfare gains appropriately, and especially in the case of Glyphosate resistant soybean, studies show the importance of taking into account the characteristics of the sectors involved. Because the GM technology innovator holds a patent, it is given some market power in order for it to recoup its investments in research. This is why, as explained by Moschini and Lapan, Price *et al.* and Falck-Zepeda *et al.,* while the output market is still under perfect competition, the input market is not.

The 3 studies, previously mentioned, have a similar approach for calculating welfare gains due to the introduction of Glyphosate resistant soybean. They first try to estimate an average cost saving per acre and use it to calculate the supply shift. Once supply shift is combined with demand and supply elasticities provided by the literature, they can estimate the surplus that will go to producers and to consumers. Monopoly profit is then measured by estimating the royalty fee per acre collected by the innovator.

There are several limitations in the previous studies from the way the model was constructed. First, those studies rely heavily on the assumptions made concerning market elasticities as well as the cost savings of the GM technology. Generally, cost saving was calculated using crop budgets, surveys or other specialists' inputs on the dollars saved per acre for Glyphosate resistant soybean compared to regular soybean.

Second, while numerous studies have shown concerns especially amongst European consumers toward GMOs, U.S. soybean export demand shift does not seem to have been accounted for while measuring welfare, except in the case of the Sobolevsky *et al.* study. This is somewhat disconcerting as during the last 10 years Europe has been an important if not the most important world importer of soybean.

Third, while looking at transmission of technology, it is very important to consider how the IPR are going to be respected. Indeed, evidence exists that IPRs do not have the same significance in foreign countries. For example, according to Moschini *et al.* it is not possible in Argentina to legally prevent the farmers from using their harvested grain as seed from one year to another. This indeed gives a competitive advantage to Argentinean producers and lessens the profit of the innovating company.

Last but not least, because of the nature of the model used in the studies that have looked at welfare issues concerning the introduction of Glyphosate resistant soybean, only one year is considered. This is due to the fact that the models have to be calibrated but it is somewhat restrictive as the analysis is static. Even Qaim and Traxler's study, which looks at several years, calibrates the model for each year using a model less flexible that the one used in this study.

The model that will be presented below will attempt to address some of the issues not dealt with in the welfare literature concerning the introduction of Glyphosate resistant soybean. First and foremost, while most studies note that consumer acceptance of those products may not be 100%, few of them attempt to model an eventual shift in the demand due to consumers' resistance to genetically engineered crops. This is very important, because it means that if there is such a shift, then without the adoption of GMOs, prices would have been higher not only because of a smaller supply, but also because of a stronger demand. When calculating the counterfactual price, the demand shift needs to be accounted for; otherwise the results are biased toward overestimating the overall welfare gain, especially from the producer standpoint.

Second, the study will be performed over multiple years to see whether, and how, variations from one year to another affect the results. Calculations performed only on one year may potentially miss the market dynamics and this study will attempt to account for that by evaluating the period 1998-2005.

Lastly, it is largely accepted that producers are one of the main beneficiaries from this technology as it improves their ability to minimize cost. However, assuming that the consumer responds negatively to it, demand will be reduced and prices will fall. Even though the technology reduces farmers' costs, it is conceivable they still suffer a welfare loss overall. Here, a key question is how large a demand reduction is necessary from, say, European consumers, to make U.S. producers potentially worse off by the adoption of this technology. The model in this study will be capable of addressing this question.

CHAPTER 3 - Conceptual Model

Following Moschini's and Lapan's lead, the conceptual framework is based on the following assumptions. The U.S. is a large soybean exporting country, adopting a new technology, which faces competition in the export market mainly from Brazil and Argentina. As suggested by several studies, home consumers are not sensitive in general to the introduction of GM engineered foods. Foreign consumers such as Europeans or Japanese seem to be more reserved concerning GM engineered food than Americans. The innovator of the technology holds a patent on Glyphosate resistant soybean, which means that it is allowed, if desired, to act as a monopoly in order to recoup the investment in research that resulted in the discovery of the new product.

Similar to Moschini *et al.* (2000), and using the same notation, we can represent soybean production as: $Y_B = L \cdot y$ where Y_B is total production, L is the acres of land allocated to soybean production and y denotes yield per acre. Soybean yield per acre depends on the seeds planted per acre (also known as seed density), x, and a set of other inputs represented by the vector z. The per-acre production function is defined as $y=f(x,z)$, where w and r are respectively the price of seeds and the price vector of other inputs (z). The profit function per acre can be defined as:

(1) $$\pi(P_B, r, w) = \max_{z,x}\left\{P_B f(z,x) - r \cdot z - wx\right\} ,$$

where π is the profit per acre and P_B is the price of one metric ton of soybean.

Seed rate recommendations often are not related to other input decisions. Let δ denote the optimal seed density rate and assume that it is "irrespective of the use of other inputs" (Moschini *et al.* (2000) p. 36). Equation (1) then can be simplified to:

(2) $$\pi(P_B, r, w) = \tilde{\pi}(P_B, r) - \delta w\,,$$

where $\tilde{\pi}(P_B, r) = \max_z \{P_B f(z, \delta) - r \cdot z\}$. The result of the assumptions above is that the optimal yield does not depend on the seed price. By Hotelling's Lemma,

(3) $$\frac{\partial \pi(P_B, r, w)}{\partial P_B} = \frac{\partial \tilde{\pi}(P_B, r)}{\partial P_B} \equiv y(P_B, r)\,.$$

Land allocation to soybean production is the result of the maximization of overall farm profits. It is the allocation of acreage based on net returns per acre that will allocate the land use between soybean production and other competing crops:

(4) $$L = L(\pi)\,.$$

This implies that the total supply of soybean is

(5) $$Y_B = L(\tilde{\pi}(P_B, r) - \delta w) \cdot y(P_B, r)\,.$$

Similarly, the total demand for soybean seeds can be written

(6) $$x(P_B, r, w) = L(\tilde{\pi}(P_B, r) - \delta w) \cdot \delta\,.$$

As the seed density is assumed to be the same between the old and the new technology, the new technology is adopted only if it provides a larger profit per acre. Letting the subscript "1" denote the new technology, farmers will adopt only if

(7) $$\tilde{\pi}_1(P_B, r) > \tilde{\pi}(P_B, r)\,.$$

The monopolist will price the seed such that it maximizes its overall profit. Assuming that the innovator will market this new technology in *N* countries numbered from 1 to *N*, the monopolist's (direct) profit function to be maximized can be written

(8) $$\Pi^M = \sum_{i=1}^{N} x_i(P_{B,i}, r_i, w_{1,i})\left[w_{1,i} - c\right],$$

where c is the constant per unit production cost of the seeds, and $w_{1,i}$ is the per unit sales price of the new technology seeds in country *i*. However, in selecting a profit-maximizing seed price, the monopolist needs to take into account two feedback effects on farmers' profit levels. First, the seed price will influence the farmer's gain from adopting the new technology. Thus, the monopolist will want to ensure it chooses a $w_{1,i}$ so that the new technology increases profits. This implies the decision problem is subject to the constraint:

(9) $$\tilde{\pi}_{1,i}(P_{B,i}, r_i) - \delta w_{1,i} \geq \tilde{\pi}_i(P_{B,i}, r_i) - \delta w_i\,.$$

Second, the price chosen for seeds will affect the soybean supply by changing the land allocated to soybean production and/or by changing the yield per acre. Therefore soybean price is affected by the price charged by the monopoly for seed. We can write: $P_{B,i} = P_{B,i}(w_1)$ where w_1 is the vector of innovated input prices in each of the different producing countries. These feedback effects imply that the monopoly will have to solve the following problem to set the price of seeds:

(10) $$\max_{w_1}\left\{\sum_{i=1}^{N} x_i(P_{B,i}(w_1), r_i, w_{1,i})\left[w_{1,i} - c\right]\right\}$$

$$\text{s.t. } \tilde{\pi}_{1,i}(P_{B,i}(w_1), r_i) - \delta w_{1,i} \geq \tilde{\pi}_i(P_{B,i}(w_1), r_i) - \delta w_i \;,\; \forall i$$

Temporarily dropping the country specification (i.e., not including the "*i*"), and assuming as previously mentioned that seed density is constant and equal to δ, the maximized profit per acre for the two technologies can be written as follows:

(11) Standard technology: $$\pi = A + \frac{G}{1+\eta} P_B^{1+\eta} - \delta w$$

(12) Glyphosate resistant technology: $\pi = A + \alpha + \frac{(1+\beta)G}{1+\eta} P_B^{1+\eta} - \delta w(1+\mu)$

With:

η = elasticity of yield with respect to soybean price

A, G= parameters subsuming all other input prices (the vector r)

β= coefficient of yield change due to the Glyphosate resistant technology.

α= coefficient of unit profit increase due to the Glyphosate resistant technology (e.g., from herbicide and herbicide applications cost savings).

μ=markup on Glyphosate resistant seed price (reflecting technology fee)

In this specification, the profit advantage of the new technology is affected in two ways, first by the parameter β which affects the yield, and through the parameter α directly. Applying Hotelling's lemma, this specification leads to a constant elasticity output supply function of soybean. In particular, the yield functions (i.e., production per acre) are $y = GP_B^{\eta}$ for the standard technology and $y = (1+\beta)GP_B^{\eta}$ for the Glyphosate resistant technology.

Producers face different production conditions and have different technology adoption strategies. When a new technology such as Glyphosate resistant soybean is introduced, the adoption is not instantaneous; some farmers will adopt it immediately while others will wait until the technology has proven its merit to their eyes. In this case we assume that the new technology in fact increases profits (i.e., $\tilde{\pi}_1(\cdot) - \delta w_1 > \tilde{\pi}(\cdot) - \delta w$), making adoption beneficial for all farmers. However, perhaps due to limited information about the gain in profits, some farmers do not adopt. At a given point in time, an exogenously determined fraction $\rho \in [0,1]$ of farmers have adopted the new technology.[3] The average profit per acre becomes:

$$\textbf{(13)} \qquad \bar{\pi} = A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta} P_B^{1+\eta} - \delta w(1+\rho\mu),$$

and the average yield is then $y = (1+\rho\beta)GP_B^{\eta}$. The overall supply of soybean depends on yield as well as the acreage planted to soybean.

Land supply for soybean production is based on average land rents, which are affected by output price as well as the adoption rate (see figure 9 in chapter 5 for a graphical representation). Assuming a constant elasticity form, land supply can be written

$$\textbf{(14)} \qquad L = \lambda\bar{\pi}^{\theta},$$

where θ is the elasticity of land supply in response to the profitability of soybean production, and λ is a scale parameter. The aggregate supply is obtained by multiplying yield by the number of acres devoted to soybean production. Total production can be written as follows:

$$\textbf{(15)} \qquad Y_B = \lambda\left[A + \rho\alpha + \frac{(1+\rho\beta)G}{1+\eta} P_B^{1+\eta} - \delta w(1+\rho\mu)\right]^{\theta} (1+\rho\beta)GP_B^{\eta}$$

The demand functions for the three different products made from soybean (soybean grain, soybean oil, soybean meal) will have to be estimated for each of the

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[3] There is a large literature examining the causes of delayed adoption of profitable technologies (e.g., Sunding and Zilberman, 2000; Dong and Saha, 1998; McWilliams and Zilberman, 1996). The interest of the study here is not in explaining the rate of adoption, but rather on evaluating the market consequences of a given adoption rate. Thus I do not formally model the way ρ changes through time, although that is a possible extension of this work.

different regions of the study. Moschini *et al.* assume those demand curves do not shift in response to the introduction of Glyphosate resistant technology (i.e., GM food) in the market. Here, the possibility that the demand may have shifted in some regions is accounted for, reflecting, for instance, numerous polls in Europe showing that consumers are concerned about biotechnology modified foods.

Soybean is traded under three different forms, soybean grain, soybean oil or soybean meal. If P_O, P_M and P_B are respectively the prices for soybean oil, soybean meal and soybean grain, the associated demand functions can be written as $D_O(P_O)$, $D_M(P_M)$ and $D_B(P_B)$. The demand functions, assuming a no-labeling scenario, for those products in constant elasticity form are specified as:

(16) $$D_{B,i}(P_{B,i}) = \kappa_{B,i}(1-\varphi_{B,i})^{\rho_w} P_{B,i}^{-\in_{B,i}}$$

(17) $$D_{O,i}(P_{O,i}) = \kappa_{O,i}(1-\varphi_{O,i})^{\rho_w} P_{O,i}^{-\in_{O,i}}$$

(18) $$D_{M,i}(P_{M,i}) = \kappa_{M,i}(1-\varphi_{M,i})^{\rho_w} P_{M,i}^{-\in_{M,i}}$$

where $\in_{j,i}$ is the constant demand elasticity for product *j* in region *i*, ρ_w is the world adoption rate of the new technology, and $\varphi_{j,i}$ is a measure of consumer sensitivity to genetically modified food. The terms in parentheses account for demand shifts due to Glyphosate resistant technology adoption. While ρ_w is also a supply shifting parameter, it is used here in the demand function as a proxy for the consumer's perception of the likelihood they are consuming genetically modified soybean products.

The index $\varphi_{j,i} \in [-1,1]$ measures the consumer sensitivity in country *i* to consuming product *j* that contains genetically modified soybean. The κs are scalars subsuming all other demand shifters (price of substitutes, income, etc.).

As Moschini *et al.* state, (p. 41) “Suppose that crushing one unit of soybean produces γ_0 units of oil and γ_m units of meal, and that a unit crushing costs in region i are constant and equal to m_i (the so-called crushing margin). Then, for given regional supply quantities $Y_{b,i}$ of soybean, and given changes in stocks $\Delta S_{j,i}$ for product j, in region i, the spatial market equilibrium conditions are written as:”

(19) $$\frac{1}{\gamma_0}\left\{\sum_{i=U,B,A,E,C,R}\left[D_{O,i}(P_{O,i})+\Delta S_{O,i}\right]\right\}+\sum_{i=U,B,A,E,C,R} D_{B,i}(P_{B,i})=\sum_{i=U,B,A,E,C,R}\left[Y_{B,i}-\Delta S_{B,i}\right]$$

The previous equality says the that total quantity of soybean produced minus the total change in stock has to be equal to total quantity of soybean demanded as grain plus total quantity of soybean grain demanded crushed into oil, plus the changes in oil stock (converted back to grain equivalent). This obviously assumes that there are no wastes of soybean between production and consumption.

(20) $$\frac{1}{\gamma_0}\left\{\sum_{i=U,B,A,E,C,R}\left[D_{O,i}(P_{O,i})+\Delta S_{O,i}\right]\right\}=\frac{1}{\gamma_M}\left\{\sum_{i=U,B,A,E,C,R}\left[D_{M,i}(P_{M,i})+\Delta S_{M,i}\right]\right\}$$

The previous equality assures that the quantity of soybean oil and soybean meal demanded are linked by the technical coefficients γ_O and γ_M. Indeed when crushing soybean, about 20% by weight is transformed into oil and the remaining 80% is soybean meal. Therefore the demands of those products has to reflect this technicality, implying that prices of the three products obey the relationship

(21) $$P_{B,U}+m_U=\gamma_O P_{O,U}+\gamma_m P_{M,U}\,.$$

The previous equality ensures that there is no incentive left for someone to crush some more soybean to make a profit. Prices of a given product in different regions must differ by transportation costs and tariffs. These conditions are:

$$P_{B,B} = P_{B,U} + t_{B,B}$$

$$P_{M,B} = P_{M,U} + t_{M,B}$$

$$P_{O,B} = P_{O,U} + t_{O,B}$$

$$P_{B,A} = P_{B,U} + t_{B,A}$$

$$P_{M,A} = P_{M,U} + t_{M,A}$$

$$P_{O,A} = P_{O,U} + t_{O,A}$$

$$P_{B,E} = P_{B,U} + t_{B,E}$$

$$P_{M,E} = P_{M,U} + t_{M,E}$$

$$P_{O,E} = P_{O,U} + t_{O,E}$$

$$P_{B,C} = P_{B,U} + t_{B,C}$$

$$P_{M,C} = P_{M,U} + t_{M,C}$$

$$P_{O,C} = P_{O,U} + t_{O,C}$$

$$P_{B,R} = P_{B,U} + t_{B,R}$$

$$P_{M,R} = P_{M,U} + t_{M,R}$$

$$P_{O,R} = P_{O,U} + t_{O,R}$$

where $t_{j,i}$ is the price differential for product *j* in region *i* (relative to the United States) that reflect (constant) transportation costs (as well as possibly equivalent specific tariffs of existing commercial policies) and m_U is the crushing margin in the U.S. The country indicators are defined as "*U*" representing the U.S., "*B*" for Brazil, "*A*"for Argentina, "*E*" for the European Union, "*C*" for China, and "*R*" for the Rest of the World.

CHAPTER 4 - Calibration

The assumptions made during the calibration process of a partial equilibrium model are critical in interpreting the findings appropriately. Presented below are the different assumptions made as well as the calculations leading to the different supply and demand parameters. In this study, parameters are calibrated for each individual year based on year-specific data. This means that in the period 1998-2005, 8 supply functions and 24 demand functions were calibrated. This is unique to this study, as other welfare analyses of Glyphosate resistant soybean were based on a single year.

Prices Calibration

Soybean grain, soybean oil and soybean meal prices are important components of the calibration for the model. The historical data series of prices were obtained from the USDA and are reported in table 1. They were converted to dollars per metric tons to be consistent with the quantity data.

The United States has a price support system such that producers do not face world price if it is below the loan rate. The Loan Deficiency Payments (LDP) program set a minimum price below which the U.S. government will provide the difference to farmers. This distorts the market because when making production decisions, farmers receive the maximum of the world price and the loan rate. Consumers, however, pay the world price, so that there may be a discrepancy in the U.S. between the prices received by producers and the prices paid by consumers. The calibration of the model accounts for these policy features by setting the price faced by producers as the maximum of world price and loan rate.

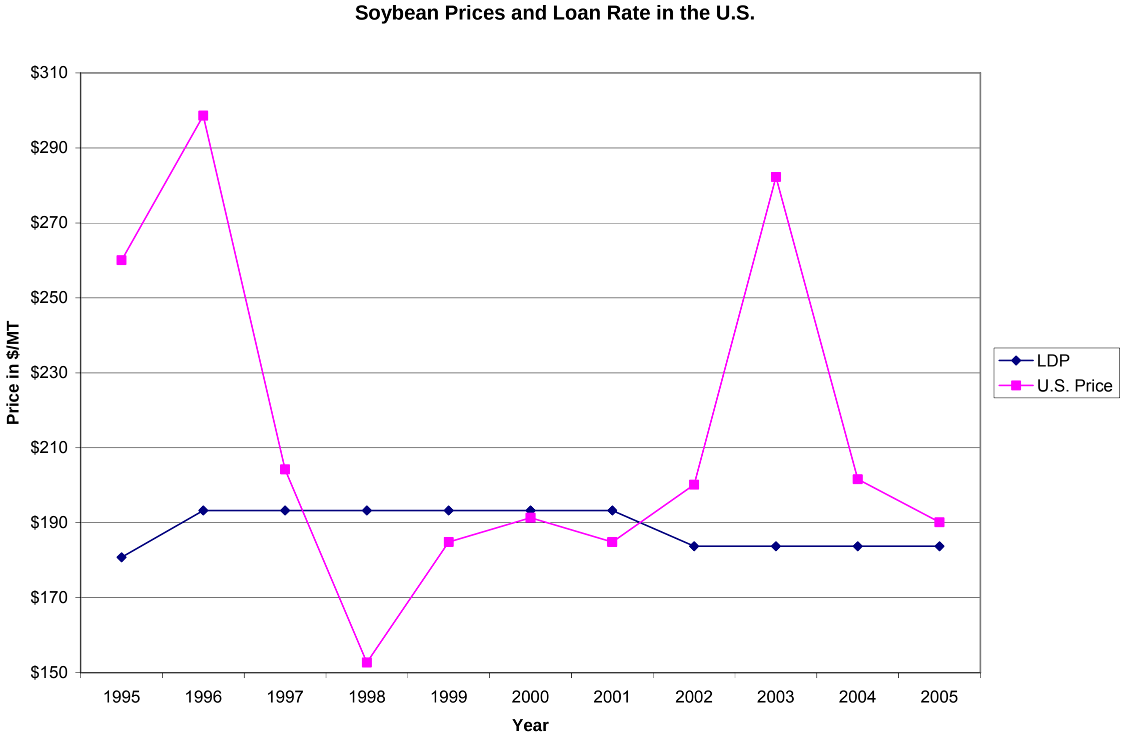


Figure 3: Soybean price versus soybean loan rate in the U.S.

Table 1: Soybean prices in the U.S.

Year beginning October 1	Price 48% protein, Decatur (solvent)	Price 48% protein, Decatur (solvent)
	$/ton	$/MT
1995	235.92	$260.06
1996	270.90	$298.62
1997	185.28	$204.24
1998	138.55	$152.73
1999	167.70	$184.86
2000	173.60	$191.36
2001	167.70	$184.86
2002	181.60	$200.18
2003	256.05	$282.25
2004	182.90	$201.61
2005	172.50	$190.15

1/ Includes millfeed (hull meal). 2/ Forecast.
Sources: Agricultural Marketing Service, USDA and Bureau of the Census.

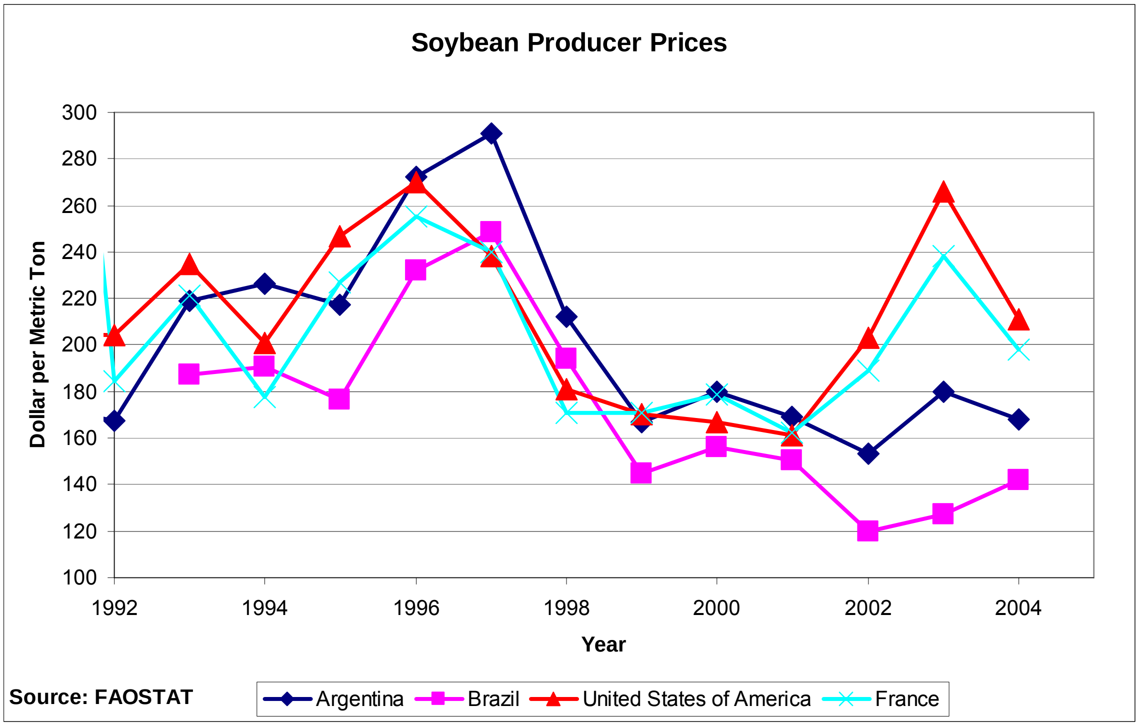
Year beginning September 1	Price Average received by farmers	Price Average received by farmers
	$/bu.	$/MT
1995	6.72	$246.92
1996	7.35	$270.07
1997	6.47	$237.73
1998	4.93	$181.15
1999	4.63	$170.12
2000	4.54	$166.82
2001	4.38	$160.94
2002	5.53	$203.19
2003	7.34	$269.70
2004	5.74	$210.91
2005	5.70	$209.44

1/ Total supply includes imports. 2/ Forecast.
Sources: National Agricultural Statistics Service, USDA and Bureau of the Census.

Year beginning October 1	Price Crude, Decatur	Price Crude, Decatur
	Cents/lb.	$/MT
1995	24.70	$544.54
1996	22.51	$496.26
1997	25.83	$569.45
1998	19.80	$436.52
1999	15.59	$343.70
2000	14.15	$311.95
2001	16.46	$362.88
2002	22.04	$485.90
2003	29.97	$660.73
2004	23.01	$507.28
2005	22.00	$485.10

1/ Forecast.
Sources: Agricultural Marketing Service, USDA and Bureau of the Census.

Figure 3 depicts the variations in soybean prices and loan rate over time. It shows that, from 1998 through 2001, the government had to compensate the difference in prices between the U.S. price and the loan rate to producers, while consumers enjoyed low market prices. While computing LDPs based on the average annual prices is appropriate in the context of this model, it should be noted that it may introduce bias. For example, these calculations assume that LDPs were granted on all production in 1998, but it might not have been the case because of intra-year price fluctuations as well as producers' marketing arrangements.



Source: FAOSTAT

Figure 4: Soybean producer prices ($/MT) over time

The $t_{j,i}$'s are set based on the values used by Moschini *et al.* (2000). Because of the phenomenon of arbitrage, it is indeed expected that all prices should be equal once transportation costs and tariffs[4] are accounted for. Transportation costs are assumed to remain constant over the study period at the levels presented in table 2.

Table 2: Price differential between countries in $/MT

	U.S.	E.U.	ROW	China	Argentina	Brazil
Soybean grain	$ -	$ 30	$ 30	$ 30	$ (10)	$ (10)
Soybean oil	$ -	$ 60	$ 60	$ 60	$ (10)	$ (10)
Soybean meal	$ -	$ 30	$ 30	$ 30	$ (10)	$ (10)

Demand System

Each year, demand equations are calibrated such that, based on price, estimated demand would be equal to observed quantity consumed. This can be formulated as follows. Recall from the previous chapter that the demand for soybean, equation (16), is modeled as $D_{B,i}(P_{B,i}) = \kappa_{B,i}(1-\varphi_{B,i})^{\rho_w} P_{B,i}^{-\epsilon_{B,i}}$. Given values of the parameters φ, ρ, and ϵ, along with an observed price, $P_{B,i}$, and quantity, $D_{B,i}(P_{B,i})_{obs}$, the unknown scalar κ can be computed as:

$$\kappa_{B,i} = (1-\varphi_{B,i})^{-\rho_w} P_{B,i}^{\epsilon_{B,i}} . D_{B,i}(P_{B,i})_{obs}$$

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[4] A higher price differential for soybean oil for some countries reflects higher imports duties. This is very common for many countries importing vegetable oil (Meilke *et al.*, 2001)

Assuming initially that φ=0, the previous equation simplifies to

$$\kappa_{B,i} = P_{B,i}^{\in_{B,i}} .D_{B,i}(P_{B,i})_{obs} .$$

In this version of the model, demand does not shift due to consumers' wariness about GM products. Later this assumption will be relaxed and the value of φ for Europe making the U.S. worse off will be estimated.

Similarly, we get respectively for oil (17) and soybean meal (18):

$$\kappa_{O,i} = P_{O,i}^{\in_{O,i}} .D_{O,i}(P_{O,i})_{obs}$$

$$\kappa_{M,i} = P_{M,i}^{\in_{M,i}} .D_{M,i}(P_{M,i})_{obs}$$

Demand elasticities are defined as being equal to 0.4 as assumed by Moschni *et al.* (2000), an assumption based on the findings of various other studies these authors cite. Therefore, $\epsilon_{B,i} = \epsilon_{O,i} = \epsilon_{M,i} = 0.4$.

Supply Curve

In order to calibrate the supply curve for each country, numerous data are needed. Information such as yield per country, acreage harvested by country, the profitability difference between Glyphosate resistant soybean and regular soybean, as well as the seed price markup for the Glyphosate resistant seeds, is necessary.

Production data, such as yield, acres harvested and total production of soybean grains are provided by the USDA. Other production data, such as seed cost or herbicide cost, are provided by the Kansas State University Extension service. The profitability difference between Glyphosate resistant soybean and regular soybean, $\Delta\pi$, can be derived from subtracting equation (11) from equation (12): $\Delta\pi = \alpha + \frac{\beta G}{1+\eta} P_B^{1+\eta} - \delta w \mu$

Assuming that the technology is not yield improving (i.e., setting β=0), the profitability advantage reduces to the cost saving on herbicide, α, minus the extra cost of more expensive seeds, $\delta w \mu$. The estimates of these components are described in turn below.

Figure 5 shows the cost for herbicide associated with growing Glyphosate resistant soybean versus regular soybean. These costs were calculated based on Kansas State University Extension weed scientist recommendations (Peterson, 2006). For regular soybean, the recommendation was the pre-emergent application of a mixture of Boundary (1.5 pt/acre) (Squadron before 2000). The post-emergent herbicide recommended is Firstrate (0.3oz/acre) and Flexstar (0.75 pt/acre). For the Glyphosate resistant soybean, a sole application of Glyphosate was recommended at 1.5 pt per acre once a season. Acknowledging the fact that some farmers may spray Glyphosate on their crops twice a year, I multiplied the cost associated with this process by 1.5 to capture some of this double application. The Glyphosate cost was computed by assuming, consistent with most farmers' actions, that the cheapest available Glyphosate product will be applied, even if it is a generic brand.

Table 3: Regular soybean, herbicide recommendations

Year	PRE	rate	unit	Chem. cost	unit cost	POST	rate	unit	chem cost	unit cost	POST	rate	unit	Chem. cost	unit cost
2006	Boundary	1.5	pt	$70	6.5 lb/gal	Firstrate	0.3	oz	$28	oz	Flexstar	0.75	pt	$110	gal
2005	Boundary	1.5	pt	$67	6.5 lb/gal	Firstrate	0.3	oz	$27	oz	Flexstar	0.75	pt	$91	gal
2004	Boundary	1.3	pt	$82	8 lb/gal	Firstrate	0.3	oz	$27	oz	Flexstar	1	pt	$90	gal
2003	Boundary	1.3	pt	$72	8 lb/gal	Firstrate	0.3	oz	$27	oz	Flexstar	1	pt	$90	gal
2002	Boundary	1.3	pt	$76	8 lb/gal	Firstrate	0.3	oz	$25	oz	Flexstar	1	pt	$95	gal
2001	Boundary	1.3	pt	$75	8 lb/gal	Firstrate	0.3	oz	$26	oz	Flexstar	1	pt	$93	gal
2000	Boundary	1.3	pt	$82	8 lb/gal	Firstrate	0.3	oz	$25	oz	Flexstar	1	pt	$93	gal
1999	squadron	3	pt	$42	2.33 lb/gal	Firstrate	0.3	oz	$24	oz	Flexstar	1	pt	$92	gal
1998	squadron	3	pt	$62	2.33 lb/gal	Firstrate	0.3	oz	$22	oz	Flexstar	1	pt	$54	gal

Table 4: Glyphosate resistant soybean, herbicide recommendations

RR	rate	unit	chemical cost	unit cost
glyphosate	1.5	pt	$15	gal
glyphosate	1.5	pt	$18	gal
glyphosate	1.5	pt	$29	gal
glyphosate	1.5	pt	$39	gal
glyphosate	1.5	pt	$39	gal
glyphosate	1.5	pt	$39	gal
glyphosate	1.5	pt	$39	gal
glyphosate	1.5	pt	$45	gal
glyphosate	1.5	pt	$54	gal
glyphosate	1.5	pt	$54	gal
glyphosate	1.5	pt	$49	gal

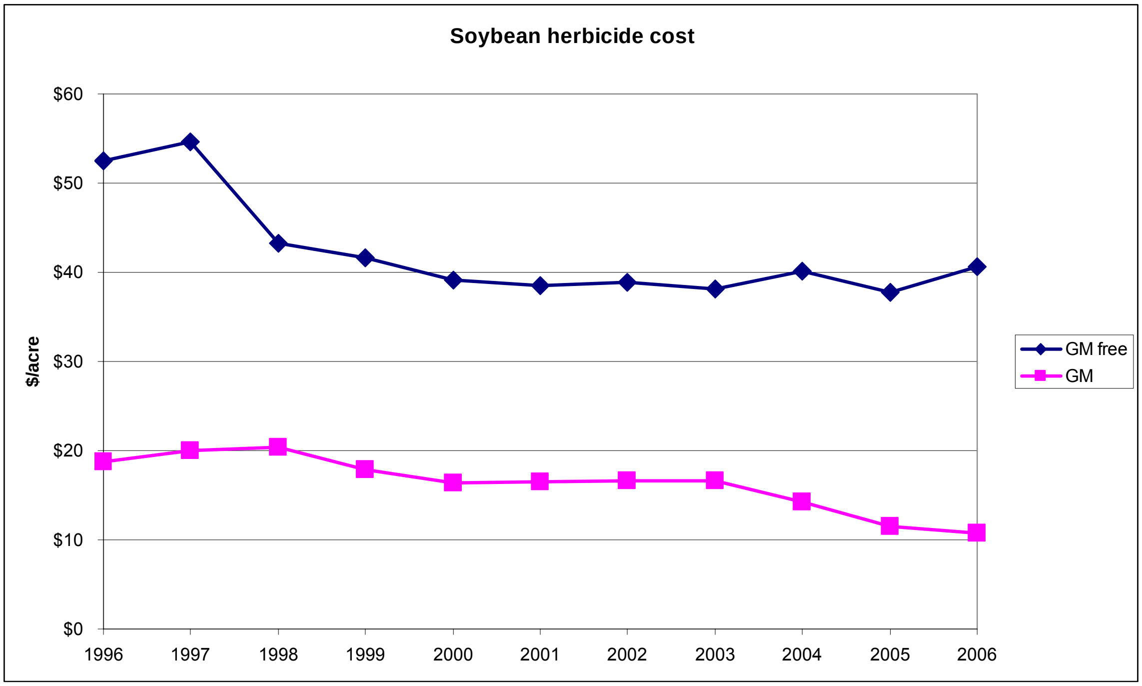

Figure 5: Soybean herbicide (chemical and application) cost in dollars per acre (Source: KSU: SRP958).

Application costs were gathered from the Kansas Statistical Agriculture Service and are shown in Figure 6.

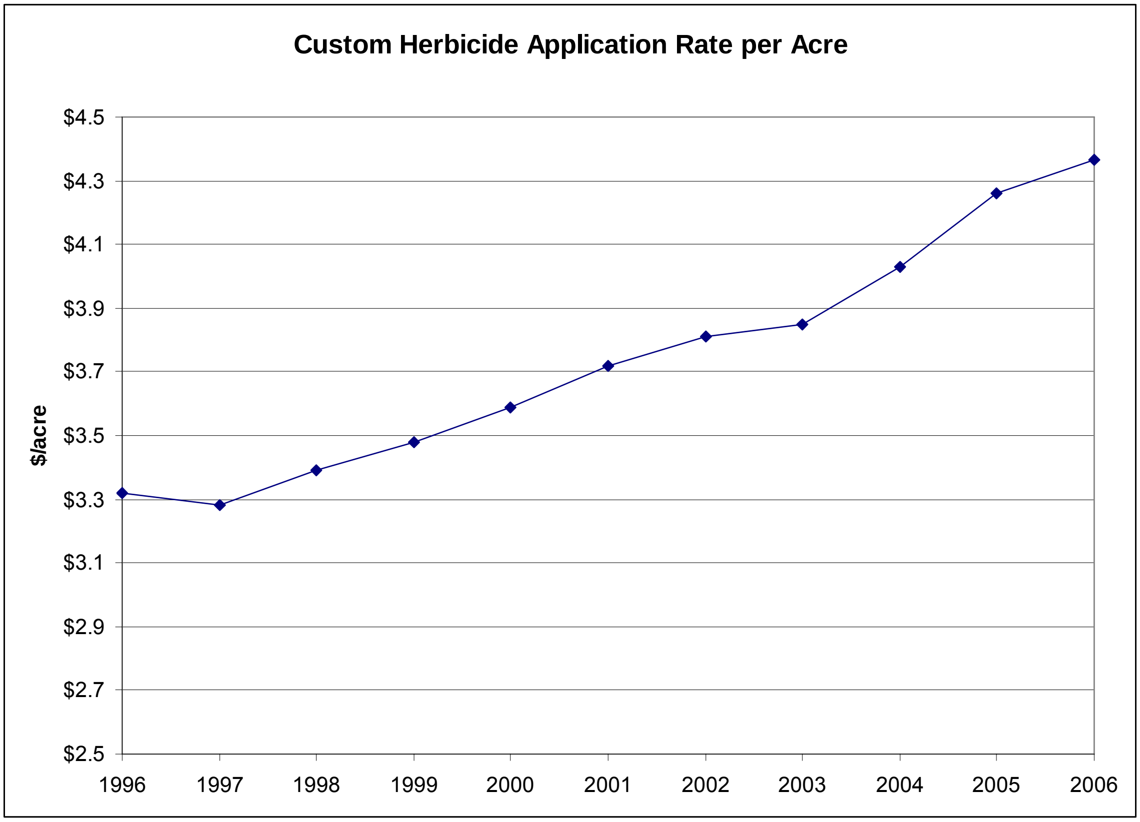

Figure 6: Custom rate of herbicide application in dollar per acre (Kansas Agricultural Statistical Service)

Kansas State University Extension budgets have tracked the seed cost for herbicide resistant soybean as well as regular soybean (figure 7). Assuming 150,000 plants per acre, which means planting 50 lbs. of seed per acre, δw was computed for every year. Moschini *et al.* argue that intellectual property rights on seeds are less likely to be enforced and that, in general, seeds are cheaper in countries outside the United States. Therefore δw was set at 88.9% (Moschini *et al.*) of the U.S. value for all other countries.

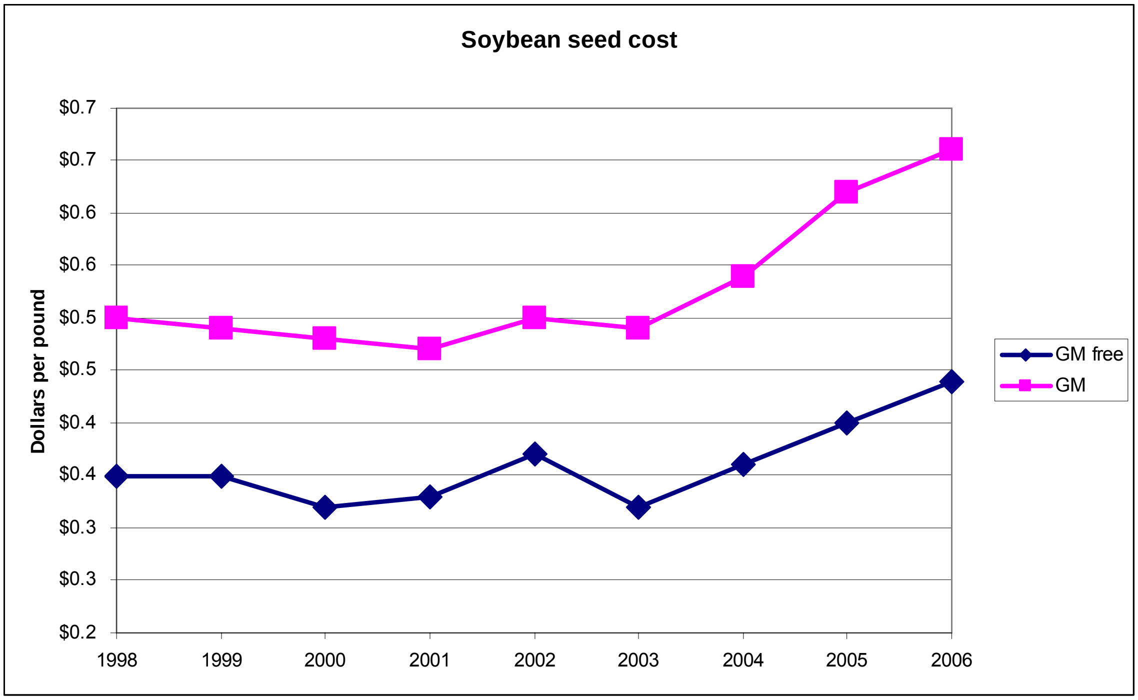

Figure 7: Soybean seed cost in dollars per pound (Source KSU)

Data presented in figure 7 were used to calculate the percentage markup on the Glyphosate resistant seeds (the parameter μ, defined in equation (12)) by stating that $\mu = \frac{\text{GM Seed Cost} - \text{Regular Seed Cost}}{\text{Regular Seed Cost}}$. This markup was calculated for each specific year and represents the extra percentage charge on seeds because of their Glyphosate resistant characteristic. Figure 8 shows that the markup followed an upward trend, and that lately it has been varying between 50 and 55%. Figure 7 shows that, while seed prices were fairly flat up to 2003, they increased significantly since then. It also appears that Glyphosate resistant seed prices are increasing at a slightly faster rate than regular seed prices. Part of this difference may be due to the increase in the "tech fee" charged by the monopoly to compensate for the loss of patent on Roundup.[5]

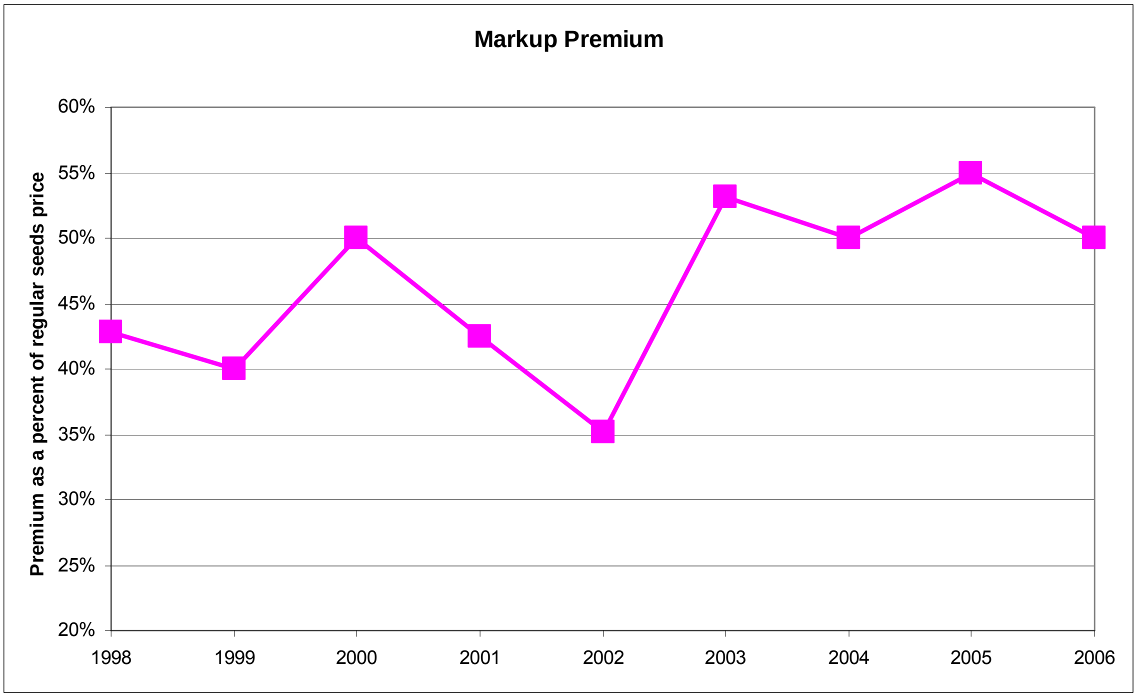

Figure 8: Evolution of seed premium markup (μ) over time in the U.S.

Because IPR protection is a lot weaker in the rest of the world, it is difficult for the monopoly to prevent farmers in these countries from using some of their harvested beans as seed the following year. In the U.S., this practice is prohibited by a contract between Monsanto and the seed buyer, but no such contract can be applied in Argentina, for instance, where a farmer's right to use harvested grain as seed is protected by law

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[5] As noted above, Roundup is the product name under which Monsanto sells Glyphosate. After Monsanto's patent on Roundup expired in 2000, producers have the choice of purchasing generic Glyphosate.

(Qaim and Traxler 2005). Therefore the markup rate is set to one-half the U.S. value for South American countries and to one-fourth of the U.S. value for all other countries (ROW).

The difference in profit due to the adoption of the technology ($\Delta\pi$) is a very important variable as it is used to compute several of the profit function coefficients. $\Delta\pi$ is calculated by computing the difference in herbicide and seed costs between the Glyphosate resistant technology and the conventional technology. As noted above, this implicitly assumes that there is neither a yield reduction nor a yield improvement due to the technology adoption (i.e. $\beta=0$). Similarly, yield is assumed to be unaffected by the weed control techniques considered, so that profit is affected only by the difference in the combined herbicide and seed cost.

The scale parameter, λ, can be calibrated by simply dividing the observed harvested area by π^{θ}:

(22) $$\lambda = \frac{L_{obs}}{\pi^{\theta}}.$$

The parameter G can be calculated using the following formula:

(23) $$G = \frac{y_{obs}}{(1+\rho.\beta).P_B^{\eta}}$$

The formula to calibrate the value of *A* is as follows:

(24) $A = \pi + \alpha + \frac{(1+\beta)G}{1+\eta} p_B^{1+\eta} - \delta w(1+\mu)$ where *π* (at the calibrating stage) is assumed to be 40% of the gross income.[6]

The parameter *θ* can be rewritten as follows:

(25) $$\theta = \frac{\partial L}{\partial \pi} . \frac{\pi}{L} = \frac{\partial L}{\partial P_B} . \frac{\partial P_B . \pi}{\partial \pi . L} = \frac{\partial L}{\partial P_B} . \frac{P_B}{L} . \frac{\partial P_B . \pi}{\partial \pi . P_B} = \frac{\psi . \pi}{y . P_B}$$

with

(26) $$\psi = \frac{\partial L}{\partial P_B} \frac{P_B}{L},$$

Where *ψ* is the elasticity of soybean acreage with respect to soybean price. Moschini *et al.* make the argument that price-based land supply elasticities in the literature may underestimate the ability of producers to change from one crop to another. Following their recommendation, we assume that *ψ* takes the value 0.8 in the U.S., 1.0 in South America, and 0.6 for the rest of the world. This translates to a computed value of *θ* of 0.32, 0.4, and 0.24 for the three regions, respectively.[7] Because it is broadly accepted that the response of yield to changes in prices is limited, we set *η* to be equal to 0.05, identically to what was done by Moschini *et al.*

Finally, the observed prices, quantities, and changes in stocks are inserted in equations (19), (20), and (21), which are then solved for the remaining unknown

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[6] To calibrate parameter *A*, it is necessary to have an estimate of profit. Like Moschni *et al.* we chose to use 40% of gross income per ha to represent profit. This parameter is essentially a scaling constant.

[7] At the calibrating stage, $\pi = .4 \times y.P_B$, which results in $\theta = .4 \times \psi$ after simplification

parameters: the technical coefficients γ_O, γ_M and the crushing margin m_U. Once all the parameters are estimated, the quantities produced are equal to quantities demanded plus or minus changes in stock, production matches observed production, estimated yield matches observed yield, estimated acreage harvested matches observed acreage, and the arbitrage has played its role and there are no profit opportunities left to crush soybean grain in soybean meal and oil.

Although not part of the calibration process per se, another parameter needed in the model is the adoption rate of Glyphosate resistant soybean, ρ. Table 5 summarizes the observed adoption rate by year. These data were compiled from different sources: USDA, ISAAA, and Qaim & Traxler.

Table 5: Glyphosate resistant soybean planted as a percentage of total soybean acreage by country.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
U.S.	0	8	17	45	55	54	68	75	81	85	87
Brazil	0	0	0	0	0	0	0	0	1	5	29
Argentina	0	6	25	59	77	90	98	100	100	100	100

Table 6 presents the value of the key parameters that do not change from one year to another for all the different countries considered.

Table 6: Base values of key parameters

	U.S.	E.U.	China	ROW	Argentina	Brazil
Price differential for beans (t_B)	0	30	30	30	-10	-10
Price differential for oil (t_O)	0	60	60	60	-10	-10
Price differential for meal (t_M)	0	30	30	30	-10	-10
RR yield change coefficient (β)	0	0	0	0	0	0
Price elasticity of yield (η)	0.05	0.05	0.05	0.05	0.05	0.05
Supply (area) elasticity (ψ)	0.8	0.6	0.6	0.6	1	1
Land supply elasticity (θ)	0.32	0.24	0.24	0.24	0.4	0.4
Bean demand elasticity ($-\epsilon_B$)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Oil demand elasticity ($-\epsilon_O$)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Meal demand elasticity ($-\epsilon_M$)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4

The calibration steps described above will create a model that reproduces the consumption, production, and changes in soybean stocks observed from year to year, where farmers adopt the technology at the observed rate. The relevant counterfactual comparison is a situation where Glyphosate resistant soybean were not adopted. Very likely, changes in stock would have been different in that situation, but because it is counterfactual there are no data on the changes in stocks that would have occurred. Because the goal of this study is not to model changes in stock, but to measure the welfare implications of technology adoption, the calibrated model must be modified so that changes in stock are equal to zero in both cases. This modification accords with previous studies (e.g., Moschini et al.) and makes the interpretation of computed welfare effects more straightforward. Additionally, it allows for consistent comparisons across model years.

To develop the desired model, two additional stages of calibration are required, making calibration a three-step process overall. The first step is to determine the parameters based on observed data and observed changes in stock, as described above.

Once those parameters are calculated, the adoption rate for each country as well as the changes in stock are set to zero and prices for beans, meal and oil are calculated so that the markets clear and all conditions are satisfied. That is the second step. The third step calculates the different prices using the adoption rates used during step #1 but this time assuming that changes in stock are equal to zero.

CHAPTER 5 - Results

Welfare measures once supply and demand functions are known are usually fairly straightforward. The following section will present the empirical findings resulting from the calibration process shown previously, but first the results calculations will be explicated. Finally, the effect of GMO on Europe's demand will be assessed from two different angles. The first perspective will look at how much demand would need to shift to make the U.S. as a whole worse off. The second approach will assume that the structure of European demand did not change, except for the impact of GMO introduction on consumer preferences. The resulting value of φ (index of consumers' sensitivity to GMO) is calculated so that the model demand functions match observed consumption data.

Welfare Measures of Interest

The welfare changes are calculated from the calibrated supply and demand curves. First, let us represent the observed price for product *j* in region *i* by $\overline{P}_{j,i}$ and let $\hat{P}_{j,i}$ be the price that would be observed if the Glyphosate resistant technology had not been introduced. The change in consumer surplus is then:

$$\textbf{(27)} \qquad \Delta CS_{j,i} = \int_{\overline{P}_{j,i}}^{\infty} D_{j,i}(\rho_w, v)dv - \int_{\hat{P}_{j,i}}^{\infty} D_{j,i}(0, v)dv \,.$$

Similarly $L_i(\pi_i)$ is the optimal allocation of land to grow soybean in country *i* based on soybean profit per acre in country *i*. Using parallel notation as for consumer surplus, the change in producer surplus can be written

(28) $$\Delta PS_i = \int_{\hat{\pi}_i}^{\bar{\pi}_i} L_i(v)dv$$

This is depicted in figure 9, which illustrates the fact that soybean compete with corn in the acreage allocation process. As more soybean are planted, less acres are planted into corn.

The allocation process is resolved when the profit of the last acre planted to soybean is equally as profitable as the last acre planted to corn. Increasing the profitability of soybean from $\hat{\pi}$ to $\bar{\pi}$ will shift some acres from corn to soybean production, as reflected by the dashed lines on either side of area e. The underlying assumption of such a graph is that the land supply function for soybean does not shift over time. This can be a strong assumption, especially in the coming years with the pressure to grow corn to supply ethanol plants. Therefore, if there is a bias in these calculations, it is very likely to be on the side of overestimating the real producer gains.

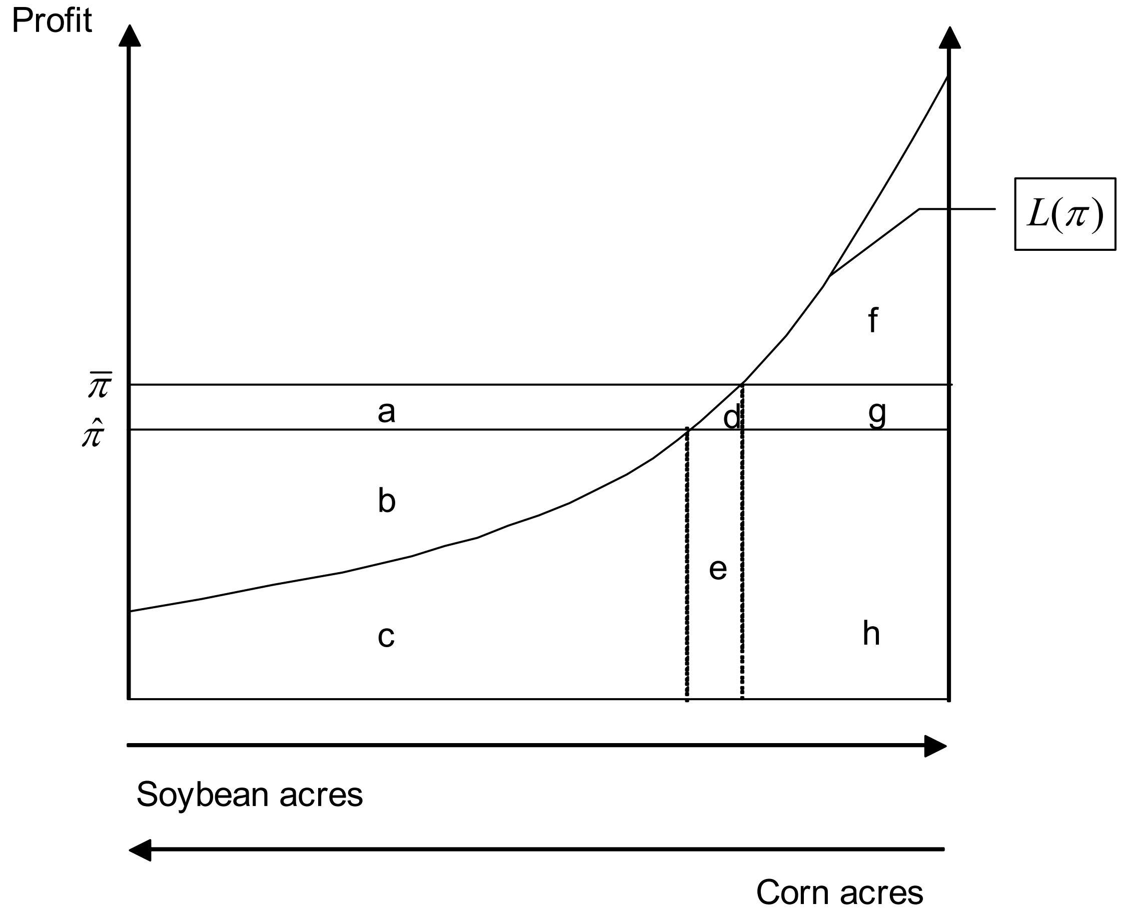

Figure 9: Graphical representation of producers' welfare gains calculation

In order to measure producers' net gain due to the introduction of Glyphosate resistant soybean, the loss from the corn side of the market needs to be considered. However, the losses in the corn market are already included in the expression for *ΔPS* in equation (28). To verify this, table 3 shows the welfare calculation based on the areas in figure 9, delineating the welfare effects for corn and soybean. As shown in the table, the net effect on producers, taking losses in the corn market into account, is area a. This is the same area traced out by the integral in equation (28).

Table 7: Producers' welfare gains calculation

	Profit Before Innovation	Profit After Innovation	Change in profit
Soybean	b+c	a+b+c+d+e	a+d+e
Corn	d+e+f+g+h	f+g+h	-d-e
Total Profit	b+c+d+e+f+g+h	a+b+c+d+e+ f+g+h	a

The last welfare measure of interest is the monopolist's profit. The monopolist's profit in each country *i* is calculated by determining how many acres are planted to the new technology ($\bar{\rho}_i \bar{L}_i$) and multiplying it by the seeding rate and the markup. The total profit is to the innovator is then given by

(29) $$\Pi^M = \sum_{i=U,S,R} \bar{\rho}_i \bar{L}_i \mu_i \delta w_i$$

Note that in this study, the innovator's profit is mainly determined by exogenous variables. The only variable that is endogenously calculated is the total acreage planted into soybean. Price of seeds is taken as a given and it is not calculated by explicitly solving the innovator's profit maximization problem in equation (10). Assessing the optimality of the observed prices is a possible extension of this work.

Empirical Findings, No Demand Shift

The period of analysis is 1998-2005, corresponding to the years when all relevant data were available. Table 8 reports the change in Producer and Consumer Surplus from the introduction of the Glyphosate resistant technology, as well as the cost to the U.S. government through the LDP program and the gains to the monopolist selling the new technology.

Table 8: Change in welfare, monopoly profit and government cost, from glyphosate resistant soybean, by country and market sector, 1998-2005 ($ million)

	1998	1999	2000	2001	2002	2003	2004	2005
US PS	480.73	652.21	567.86	726.00	488.69	414.21	592.02	451.54
EU PS	(7.01)	(7.61)	(6.51)	(8.49)	(4.49)	(3.12)	(4.57)	(5.23)
China PS	(68.88)	(88.87)	(84.36)	(99.99)	(83.44)	(75.90)	(101.22)	(104.26)
ROW PS	(79.39)	(105.67)	(93.42)	(105.14)	(86.55)	(98.43)	(120.74)	(132.95)
Argentina PS	94.19	139.25	192.03	218.94	316.29	271.08	387.46	332.70
Brazil PS	(144.70)	(218.10)	(220.76)	(287.70)	(268.48)	(242.84)	(265.84)	(88.42)
US CS	189.12	249.55	231.42	280.32	221.27	196.12	282.53	281.19
EU CS	119.44	181.05	182.63	225.28	173.45	153.57	198.64	204.24
China CS	104.56	146.92	147.96	182.59	194.47	186.11	264.44	300.15
ROW CS	241.38	317.63	308.27	391.08	318.08	287.38	398.91	417.88
Argentina CS	6.41	9.06	9.22	13.05	11.89	12.38	15.51	17.24
Brazil CS	57.83	79.51	71.48	89.59	76.33	70.70	98.70	100.16
Monopoly	112.60	133.47	160.62	175.90	183.90	250.57	301.25	387.01
US Gov	(341.86)	(492.57)	(446.34)	(576.29)	-	-	-	-

Consumers (assuming here that no consumers have changed their consumption habits due to the introduction of GMO) gained worldwide from the introduction of the new technology. The monopoly gain increased steadily as the adoption rate rose worldwide. Because of the LDP program, the U.S. government encountered large losses at first, over $576 million in 2001, but as soon as the loan rate was dropped to a lower level, the adoption of the technology appears to be cost free from the U.S. government perspective. The results for producers are mixed. Producers in the countries where the technology was adopted early, such as Argentina and the U.S., have large producer gains (for U.S. producers, the smallest gain was 9% in 2003 and the largest was 19% in 2001). Producers in other countries, such as Brazil, where the technology was adopted later, or Europe, where it was never adopted, were affected negatively by the innovation. As discussed in more detail below, the experience of Brazil illustrates the difficulty in overcoming late adoption and that significant gains will be foregone by doing so.

Figure 10 shows the uneven distribution of producer gains among the different players in the soybean industry. As noted above, only the U.S. and Argentina, the early adopters, obtained positive producer gains. Interestingly, immediately after the U.S. LDP program became less generous to U.S. producers in 2001, Argentinean producers saw an increase in welfare from the new technology. Meanwhile, U.S. producers suffered an even larger reduction in their gains, which decreased by $238 million from 2001 to 2002, despite an increase in U.S. acreage converted to Glyphosate resistant soybean at the time.

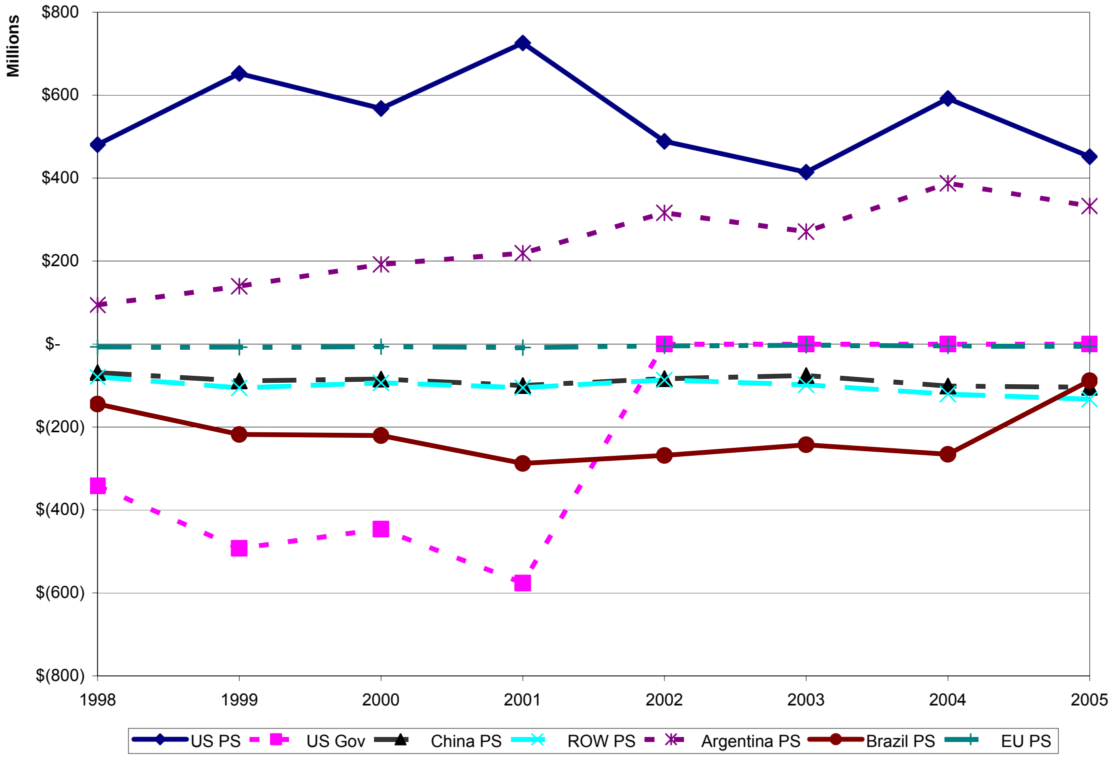

Figure 10: Producer surplus gains ($ million) due to glyphosate resistant soybean adoption

Of course, the largest beneficiaries of the policy change were U.S. taxpayers, who saw a $600 million reduction in government expenses from 2001-2002. Before that period, when prices were below the loan rate, government expenditures on the LDP program grew quite steadily from their 1998 level of about $230 million. This can be understood as a consequence of the new technology. The technology shifted supply to the right, which, *ceteris paribus*, meant that more was produced for the same price. Government expenditures on the LDP program grew in direct proportion to the increased production. In the 1998-2001 period, all but $150 million of the producer welfare gain came from the LDP program.

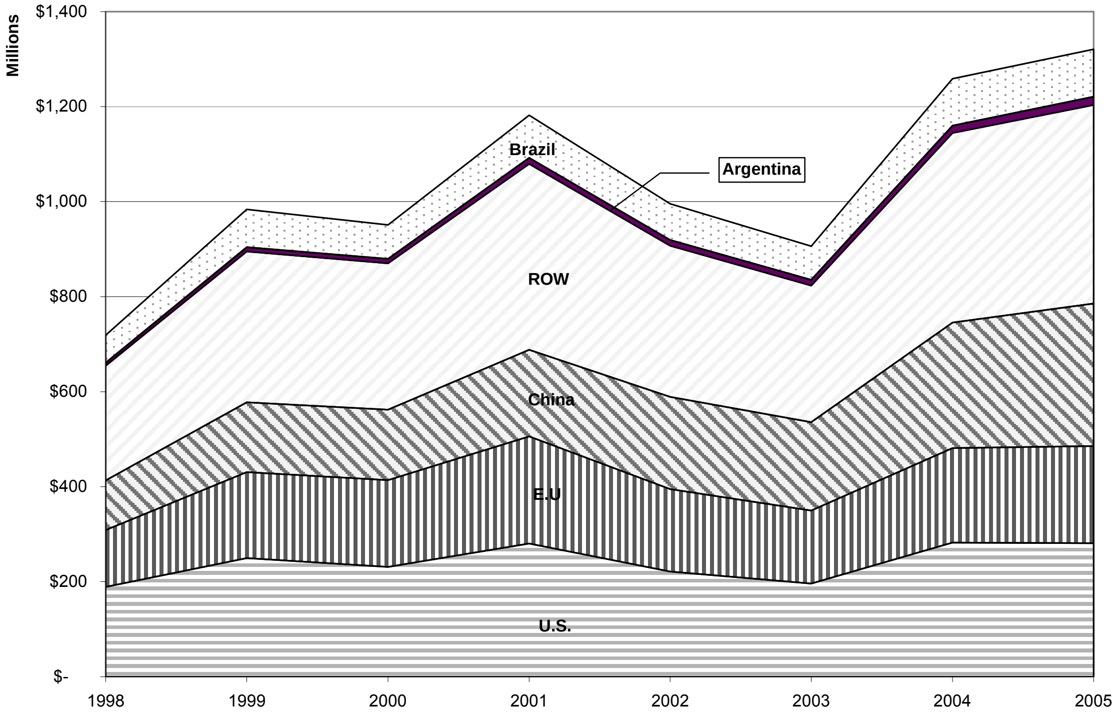

Figure 11: Consumer surplus gains over time ($ million), assuming no demand shift due to GM food products.

Figure 11 shows that consumers worldwide gained from the technology adoption (again, under the assumption of no demand shift). While all gains were positive, they were uneven over time. Overall, they followed an upward path toward a maximum in 2005 of over $1.3 billion, mirroring the steadily increasing rate of technology adoption. However, the gains departed from this path in the years following 2001 when the U.S. LDP payments ceased. This can be explained by the fact that consumer gains were artificially inflated while the LDP was depressing world prices by giving U.S. farmers an incentive to overproduce. In these early years, consumer gains were disproportionately large compared to the technology adoption rate. Once the loan rate in the U.S. was readjusted, consumers' gains fell as they started facing higher prices because prices were above the loan rate and U.S. production was commensurate with market signals.

Figure 12 shows the total gains by country. For most countries, it is the sum of consumer and producer surplus, but for the U.S. it also includes the monopoly gains as well as the LDP cost to the government.

The overall gains from the technology are largest in the U.S., where they grew from slightly over $400 million in 1998 to almost $1.2 billion in 2004. Figure 12 also shows the effects of LDP on the overall gains in the U.S. - in 2002 when the loan rate was decreased, so was the cost to the government. Another changing factor between 2001 and 2002 was an increase in world prices (Figure 3). This obviously improved the gains to U.S. producers, but also the gains of producers in the other adopting country - Argentina. Later, as more Brazilian producers adopted the technology, the gains received by Argentina and the U.S. began to decrease slightly (i.e., from 2004 to 2005).

Countries with low production that are mainly soybean consumers appear to receive a small welfare gain from the Glyphosate resistant technology. For the final years, gains increased to around $200 million for the European Union, and to about the same level for China.

Brazil, which is mainly a producing country and a major player in the world soybean market, presents an interesting dynamic. Unlike Argentina, it was very slow to adopt the technology, as Brazilian producers were prohibited from using it up to 2002. While several studies mentioned that a share of the Brazilian production was already produced with Glyphosate resistant soybean before 2003, no reliable data were found to be used in the calculations. More accurate data would have affected the gains faced by Brazilian producers. Nevertheless, Brazil's adoption delay had significant impacts on the overall gains from the technology. The model results indicate that, until 2005, Brazil did not show a positive gain, as it faced lower prices than it would have had without the technology while not enjoying the cost savings provided by it. The positive gain in 2005 was made at the expense of the 2 other large soybean producers, the U.S. and Argentina.

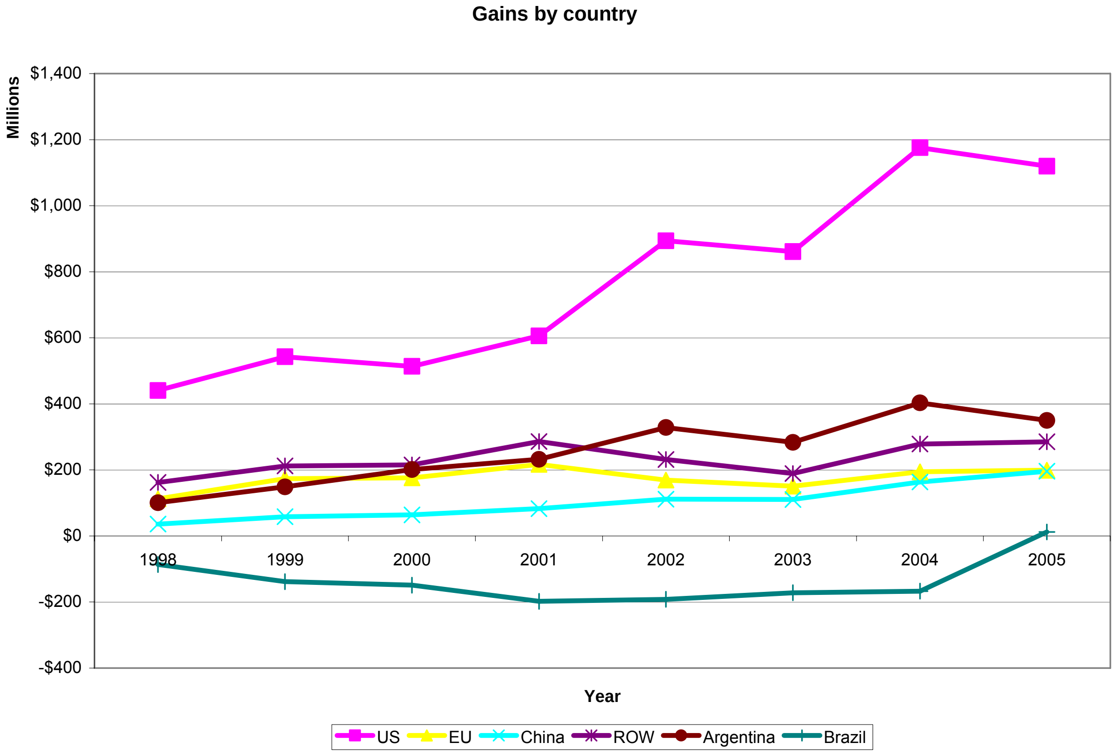

Figure 12: Welfare gains by country including monopoly gains and government cost

As the adoption process is continuing, especially in Brazil, the share of the gains captured by the U.S. producers is going to decrease (figure 10, 12 & 13). As more acres are grown using this technology, the more the supply curve shifts to the right and the lower the price faced by producers. U.S. producers, having adopted the technology on most of the available acreage, will see their gains start to erode as the adoption process in Brazil plays out. The monopoly, on the other hand, while not capturing the full markup from the adoption in South America, is still capturing more and more of the gains due to the increase Glyphosate resistant soybean acreage planted, as well as from the increase in the technology fee charged to producers.

Consumers in the U.S. benefited from the technology throughout the study period, although the size of their gains over time fluctuated depending on the market distortions introduced by the LDP program. By providing a minimum price for producers, the LDP program generated a non optimal level of planted acres, which combined with an increase of profitability per acre, resulted in lower prices faced by the consumers. A share of that lower price can be attributed to the Glyphosate resistant technology and therefore shows in the graph below.

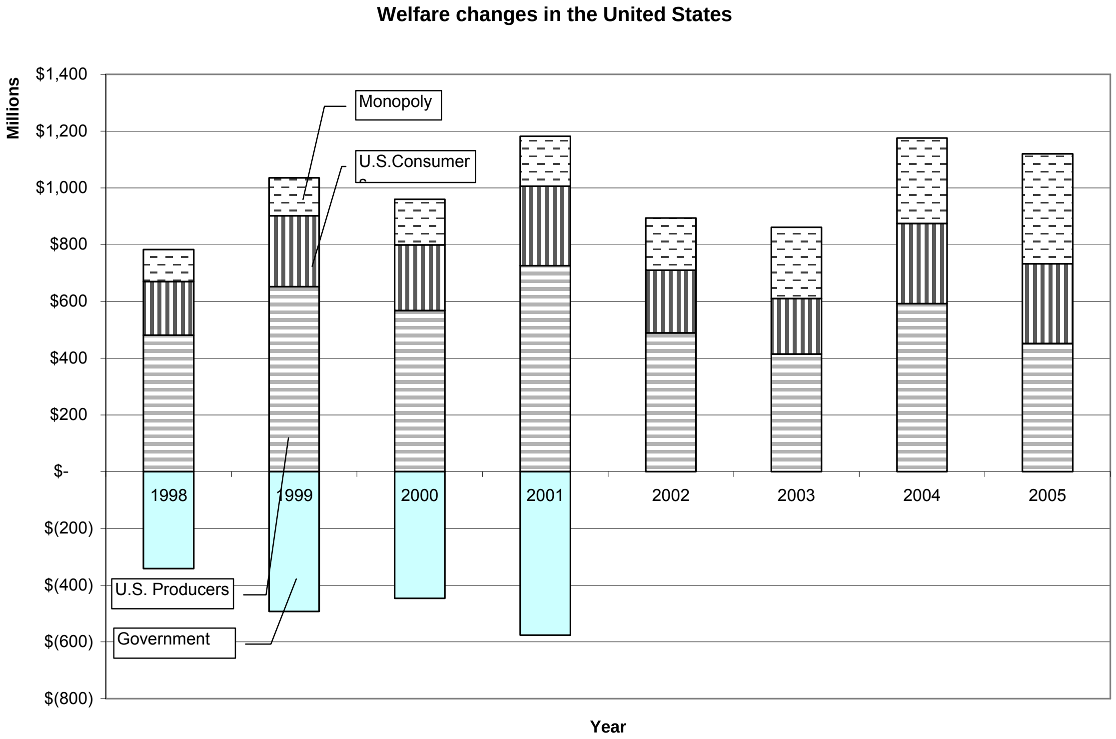

Figure 13: Welfare change ($ million) in the U.S. by sectors

Figure 13 clearly shows that, while producers in the U.S. captured the largest share of national gains in the early years, probably due to the rapid rate of adoption during that time, the distribution of the gains has changed over time. In 2005, the gains are distributed in nearly 3 equal parts among the different players. For 2005, U.S. producers are still the main beneficiaries from the situation, but the monopoly is close behind, while U.S. consumers capture the smallest share of gains from the technology. Future years should generate even larger monopoly gains because of the adoption in Brazil and the proprietary fees funneling back to the U.S. This increased adoption in Brazil should translate to lower prices that will benefit U.S. consumers but reduce the gains to U.S. producers.

Consequences of a Demand Shift in Europe

All of the results reported above assume that the demand for soybean is not sensitive to the introduction of Glypthosate resistant soybean, *ceteris paribus*. This assumption is now relaxed. In particular, this section reports the results from a version of the model where the demand in Europe is reduced as more acres worldwide are planted to Glyphosate resistant soybean. Sobolevsky *et al.* found that, if it were not for the government payments (LDP), a demand shift in Europe would leave U.S. producers worse off than without the technology (unless one assumes no segregation cost to separate Glyphosate resistant soybean from regular soybean). With the presence of the LDP and the fact that Glyphosate resistant soybean is providing a significant production cost saving, there is no reason to believe that U.S. producers could be made worse off by such a technology. On the other hand, the U.S. as a whole could be made worse off if

European consumers show some resistance concerning the purchase of products that have been genetically enhanced.

Following that logic, I estimated the size of the demand shift needed in Europe to completely eliminate the gains in the U.S. from the new technology. In this version of the model, the demand in Europe is multiplied by the scaling factor $s = (1 - \varphi_{j,i})^{\rho_w}$ where j represents soybean grain, soybean meal, or soybean oil, and i represents the country considered. For simplicity, we assume that the index representing the consumers' sensitivity toward GM products, φ, is the same among all three products (soybean grain, soybean oil, and soybean meal). Therefore 1-s represents the proportional reduction in demand. Table 5 reports the value of 1-s for Europe such that the U.S. gains from the technology equal zero.

Table 9: European demand reduction necessary to reduce the U.S. gains from the technology to zero[8].

	1998	1999	2000	2001	2002	2003	2004	2005
European Demand Drop	35.9%	42.7%	41.3%	48.4%	N/A	N/A	N/A	N/A

The results in Table 5 are interesting in various respects. First, it shows that even in the worst year, it still requires at least a 36% drop in demand in Europe before the U.S. as a whole does not benefit from the technology. Second it shows that, after 2001, even if

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[8] N/A in years 2002-2005 stands for the fact that the U.S. gains on that period cannot be eliminated even with a 100% demand reduction in Europe.

Europe were to forgo the use of soybean products completely, it still would not make the U.S. as a whole worse off than a situation without Glyphosate resistant soybean.

These results reflect the consequences of different factors affecting the soybean market. First and foremost, the years where the U.S. gains could have been eliminated correspond to the period where the LDP program was active. One interpretation of this result is that the program prevented the U.S. from capturing all the potential welfare gains from the technology. Second, the increase in volume of a major customer (China), whose consumers are considered insensitive to technology adoption, may have significantly affected the welfare gain distribution. The growing Chinese market provided a new outlet for soybean products even if European consumers were to avoid them.

Table 5 shows that European consumers would need to be very sensitive to GM products to eliminate the U.S. gains, and also that the sensitivity would have to be increasing over time. To get some sense of how European consumer preferences have been evolving over time, the European demand functions were calibrated each year by holding κ constant and allowing the φ parameter to change. Figure 14 shows the results of this exercise, revealing the meaning of the assumptions in the demand system model when consumers are sensitive to their perception of GM products.

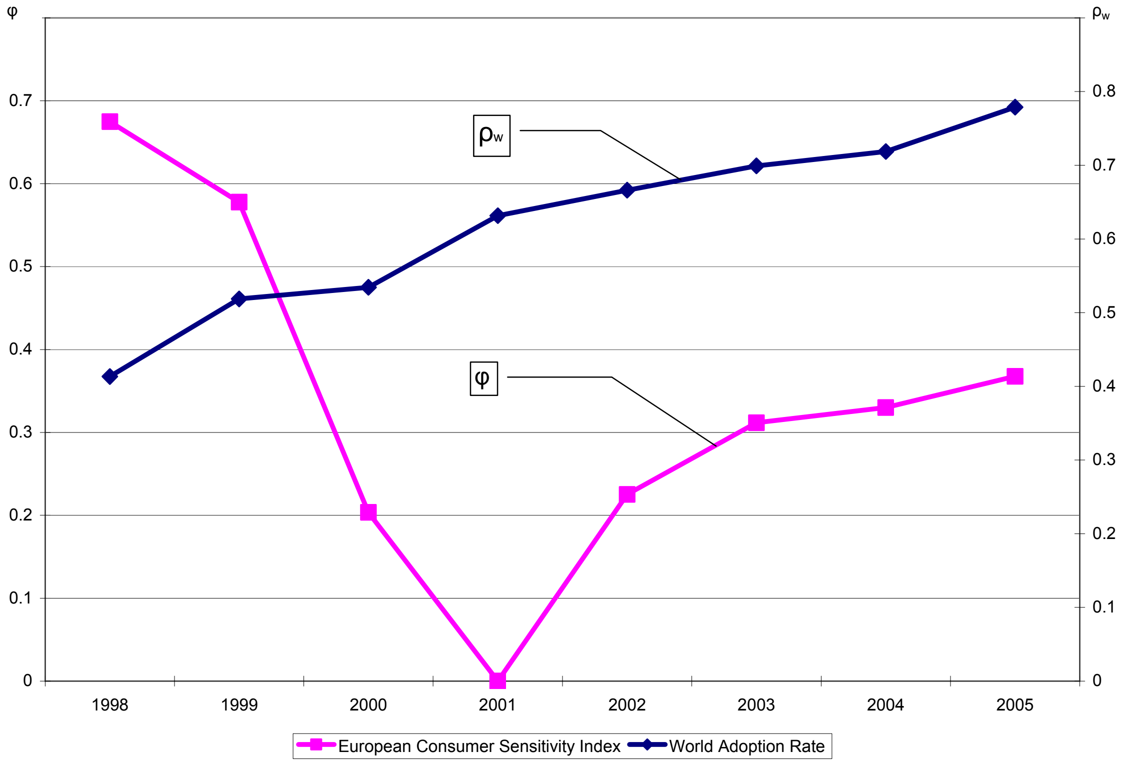

Figure 14: Representation of φ, ρ_w overtime

To interpret the figure, recall first that φ is an index of population perception of GM products. The larger the value, the lower soybean consumption is going to be. For example, a value of 1 means that the representative customer is very apprehensive about using GM products, and if there is no way for him to identify what the goods are made of, he will just not purchase them. On the other hand, a value of zero means that the consumer is unaffected by the presence of GM products and his decision process will be solely based on prices.

Second, note that this calibration procedure presumes that if it were not for GM products, the European demand would not have shifted. The main underlying assumptions are that the income allocation to food purchases have not changed, which is reasonable, but also that substitute products prices have not changed relative to soybean prices. This assumption is more difficult to justify. A third assumption is that consumers' preferences changed only with respect to their attitudes toward GM food.

As in the U.S., European consumers were confronted with massive amounts of information concerning GMO products. However, Europeans are more sensitive to the issue, as shown by Gaskell *et al*., and they also have a higher scientific knowledge concerning GMOs than Americans. Because the introduction of GMOs is such a huge topic in Europe, there is hardly a day without some sort of public debate or propaganda manifestation that will reinforce one feeling or another toward the adoption of GMO products. All of this contributes to shaping consumers' demand by shifting it based on the consumer's perception of what the soybean he consumes is made of. That is the reason why world adoption rate is used as a proxy to describe consumers approximation of what the mix of soybean they are consuming is made of.

The κs in the demand functions are scalars; because the true κ is unknown, I simply use the largest one (corresponding to the calibration year 2001) as the basis to calculate the different values of φ for all the different years for soybean grains. The main purpose here is to gain insight on the way $\boldsymbol{\varphi}$ likely evolved over time rather to estimate its true value.

Figure 14 shows an initial decline of φ, which could be interpreted as an acceptance of the technology, and then a slight raise after 2001. This increase in the later years may reflect either a slow growing concern from the population, or some other factors that we have assumed constant while they are not. Gaskell *et al.* (2003) argue also that from 1999 through 2002 the European population appeared to be more accepting of the new biotechnology, which would be consistent with our findings. Care needs to be taken in interpreting the numerical values in the results; while consistent with previous studies, they may have been affected by other factors not included here.

Although some of the numbers presented are subject to the influence of the assumptions made during the calibration process, the story told would hold true for other assumptions as well. A sensitivity analysis was conducted and presented in Appendix A, B, C, and D. The assumptions on some key parameters were tested and the same pattern was found in the results. The U.S., as an early adopter and home of the monopoly/innovator, gains from the technology while late adopters like Brazil incurred a welfare loss. Other countries, such as Europe, benefited from the technology even though its producers could not adopt, as it faced lower prices. The U.S. price support program in the form of LDPs had an impact on the outcome of the model in all cases.

CHAPTER 6 - Conclusions

Technological changes have always been subject to numerous debates and studies to establish if and how much they benefit society. Glyphosate resistant soybean is such a technological improvement that has generated numerous studies attempting to measure its welfare gains. There are obvious gains from adopting the technology from a production efficiency standpoint, as it significantly decreases production cost and simplifies weed control management. However, with some consumers being reluctant to embrace such a change, especially in Europe, it is not obvious that overall welfare gains are positive. This study attempts to address some shortcomings perceived in recent economic literature, namely the disregard of consumers' demand responses and the lack of analysis over time.

This study builds on previous research, mainly Moschini *et al.* (2000) and Sobolevsky *et al.* (2005), to measure welfare gains in the soybean complex in the period 1998-2005. It creates a partial equilibrium model where supply and demand functions are calibrated to observed prices and quantities as well as the adoption rate, the cost savings provided by the technology, and production information such as yield, and harvested acreage. The model developed considers 6 different regions, namely the U.S., Europe, China, Argentina, Brazil and the rest of the world, and develops for each one of them a supply function and three demand functions for soybean grain, meal, and oil. Once those are calibrated, the gains for the different players in the industry are computed.

Results reveal the distribution of gains among the different groups. Assuming first that consumers' preferences are unaffected by the introduction of GM technology, results indicate that consumers in all regions gained from it. The gains to consumers in different countries are proportional to their shares of world demand. The deficiency payments in the U.S. during the early years of the study period enhanced the gain to consumers, so that the growth in consumer surplus was disproportionate to the growth in the technology adoption rate during that time. Producers in some countries gained from the technology while in other countries they lost, depending on whether they adopted it. Countries like the U.S. or Argentina, who were the early adopters, clearly saw an increase in their producer surplus from the adoption of the technology. Brazil, which delayed adopting the technology for political reasons, faced a significant loss due to lower prices without the benefit of enjoying a cost-saving production technology. The innovator that developed the Glyphosate resistant technology was given a patent, which made it a monopoly. The gain realized by this entity increased over time as the adoption rate increased.

At the national level, the U.S. is without doubt the country that benefited the most from the technology. There are several reasons for this. First, the U.S. has the largest acreage of soybean grown using the Glyphosate resistant technology. Second, the U.S. consumer base for soybean products is larger than in the other regions. Finally, the monopoly is a U.S.-based company and therefore some of the gain captured abroad by the monopoly funnels back to the U.S. But other countries have also benefited from the technology. Argentina’s benefits came from the fact that it adopted the technology early, at an even faster rate than the U.S. Brazil, on the other hand, which has a large number of soybean acres, did not benefit as much from the innovation because adoption was delayed and there were not enough gains generated on the consumer side to overcome the loss on the producer side. Europe (assuming here that preferences did not change) and other large importing countries benefited from the technology even though their smaller production sectors suffered from their inability to use the technology. Because consumers in these countries faced lower prices due to more efficient production abroad, the technology generated a gain that overcame the loss on the producer side.

While the distribution of the gains found is similar to the ones found in previous studies, the gains appear to be in general larger. The driving factor behind the valuation of the gains is the change of profitability between the different technologies. The difference in profit per acre drives the overall gains to the different players of the industry up or down. Recommendations by the Kansas State University Extension services concerning weed management program resulted in profitability differences somewhat larger than the ones used in previous studies. Appendix B presents what the results would have been if the profitability of the new technology per acre was different. While the overall gains are decreased for each player in the industry, the story over time remains the same.

Does it matter from a U.S. standpoint what European consumers think about the new technology? It does matter for the size of the gain but probably not to determine if it is a positive or negative gain. This study shows that from 2002 to 2005, even if the European consumer completely stopped purchasing soybean, the U.S. as a whole still would have benefited from the technology. For the earlier period 1998-2001, the study shows that if Europe had decreased its demand from 35% to 48% (depending on the year), the U.S. as a whole could have been made worse off by the technology. This results from the cost faced by the U.S. government for the LDP program at that time, but also from the fact that less acreage was planted using that technology, which made the cost savings smaller.

This study contributes to the literature in two ways. First, it shows the gain distribution over time to the different actors resulting from the technology adoption. Second, it attempts to isolate over time the resulting effects that a demand shift in Europe from the adoption of the technology could have had. It also measures how large the shift would have had to have been to make the U.S. as a whole worse off because of the introduction of herbicide resistant soybean.

Those findings suggest that, despite a potential loss of some of the European demand, it is still very likely that the U.S. as a whole benefited from the innovation. By assuming that demand was unaffected by the presence of GM products, the results are the upper bound of the gains. More research aimed at estimating European consumers' response to GM food would prove itself insightful and would improve the gains calculation presented in this study.

Research on the optimal patent length could nicely be combined with this study to assess the pricing strategy of the monopoly as well as the effect it has on overall gains. Patents are valid instruments only if they can be enforced. Any kind of derogation to the rule obviously affects the patent holder as well the socially optimal length of the patent. Glyphosate resistant soybean patent violations in South America have been the source of various lawsuits filed by the patent holder. Such violations have significant effects on the distribution of the gains among the industry players. Indeed, if producers in South America are not forced to pay, or pay only partially for the property rights attached to the seed, it gives them a competitive advantage over their U.S. counterparts. The model presented here could provide some valuable insights concerning the importance of those gains, as well as what situation would be likely if the IPR were enforced in South America. For instance, this model could be applied to address questions such as how the gain from enforcing those rules would be distributed between U.S. producers and the monopoly.

Another potential research avenue lies in understanding the dynamics of the monopoly gains. Figure 15 shows the monopoly and U.S. producer gains from a different perspective, where the data from table 8 were reorganized to show the growth in gains in percentage terms since 1998.

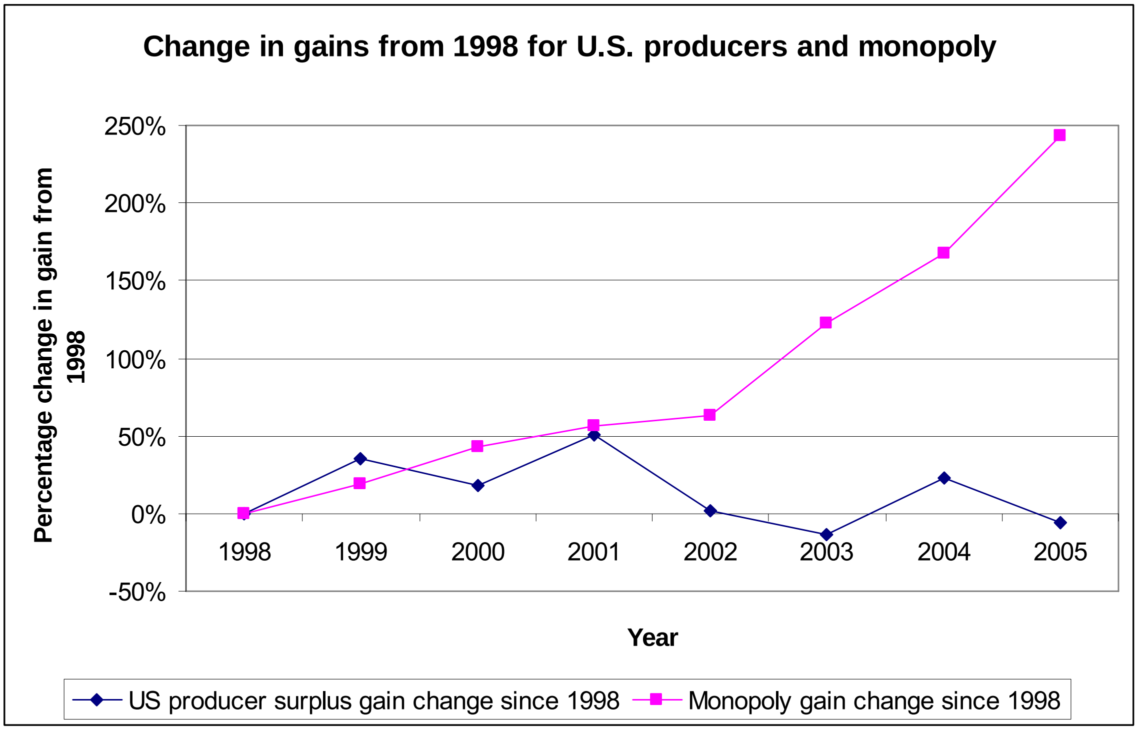

Figure 15: Change in gains from 1998 for U.S. producers and monopoly

Figure 15 conveys some of the perceptions of producers who feel that they did not gain as much from the technology compared to the monopoly. While U.S. producers' grain from the technology was quite flat since 1998, despite more acres being planted to Glyphosate resistant soybean, the monopoly gains increased exponentially since 1998. This raises interesting questions about the pricing strategy followed by the monopoly, in terms of how prices were set over time and whether those prices in fact maximized the innovator's profit.

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Appendix A

The graphs and table presented below were computed every year by calibrating transportation cost based on observed price differential of soybean grain between countries. Because numerous countries have some kind of tariff on oil, Moschni *et al.* simply added an extra $30 in transportation cost per metric ton for the E.U., China and ROW. This is the assumption used in the model above, while here, the price differentials reflect the observed differences in regional prices every year. Of course, the observed difference in prices between any two regions varies from one year to the next, implying that the $t_{i,j}$ parameters in this model are not constant. International data were unavailable from the FAOSTAT, therefore calculations stopped in 2004.

Table 10: Change in welfare from glyphosate resistant soybean, by country and market sector, with different yearly transportation cost 1998-2005 ($ million)

	1998	1999	2000	2001	2002	2003	2004
US PS	$ 480.73	$ 652.21	$ 567.86	$ 726.00	$ 505.78	$ 509.06	$ 600.84
EU PS	$ (7.19)	$ (8.22)	$ (6.32)	$ (8.36)	$ (4.25)	$ (2.24)	$ (4.47)
China PS	$ (70.25)	$ (95.85)	$ (81.31)	$ (97.69)	$ (78.78)	$ (54.38)	$ (98.64)
ROW PS	$ (81.30)	$ (114.08)	$ (90.34)	$ (103.08)	$ (81.92)	$ (70.55)	$ (117.73)
Argentina PS	$ 92.19	$ 128.63	$ 197.03	$ 222.91	$ 323.71	$ 313.30	$ 391.53
Brazil PS	$ (147.73)	$ (235.56)	$ (213.52)	$ (282.15)	$ (259.13)	$ (171.24)	$ (262.55)
US CS	$ 193.32	$ 183.95	$ 223.98	$ 275.00	$ 210.73	$ 353.84	$ 277.02
EU CS	$ 121.78	$ 127.75	$ 175.08	$ 219.35	$ 163.02	$ 278.37	$ 192.43
China CS	$ 107.18	$ 120.62	$ 143.30	$ 179.45	$ 185.66	$ 301.00	$ 259.65
ROW CS	$ 246.79	$ 239.84	$ 298.58	$ 383.92	$ 302.84	$ 491.60	$ 391.06
Argentina CS	$ 6.57	$ 8.34	$ 8.97	$ 12.86	$ 11.36	$ 15.41	$ 15.25
Brazil CS	$ 59.23	$ 59.82	$ 69.43	$ 88.09	$ 72.53	$ 118.55	$ 96.57
Monopoly	$ 112.56	$ 133.38	$ 160.54	$ 175.85	$ 183.46	$ 252.24	$ 300.63
US Gov	$ (348.60)	$ (529.24)	$ (433.16)	$ (566.63)	$ -	$ -	$ -

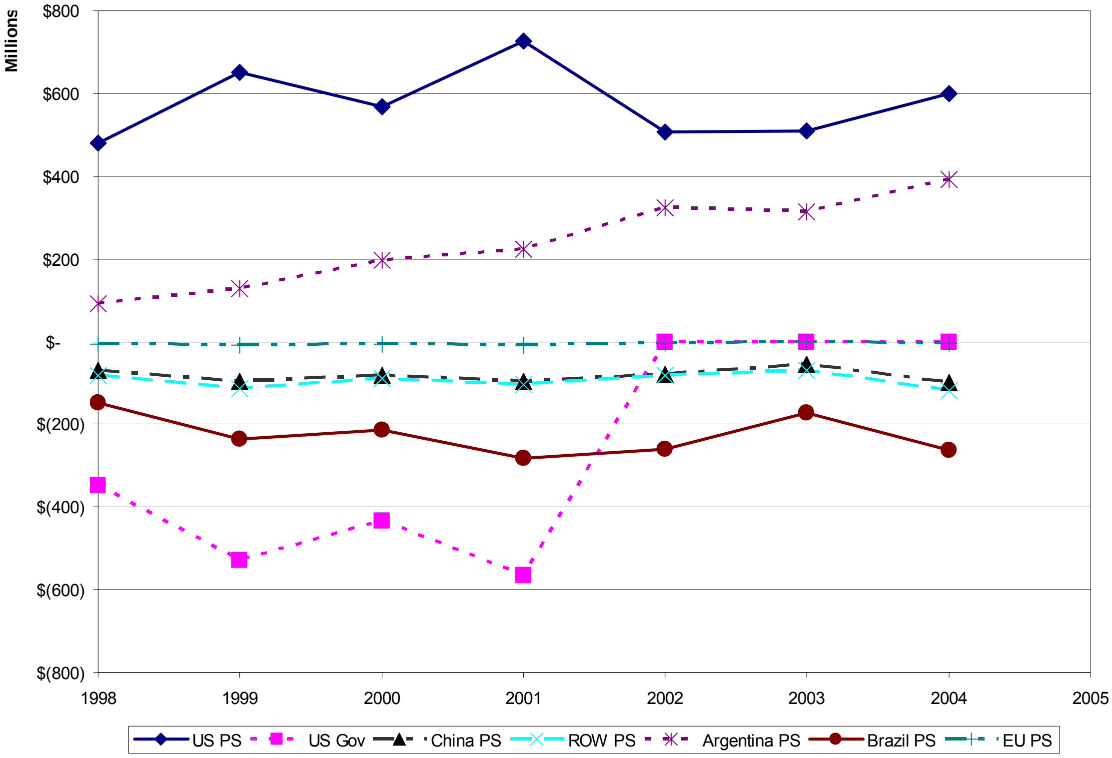

Figure 16: Producer surplus gains ($ million) with different yearly transportation cost

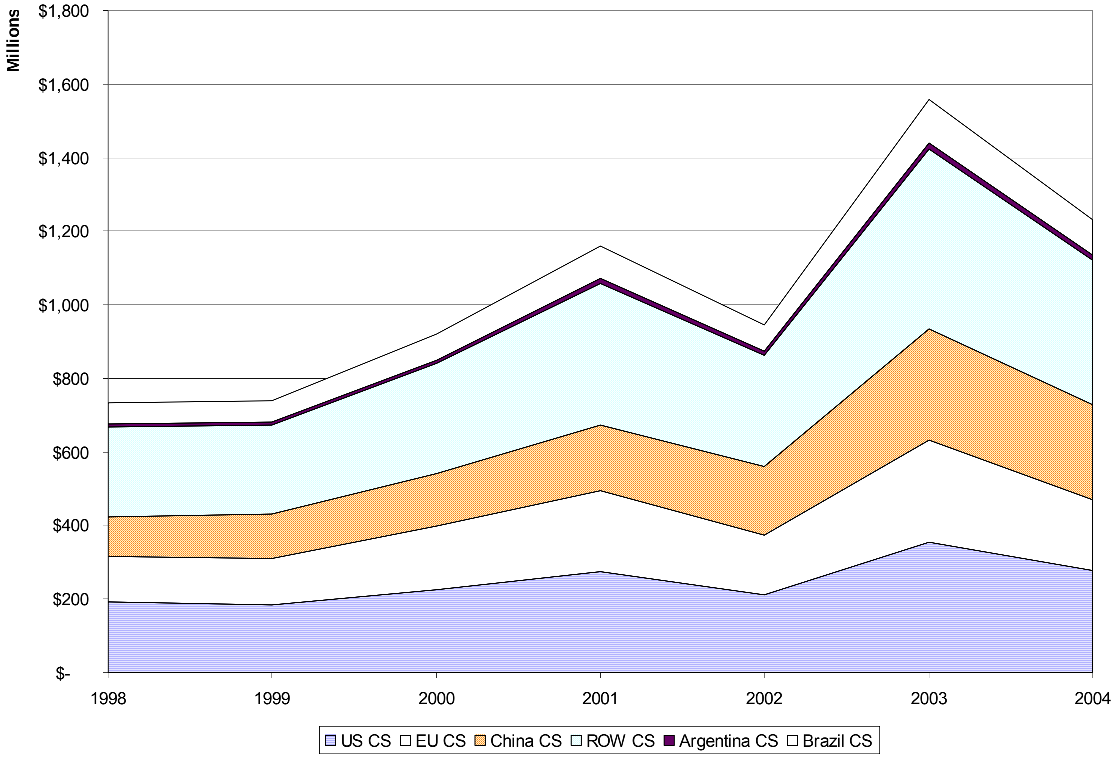

Figure 17: Consumer surplus gains over time ($million) with different yearly transportation cost

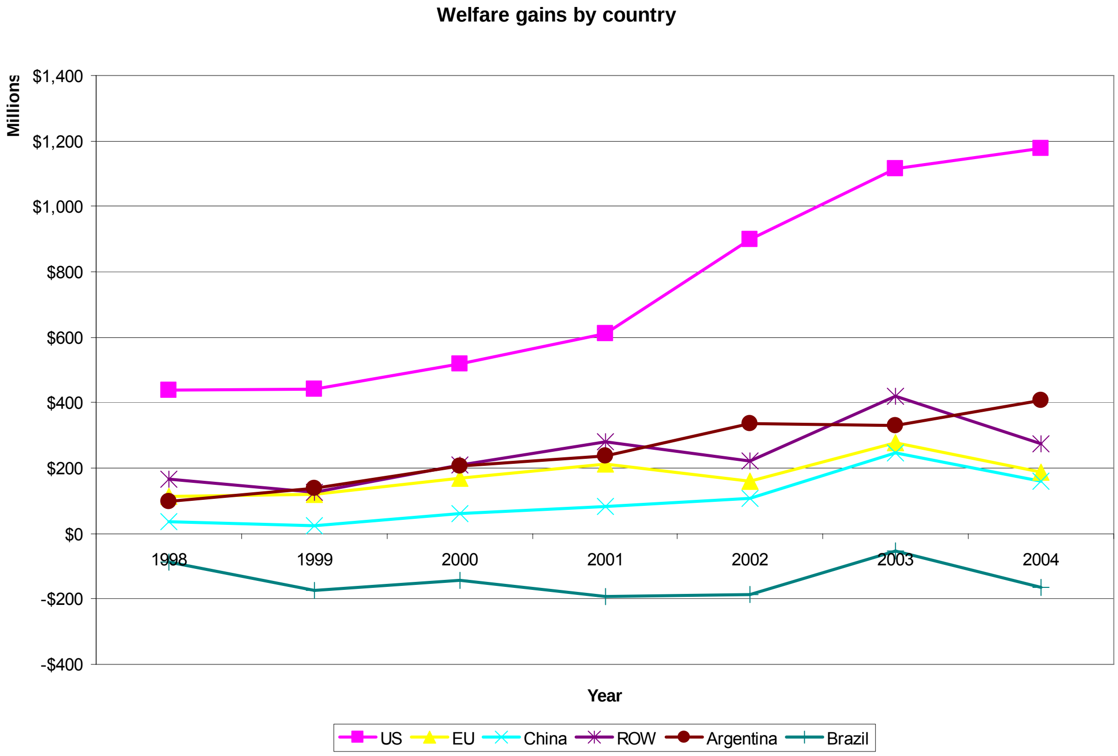

Figure 18: Welfare gains ($ million) by country with different yearly transportation cost

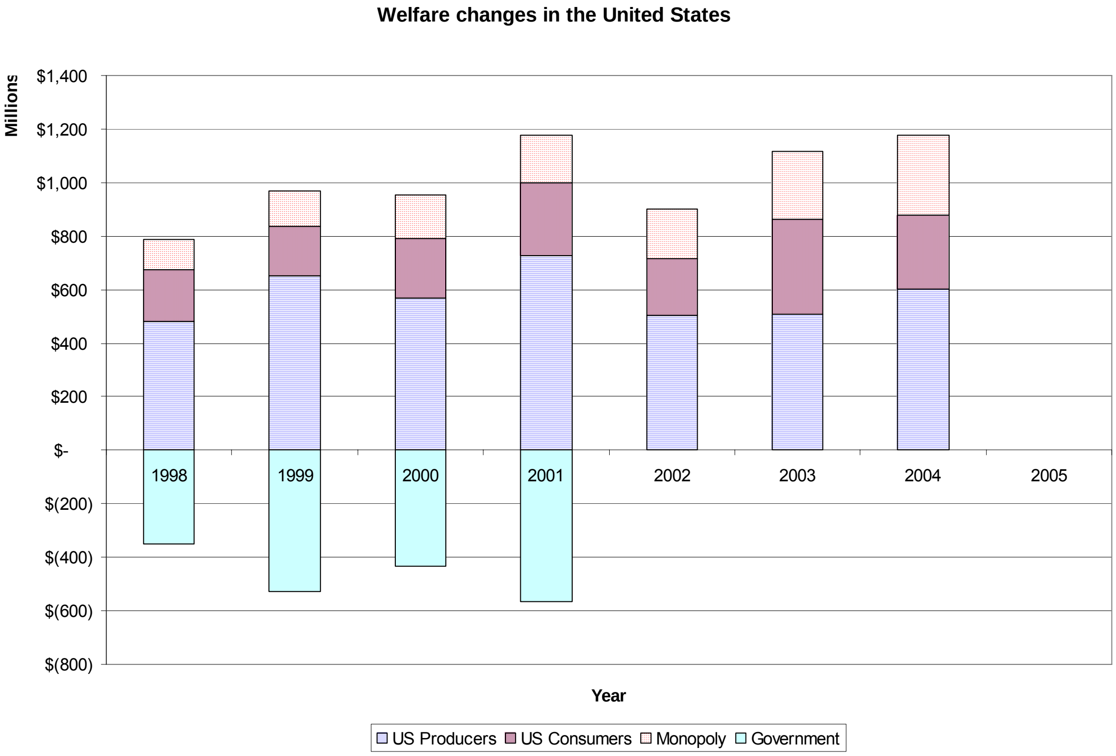

Figure 19: Welfare change ($ million) in the U.S. by sector, with different yearly transportation cost

Appendix B

The figures and tables below were computed by assuming that the profit advantage of Glyphosate resistant soybean, *Δπ*, was only half of what was used in the base calibration.

Table 11: Change in welfare from glyphosate resistant soybean, by country and market sector, with ½ profit change 1998-2005 ($ million)

	1998	1999	2000	2001	2002	2003	2004	2005
US PS	$ 242.06	$ 329.41	$ 286.31	$ 366.77	$ 248.42	$ 209.97	$ 301.08	$ 229.35
EU PS	$ (3.43)	$ (3.69)	$ (3.17)	$ (4.12)	$ (2.21)	$ (1.54)	$ (2.25)	$ (2.58)
China PS	$ (33.70)	$ (43.07)	$ (41.10)	$ (48.46)	$ (41.03)	$ (37.43)	$ (49.78)	$ (51.44)
ROW PS	$ (38.85)	$ (51.22)	$ (45.51)	$ (50.95)	$ (42.56)	$ (48.55)	$ (59.38)	$ (65.60)
Argentina PS	$ 48.24	$ 72.07	$ 98.71	$ 113.32	$ 161.13	$ 137.66	$ 197.47	$ 169.26
Brazil PS	$ (70.58)	$ (105.19)	$ (107.10)	$ (138.69)	$ (131.62)	$ (119.45)	$ (130.12)	$ (42.50)
US CS	$ 93.06	$ 121.93	$ 113.53	$ 136.99	$ 109.38	$ 97.13	$ 139.77	$ 139.65
EU CS	$ 58.75	$ 88.42	$ 89.55	$ 110.04	$ 85.72	$ 76.05	$ 98.24	$ 101.40
China CS	$ 51.44	$ 71.76	$ 72.56	$ 89.20	$ 96.11	$ 92.17	$ 130.79	$ 149.01
ROW CS	$ 118.74	$ 155.13	$ 151.17	$ 191.04	$ 157.20	$ 142.31	$ 197.29	$ 207.46
Argentina CS	$ 3.16	$ 4.43	$ 4.53	$ 6.38	$ 5.88	$ 6.13	$ 7.67	$ 8.56
Brazil CS	$ 28.46	$ 38.85	$ 35.07	$ 43.79	$ 37.73	$ 35.02	$ 48.83	$ 49.75
Monopoly	$ 112.60	$ 133.47	$ 160.62	$ 175.90	$ 183.90	$ 250.57	$ 301.25	$ 387.01
US Gov	$ (170.17)	$ (244.48)	$ (221.78)	$ (285.99)	$ -	$ -	$ -	$ -

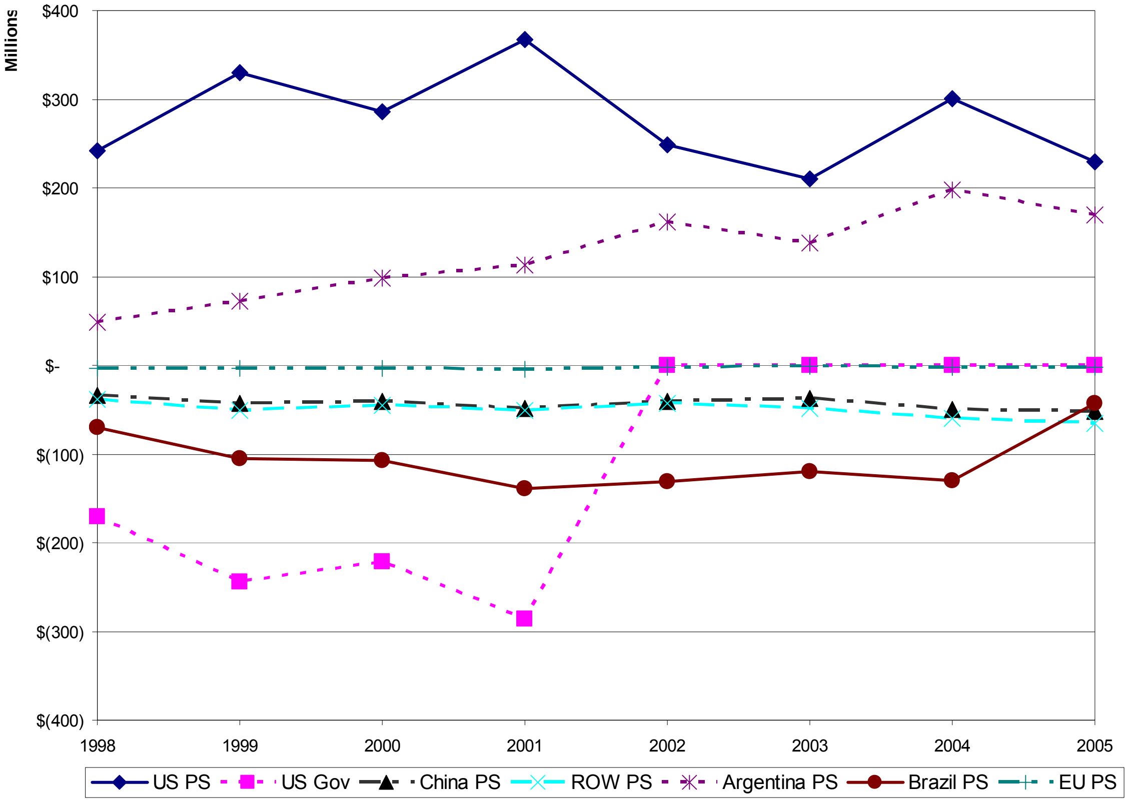

Figure 20: Producer surplus gains ($ million) with ½ profit change

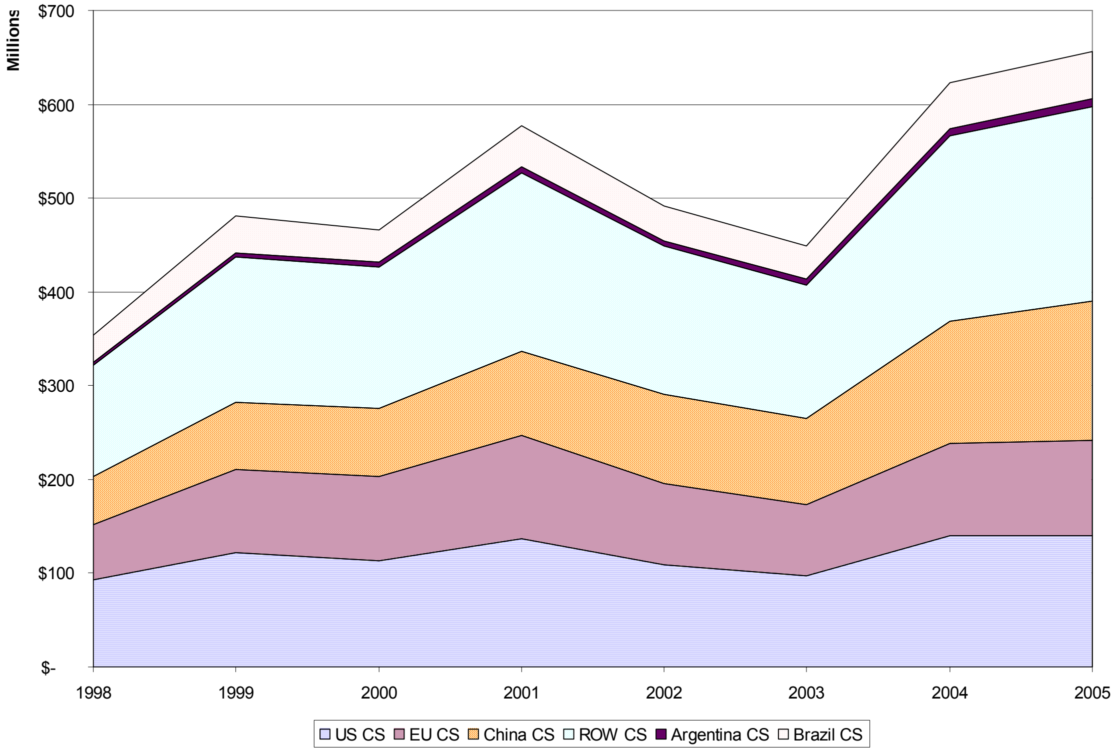

Figure 21: Consumer surplus gains over time ($million) with ½ profit change

Figure 22: Welfare gains ($ million) by country with ½ profit change

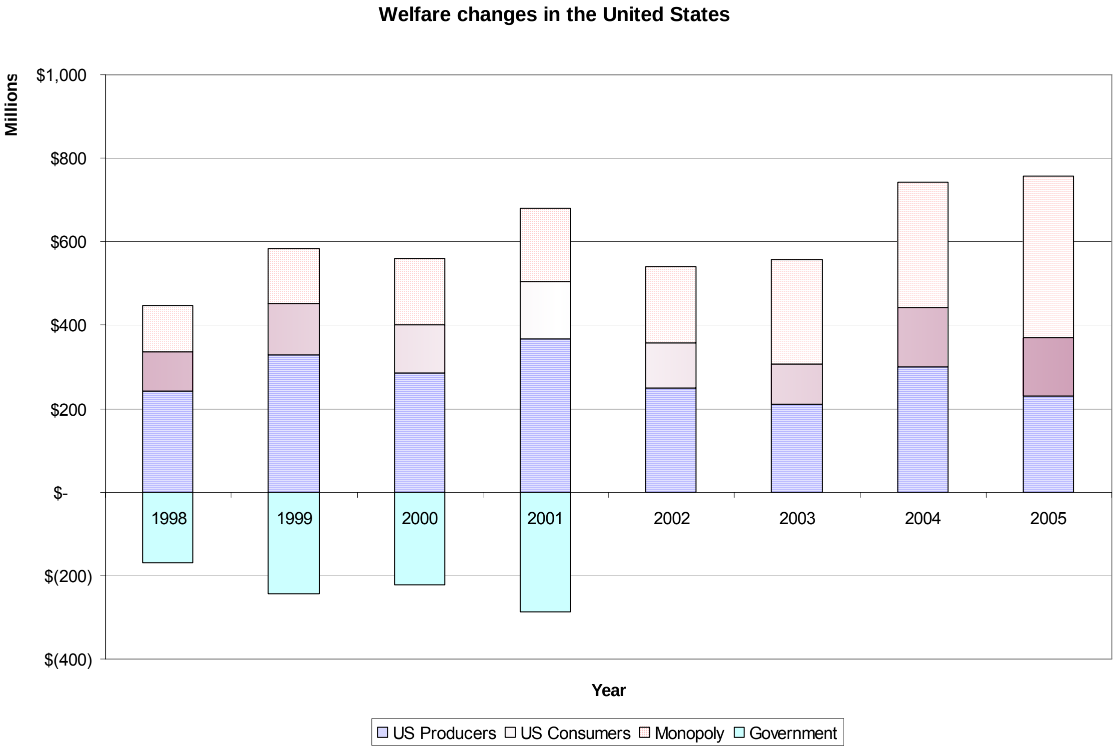

Figure 23: Welfare change ($ million) in the U.S. by sector, with ½ profit change

Appendix C

The figures and table below shows the results of reducing all demand elasticities (see Table 6 for original values) in half.

Table 12: Change in welfare from glyphosate resistant soybean, by country and market sector, with ½ demand elasticities 1998-2005 ($ million)

	1998	1999	2000	2001	2002	2003	2004	2005
US PS	$ 480.73	$ 652.21	$ 567.86	$ 726.00	$ 433.31	$ 370.48	$ 515.45	$ 374.52
EU PS	$ (8.96)	$ (9.43)	$ (8.06)	$ (10.38)	$ (5.19)	$ (3.54)	$ (5.34)	$ (6.05)
China PS	$ (88.13)	$ (110.18)	$ (104.50)	$ (122.22)	$ (96.55)	$ (85.98)	$ (118.28)	$ (120.81)
ROW PS	$ (101.58)	$ (131.02)	$ (115.73)	$ (128.51)	$ (100.15)	$ (111.51)	$ (141.08)	$ (154.05)
Argentina PS	$ 70.13	$ 109.53	$ 158.51	$ 179.04	$ 291.09	$ 249.52	$ 354.01	$ 296.64
Brazil PS	$ (185.97)	$ (271.12)	$ (274.69)	$ (353.02)	$ (311.65)	$ (275.74)	$ (320.31)	$ (141.39)
US CS	$ 241.56	$ 310.36	$ 287.01	$ 342.76	$ 256.69	$ 221.84	$ 331.41	$ 326.93
EU CS	$ 154.77	$ 220.94	$ 225.16	$ 275.49	$ 201.47	$ 174.79	$ 232.60	$ 235.23
China CS	$ 133.45	$ 182.30	$ 183.29	$ 223.16	$ 225.39	$ 210.25	$ 309.91	$ 348.86
ROW CS	$ 307.76	$ 394.96	$ 382.26	$ 477.86	$ 368.72	$ 325.28	$ 467.45	$ 485.36
Argentina CS	$ 8.13	$ 11.37	$ 11.47	$ 15.96	$ 13.79	$ 13.96	$ 18.20	$ 20.14
Brazil CS	$ 73.43	$ 99.57	$ 88.90	$ 109.55	$ 88.52	$ 79.83	$ 115.83	$ 116.70
Monopoly	$ 112.69	$ 133.48	$ 160.79	$ 176.02	$ 184.61	$ 249.88	$ 302.95	$ 387.85
US Gov	$ (428.42)	$ (593.24)	$ (535.16)	$ (679.11)	$ -	$ -	$ -	$ -

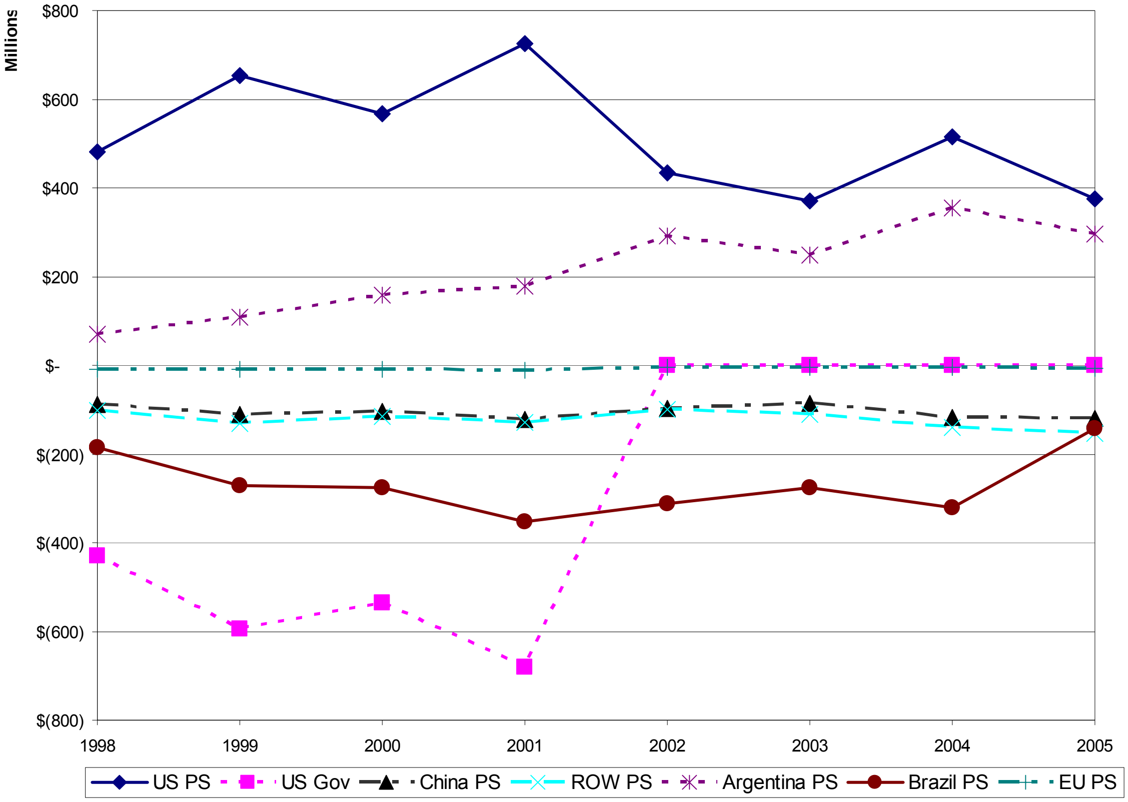

Figure 24: Producer surplus gains ($ million) with ½ demand elasticities

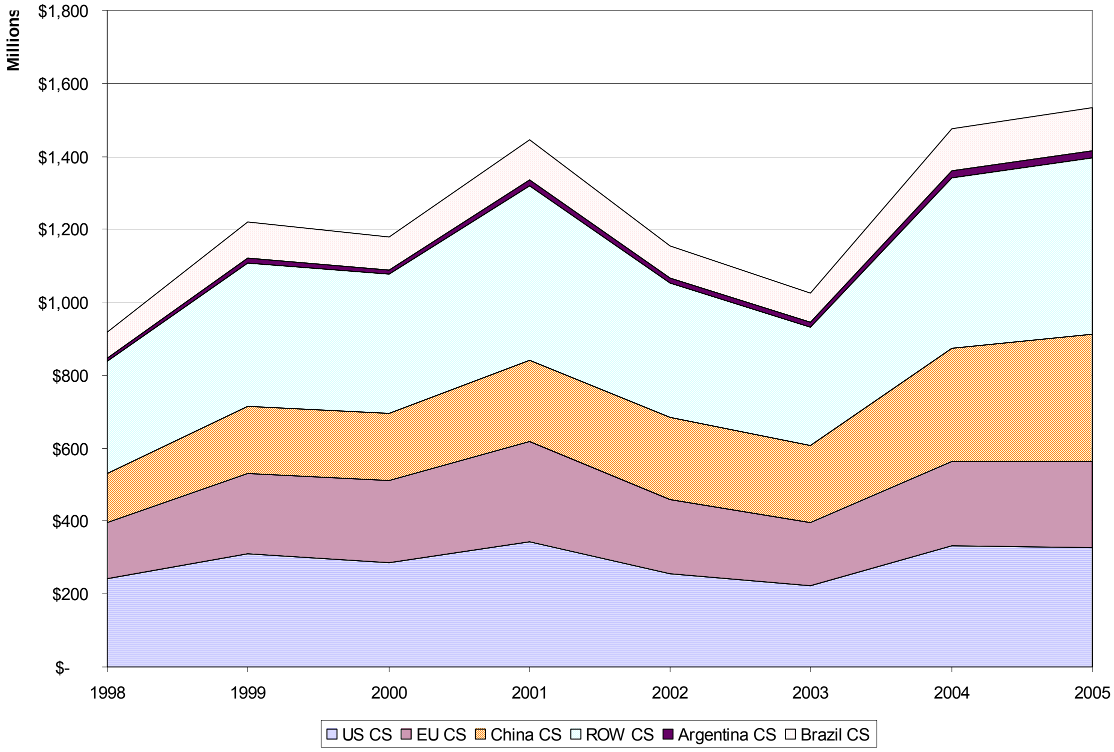

Figure 25: Consumer surplus gains over time ($million) with ½ demand elasticities

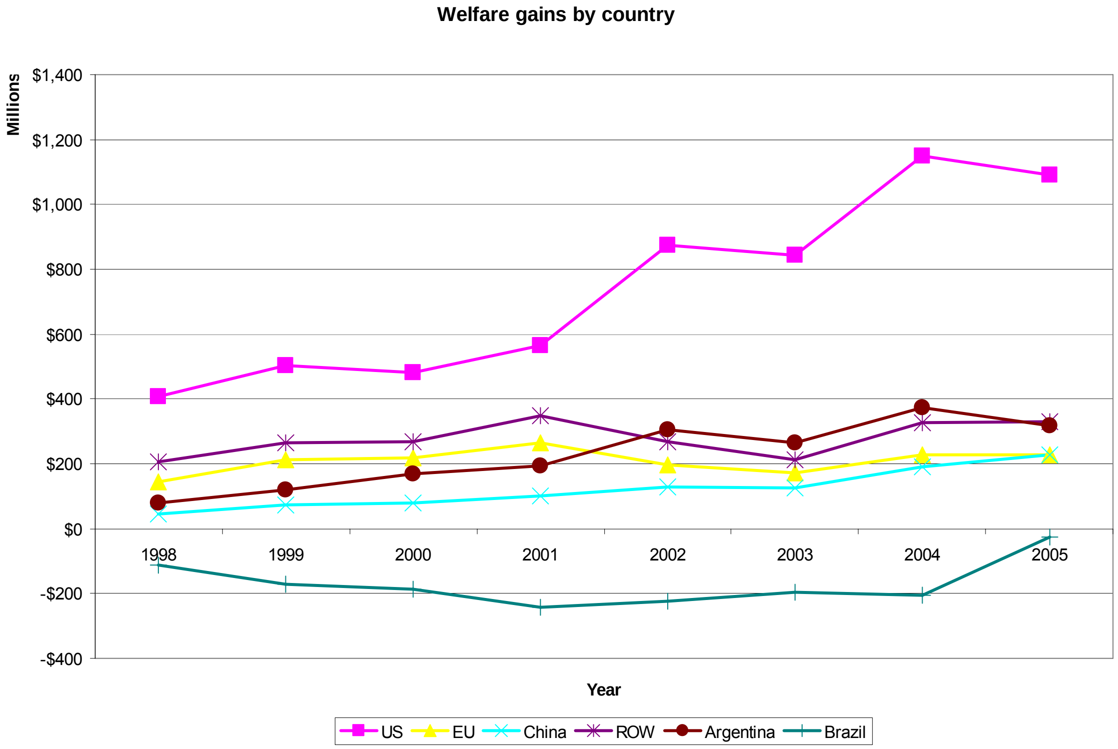

Figure 26: Welfare gains ($ million) by country with ½ demand elasticities

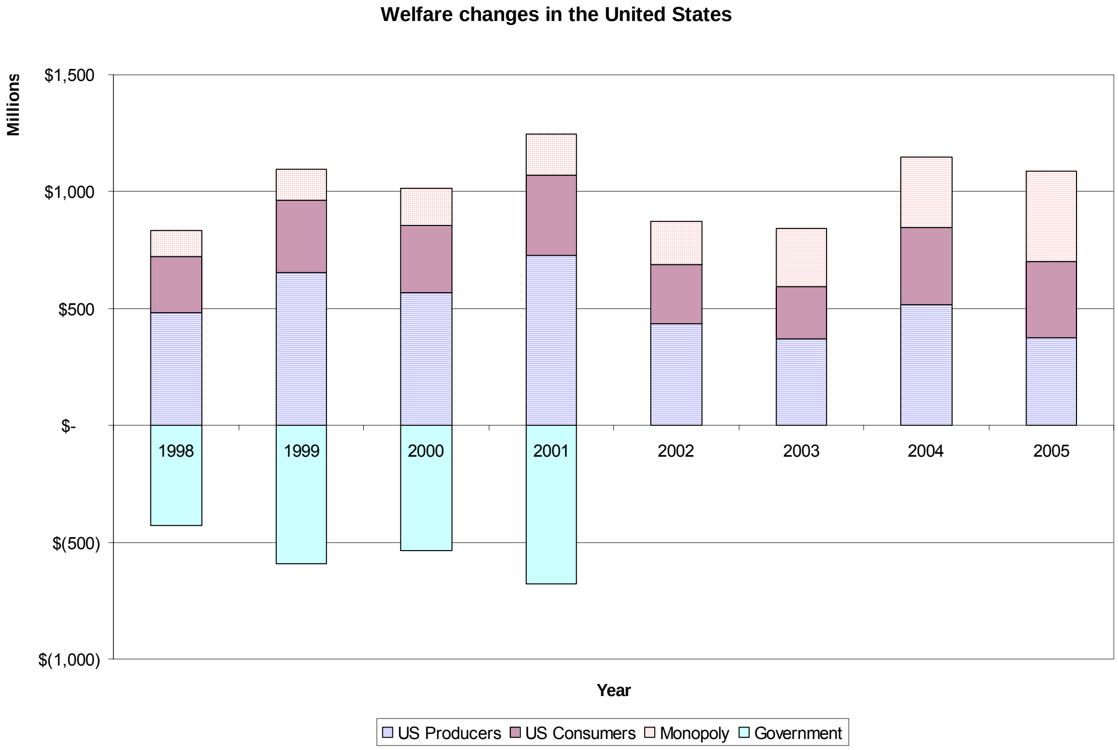

Figure 27: Welfare change ($ million) in the U.S. by sector with ½ demand elasticities

Appendix D

The figures and table below shows the results of increasing all demand elasticities (see Table 6 for original values) by a factor of 2.

Table 13: Change in welfare from glyphosate resistant soybean, by country and market sector, with 2 times demand elasticities 1998-2005 ($ million)

	1998	1999	2000	2001	2002	2003	2004	2005
US PS	$ 480.73	$ 652.21	$ 567.86	$ 726.00	$ 562.54	$ 477.16	$ 691.24	$ 554.49
EU PS	$ (4.89)	$ (5.50)	$ (4.71)	$ (6.25)	$ (3.54)	$ (2.53)	$ (3.57)	$ (4.11)
China PS	$ (48.09)	$ (64.22)	$ (61.10)	$ (73.57)	$ (65.86)	$ (61.41)	$ (78.94)	$ (82.05)
ROW PS	$ (55.42)	$ (76.36)	$ (67.67)	$ (77.36)	$ (68.31)	$ (79.65)	$ (94.16)	$ (104.63)
Argentina PS	$ 119.89	$ 173.43	$ 230.20	$ 265.77	$ 349.72	$ 302.14	$ 430.48	$ 380.74
Brazil PS	$ (100.53)	$ (157.15)	$ (159.06)	$ (210.66)	$ (210.97)	$ (195.46)	$ (195.37)	$ (17.77)
US CS	$ 132.16	$ 180.06	$ 167.48	$ 206.13	$ 173.99	$ 158.92	$ 219.20	$ 220.53
EU CS	$ 82.89	$ 131.87	$ 132.62	$ 165.72	$ 136.39	$ 124.02	$ 154.39	$ 161.01
China CS	$ 73.13	$ 106.14	$ 107.18	$ 134.34	$ 153.08	$ 150.89	$ 205.43	$ 235.54
ROW CS	$ 168.90	$ 229.25	$ 223.22	$ 287.79	$ 250.37	$ 232.75	$ 309.92	$ 328.05
Argentina CS	$ 4.50	$ 6.51	$ 6.66	$ 9.59	$ 9.35	$ 10.05	$ 12.02	$ 13.48
Brazil CS	$ 40.53	$ 57.16	$ 51.65	$ 65.87	$ 60.01	$ 57.35	$ 76.53	$ 78.46
Monopoly	$ 112.50	$ 133.46	$ 160.41	$ 175.75	$ 182.95	$ 251.55	$ 299.00	$ 385.89
US Gov	$ (247.43)	$ (375.35)	$ (342.84)	$ (453.05)	$ -	$ -	$ -	$ -

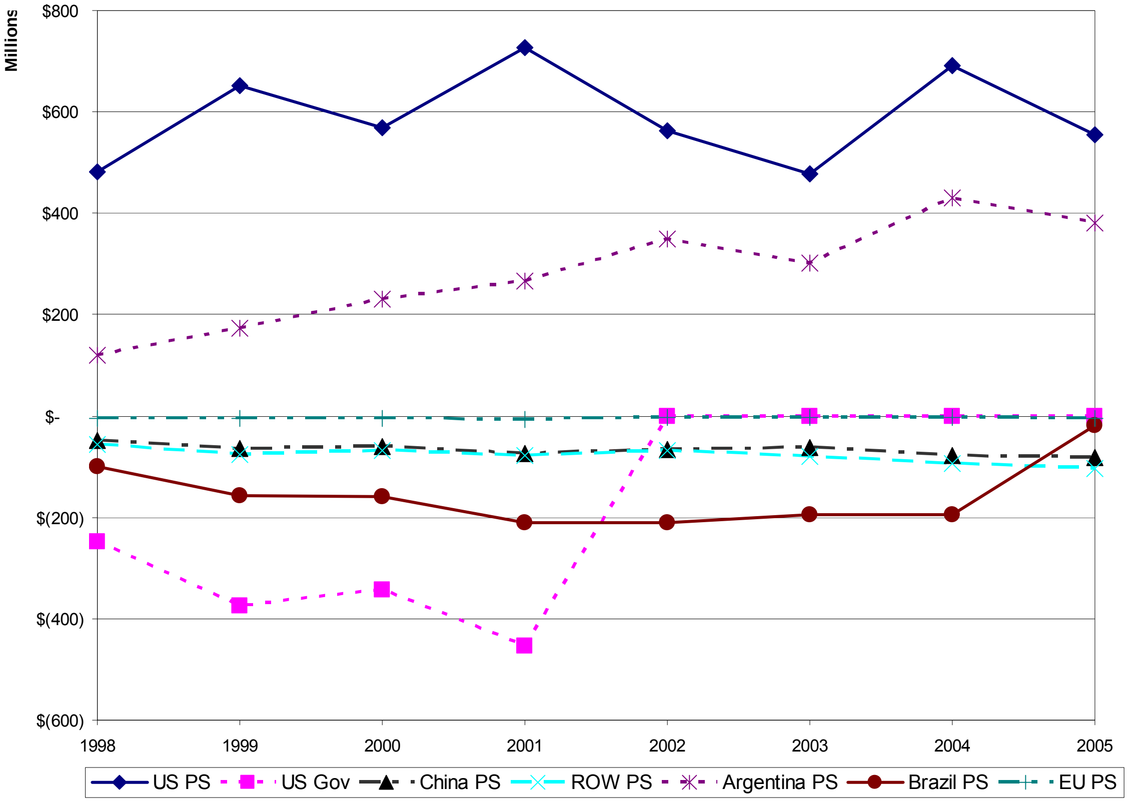

Figure 28: Producer surplus gains ($ million) with 2 times demand elasticities

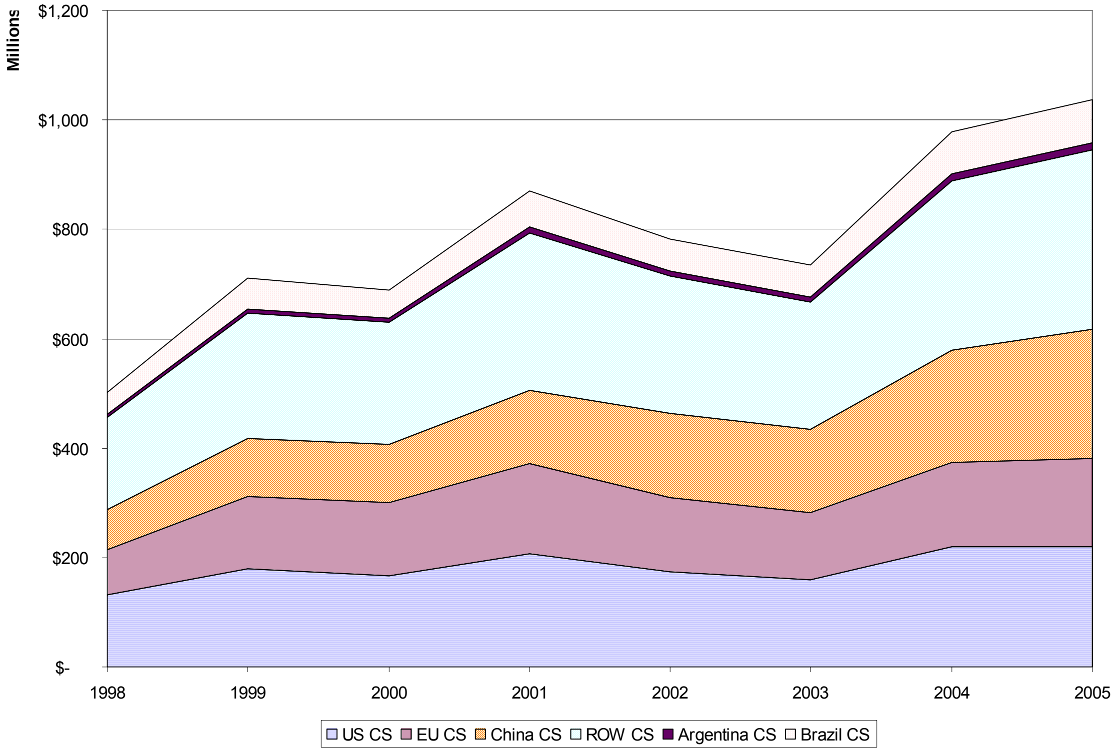

Figure 29: Consumer surplus gains over time ($million) with 2 times demand elasticities

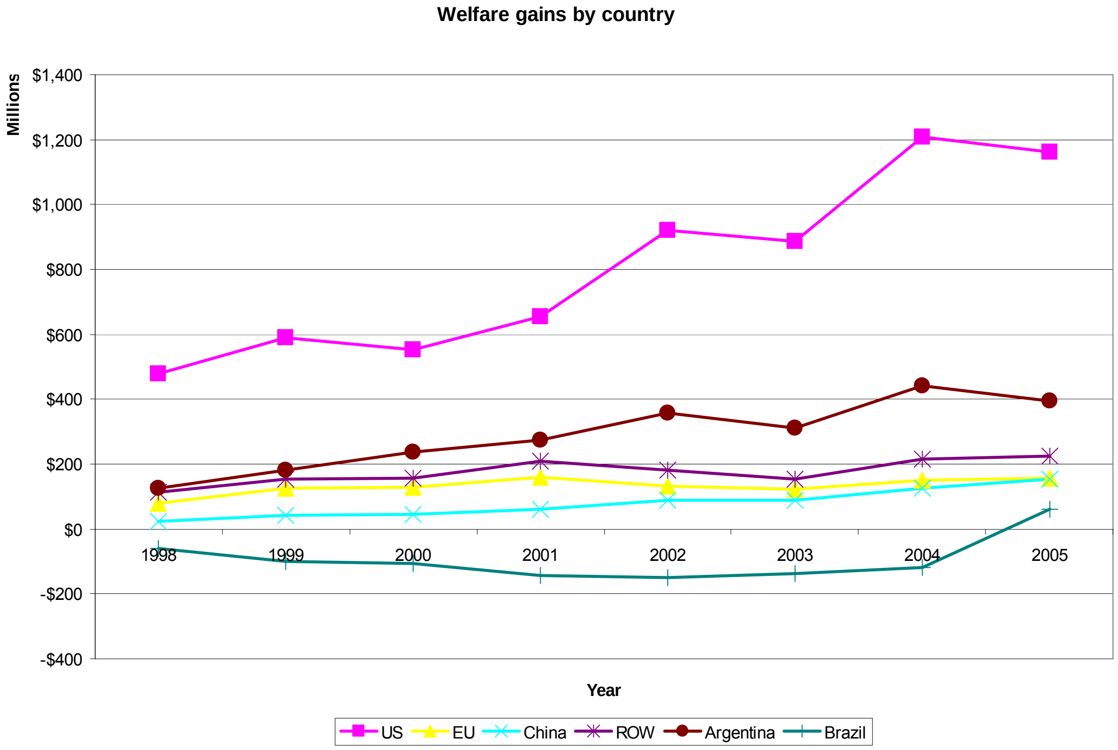

Figure 30: Welfare gains ($ million) by country with 2 times demand elasticities

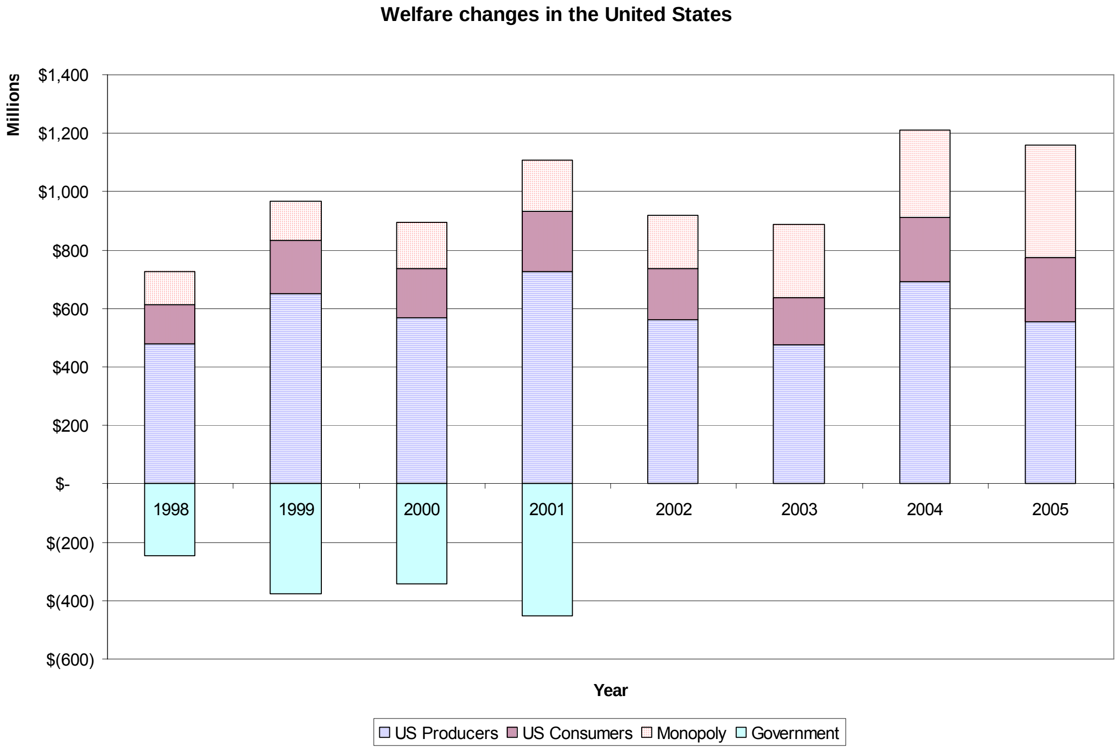

Figure 31: Welfare change ($ million) in the U.S. by sector, with 2 times demand elasticities