PRICING GENETICALLY MODIFIED OUTPUT TRAITS

AND EFFECTS ON COMPETING TECHNOLOGIES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

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This study develops a framework for pricing output traits derived from agriculture biotechnology and the effects on competing technologies post-introduction of the genetically modified (GM) variety. The price impact model determines processor or consumer adoption rates and changes in processor, farmer, and tech firm surplus as a result of the release of the new GM variety.

Several implications result from this research. First, adoption of the GM variety may not be as high as expected due to the lower cost of using conventional varieties for processing or consumption inputs. Second, both processors who adopt the GM variety and those who continue to use conventional varieties will have an increase in surplus as a result of the introduction of the GM variety. Lower costs of conventional varieties will also result in new entrants into the market.

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CHAPTER 1
STATEMENT OF PROBLEM

Introduction

In recent years, plant biotechnology has revolutionized production agriculture and the agriculture industry as a whole. The first generation of biotechnology used crop input traits, such as herbicides and pest resistance, to affect crop production. Plant biotechnology's second generation produced crops with enhanced output characteristics, such as high oil content or other specialized features (Shoemaker, 2001). These characteristics were designed to provide field crops with value-enhanced qualities for end-users.

The industry is evolving into a system in which farmers grow crops designed for the specific needs of end-users in food manufacturing, the livestock sector, and even the pharmaceutical industry. To succeed, however, the products first must deliver not only improved quality traits, but also good agronomic performance. Second, but no less important, the crops must prove their overall value to the producer and end-user. In many cases, pricing and marketing arrangements will not be business as usual and may require several changes (Riley and Hoffman, 1999).

The development of the next generation of output-trait products will take advantage of many significant and developing agribusiness sectors. These output-trait products will be used in consumer-based products, such as food, feed, and nutrition, and processor-based products that focus on food and industrial processing and the medicinal industries. Consumer-based products will improve specific qualities of the commodity products to meet the cost, quality, and health demands of increasingly sophisticated consumers. Processor-based products include qualities that improve processing efficiency and consistency with reduced waste in foods and industrial products, such as bio-energy products. Medicinal trait products include those containing genes that alter the yield/efficacy of nutraceuticals or pharmaceuticals derived from natural plant products (McElroy, 2003). Continued advances in technology will allow both consumers and processors to use more efficient and healthy products.

Farmers were quick to adopt the first generation of genetically modified (GM) crops, which were primarily herbicide-tolerant (HT) and insect-resistant (IR) varieties. These varieties had specific benefits to the farmers that allowed them to decrease the use of herbicides and pesticides. Adoption of the second generation may proceed more slowly, as the market must confront how to determine price, how to share the value, and how to examine the additional changes and costs to bring the crops to market. The added costs of such specialization will have to be justified by the value of the new crop to the buyers and the farmers.

Development of New Traits

Many of the traits currently being developed involve combining, or "stacking," traits such as herbicide tolerance and insect resistance. Input traits being developed in soybeans increase the yield and include *Roundup Ready2 yield* (RR), insect resistance, and drought tolerance. Traits currently being developed in the corn industry are producing crops that are insect resistant, drought tolerant, and nitrogen utilizing—while also increasing yield.

Although the majority of GM traits currently available commercially are input traits, development of new traits, both input and output, are rapidly underway. In 2005, Monsanto launched one of the first products in the industry with direct consumer benefits.

Monsanto's *Visitive* low-linolenic soybeans with low levels of linolenic acid reduce the need for hydrogenation in food processing and help to reduce the amount of trans fats in processed foods. These soybeans are produced using conventional plant breeding and marker-assisted breeding technology to achieve the *Visitive* trait, and they will then be bundled with GM Roundup Ready technology. For the 2006 growing season, Archer Daniels Midland Company (ADM) will be contracting up to 40,000 acres of *Visitive* soybean production, and Monsanto expects nearly 500,000 acres to be grown. Commercialization of many more traits is in the near future.

Development of output traits is moving along quicker than input traits because they have a benefit to the end user or processor. Adoption of these traits has moved more slowly, however, due to questions about consumer acceptance and development of the market. A few of the output traits currently being developed are high value corn with lysine, corn with balanced proteins, high-value, high oil, improved-protein, low linolenic acid, and omega-3 soybeans.

Some of the traits currently being developed may have benefits to both producers and end-users. Wheat that is resistant to fusarium, a devastating fungal disease that causes yield loss and damages grain quality, is currently being developed. Farmers will receive the benefits of this trait in the form of increased yields and a decreased need for fungicides and pesticides. Processors and end-users will have the benefit of receiving high quality and chemical free grain with less chance of rejection by bakery customers due to exceeding the FDA limits on products.

Pricing and Competition of GM Traits

Currently, most specialty crops receive price premiums relative to a futures reference price or a spot cash price at a specific location, and many of the new output-trait crops may be priced similarly (Riley and Hoffman, 1999). For output-trait crops to be effectively adopted, farmers must be able to receive a premium over traditional varieties, and processors and end users must receive a reduction in input costs. Examples of these premiums are displayed in Table 1.1.

Table 1.1. Premiums for Value-enhanced IP Grains

Product/differentiating characteristics	Pricing, cents/bu. (delivered to elevator)
Food grade yellow corn/ High amount of vitreous endosperm	Mostly +7-15; variety specific +15-25
High oil corn/ oil content of 6.5% or greater	+25-35 depending on oil content
High-starch corn/ extractable starch with yields greater than 69-70%	+10-15 CBOT; buyers call
Waxy corn/ starch more than 99% amyl pectin	+20 CBOT; variety specific +40-50
Non-GM corn processor	Mostly +5-10; a few +10-15
Organic white corn Organic yellow corn	\$5.00-6.00/bu. Food/feed grade, FOB farm \$5.15-5.50/bu. Food/feed grade, FOB farm
Edible soybeans	+55 CBOT; +2.50 variety specific
High-protein soybeans	+50-55 variety specific
Organic food grade soybeans	\$12.50-17.50/bu. FOB farm
Organic feed grade soybeans	\$10.50-12.50/bu. FOB farm

Source: USDA, Illinois Market News, (2006).

Price premiums were paid for high-oil corn on a sliding premium scale based on the level of oil content in the corn. Contracts for premiums are priced either as a basis over the nearby Chicago Board of Trade (CBOT) futures contract at the time of delivery or as a straight premium over the spot cash price. Competition remains stiff from the traditional oil markets; however, it is significant that a market exists for high-oil corn, which shows there is the possibility for future growth.

In the past, input-oriented GM traits eliminated the need for conventional herbicides and pesticides. This resulted in a downward shift in demand for the conventional herbicides and pesticides, a lower price for the products, and lower input costs for conventional varieties. The same result would be expected for output-oriented traits, such as FR wheat causing a downward shift in demand for traditional fungicides and allowing for lower input costs. Processors will make purchasing decisions based on the level of scab infestation in the wheat variety. The GM FR wheat is assumed to be 100 percent scab free, which is preferred over wheat with any levels of scab. This preference will result in an upward shift in demand for the scab free wheat, allowing for higher prices for the wheat.

Development in Output Traits

Currently, there are no varieties of GM wheat available commercially. Roundup Ready Wheat (RRW) was one of the first GM traits for the wheat sector and was under review by regulatory agencies in the United States and Canada when Monsanto withdrew it from further consideration (Wilson, DeVuyst, Koo, Taylor, and Dahl, 2005). Overall, the development and marketing of biotech wheat has lagged behind that of other biotech food crops such as corn, canola, and soybeans. This is in part because the genetics of wheat are quite complicated. But it is also because wheat farmers are very concerned about consumer acceptance of GM wheat.

Several forms of output-oriented genetically modified crops are currently being researched and developed. Syngenta is currently working on developing fusarium resistant wheat. Fusarium head blight (FHB) is a fungus disease that can occur on all small grain crops, but is most commonly seen in North Dakota on spring wheat, durum, and barley (McMullen and Stack, 1999). Besides yield reduction, FHB causes reduction in quality, which results in price discounts. Fusarium resistant technology would eliminate the concerns of producers, food processors, and consumers.

Monsanto is currently developing omega-3 soybeans. Research has linked omega-3 consumption with a reduced risk of heart disease, diabetes, and vision impairment. The American Heart Association recommends eating fish high in omega-3 fatty acids at least twice a week to prevent coronary heart disease. The recommended ratio of omega-6 to omega-3 is 4:1, respectively; the average ratio in the United States is currently 80:1. The goal is to build on the demand for omega-3 soybeans. Omega-3 supplements are currently available in fish oils as well as omega-3 golden flax. Monsanto is currently in the advanced product development in breeding plants with this desired trait.

Other output traits being developed that will have desirable qualities for processors are soybeans and canola that have high oil content desirable for the production of bio-diesel. Bio-diesel is a potential replacement for a portion of the diesel fuel used in transportation. Bio-diesel fuels generally take the form of methyl esters (ME) of plant and animal oils produced by means of the transesterification process (Allen & Watts, 2000). Genetically modified crops can aid in making this transesterification process more efficient and may produce a renewable fuel source that could also preserve the environment.

Problem Statement and Elements of the Problem

The purpose of this thesis is to develop a model to price GM output traits and evaluate strategies for commercializing these traits. Traditionally, the open-market has determined prices for commodities and provides signals for grain production. This system has minimal control from the buyer. In this market, transactions are typically spot oriented and lack specificity to special quality requirements such as protein, oil, and fat content. A system of grades and standards provides a set of criteria that can distinguish grain by its physical characteristics. Prices are then discovered through futures markets and applied to these characteristics. In this market, all commodities are assumed homogeneous and prices do not always transmit specifications desired by end-users. Thus, the existing open market does not work well for some commodities with value-enhanced traits and needs to be changed, supplemented, or replaced by other coordinating arrangements (Shoemaker ed., 2001).

Little has been done to study the effects and develop a model for output trait pricing in GM grains and oilseeds. Knowledge of the effects of output trait pricing is needed to understand the effects on farmer and consumer behavior toward GM products. The effects of output trait pricing will influence farmers' decisions to adopt the new technologies and will influence consumers' and processors' decisions to use the new products or the conventional varieties.

Competing Technologies of Genetically Modified Output Traits

Many output trait GM crops are under development and moving toward commercialization, but adoption is slow because of consumer, government, and environmental concerns. Output trait products have potential benefits to consumers and possibly to farmers. These benefits include, but are not limited to, fungal disease-free foods, improved protein, lowered fat content, low lanoline acid, and high levels of omega-3. Other benefits may include increased farm income from premiums that can be attained with these specialized crops.

Adoption of many of these GM crops may be limited because all farmers may not benefit equally from these crops. Several factors may lead farmers not to adopt these crops. These include market uncertainties, segregation costs of keeping the GM crops separate, and the possible decrease in costs of the traditional varieties.

The release of Roundup Ready soybean in 1996 resulted in a 40 percent price decrease of two major herbicides, Chlorimuron and Imazethapyr (Gianessi & Carpenter, 2000). A similar price decrease may be expected in wheat fungicides, such as Tilt and Folicur, due to a downward shift in demand for these products after fusarium resistant wheat is released. The lower price of these products will result in lower input costs of traditional wheat varieties. This may cause some farmers to stay with the traditional varieties and will result in lower adoption of the GM variety.

The demand for omega-3 soybeans is being influenced by our desire to add more omega-3 rich foods to our diets. The level of adoption of this product will be dependent on the demand from processors and consumers in the feed and food grade market as well as the willingness of farmers to produce the crop. The GM varieties of omega-3 soybeans must contain levels of omega-3 that are efficiently above that of the traditional varieties and must also provide good agronomic performance. Farmers may be reluctant to adopt this product based on their agronomic needs, such as herbicide tolerance or insect resistance. Stacking these traits with omega-3 may be beneficial.

Adoption of canola for biodiesel will be dependent on many factors. The continued high demand and prices in the United States and globally for fuel products will be a major influence on adoption. Most commercial biodiesel in the United States comes from soybeans. By contrast, most European biodiesel is produced from rapeseed, the parent plant of canola. For canola to be effectively adopted, it must not only provide a cost effective and efficient means to produce bodies, but also good agronomic performance and value added properties for growers.

GM Trait Competition

Adoption of GM traits depends on the varying needs of farmers. The need to clean up weeds or control pest infestation has affected the demand for HT and IR corn and soybeans in the past. Farmers with weed problems will demand the herbicide tolerant variety, and farmers with insect pressure will demand the insect resistant variety.

With the development and commercialization of fusarium resistant wheat (FRW) on the horizon, farmers will have to choose whether to adopt this technology. Farmers in areas with wet, hot weather, which are highly susceptible to scab, will have a higher need for the trait. Farmers in areas less susceptible may choose to wait and apply fungicide if and when it is needed.

Omega-3 soybeans are currently in the advanced development phase of Monsanto's product pipeline. In addition to omega-3 soybeans, many varieties of output-oriented GM soybeans are currently being developed, including low-lanoline acid, high-protein, and high oil soybeans. Processors and end users will choose the products that best suit their production and consumption needs. Farmers will choose to grow the trait based on the demand and expected profits for each individual trait and their own production needs.

Researchers are beginning to test the properties of canola oil-based biodiesel. The performance of canola-based biodiesel in regard to exhaust and horsepower and its effects on fuel systems and engine components will have a large influence on the level of adoption. Soybeans are currently used for the majority of biodiesel in the United States.

Soybean-based biodiesel as well as high-ethanol GM corn will be major competitors in determining the adoption level of canola.

Objectives

There are two primary objectives in this research. The first objective is to develop a model reflective of technology competition to derive optimal prices and strategies for market traits. In achieving this objective this paper will 1) document the changes from GM modifications and how they occur in existing GM grains; 2) select desirable traits that have promise for demand from the many traits being developed and nearing commercialization; 3) identify issues such as consumer acceptance, adoption, and potential release of the new products; and 4) identify changes in surplus as a result of the new product. The second objective is to use the theoretical model to develop a method of pricing output traits and to determine optimal strategies of the agbiotechnology firm, processors and consumers, and farmers when making decisions about commercialization, processing and consumption, and planting varieties.

Hypothesis

It is expected that the release of these output-oriented GM varieties will result in incentives to lower prices for conventional varieties of the crop. These varieties will also provide increased efficiencies and utility for consumers and processors. This will result in an increase in surplus for both consumers and producers of the product. It will also be expected that the overall market will benefit from the introduction of a new technology choice and increased competition.

Methodology

The methodology in this paper includes an analysis of adoption and diffusion models applied to genetically modified output traits. Past studies in GM input-traits are examined to aid in theory development. Biodiesel production, including possible extraction increases from high-oil canola and input costs; ethanol production, including possible extraction increases from high-fermentable corn; and omega-3 consumption, including potential consumer benefits from GM omega-3 soybeans, are used in the models.

Analysis is done using partial equilibrium models. A partial equilibrium model is used to model one market at a time. The partial equilibrium model concentrates on a particular subsection of the economy, with all other variables being treated as exogenous to the model, whereas general equilibrium models examine the market as a whole.

The model used to determine competing technology pricing and adoption of output-traits is similar to that used in Lemarie and Marette (2003) and Huso and Wilson (2006). The model looks at the introduction of a new technology in a market where previously only conventional technology was available. This is used to look at the effect on price and adoption of the new technology.

Stochastic simulation is used to account for random variables in the model representing the uncertain outcomes associated with the new product. Random variables associated with the release of GM output-traits are production efficiency of the GM crop, input costs, and market acceptance. In situations where historical data is not available, simulation can be used to display possible outcomes.

CHAPTER 2
BACKGROUND AND REVIEW OF STUDIES

Introduction

The rapidly growing popularity and acceptance of GM crops, as well as the continued development and upcoming commercialization of many new GM crops, has led to a wide array of research in this area. This research includes pricing mechanisms of GM crops and competing technologies, crop segregation, consumer and government acceptance as well as issues with intellectual property rights. The specific topics in this thesis have not been addressed, specifically, output traits and the pricing and benefits of these traits.

The current accelerating interest in GM crops is largely due to the success of GM input traits, especially Roundup Ready crops. The development of GM output traits has led to many new issues that include, but are not limited to, the difference in consumers' acceptance among foreign countries, especially Europe and the United States. Producers are also concerned about the potential loss of markets and trading partners from the release of these products. They may also be faced with additional marketing costs derived from keeping grains segregated or from identity-preserved marketing.

This chapter discusses the issues that have arisen with the development of new GM output crops. The first section discusses consumer and producer issues such as acceptance, regulations, labeling, and adoption rates. The second section covers the ag-biotechnology industry and the status and development of GM crops. The third section discusses pricing mechanisms for GM crops from many different perspectives as well as reviews of previous studies.

Biotechnology Issues

Consumer responses to genetically modified crops and foods have varied widely worldwide. Consumers in the United States have been less vocal about opposition to GM crops than consumers from the EU and around the world. The introduction of GM output crops will have a direct impact on consumers and their perception of GM crops. This section will address issues involving consumer awareness, food safety and regulations, food labeling policies, benefits of biotechnology, and effects on producers.

Consumer Awareness

Over the past decade, consumers in most countries have become increasingly aware of the presence of GM ingredients in many of their foods. Many remain largely unaware that the foods they are eating contain GM products, however. In the 1997 survey, 40 percent of respondents said they believed that GM products could be found in supermarkets while 37 percent said they could not; the remainder did not know (Hoban and Katic, 1998). Many foods Americans consume, such as corn chips, are processed from grains that have been grown using GM technology. Because these foods are deemed substantially equivalent to their non-biotech counterparts, they are not labeled as "biotech" (Shoemaker, Johnson, and Golan, 2003). In the United States the inclusion of the GM ingredients remains invisible to consumers. Unlike their European counterparts, American consumers have, so far, not been vocal about their opinions on biotech food, though they have been eating it (Shoemaker, Johnson, and Golan, 2003).

Consumer acceptance of GM foods has varied greatly worldwide. Consumers in the United States and Canada have had the most positive attitudes and have voiced little objection to GM foods, while consumers in the EU have been vocal about their negative attitudes regarding GM foods. Consumers in Japan and Australia have had a generally favorable attitude toward GM crops. Surveys that asked the same questions of both EU and United States consumers generally elicited less favorable responses toward genetic engineering in food from EU consumers than from United States consumers (Shoemaker ed., 2001). Consumers in the EU and Australia seem more likely to attach risk to GM foods than United States consumers. These differences in responses have resulted in differing regulatory policies and trade restrictions throughout the world.

Consumers worldwide have generally shown greater approval of GM foods with desirable characteristics (output traits). Lusk et al. (2002) found that consumers derived positive utility from corn chips produced with genetically modified corn engineered to increase chip shelf life. The results also suggest that a relatively small premium exists for chips manufactured with corn genetically engineered to increase shelf life (Lusk et al., 2002). Estimates from a survey of college students indicate that the average student would be willing to pay a $0.33 premium for a bag of chips made from corn modified to increase shelf life as compared to a bag of chips made from corn modified to increase farmers' crop yield (Lusk et al., 2002). Consumers demand variety and quality from foods that can be achieved from second-generation GM crops. The success of these foods will depend on consumer attitudes toward agricultural biotechnology.

Labeling Policies

An important consideration facing the food industry involves labeling policies of GM foods. The United States requires labeling of food products as a product of biotechnology only if the GM version of the crop is significantly different from its traditionally bred counterpart. The EU requires that all foods containing GM ingredients be labeled as such. Japan, Australia, and New Zealand also require mandatory labeling of GM foods, even without scientific evidence of health risks to consumers.

Studies have shown that the majority of consumers support the FDA position on labeling. A national survey of American consumers conducted in 1997 found that over three-quarters of consumers supported the FDA labeling policy (Hoban and Katic, 1998). While the majority supports the FDA, many surveys have shown that consumers favor mandatory labeling of GM food products. Consumers are concerned about their "right to know" about the foods they are consuming, but are likely to pay little attention to the labels and are even less likely to pay more than a trivial amount to receive that information. For example, Hallman, et al. (2002) found that although 90 percent of Americans thought GM food products should be labeled as such, only 53 percent reported they would look at food labels for this information, and only 45 percent expressed a willingness to pay more for non-GM foods. The American Medical Association states that as of December 2000, there is no scientific justification for special labeling of genetically modified foods, as a class, and that voluntary labeling is without value unless it is accompanied by focused consumer education (American Medical Association, 2000).

Labeling requirements increase costs that will likely be passed on to consumers. Keeping GM crops separate along the supply chain requires added expenses including added handling measures, testing requirements, and segregation costs. If the same truck, shipping containers, and processing plants have been used for GM as well as non-GM varieties, cross-contamination can occur. Therefore, requirements for labeling GM versus non-GM will have to specify some minimum tolerance level for GM material (Shoemaker ed., 2001). Governments around the world have enacted differing tolerance levels.

Consumer surveys have shown they are not willing to pay extra to have foods labeled as a product of biotechnology (especially when this information has no meaning) (Hoban, 1998).

Regulatory Issues and Food Safety

There are numerous regulatory issues related to GM crops. Biotech crops undergo years of rigorous testing through a number of agencies to ensure they are safe for people, animals, and the environment. Biotech crops have been more thoroughly tested than traditional varieties. Nearly every country has a different approach to regulating GM crops and their food system, resulting in scrutiny and trade restrictions for foreign exports.

The United States has incorporated the regulation of biotech crops into its current regulations for foods, plants, and pesticides (Shoemaker ed., 2001). The United States and Canada have a three-part regulatory system that focuses on biotechnology's end products and not the process by which they are created. The United States requires just a few extra regulatory steps to ensure a GM variety is safe for consumption and the environment. The Food and Drug Administration (FDA) regulates food applications of crops produced with biotechnology. The FDA relies on current laws that consider GM foods safe if they are not significantly different. The USDA's Animal and Plant Health Inspection Service (APHIS) oversees field testing and the release of crops developed through biotechnology. The Environmental Protection Agency (EPA) regulates a biotech plant's environmental safety, such as its pesticide properties, possible effect on wildlife and method of breakdown in the environment. The EPA regulates the substance as a pesticide and determines how much of the substance may be present in food (Shoemaker ed., 2001). The EPA may exempt the crop from the requirement of tolerance if it is found safe for consumption. The agency must also approve the use of pesticidal substances and herbicides on the crops. The Canadian and Japanese system of regulating biotech crops is very similar to that of the United States, but Japan has labeling requirements.

The EU system of regulating GM crops differs from that of the United States. The EU has designed regulatory processes specifically for GM crops, and each GM crop is evaluated, regardless of similarity to existing varieties (Shoemaker ed., 2001). Under the EU system, scientific evidence of the GM crop not exceeding a set level of risk must exist before the crop is approved for release. All crops sold for food use must also go through an approval process before the crop may be sold. All food crops sold in the EU must be labeled as GM. The EU regulatory system is much more complex than that of the United States.

Much of the regulatory processes and labeling requirements throughout the world exist to ensure that GM foods are safe for consumers, animals, and the environment. There are many arguments for and against GM foods. These arguments have been based on emotions, political views, marketing tactics, and scientific research. There has never been a documented case of illness related to food developed with biotechnology. Foods produced from biotechnology may have the ability to reduce allergic reactions caused from food. Because of the extensive testing of GM crops, many believe they may be even safer than traditional varieties. The AMA recognizes the many potential benefits offered by genetically modified crops and foods, does not support a moratorium on planting genetically modified crops, and encourages ongoing research developments in food biotechnology (AMA, 2000). Still, biotech opponents claim that inadequate research exists to determine that GM foods are safe to eat and have no long-term effects. Despite the controversy, Americans have displayed their trust in the food supply.

Producer Issues

Producers have rapidly adopted the first round of GM crops with total acres increasing year after year. Producer acceptance is being driven by expectations of higher profitability. Producers have seen higher yields and lower input costs from reduced tillage costs and reduced pesticide use made possible from GM crops. The convenience of being able to use fewer chemicals and make fewer passes over the field has also driven the high adoption rates.

For GM output crops to be effectively adopted by producers, the crops must not only provide good agronomic performance, but must also provide significant premiums for farmers. An essential factor in determining adoption of a new technology is that it must be more profitable relative to existing alternatives (Shoemaker ed., 2001). While profitability is key to explaining the extent and rate of technology adoption, heterogeneity among farmers may explain why farmers may not adopt the innovative product. Differences influencing readiness to adopt include farm size, tenure, operator education/experience, and access to information and credit (Fernandez-Cornejo and McBride, 2002). Marketing arrangements may be necessary for producers to adopt output-oriented GM crops.

Genetics, production practices, harvesting, handling, storage, and processing may need to be more closely coordinated in order to preserve the desired traits for the end-user. Producers of value-enhanced commodities may need to know their price before they produce because of increased complexity and costs (Shoemaker ed., 2001). An array of marketing arrangements may need to be developed including spot/cash market, specifications contracts, strategic alliances, formal cooperation, and complete vertical integration to control the end product and encourage producers to adopt output-oriented crops.

Research and Development of Plant Biotechnology

Plant breeding and seed manipulation had been a large part of agriculture for centuries. Farmers and ranchers have been attempting to grow the best and most efficient livestock and crops throughout history. Plant biotechnology has significantly changed the environment of research and development (R&D) in the seed and chemical industry. Biotechnology, seed, and chemical companies have become substantially more concentrated and vertically integrated (VI) in recent years. The sources of R&D, costs, and changes in patent laws have also contributed too many changes.

In 1980, the United States Supreme Court ruled that isolated genes and genetically modified plant varieties were patentable (Chan, 2006). Other countries followed suit and changed their laws in similar ways. Greater protection of Intellectual property (IP) for seed innovations has led to increased R&D in private industry. This protection has also led to market power that facilitated higher levels of industry concentration.

In the last ten years the seed and pesticide industries have undergone a substantial number of structural changes (Fulton and Giannakas, 2001). Mergers and acquisitions (M&A) are a key component of the new business relationships that have emerged (Fulton and Giannakas, 2001). The high cost and extensive time needed to develop plant biotechnology has been the driving factor in many of the mergers and acquisitions over recent years. Mergers and acquisitions are an important business strategy for companies to acquire technological capabilities such as knowledge and expertise, business experience with the technology, and intellectual property rights (King and Schimmelpfennig, 2005). Alternatives to M&A are internal development of technology as well as licensing traits. However, these processes can be very costly, it may take years to develop the technology, and competition to negotiate licensing costs may make licensing slow and expensive.

Two standard measures of analyzing industry concentration are the *Herfindahl-Hirshfield Index* (HHI) and the *Four-Firm Concentration Ratio* (CR-4). Each of these measures is based on the assumption that market power is related to market share—in this case market share being the proportion of patents owned or field trials conducted by a firm (Brennan, Pray, Naseem, and Oehmke, 2005). The industry concentration (CR-4) and implications have been discussed in several other papers (Brennan, Pray, Naseem, and Oehmke, 2005; Fulton and Giannakas, 2001; Oehmke and Wolf, 2003; and Oehmke, 2001; among others), so they will only be briefly mentioned here.

Field trial data has been used to evaluate the concentration in the innovation markets. Brennan et al. (2005) found that the top four firms conducted 87 percent of field trails in 1988, declined to a low of 63 percent in 1995, and has consistently risen to 80 percent in 2001. During the late 1980s and early 1990s, field trials were highly concentrated among a few firms, with CR-4s exceeding 60 percent (in some years over 80 percent) (Brennan, Pray, Naseem, and Oehmke, 2005). Oehmke (2001) found that the CR-4 of HT and IR traits both had an initial CR-4 of 100 percent in 1987 and has fluctuated since then with HT traits reaching a secondary peak in 1998 and IR traits reaching a secondary peak in 1992 of 92 percent. The less concentrated period of the mid-'90s led to increases in M&A activity and new firms entering the industry. These findings indicate that the industry is highly concentrated but the level of concentration has not reduced the level of R&D activity, although the industry leaders have the ability to reduce the level of R&D throughout the ag-biotechnology industry.

In developing agricultural biotechnology, many companies utilize the same gene construct through license agreements and contracts to develop GM seeds. From this, Oehmke and Wolf (2003) developed a CR-4 type measure based on gene construct field trials to calculate industry concentration called the GR-4 (GR for gene related). The phenotype-based GR-4 was uniformly more concentrated than the traditional firm-based CR-4 measure for two of the four most popular phenotype categories through the end of 2000 (Oehmke and Wolf, 2003). The new GR-4 measure indicates the transgenic seed industry is highly concentrated, and very few firms have successfully deregulated GM seeds. The number of innovating firms has been reduced due to M&A (e.g., Monsanto purchased Calgene), further concentrating the industry.

Genetically modified crop field trials have continually been dominated by a small number of firms. By 2002, the "Big Six" agricultural biotechnology firms also controlled over 40 percent of private-sector agricultural biotechnology patents issued in the United States through 2000 (King and Schimmelpfennig, 2005). These firms—United States firms Dow, Dupont, and Monsanto and European firms BASF, Bayer, and Syngenta—dominate the ownership of agricultural biotechnology utility patents (King and Schimmelpfennig, 2005). Many, if not most, patent stocks held by these parent companies were developed by subsidiary companies that were acquired through M&A activities. Mycogen contributed 87 percent of Dow Agroscience's total patents. Monsanto, which holds the largest number of agricultural biotechnology patents, obtained significant patent stocks through acquisitions of Dekalb Genetics (17 percent), Calgene (14 percent), and Holden's Foundation Seeds (9 percent) (King and Schimmelpfennig, 2005). Similar patterns hold for many of the companies.

In addition to the many mergers and acquisitions along with internal growth, the agricultural biotechnology industry has changed through vertical integration. Many of the seed, chemical, biotechnology and pharmaceutical companies combined into single firms, although most of the pharmaceutical companies have now been spun off. Major biotechnology companies have purchased seed companies to place their biotech traits into the seed. As an example, in 1997, Monsanto acquired a 30 percent share of the Brazilian corn seed market with the acquisition of Sementes Agroceres, and now controls over half the Argentine Maize seed market with the 1998 purchase of Cargill's international seed division (Fulton and Giannakas, 2001). Dow AgroSciences, along with other agricultural biotechnology companies, have made similar acquisitions. Agricultural companies may also be encouraged to vertically integrate to take advantage of the benefits of output-trait GM crops and to develop to infrastructure to successfully commercialize these traits.

The driving force behind consolidation appears to be sunk costs and escalation strategies. Research and development and costly regulatory process are the two major sources of sunk costs in the agriculture biotechnology industry. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS), through its Biotechnology Regulatory Services (BRS) program, is responsible for regulating the introduction (importation, interstate movement, and field release) of genetically engineered organisms such as plants, insects, micro-organisms, and any other organisms that are known to, or could be a plant pest (BRS, 2006). The regulatory approval costs for ag-biotechnology products are estimated to have increased from \$5-10 million per transgenic crop product during the '90s to closer to $20-30 million as of 2003 (McElroy, 2003). Therefore, companies strive to create economies of scale and scope to spread out costs and lower the average cost of production. Firms also use escalation strategies to become the dominant firm in the market.

Greater protection of IP rights for GM seeds has created incentives for large amounts of R&D spending increases from the private side of the industry, while the public sector has remained virtually constant. Patents and plant variety protection give companies a virtual monopoly on the product and, thus, incentive to increase spending. Private sector spending on overall agricultural R&D in the United States jumped from $2 billion in 1970 (expressed in 1996 dollars) to $4.2 billion in 1996, while federal and state spending has flattened out at around $2.5 billion since 1978 (Fernandez-Cornejo and Schimmelpfennig, 2004). Current estimates of private sector spending are hard to come by, but spending has increased even more since 1996.

Status and Development of GM Crops

In recent years, farmer demand has driven annual double-digit increases in biotech crop adoption since the crops were commercialized a decade ago. Since initial commercialization in 1996, global planted area of biotech crops has soared by more than fifty-fold from 4.2 million acres in six countries to 222 million acres in 21 countries in 2005 (James, 2005).

Globally, farmers are currently growing biotech soybeans, corn, cotton, and canola, and in 2005, GM rice was grown for the first time in Iran. Among these crops, the most widely adopted trait continues to be herbicide-tolerant soybeans, accounting for 60 percent of total global acres. The preference for crops with stacked traits is also growing, accounting for 10 percent of the global area of GM crops. Due to low regulations and widespread acceptance, the United States grew 123 million acres of biotech crops, which accounts for 55 percent of the world's biotech area.

A broad spectrum of innovative new products is currently being developed in the ag-biotechnology industry (McElroy, 2003). Many of these products have benefits to end-users or processors and are considered output traits. Commercialization and adoption of these crops will result in increased acreage of GM crops.

GM Trait Pipeline

The heart of Monsanto's and other biotechnology companies' research and development is the product pipeline. The biotechnology and trait pipeline is an engine for delivering the next generation of products that provide beneficial genetic traits to enhance plants' growth or to provide nutritional or other benefits to farmers, food and feed processors, or consumers (Monsanto, 2005). The pipeline projects are sorted into categories by which they offer benefits to farmers, processors, or consumers. The project pipeline is also divided among the various stages of development. Activities of each stage of the product pipeline are described in Table 2.1.

The initial phase of R&D in Monsanto's product pipeline is the discovery phase, where valuable genes and/or traits that can be used to improve plants through biotechnology or conventional breeding, respectively, are identified. These genes and traits are screened to identify the categories of greatest interest and then investigated.

Following discovery is Phase I through Phase IV, with Phase I being the proof of concept phase. In Phase I, conventional breeding plants are bred from parents with desired traits. For GM products, gene configurations are screened for desired performance. In this phase, it is determined which traits and genes show the most promise for application in crop plants. In Phase II, field trails and lab and field testing are done to select candidates that can be commercialized and can meet regulatory requirements. In Phase III, the performance of the hybrid or variety developed through conventional breeding, or the efficacy of a biotechnology trait in elite germplasm, is demonstrated (Monsanto, 2005). Regulatory data is also developed. Phase IV is the prelaunch phase where bulk seed is produced for sale, strategies for commercialization are developed, and final regulatory approval is pursued. If a company is successful moving a trait through its product pipeline, the seed will be commercialized and ready for sale.

Table 2.1. Monsanto Product Pipeline

	DISCOVERY Gene/Trait Identification	**PHASE I** Proof of Concept	**PHASE II** Early Development	**PHASE III** Advanced Development	**PHASE IV** Pre-launch
AVERAGE DURATION	24 to 48 months	12 to 24 months	12 to 24 months	12 to 24 months	12 to 36 months
AVERAGE PROBABILITY OF SUCCESS	5 Percent	25 Percent	50 Percent	75 Percent	90 Percent
GENES IN TESTING	Tens of Thousands	Thousands	10s	<5	1
KEY ACTIVITY	-High-throughput screening -Model crop testing	-Gene optimization -Crop trans-formation	-Trait Development -Pre-regulatory Data -Large-scale transformation	-Trait Integration -Field testing -Regulatory data generation	Reg-ulatory Approval -Seed bulk-up

Source: Monsanto (2005).

Crops Under Development

The rapid adoption of the currently available biotech crops has led to the development of many new crops with both input and output traits. While the majority of crops being developed continue to be GM input traits, the number of output-trait crops is growing rapidly. During 2005, over 1,400 biotech notifications were acknowledged, over 500 permits were approved, and six biotech crops were deregulated (BRS, 2006). The Animal and Plant Health Inspection Service (APHIS) has granted many field testing permits and has received many petitions for deregulation of biotech crops. As of May 16, 2006, APHIS has granted non-regulated status for 70 GM crops (USDA APHIS, 2006). Many more crops are expected to become deregulated in the near future.

The "Big Six" agricultural biotechnology companies continue to be the leaders in developing new traits and applying them to new crops. Corn, soybeans, and cotton have the largest number of new traits being developed and pending approvals. Biotechnology traits are also being developed in many new crops ranging from wheat to fruits and vegetables. Some of the new crops will be available in the next couple of years, but many of them are still in the early stages of development. Examples and the status of many crops being developed are displayed in Table 2.2.

In corn and soybeans, many of the genes and traits being developed have very similar characteristics. Monsanto has new products nearing release in corn that are focused on reducing inputs. Monsanto's improved 2nd-Generation *YieldGard* products protecting against rootworm and corn borer are in Phase IV and Phase III of development, respectively.

Table 2.2. Status of Crops Being Developed

Benefits	Crop	Trait	Company	Status
Farmer	Soybeans	RR2 Yield	Monsanto	Adv. Development
Farmer	Canola	RR2 Yield	Monsanto	Early Development
Farmer	Soybeans	Dicamba-tolerant	Monsanto	Early Development
Farmer	Corn	2nd Gen Rootworm	Monsanto	Pre-launch
Farmer	Corn	2nd Gen corn borer	Monsanto	Adv. Development
Farmer	Soybeans	Insect protected	Monsanto	Early Development
Farmer	Corn	Yieldgard rootworm II	Monsanto	Early Development
Farmer	Soybean	Nematode-resistant	Monsanto	Proof of Concept
Farmer	Corn	Drought tolerant	Monsanto	Early Development
Farmer	Canola	Higher yielding	Monsanto	Early Development
Farmer	Soybeans	Drought tolerant	Monsanto	Proof of Concept
Farmer	Corn	Higher yielding	Monsanto	Proof of Concept
Farmer	Corn	Nitrogen utilization	Monsanto	Proof of Concept
Farmer	Soybeans	Higher yielding	Monsanto	Early Development
Farmer	Canola	Sclerotina resistant	DuPont	Unknown
Farmer	Corn	Herculex rootworm	Dow	Unknown
Farmer	Sugar Beet	Roundup Ready	Monsanto	Unknown
Farmer	Wheat	Fusarium Resistant	Syngenta	Unknown
Farmer	Corn	IR/HT	Syngenta	Unknown
Farmer	Soybeans	IR/HT	Syngenta	Unknown
Processor	Corn	Mavera with lysine	Monsanto	Pre-launch
Processor	Soybeans	Mavera high-value	Monsanto	Pre-launch
Processor	Corn	2nd Gen high-value	Monsanto	Proof of Concept
Processor	Soybeans	High oil for processing	Monsanto	Early Development
Processor	Corn	Increased Energy	DuPont	Unknown
Processor	Corn	Nutritionally Enhanced	Dow	Unknown
Processor	Corn	Ethanol Enzyme amylase	Syngenta	Unknown
Consumer	Soybeans	Improved-protein	Monsanto	Pre-launch
Consumer	Soybeans	Visitive low lin	Monsanto	Adv. Development
Consumer	Soybeans	Visitive low lin, Low Sat	Monsanto	Early Development
Consumer	Soybeans	Omega-3	Monsanto	Adv. Development

Source: Monsanto (2005), Syngenta (2006), Biotechnology Industry Organization (2005).

Many other input-trait corn products include drought-tolerant corn (Monsanto and DuPont), higher yielding and better nitrogen utilization corn (Monsanto), and many corn products with stacked traits (Monsanto, Dow AgroSciences, Syngenta, and Dupont). Soybean varieties being developed include many for improved weed control, LibertyLink soybeans (Bayer CropScience) and Roundup RReady2Yield soybeans (Monsanto). Other varieties include dicamba-tolerant, insect-protected, soybean nematode-resistant, drought-tolerant, and higher-yielding soybeans, all from Monsanto.

Many other input traits are being developed for other crops. Monsanto, Dow AgroSciences, and Syngenta are producing many varieties of cotton with advanced weed control and insect protection. Monsanto is also working on Roundup Ready lettuce, sugar beets, and creeping bentgrass. Apples that are insect-protected are being developed with Monsanto technology and disease-resistant bananas being developed by DNA Plant Technology Corporation are some of the fruits being researched. Syngenta has been working on fusarium-resistant wheat that will help farmers combat fusarium head blight. This technology will also provide a benefit to processors and bakers, as they will prefer wheat that is 100 percent free of fusaruim head blight.

Output-trait crops will offer benefits to two primary groups: consumers and processors. Crops aimed at benefiting consumers will have characteristics such as improved nutrition. Crops aimed at benefiting processors will have characteristics that will aid and increase efficiency in the production process. Examples of such crops include Monsanto's Omega-3 soybeans and Syngenta's corn amylase project, respectively.

The number of output-trait crops being produced has increased noticeably in the past few years. Cargill and Monsanto's joint venture, Renessen, is a leading innovator in developing improved ingredients/inputs for the feed and processing industry. Renessen's *Mavera* line of products uses biotechnology and breeding to produce corn and soybeans with higher levels of nutrients such as oil, protein, and amino acids, which are important in feeding animals and processing grain (Renessen, 2006). Monsanto is also working on second-generation high-value corn with lysine, feed corn with balanced proteins, and high oil soybeans with processor benefits in mind.

The recent changes in the bio-fuel industry may have significant implications for the biotechnology and agriculture industry. DuPont is developing increased-energy-availability corn and Syngenta is working on corn amylase designed to increase the efficiency of ethanol production, both with enhanced processor benefits. Pending the achievement of a number of technical, commercial and regulatory milestones, Syngenta expects the new trait to be a significant advancement for the ethanol industry by delivering a novel alpha amylase enzyme necessary for ethanol production with the enzyme being expressed directly within the corn seed itself (Syngenta, 2006). Many other output-trait crops with bio-fuel processors in mind are being developed, including canola and improved soybeans for biodiesel.

Many of the upcoming output-trait crops have specific benefits for consumers. These traits are being developed through conventional and marker-assisted breeding (*Visitive)* as well as GM technology (Monsanto, 2005). Monsanto is producing improved protein soybeans, improved *Visitive* low lin-mid oleic- low saturated fat soybeans and Omega-3 soybeans. DuPont also has an improved protein soybean nearing release, and Dow AgroSciences is working on a nutritionally enhanced corn. Fusarium-resistant wheat, being developed by Syngenta, will have benefits for processors as well as consumers.

Agritope, Inc. is developing fruits and vegetables that have longer shelf life and last longer. Pending approval, and expected acceptance from the majority of consumers, many of these products may be on the market within the next few years.

Mechanisms of Pricing GM Crops

The mechanism of pricing output-trait GM crops is expected to be different than that of conventional and input-trait GM varieties. The perspective of the biotechnology trait provider and seed companies pricing their traits will be very similar to the past, although there appears to be changes in the future due to increased vertical integration. Producers of these enhanced-output crops will face greater challenges when pricing their crops. This will require greater exchange of information and greater coordination along the production and marketing lines. Previous studies on pricing value-enhances crops (VEC) will provide valuable information for pricing GM-VECs.

Perspective of Seed Firms and Biotechnology Trait Provider

Due to recent changes in the seed and biotechnology industry, most biotechnology companies now release their traits as a "bundled" package with seed through their own seed companies. The chemical is often included in the "bundled" package of seed and GM trait. Licensing agreements are another important mechanism that allows the traits to reach producers. The licensing agreement allows the seed company to sell the GM trait in their seed. The technology provider will then receive royalties from the sale of their traits by the seed company. Examples of technology fees in 2005 are shown in Table 2.3.

To access the technology of GM seeds, farmers must pay a technology fee to obtain the right to use the seed and must agree not to keep the harvested seed for future planting or for reselling to other farmers. Technology fees are a way for biotechnology firms to capture

Table 2.3. Technology Fees of Biotechnology-derived Crops Planted in 2004

Crop	License	Cost $/acre
Roundup Ready Canola	Technology fee + 0.375lb ai/A of glyphosate	$15.00/acre
Roundup Ready Corn	Seed premium/ Tech fee	$6.00/acre
Roundup Ready Soybeans	Seed premium/ Tech fee	$8.00/acre
BT Corn Borer Resistant Corn	Seed premium/ Tech fee	$9.00/acre
Herculex I Corn	Seed premium/ Tech fee	$10.00/acre
Yieldgard Rootworm Resistant Corn	Seed premium/ Tech fee	$17.00/acre

Source: Sankula, Marmon, and Blumenthal (2005).

rents from intellectual property. Monsanto was unable to obtain patent protection in Brazil or Argentina for RR technology, thus the use of technology fees has become controversial, because United States producers feel they are paying for research that helps their foreign competitors.

Starting in the 2002 growing season, Monsanto eliminated the technology fee paid to them by growers who plant selected varieties of seed with Monsanto technology and replaced it with a royalty paid by seed companies licensed to market those products (Monsanto, 2001). This change is based on requests from growers and seed companies to change the technology fee structure. Now, growers will make a single payment to the seed company for technology and seed, rather than one payment to the seed company and a separate payment to Monsanto for the right to use Monsanto's patented technology (Monsanto, 2001). The new royalty pricing structure allows seed companies to price the individual trait just as they price their seed. Each seed company will set the price for corn and soybean technology in its branded seed based on the value the products bring to the marketplace (Monsanto, 2001). The royalties make the purchase of biotech simpler while enabling Monsanto to continue R&D of new technologies.

Two recent studies provide estimations of the impacts of pricing GM seeds and competing technologies. Lemarie and Marette (2003) and Huso and Wilson (2006) use a vertical differentiation model to evaluate the effect adoption of GM seeds has on output prices as well as competing inputs. Lemarie and Marette (2003) developed the idea that incomplete adoption is explained by the heterogeneity of the farmers and the competition with the conventional seed and chemical inputs. Genetically modified seeds compete with traditional seeds and traditional plant protection practices. The diffusion of GM seeds is expected to negatively impact the sales of the pesticide industry. Due to competition, the prices of synthetic pesticides may decrease, which would lead to an increase in the surplus for farmers who are still using the conventional pesticide. Diminishing pesticide prices may also affect the pricing of GM seed (Lemarie and Marette, 2003). The agbiotechnology firm will determine a profit maximizing technology fee ($/acre) for its GM trait (Huso and Wilson, 2006).

When the biotechnology company has property rights only to the HT technology, it typically charges a price premium on the seeds corresponding to the market power of the bundle (HT seed + burndown herbicide). Conversely, when the biotechnology company has the property rights to both HT seeds and herbicide, then the markup comes from the herbicide instead of a price premium for the seed (Lemarie and Marette, 2003). Biotechnology firms charge a price premium for GM seed as a return for R&D expenses. Huso and Wilson (2006) state that the agbiotechnology firms gain profit from both the sale of complementary pesticides to their GM traits and from the license price received from the sale of GM seeds.

Fulton and Giannakas (2001) found that two broad conclusions can be drawn from the literature. First, pricing by the seed and chemical companies is largely strategic in nature. Second, these strategic decisions can have important impacts on the distribution of the benefits obtained from R&D. Strategic pricing means that prices are actively chosen by firms rather than being determined exogenously. Strategic pricing is closely linked to sunk costs, which are a key feature of the seed and chemical industries. The existence of substantial sunk costs and relatively low marginal costs means that firms must have some ability to price above marginal cost if they are to have an incentive to undertake R&D expenditures (Fulton and Giannakas, 2001).

Similar conclusions can be drawn from Lemarie and Marette (2003) and Huso and Wilson (2006). The introduction of GM seed transfers surplus from chemical companies to the agbiotechnology companies. Overall, farmers benefit from the introduction of the new IR product. Lemarie and Marette (2003) found that a large portion of the benefit goes to the farmers with the highest need of insecticide. Farmers who use traditional practices also benefit from the introduction of the new product due to price decreases. The results are slightly different for the release of GM HT seed where two competing firms provide burndown herbicide. Once again, farmers benefit, but the profit for the biotechnology firm is lower than the IR case.

Huso and Wilson (2006) found the introduction of GM FRW transfers a majority of firm payoffs from the conventional to the agbiotechnology firm. Much of the farmer surplus shifted to those farmers who adopted GM FRW, while conventional farmer surpluses decreased. Similar results were found for the introduction of GM RRW. Farmers benefit from the introduction of RRW, but surplus is mostly shifted from conventional farmers to those farmers that adopt RRW. The payoffs to conventional herbicide producing firms decreases, while the glyphosate producing firm and agbiotechnology firm increases. Overall sector welfare increases in both simulations.

Strategies of Pricing Specialty Crops

Pricing new products is one of the most important and challenging issues facing farmers, processors, and consumers. Due to the difficulty of pricing them correctly, many new products will fail. Potential applications of GM output-trait crops may not be able to be foreseen with precision, resulting in error in the forecasts of demand, cost, and competitors' capabilities. Dean (1969) provides valuable insight about issues and strategies of pricing pioneering products.

A "pioneer" product is here defined as one that incorporates a major innovation (Dean, 1969). Many GM output-trait crops may be considered pioneer products if they are able to distinguish themselves in the marketplace and provide benefits for consumers and processors. If a product is truly novel, the new product pricing is, in essence, monopoly pricing. Monopoly pricing will be the price that will maximize profits, taking into account the price-sensitivity of demand and the incremental promotional and production cost of the seller (Dean, 1969). The competitive setting of the product will modify monopoly pricing.

The maximum profit pricing of the new product will depend on two things: price range and price-volume relationship. The price range is determined by the indirect competition of substitutes, which set limits to the monopoly power of the new product (Dean, 1969). The price volume relationship is the most difficult to estimate in pricing. In general, the lower the price, the greater will be the volume of sales of the product.

For every new product, there are alternatives, and how the new product is differentiated from them will determine pricing. Determining the added performance will be crucial for the buyers' decisions to purchase the product and to estimate the superiority premium. The superiority premium is pricing the performance differential in terms of what the superior solution supplied by the new product is worth to buyers of various categories (Dean, 1969). Determining this premium is one of the most challenging problems of new product pricing.

Determining buyers' cost, competitors' cost, and producers' cost is essential in product pricing. Pricing structure is another important consideration. Major strategies are skimming pricing, which is launching the product with a high price to skim the top of the market willing to pay top price, then making successive price reductions to further skim the market. Penetration pricing is to enter with low pricing to achieve high volume.

New trends are emerging in production agriculture. More sophisticated consumers and processors have led to more customized and smaller "niche" markets that are tailored to consumers' and processors' needs. Many farmers view these more specialized markets as opportunities, since they often entail a cash incentive or premium that can boost farm income and improve market security (Swanson et al., 2001). The producers' goal to increase profits will be a key to encouraging adoption of new GM output-trait crops, which may further enhance these markets. Consumers' willingness to pay for value-enhanced crops will depend on the benefits they receive from them.

A recent study of value-enhanced corn and soybean production in Illinois (2001) identified recent developments and factors that Illinois producers should consider as they seek to capture more value from different types of value-enhanced crops. In the future, more farmers will likely produce crops embodying distinct traits that are demanded by end use markets, that is, becoming more in tune with what end-users and consumers say they want and need (Swanson et al., 2001). Farmers' income will increasingly depend on their ability to adapt to meet these changing needs. GM output-trait crops will help farmers satisfy the needs of end-users and capture added premiums.

The purpose of the Value Project was to identify effective ways for farmers to find, participate, and profit in these expanding markets. This involved many elements, including marketing opportunities, researching crops and expected profitability of these crops, and the decisions of farmers to grow these crops. Many of these elements may be useful in researching and decision making of producing new output-trait GM crops.

Grain handlers have aggressively been responding to the changes in the grain industry by implementing IP grain handling and testing procedures to avoid contamination. This has been an important factor for farmers considering raising value-enhanced crops. With the value-enhanced grain market growing, an increasing number of farmers were contracting to produce value-enhanced crops, such as high-oil corn or food-grade soybeans (Swanson et al., 2001). These producers tend to be full-time farmers with more land resources.

The value-enhanced corn and soybean production in Illinois (2001) focused on four value-enhanced varieties for corn including hard endosperm, waxy, high oil, and white food-grade corn, and three varieties of soybeans: STS, Tofu, and Natto. Results in these two crops show that for three of the four value-enhanced corn varieties, there was significant added value for both years, while high oil corn showed a loss for both years. The results for soybeans showed a similar mixed pattern, with STS and Tofu showing a loss and the Natto variety showing a gain in net profit (Swanson et al., 2001). The analysis was shown as additional net income per acre, in comparison with conventional varieties.

Profitability is a major concern for producers. Some value-enhanced crops, such as high-amylose corn, have a considerable "yield drag" and may not be as profitable as conventional corn, even with attractive premiums (Swanson et al., 2001). GM value-enhanced crops may not face this problem if they are "stacked" with traits that support good agronomic performance. Of Illinois farmers who responded to the survey, 64 percent indicated that growing a value-enhanced crop did increase their farm income, 30 percent said it had no effect, and 6 percent reported a decrease in income. For those producers who reported an increase, the average increase in net income per producer was 12.4 percent (Swanson et al., 2001).

The decision of whether to grow value-enhanced crops has been evaluated. The primary reason for not growing value-enhanced crops was lack of markets, followed by the uncertainty of how much money can be made growing these crops. The primary mechanism for enticing farmers into growing value-enhanced crops is a premium or some other economic incentive (Swanson et al., 2001). A substantial range of additional income was reported, as shown in Table 2.4. Value-enhanced crop production is most successful when there is a guaranteed market and attractive premiums (Swanson et al., 2001).

Contracts and other marketing alliances help to aid these guarantees. Production and marketing contracts govern 36 percent of the value of United States agricultural production, up from 12 percent in 1969 (MacDonald et al., 2004). Contracts are likely to govern a growing share of agricultural products over the next decade. First, demand for differentiated products to meet specific consumer preferences should continue to grow, and

Table 2.4. Farmers' Estimates of Additional Income Needed Per Acre to Grow a Value-enhanced Crop

Dollars per acre of increased income	Percent of farmers requiring this amount to switch
1-9	5
10-19	25
20-29	32
30-39	17
40-49	16
50 or more	5

Source: Swanson et al., (2001).

such products are generally under contract. Second, pressures will mount to ensure traceability of products for health and consumer concerns, and contracts provide one way to ensure traceability (MacDonald et al., 2004). Genetically modified output-trait crops will be greatly affected by contracts.

Farm products are becoming more differentiated and are often tailored to buyers' specific requirements in an effort to attract consumers through special product attributes. Contracts may more closely tie prices to commodity attributes, and hence reward producers who can deliver those attributes and penalize those who do not (MacDonald et al., 2004). Accurate pricing will stimulate production of crops that have product attributes that consumers and processors prefer.

Processors may want to use contracts for many reasons. Contracts will help firms procure crops with specific attributes by setting specific guidelines. Buyers are also increasingly interested in IP products. Contracts may reduce the costs associated with identity preservation. Contracting helps to facilitate coordination among stages of production and helps to speed technology adoption, improve information flows, manage quality, uniformity, and delivery (MacDonald et al., 2004). Contracts can also be used to regulate product flows to processing plants, allowing cost cutting measures. Food companies face increasing pressure to document where and how their products are produced and distributed through the food system. Contracts aid traceability and ensure quality characteristics (MacDonald et al., 2004).

Previous Studies

Jefferson-Moore, Traxler, and Kinnucan (2005) present an economic model of the supply and demand for the second wave of GM crops, output-trait or value-enhanced crops. The study uses a Muth type model to simulate benefit distribution under varying market structure and technological parameter assumptions (Jefferson-Moore, Traxler, and Kinnucan, 2005). Because no GM-VEC had yet attained a significant market presence when the study was underway, the model is illustrated using parameters from the market for high oil corn (HOC) in the United States (Jefferson-Moore, Traxler, and Kinnucan, 2005). The price premium is directly related to the amount of value added minus additional handling fees. Whether consumers will be willing to pay for the value-added commodity remains to be seen.

The study found that most GM-VECs must be sold into separated markets if a price premium is to be realized. The seed developer may also be involved in buying the VEC crops. Licensing and contractual agreements will likely play an important role in market development of value-enhanced products because they make it possible to guarantee supply to product end-users and to guarantee a market for producers (Jefferson-Moore, Traxler, and Kinnucan, 2005). The study uses an equilibrium displacement model (EDM) to examine the introduction of a VEC into a market in which previously only a conventional product was produced and marketed.

The EDM model is used to examine two issues: pure competition and monopoly power. Farmers choose to pay seed price plus a technology fee to receive higher revenues downstream. Under pure competition, as expected, a $20 technology fee reduces the quantity of seed demanded and of corn produced, while high oil corn prices rise slightly (Jefferson-Moore, Traxler, and Kinnucan, 2005). Under monopoly power conditions, as market power is imposed on the model, the quantity of high oil corn produced falls slightly. The high oil corn price at the elevator increases by $0.01, thus increasing producer premiums from $0.20 to $0.21 per bushel (Jefferson-Moore, Traxler, and Kinnucan, 2005).

The long-run welfare effect is examined under both market conditions. Under pure competition, the HOC seed industry surplus increases by $1.7 million due to the technology fee of $20. Corn consumers suffer a loss of $11.3 million. Substitution at the seed level causes the conventional corn seed sector to capture an additional $10.2 million. The total welfare loss from the technology fee is $10.3 million (Jefferson-Moore, Traxler, and Kinnucan, 2005). Under monopoly conditions, consumers experience a loss of $12.6 million, HOC seed producers and farmers lose, while conventional corn seed producers gain. The total net effect of monopoly power conditions is estimated to be a loss of $16.2 million (Jefferson-Moore, Traxler, and Kinnucan, 2005).

The study found that neither the existence of a technology fee nor the presence of market power has very significant market effects. Several major challenges face the GM-VEC industry. First, GM-VEC crops must offer large per acre profits compared to alternatives for producers to adopt. Risk adverse farmers adopt a new technology only if it is more profitable than existing technologies, and only if they receive a significant adoption premium (Jefferson-Moore, Traxler, and Kinnucan, 2005). Second, greater market coordination between seed developers, farmers and end-users will need to be developed for GM-VECs to be successful. Also, consumers must be willing to pay for the value-enhanced attribute.

Summary

Genetically modified value-enhanced crops hold great potential for the future of agriculture. A great deal of research is being put into the development of new GM value-enhanced crops as is evident from the large number of crops in the product pipeline. A few biotechnology companies have become clear leaders in a highly concentrated industry. Many more changes are sure to follow in the industry.

Many challenges remain before GM-VECs may be successful. Consumer acceptance and willingness to pay is essential for the success of the crops. Development of new markets remains a challenge. Small specialty markets will be utilized, and increased market coordination between seed developers, farmers, and end-users will be key to successfully developing a marketplace for GM value-enhanced crops. Increasing producer adoption remains important for GM-VECs success. Strong incentives and increased profit per acre are required to entice producers to adopt. Many challenges remain, but if successful, GM value-enhanced crops could change the way we look at production agriculture.

CHAPTER 3
THEORETICAL MODELS

Introduction

Technological innovations in ag-biotechnology have lead to research and advancements in theory of adoption, diffusion, intellectual property rights (IPR), and licensing. Licensing, IPR, and strategic interaction among firms has had effects on adoption and diffusion of superior innovations. Oligopolistic competition models are important to determine strategies to maximize profits of ag-biotechnology firms. Adoption of innovative products will also affect the equilibrium prices of other competing inputs, resulting in incomplete adoption.

This study will address issues associated with adoption and diffusion of a superior technology involving output traits in ag-biotechnology. Chapter 3 reviews the economic theories and develops the model for pricing the output trait as well as the effects on prices of competing technologies. The first section contains a review of theories of product differentiation, adoption and diffusion, and price impacts. The second section contains a detailed model for the problem. This model builds on the previous studies by Lemarie and Marette (2003) and Huso and Wilson (2006). The model differs as it is of processor traits and a new derivation of the model is applied to consumer traits, as opposed to a GM producer trait.

Adoption, Diffusion, and Price Impacts of GM Grains

Product Differentiation

Monopolistic competition is a common market structure with two important characteristics: there are many sellers and each has a differentiated product. The actions of an individual seller will not greatly affect the other sellers. Consumers will make their purchasing decision on the basis of quality factors rather than just price (Besanko et al., 2004).

Products can be differentiated in two ways, vertically and horizontally. A product is vertically differentiated when it is unambiguously better or worse than competing products (Besanko et al., 2004). Vertical differentiation enhances the attributes of the product, although consumers may differ about how much they are willing to pay for that enhancement. When a product is horizontally differentiated, only some consumers will prefer it to others. An important feature of horizontal differentiation is convenience, which allows firms to raise prices without losing many customers.

Output traits derived from ag-biotechnology contain attributes that characterize the grains as vertically differentiated from conventional or input trait varieties. These crops will contain quality attributes that will distinguish them from conventional varieties and make them more desirable to consumers and processors. Quality factors for output-trait GM crops may include increased processing efficiency for ethanol and bio-diesel, increased nutrition for consumers such as omega-3 and low saturated fat soybeans, and increased feed quality for feed grains. These quality factors for output trait GM crops can be viewed as beneficial to all processors and consumers and, therefore, can be considered vertically differentiated from conventional varieties. Further, these differ from producer traits that benefit growers.

Adoption and Diffusion of Genetically Modified Grains

Technological innovations have led to much of the economic growth that has taken place in developed countries. These innovations have been in the form of more efficient ways to produce existing products as well as completely new products (Lapan and

Moschini, 2000). The benefits gained from the new products have been shared between the discoverer of the product and the adopters and consumers. Many of the innovations have been a result of R&D efforts undertaken by the private sector that are protected by intellectual property rights, such as patents, or transferred to other adopters through licensing agreements.

For any benefit to be realized, the innovation must be adopted by firms. Adoption of an innovation requires a decision from the firm. A firm must first become aware of the new product. This is followed by interest in the product and gathering information about it. The firm will then evaluate the innovation based on its present situation, and possibly apply it on a trial basis. If all of the stages in the adoption process are successful, the firm or individual will adopt the innovative product on a full-scale basis.

The time path of adoption of new technologies can be affected for many reasons. Most recently, agriculture intellectual property rights and licensing has affected adoption rates. The observed phenomenon whereby new technologies are adopted slowly over time is known as diffusion (Lapan and Moschini, 2000). Heterogeneity among firms, such as size, availability of information, and expected profits, will influence adoption. Karshenas and Stoneman (1993) identified three different mechanisms from previous literature that influence adoption. These are rank effects, stock effects, and order effects.

The rank effects assume that differences in firms, such as size, will lead to different returns from technology. As costs of acquiring the new technology decrease over time, more firms will adopt. The stock effect assumes that the benefit to the marginal adopter decreases as the number of previous adopters increases. This is the result of production costs decreasing, leading to changes in industry output and prices. The order effects assume that the initial firms to adopt will have greater returns from adoption than the low-order adopters. At some point it will no longer be profitable to adopt, at which point adoption will cease.

A major assumption of most diffusion models is that, over time, the adoption of the superior technology occurs. In agriculture, this assumption is not necessarily true, as the innovation decreases the equilibrium prices of competing inputs. Conventional technologies will then be more profitable for some farmers than GM technology would be. In the case of output-trait consumer crops, consumer preferences for or against GM foods may have a dramatic effect on the level of adoption. Output-trait crops with specific processor benefits may have higher adoption rates, as consumer preferences will not be an issue for products such as bio-diesel.

Price Impacts of GM Adoption on Competing Inputs

Past innovations from ag-biotechnology have been widely adopted by farmers and have lead to significant economic gain. A portion of the economic gain from ag-biotechnology innovation is captured by biotechnology firms. The increase in farmers' surplus has been limited due to productivity increases from the innovation. This leads to higher output levels from the same acreage, resulting in decreased output prices. Due to the price decrease, a portion of the surplus that would be gained by farmers or biotechnology provider is passed on to downstream firms and consumers (Lemarie and Marette, 2003).

Adoption of GM crops not only affects output prices, but also on prices of competing inputs. Previous studies on producer traits have used different competing inputs to show price changes. Lapan and Moschini (2000) use land as the competing input, however, because the adjustment of land prices may be much slower relative to other input prices, it may not be the best explanation. Because of this, Lemarie and Marette (2003) and Huso and Wilson (2006) use competing conventional herbicides and insecticides for comparison. Because this model is applied to processor and consumer traits where the benefit of the trait will be realized by processors and consumers the competing technology in this study is the conventional variety of the GM output-trait crop.

There is much less information available about the effects of output traits on competing products. Processors who adopt output-trait technology will be able to increase output from the same production process. One would expect this higher output to result in decreasing output prices. As a consequence, the benefit from the innovation will not only be realized by the farmer, biotechnology provider, or processor, but some of the surplus may also be passed on to consumers.

Cournot Quantity Competition

In a market that is considered to be perfect or monopolistic competition, sellers do not believe their individual pricing or production decisions affect the overall market. If the pricing or production strategies of an individual firm are expected to materially affect the pricing or production level of the market, that market would be considered an oligopoly. Careful consideration of how firms respond to each other in the market is a central element of oligopoly models (Besanko et al., 2004).

Two of the most important oligopoly models are the Cournot model of quantity competition and Bertrand model of price competition. In Cournot's model, the goods are considered identical, so both firms charge the same price. The quantity each firm produces is the sole strategic choice of the individual firm. Each firm will choose its optimal level of production to maximize its profits given the level it expects its rival firm to choose. Each firm's optimal production level will be its "best response" to the level it expects its rival to produce (Besanko et al., 2004).

In Bertrand price competition, each firm will select a price to maximize its profits given what it expects the rival firm will select. Further, in the Bertrand model each firm views its rival's price as fixed, and its pricing practices will not affect the pricing of its rival. Rivalry between the two firms may be enough to achieve a competitive outcome. However, when products are differentiated, price competition is less intense (Besanko et al., 2004).

In markets where firms make upfront investments in plant and equipment or R&D, Bertrand competition can be unstable. As firms enter into price competition to gain market share, they may fail to cover long-run costs (Besanko et al., 2004). In markets where an innovative product is present and firms engage in Bertrand competition, then, given other input prices are constant, the equilibrium outcome will be characterized by the complete adoption of the superior innovation (Lapan and Moschini, 2000). However, due to the price competition of the competing input adoption of the superior, innovation may not be complete.

Model of Price Impacts

The introduction of specialty crops and traits, such as high-oil corn, may lead to premium prices for the specialty crop and increased surplus for conventional crops. The inclusion of technology fees may also affect output-trait demand and adoption. This section develops a model that illustrates the impacts of the GM trait introduction on the input prices for processors and consumers. Key variables and relationships used in the derivation are defined to determine the impact of different factors on the outcome. The theoretical model builds upon that of Lemarie and Marette (2003) and Huso and Wilson (2006), which is based on the vertical differentiation model of Mussa and Rosen (1978), as applied to input-traits. The equilibrium model for processor traits is very similar to these studies which were directed towards producer traits; however, the indirect utility is realized by processors. The model applied to consumer traits differs as the indirect utility functions do not require a processing input requirement.

The differentiated products envisioned here correspond to a GM processor (input) or consumer trait. Transactions between buyers and sellers occur in a single period, under perfect information. For processing bio-diesel, conventional canola or GM high-oil canola is used. For simplicity, it is assumed that only one process is used to produce bio-diesel, eliminating the possibility of more efficient processes. For consumer products, conventional soybeans or existing omega-3 products are compared with GM omega-3 soybeans. Only one product will be used to compare omega-3 soybeans, not allowing for combinations of products. A technology fee is assumed to be the instrument by which the biotechnology provider extracts a premium for the innovative product.

Alternative technology choices are indexed by i, with i=0 referring to the traditional processing input and i=1 referring to the processing input that is derived from GM technology. Technology choice i is supplied by n_i firm(s) which compete on quantity. The marginal production cost is c_i, and the input price is p_i. The costs of processing, using both conventional and GM varieties, are assumed to be the same ($c_0 = c_1$). This assumption aids in explicitly modeling innovations that take the form of vertically differentiated inputs (Huso and Wilson, 2006).

In the conventional case, the processor pays the market price of the conventional input (p_0). In the GM case, the processor pays the market price of the GM input (p_1) and the license fee (p_L) for the GM technology. The license fee is charged to farmers on a per acre basis, and processors will then only pay the market price of the GM crop. The license fee (p_L) is decided by the ag-biotechnology provider, which is assumed to have a monopoly position with respect to the particular GM trait due to patent protection. The use of the GM trait on one additional acre or additional unit of production leads to a profit increase of p_L for the biotechnology company (Huso & Wilson, 2006).

The processors' choice between the different inputs is made on a per unit basis. The technical efficiency for each processor or consumer product choice i is x_i, with $x_1 > x_0$. The processors or consumers are assumed heterogeneous where their willingness to pay is equal to θx_i, for technology choice i, and θ represents the processor or consumers idiosyncratic need for the GM variety. For simplicity, θ is assumed to be uniformly distributed between 0 and 1. Uniform distribution is used because it is continuous, and each outcome is equally likely. Processors or consumers with a high demand for GM technology (or low aversion) will choose a θ close to 1, whereas those with less demand for GM technology, or who are averse to GM technology, be represented by a θ close to 0.

Use of each technology choice i (at the required per unit input rate of each technology choice, a_i) results in the corresponding indirect utilities, u_i. The indirect utilities for a processor good are as follows:

(1)
$$\begin{cases} u_0 = \theta x_0 - a_0 p_0 \\ u_1 = \theta x_1 - a_1 p_1 - p_L \end{cases} .$$

The use of technology choice i for a consumer good will not require the per unit input rate for each technology choice, a_i. Therefore, the indirect utilities for consumer goods differ as shown

$$\begin{cases} u_0 = \theta x_0 - p_0 \\ u_1 = \theta x_1 - p_1 - p_L \end{cases} \quad (2)$$

For a given θ, the processor selects technology choice *i,* which provides the highest indirect utility when the value is greater than 0. If the indirect utility is 0, then no product is purchased, for the given level of θ. Processors or consumers will adopt the GM[1] technology when $u_1 > u_0$. The total number of units produced by processors is denoted by *N,* and is an indication of market size.

Previous studies have described the sequence of events for input-trait GM technology. The sequence of events for this study will be as follows: Period 1, the biotechnology provider determines the license price; Period 2, all sellers of conventional and GM sellers determine the quantities they produce (Cournot competition); and, Period 3, processors or consumers determine various quantities of these inputs to purchase.

Market Equilibrium with One Product: Conventional Inputs Only

The studies of Lemarie and Marette (2003) and Huso and Wilson (2006) first determine the market equilibrium with only conventional traits, followed by equilibrium with the introduction of GM technology to demonstrate the impact of the GM technology. This was done for a producer trait, in a market with only conventional inputs available. That model has been converted here to solve for the equilibrium for an output-trait technology.

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[1] Derivation of market equilibrium conditions is shown in detail in Appendix A. Computations were done using Mathcad 7.0 and Mathematica 3.0.

Without the introduction of output-trait technology, only conventional inputs are sold to processors and consumers. The model and results in the first section below are nearly identical to Huso and Wilson. They differ in that Huso and Wilson applied their model to producer traits and here the model is applied to processor traits. Nevertheless, the results are included for completeness and to contrast with the model below on consumer traits. When only technology choice 0 is available, a processor or consumer who is indifferent between buying the technology choice 0 and buying nothing is identified by the preference parameter $\hat{\theta}$. Because θ is uniformly distributed between 0 and 1, the total demand for the conventional processing input is

(3) $$Q_0 = Na_0(1-\hat{\theta}).$$

The preference parameter $\hat{\theta}$ can be determined by using the indirect utility function u_0, and assuming $u_0 = 0$:

(4) $$\hat{\theta} = \frac{a_0 p_0}{x_0}.$$

The detailed resolution of the Cournot-Nash equilibrium is in Appendix A. The equilibrium results are as follows:

(5) $$q_0^* = \frac{Na_0(x_0 - a_0 c_0)}{x_0(n_0 + 1)}.$$

(6) $$p_0^* = \frac{x_0 + a_0 c_0 n_0}{a_0(n_0 + 1)}.$$

(7) $$\pi_0^* = \frac{N}{x_0}\left[\frac{x_0 - a_0 c_0}{n_0 + 1}\right]^2.$$

Total processor or consumer surplus, s_0^*, is then:

$$s_0^* = N\int_{\hat{\theta}^*}^{1} u_0 \cdot d\theta = N\int_{\hat{\theta}^*}^{1} \theta x_0 - a_0\left(\frac{x_0 + n_0 a_0 c_0}{a_0(n_0+1)}\right) \text{ and} \tag{8}$$

Total sector welfare is defined as

$$W = n_0 \pi_0^* + s_0^* \cdot, \tag{9}$$

This represents the total profits of conventional firms plus surplus of conventional users.

Market Equilibrium with Two Products: Conventional and GM Processor Traits

The demand function for processors' inputs changes when processors are faced with two different, competing processing input options. The price that processors will pay for GM crop inputs is $p_1 + p_L$ and the price that will be paid for conventional inputs is p_0. $\widetilde{\theta}$ refers to a processor who is indifferent between technology choice 0 and 1. A processor with $\theta > \widetilde{\theta}$ will use technology choice 1, and a processor with θ such that $\hat{\theta} < \theta < \widetilde{\theta}$ will choose technology choice 0. Given θ is assumed $U[0, 1]$, the demand functions for technology choices 0 and 1 are:

$$Q_0 = Na_0(\widetilde{\theta} - \hat{\theta}) \text{ and} \tag{10}$$

$$Q_1 = Na_1(1 - \widetilde{\theta}). \tag{11}$$

Based on the condition $u_0 = u_1$, we find:

$$\widetilde{\theta} = \frac{a_1 p_1 + p_L - a_0 p_0}{x_1 - x_0}. \tag{12}$$

Detailed resolution of the two-product case is in Appendix A. The equilibrium results are as follows:

$$p_0^*(p_L) = -\frac{a_1 n_1 x_0 (c_1 + p_L) + x_0 x_1 + a_0 c_0 n_0 (-n_1 x_0 + x_1 + n_1 x_1)}{a_0 (n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1)} \text{ and} \tag{13}$$

$$(14)\ p_1^*(p_L) = \frac{-x_1(a_0c_0n_0 - n_0x_0 + x_1 + n_0x_1) + a_1((1+n_0)p_Lx_1 + c_1n_1(n_0x_0 - x_1 - n_0x_1))}{a_1(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)}$$

(15) $$\pi_0^*(p_L) = \frac{N(a_1n_1x_0(c_1 + p_L) + (-a_0c_0(1+n_1) + x_0)x_1)^2}{x_0(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)^2} \text{ and}$$

(16) $$\pi_1^*(p_L) = \frac{Nx_1(a_0c_0n_0 - a_1(1+n_0)(c_1 + p_L) - n_0x_0 + x_1 + n_0x_1)^2}{((1+n_1)x_1 + n_0(x_1 + n_1(-x_0 + x_1)))^2}$$

(17) $$p_L^* = \frac{a_0c_0n_0 - a_1c_1(n_0+1) - n_0x_0 + x_1 + n_0x_1}{2a_1(n_0+1)}$$

In the Huso and Wilson study, the technology fee, p_L^*, was charged to farmers on a per acre basis. It is not exactly clear how technology fees may be charged for output-traits. If the technology fee is charged to the processor or consumer, they will be charged p_L^*. If the technology fee is charged to farmers, this number (p_L^*) may be multiplied by the technology provider's expected yield per acre. The equations are similar to the Huso and Wilson study involving producer traits. However, in this case they are applied to processor traits.

The processors' surplus in the two product case is defined as:

(18) $$s_0^* = N\int_{\theta^*}^{\tilde{\theta}^*} u_0 d\theta \text{, and}$$

(19) $$s_1^* = N\int_{\tilde{\theta}^*}^{1} u_1 d\theta.$$

Sector welfare is then defined as:

(20) $$W = n_0\pi_0^* + (n_1 - 1)\pi_1^* + \pi_B^* + s_0^* + s_1^*$$

Market Equilibrium with Two Products: Conventional and GM Consumer Traits

When the crop is considered to have a consumer benefit rather than a processor benefit, such as omega-3 or low fat soybeans, there will not be a processing requirement, a_i, in the equations. This is detailed in the difference between Equation sets 1 and 2. Given θ is assumed $U[0,1]$, the demand functions for technology choices 0 and 1 are:

(21) $$Q_0 = N(\tilde{\theta} - \hat{\theta}) \text{ and}$$

(22) $$Q_1 = N(1 - \tilde{\theta}).$$

Based on the condition $u_0 = u_1$ we find:

(23) $$\tilde{\theta} = \frac{p_0 - p_1 - p_L}{x_0 - x_1}.$$

The demand functions for a given level of p_L for each of the two technology choices are then:

(24) $$Q_0 = N \cdot \left[\left(\frac{p_1 + p_L - p_0}{x_1 - x_0} \right) - \left(\frac{p_0}{x_0} \right) \right] \text{ and}$$

(25) $$Q_1 = N \cdot \left[1 - \left(\frac{p_1 + p_L - p_0}{x_1 - x_0} \right) \right].$$

The inverse demand functions can be found by simultaneously solving the demand functions for p_0 and p_1.

(26) $$\begin{cases} p_0(Q_0, Q_1) = -x_0 \left(\dfrac{Q_1 - N + Q_0}{N} \right) \\ p_1(Q_0, Q_1, p_L) = \dfrac{-(Q_0 x_0 + N p_L + Q_1 x_1 - N x_1)}{N} \end{cases}$$

The inverse demand functions show that the price of technology choice 0, p_0, and the price of technology choice 1, p_1, are a function of the demand for technology choice 0,

Q_0, the demand for technology choice 1, Q_1, and the license price for technology choice 1, p_L (Huso and Wilson, 2006). The license price, p_L, must be paid in addition to the equilibrium price of technology choice 1, p_1.

The firms choose quantity to maximize profit in the symmetric Cournot-Nash equilibrium. The first order conditions are

(27) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = x_0 \cdot \left(1 - \frac{q_0(n_0+1)}{N} - \frac{q_1 n_1}{N}\right) - c_0 = 0$$

(28) and $$\frac{\partial \pi_{0k}}{\partial q_{1k}} = x_1 - p_L - \left(\frac{n_0 q_0 x_0}{N}\right) - \left(\frac{q_1 x_1}{N}\right) - \left(\frac{n_1 q_1 x_1}{N}\right) - c_1 = 0$$

Simultaneously solving the first-order conditions for equilibrium quantities is then

(29) $$q_0^* = -\frac{N(c_1 n_1 x_0 + n_1 p_L x_0 - c_0 x_1 - c_0 n_1 x_1 + x_0 x_1)}{x_0(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)}, \text{ and}$$

(29) $$q_1^* = \frac{N(c_1 - c_0 n_0 + c_1 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1}{n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1}.$$

Recall, $Q_0^* = q_0^* n_0$ and $Q_1^* = q_1^* n_0$. Substituting Q_0^* and Q_1^* into the inverse demand function and solving for p_0^* and p_1^* gives

(30) $$p_0^* = -\frac{c_1 n_1 x_0 + x_0(n_1 p_L + x_1) + c_0 n_0(-n_1 x_0 + x_1 + n_1 x_1)}{n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1}, \text{ and}$$

(31) $$p_1^* = \frac{c_1 n_1(n_0(x_0 - x_1) - x_1) + x_1(-c_0 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1)}{n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1}.$$

The profit maximizing technology fee is:

(32) $$p_L^* = \frac{c_0 n_0 - c_1(1+n_0) - n_0 x_0 + x_1 + n_0 x_1}{2(1+n_0)}.$$

The technology fee, p_L^*, is a function of c, n_o, and x. As the difference in technical efficiency (x_0 and x_1) decreases, there will be increased competition between the two technology choices resulting in a decrease in p_L^*. As n_0 increases there will be increased competition resulting in a decrease in p_L^*.

Equilibrium prices and quantities are very similar to those in the two product processor case omitting the processing requirement variable. Equations 6 and 30 represent the equilibrium price for technology choice *0*, p_0^*, before and after the introduction of the new technology choice. Technical efficiencies and the number of firms producing each technology choice have the largest effect on p_0^*.

The equilibrium profits of the sellers of each technology choice are then:

(33) $$\pi_0^* = \frac{N(c_1 n_1 x_0 + n_1 p_L x_0 - c_0 x_1 - c_0 n_1 x_1 + x_0 x_1)^2}{x_0(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)^2}, \text{ and}$$

(34) $$\pi_B^* = \frac{N n_1 p_L (c_1 - c_0 n_0 + c_1 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1)}{n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1}.$$

Similar to the processor case, total consumer surplus is defined over the ranges of adoption for each technology choice:

(35) $$s_0^* = N \int_{\hat{\theta}^*}^{\tilde{\theta}^*} u_0 \, d\theta, \text{ and}$$

(36) $$s_1^* = N \int_{\tilde{\theta}^*}^{1} u_1 \, d\theta.$$

In this case, $u_0 = \theta x_0 - p_0^*$ and $u_1 = \theta x_1 - p_1^* - p_L^*$. Substituting the equilibrium prices in to the indirect utility functions and integrating, the consumers' surplus is given by the following expressions

(37) $$s_0^* = \frac{1}{2}\left(-\hat{\theta}^2 x_0 + \tilde{\theta}^2 x_0 - \left(\frac{2(\hat{\theta} - \tilde{\theta})(n_1(c_1 - c_0 n_0 + p_L)x_0 + (c_0 n_0(1+n_1) + x_0)x_1)}{n_0 n_1 x_0 - (1+n_0)(1+n_1)x_1} \right) \right)$$

(38)

$$s_1^* = \frac{1}{2}\left(x_1 - \tilde{\theta}^2 x_1 + \frac{2(-1+\tilde{\theta})((p_L + n_0(-c_0 + p_L + x_0 - x_1) - x_1)x_1 + c_1 n_1(n_0 x_0 - (1+n_0)x_1))}{n_0 n_1 x_0 - (1+n_0)(1+n_1)x_1} \right)$$

Sector welfare is then defined as $W = n_0\pi_0^* + n_1\pi_1^* + \pi_B^* + s_0^* + s_1^*$.

Summary

This chapter presents the economic theory that relates to the price impacts of releasing a new technology on competing inputs for processors and consumer goods. A detailed description of diffusion theory and a symmetric Cournot-Nash equilibrium is discussed to illustrate the impacts of the introduction of GM output-trait technology on competing inputs for processors and consumers. The distribution of surplus among processors, farmers, and biotechnology companies are also discussed.

Recent studies have examined the impact of the release of GM seed and the effect on competing technologies regarding input-traits for farmers. Lemarie and Marette (2003) and Huso and Wilson (2006) studied the impacts of GM seed on competing pesticide prices. Huso and Wilson (2006) expanded on the previous studies to show the effect when a complementary pesticide is not needed. However, little has been done to study the effect of the release of output-trait technology. The difference has been stated here to study the effect of processors and using GM technology in their processing or consumption inputs.

The results of this model show that for processor traits, the model is similar and sometimes identical to the models used in the previous studies. However, this study differs in that the model is applied to processor traits as opposed to producer traits. Further, the model for consumer traits is novel as it is a new and unique derivation.

CHAPTER 4
PRICE IMPACTS ON COMPETING TECHNOLOGIES

Introduction

This chapter outlines the empirical analysis from the theoretical model discussed in Chapter 3. A simulation model is developed and described to illustrate the possible effects from the introduction of a GM output-trait crops. Simulation models imitate real-life, but allow for the use of random variables when discrete values are not known. The analysis is focused on the potential impacts on conventional varieties for use in processing or consumer inputs once the GM variety is released. The potential rates of adoption of new technology, along with equilibrium technology fees, are also analyzed. Potential benefits and effects of surplus are an important factor in determining the impacts of the release of the new technology.

The analytical model is briefly described, including key steps and equations that are used. Simulation methods are described along with distribution estimation procedures. This is followed by variable definitions, data sources and values, and random variable distributions.

Model Description and Definition

The model is an extension of Lemarie and Marette's (2003) analytical model, which was expanded upon by Huso and Wilson (2006). Both studies focus on GM input-trait technology specifically analyzing the price impacts of conventional pesticides following the introduction of the GM trait. Lemarie and Marette (2003) focused on herbicide-tolerant (HT) soybeans and insect-resistant (IR) corn, while Huso and Wilson (2006) focused on Roundup Ready wheat (RRW) and GM fusarium resistant wheat (FRW).

The model can be applied to output-trait technology for processing or consumer uses. The potential release of high-oil canola for biodiesel production, high-fermentable corn (HFC) for ethanol production, and low-linolenic acid soybeans for consumer use are scenarios used to determine the impacts of conventional varieties of each crop following the release of the GM output-traits. The major players in the model are the growers of conventional crops, growers of GM output-trait crops, the ag-biotechnology firm (which in the base case is assumed to have a monopoly position with respect to the trait in question), and the processors and consumers who decide which processing and consumption inputs to purchase.

The sequence of events for the model is outlined by Lemarie and Marette (2003), and for this model are as follows. First, the ag-biotechnology determines the equilibrium license price (p_L) to charge the users or growers of the output-trait. Processors and consumers will then determine the quantities of the two technology choices to purchase (i.e., adoption) based on the license price and the market prices of each variety and use in their processing inputs or consumption choices (Cournot quantity competition). The growers of both conventional crops and GM output-trait crops then determine the quantities to produce.

The model begins as a model of conventional crop being available to processors and consumers. Without output-trait technology available in the first scenario, processors and consumers do not have the option to choose between the two technologies. This allows for a comparison between a market with only conventional technology and a market with conventional and GM output-trait technology available to decision makers.

The second scenario includes the availability of high-oil canola along with conventional canola available to biodiesel processors. Processors choose between purchasing conventional inputs and purchasing GM inputs with the possibility of a technology fee attached. The biotechnology provider receives profits from the technology fee associated with the GM product. The third scenario will be similar to the second but will include high-fermentable corn along with conventional corn available to ethanol processors. The fourth scenario will involve output-traits that are directed toward consumer goods. This will involve both conventional goods and goods including output-trait technology. The biotechnology provider will again gain profits from the technology fee associated with the GM product.

Key equations in the one product scenario are equations 4, 10, 12, 13, 15, and 16. The key equations in the conventional plus GM output-trait processor good are equations 19, 26, 27, 28, 29, 30, 31, 32, and 33. Finally, the equations used in the conventional plus GM output-trait consumer good are equations 34, 35, 36, 37, 38, 39, 40, 41, and 42.

Simulation Procedures

In situations where an analytic model exists, the mathematical equation(s) can be used to make decisions based on given values for certain inputs. The model will determine the value of important outputs. In situations where uncertainty exists, the analytic model becomes difficult to use and provide useful information. In these instances, a simulation model may be used and allows for the use of random variables when discrete values are unknown (Winston, 2001). Simulation can be used to apply sensitivities to key variables to help determine optimal operating conditions. Simulation models provide only an approximate answer to a problem where an analytic model does not exist; however, they provide an insightful outlook at a range of possible outcomes. Stochastic simulation is used because some of the variables are random and unknown.

Simulations are performed using *@Risk* (Palisade, 2000). Excel is used to develop the scenarios. *@Risk* is a spreadsheet add-on that contains functions that make it easier to generate observations from important random variables based on probability distributions. Distributions are determined using *Bestfit*, a distribution estimation procedure in *@Risk*. Ten thousand iterations are performed successively to adequately fill distributions and results are plausible.

Data Sources, Distributions, and Assumptions

Relationships between the variables in the model are described and displayed in Chapter 3. Data are used to represent ethanol production, biodiesel production, and expected Omega-3 soybean consumption. The variables used are described below:

$N =$ number of gallons processed or consumed in each scenario;

$n_0 =$ number of firms producing conventional processing or consumption inputs;

$n_1 =$ number of firms producing GM processing or consumption varieties;

$c_0 =$ marginal production cost of conventional variety;

$c_1 =$ marginal production cost of GM variety;

$x_0 =$ technical or production efficiency of the conventional variety;

$x_1 =$ technical or production efficiency of the GM variety;

$a_0 =$ required per gallon input requirement of conventional variety;

$a_1 =$ required per gallon input requirement of GM variety; and

$\theta =$ idiosyncratic GM variety need for each processor or consumer.

Data Sources

Table 4.1 provides a summary of the data sources used in this study. Table 4.2 provides a summary of the base case discrete parameter values. Table 4.3 summarizes the base case random variable distributions. Table 4.4 summarizes the base case assumptions.

Table 4.1. Data Sources

Model Component	Data Source
Biodiesel production in United States	Korves (2006)
Ethanol production in United States	Renewable Fuels Association (2006)
Conventional canola oil yield	Berglund (2006)
Conventional corn ethanol yield	Joos et al. (2006)
Conventional Omega-3 oil benefit	Fraley (2006)
High-oil canola yield benefit	M. Melani, personal comm., Oct. 19, 2006
High-fermentable corn yield benefit	Fraley (2006)
Omega-3 soybean yield benefit	Fraley (2006)

Table 4.2. Random Variable Distributions: Base Case

Variable	Distribution	Mean	Std. Dev.	(a_1,a_2)	(Min, Max)
Conventional canola oil yield	Logistic	41.13%	0.4558	NA	NA
Conventional corn starch yld.	Normal	66.57%	0.0321	NA	NA
Conventional Omega-3 performance	Normal	1	0.1	NA	NA
Oil increase GM canola	Uniform	NA	NA	NA	(0.03, 0.2)
Starch increase GM corn	Uniform	NA	NA	NA	(0.03,0.05)
Omega-3. Soybean performance	Uniform	NA	NA	NA	(0.18, 0.22)
Demand for GM	Uniform	NA	NA	NA	(0,1)

Table 4.3. Discrete Parameter Values: Base Case

Parameter	Base Case Value
U.S. Biodiesel Production	N=678 mgpy
U.S. Ethanol Production	N=4,049 mgpy
U.S. omega-3 soybean consumption	N=306 million bu.
Marginal production cost	$c_0 = c_1 = 0$
Required per unit use	$a_0 = 1,\ a_1 = 1{,}2$
Tech choice 0 firms	1,2
Tech choice 1 firms	1,2

Table 4.4. Base Case Assumptions

Variable/Parameter	Value	Logic
N	678 mgpy biodiesel 4,049 mgpy ethanol 306 million bu/yr	Total annual production in U.S.
n_0	1 or 2	Representing monopoly and competition among conventional pesticide firms
n_1	1 or 2	Same as above
c_0	0	Assumption for simplicity No marginal cost to produce
c_1	0	Assumed no additional cost to produce GM variety
x_0 (oil yield used as efficiency)	Mean=41.13% St. Dev.=0.4558	Reflective of 2005 ND canola variety trials
x_0 (starch yield used as efficiency)	Mean=66.57% St. Dev.=0.0321	Reflective of 2006 IA corn variety trials
x_0 (conventional O-3)	Mean=1 St. Dev.=0.1	ISU field trials across various regions
x_1 (yield of GM canola)	3-20% benefit over conventional yield	NDSU North Dakota field trials data
x_1 (yield of GM corn)	3-5% benefit over conventional yield	Monsanto field trials across various regions
x_1 (Omega-3 performance improvement)	18-22% benefit over conventional O-3	Monsanto field trails across various regions
a_0	1	Assumption for simplicity
a_1	1 or 2	Same as above, 2 to show increased capacity from GM
θ	U[0,1]	Processors/Cons. With low willingness to pay(WTP) for GM 0, high WTP for GM 1.

In the base case, total units processed or consumed in each scenario, number of firms selling conventional inputs or GM inputs, the marginal cost of production for conventional or GM crops, and the per unit processed input requirement are assigned rather than simulated. Two firms represent competition in the conventional and GM market. There are more than two sellers of conventional technology, but for simplicity and purposed of comparison, it is assumed two firms make up a competitive market. All other variables are assumed *ceteris paribus*. Demand for ethanol, biodiesel, and healthier foods is rapidly expanding but in this model we assume demand is constant. The assumptions do not provide exact representative values of variables and parameters. The percentage changes in the key variables are the key results.

Summary

This chapter provides a detailed description of the analysis that is used to measure the effects on prices of conventional technology. Simulation models are used to imitate real-life situations for variables where uncertainty exists. Data sources, distributions, and assumption of the model are outlined in this chapter. Chapter 5 provides results and sensitivities based on the assumptions outlined in this chapter.

CHAPTER 5
PRICE IMPACT MODEL RESULTS

Introduction

The focus of this analysis is pricing GM output-trait varieties in a market where previously only conventional varieties existed. The potential release of GM output-trait crops causes processors and consumers to make strategic decisions as to which technology choice to purchase. Processors and consumers with the highest willingness-to-pay for GM technology will benefit once it is released. Increased competition between conventional and GM technologies may lower the price of the GM technology, benefiting the processors and consumers who adopt the new technology with the lower price. Increases in the marginal cost of each technology, may result in an increase in prices, leading to less adoption of the GM technology. A decrease in the price of conventional technology benefits processors and consumers who continue to adopt and those that move to conventional technology.

In the market where both technology choices exist, the seed or biotech firm initially sets the license price charged to the processor or consumer. It is not exactly clear how technology fees for output-traits will be charged, so in this analysis it is assumed that the processor or consumer will pay the fee on a per unit processed/consumed basis. Once the license fee is determined, the processors will make production and input purchasing decisions (i.e., adoption decisions) based on the license fee cost and expected price of each technology. Farmers will then make production decisions based on expected prices and contracts offered to them by the processor.

The amount farmers receive from the processor or consumer is identified by p_0, the price of the conventional variety. The price of the GM variety received by farmers is p_1.

Processors who adopt the conventional variety will pay only p_0 (\$/lb), while processors who adopt the GM variety will pay p_1 (\$/lb) plus a royalty based on the amount of the product produces, p_L (\$/gallon processed). Adoption levels are expressed as percentages of the total possible market. When more than one firm has similar output-trait technology, it is assumed this increases the competition (n_i=2), and more of the GM or conventional variety will be available.

This chapter discusses the results of the empirical analysis using the theoretical model developed in Chapters 3 and 4. The base case results for each scenario are presented and described in the next section. The market with only conventional products is presented, followed by the market with both conventional and GM products. Two scenarios are shown involving processor-preferred traits, followed by one involving a consumer trait. The difference in the two scenarios is the per unit processed input requirement, a_i, for processor goods. This variable is omitted in the consumer good analysis. Sensitivities on key variables are displayed to show the effect of these variables. The chapter concludes with a section displaying variations of surplus as a result of the price changes.

Results

This section presents the results of the price impact model. Each scenario is presented beginning with the base case and ending with sensitivities. The results after the introduction of GM technology are compared to the market with only conventional technology. Processors are modeled to estimate their optimal adoption rates, surplus, and prices they are willing to pay. The base case provides results for comparison for the changes in parameters in each scenario. Three scenarios are presented, including high-oil canola, high-fermentable corn, and omega-3 soybeans, and background on these traits was contained in Chapter 2.

Market with Conventional and High-oil Canola

In a market without output-trait canola, farmers decide quantity to produce, which, along with demand forces, determines price. Canola is an oilseed in which oil and by-products are produced. With the advent of biodiesel, there is and increased effort to increase the oil content. This scenario analyzes the pricing of this trait. The conventional market is illustrated with one conventional canola producing firm (simulation 1) and with two conventional canola producing firms (simulation 2; Table 5.1) to show the effect of increased competition. In all simulations for biodiesel, the model was parameterized to reflect total number of gallons processed in the United States, which currently is around 678 million gallons per year and is expected to increase in the coming years. All results for profits and surplus are expressed in millions of dollars. Standard deviations of results are in Appendix B.

Table 5.1. Price Impact Model Results: Conventional and High-oil Canola

			p_0	p_1	p_L	Conv	GM	π_0	π_1	π_B	s_0	s_1	W
Sim.	Structure		---$ lb---		$/gal	Adopt	Adopt	------------ $ million ------------					
#1	$n_0 = 1$	$n_1 = 0$	0.10			50%		70			35		105
#2	$n_0 = 2$	$n_1 = 0$	0.07			67%		31			62		124
#3	$n_0 = 1$	$n_1 = 1$	0.09	0.08	0.13	41%	18%	47	10	15	71	25	158
#4	$n_0 = 2$	$n_1 = 1$	0.06	0.07	0.09	57%	14%	23	6	9	68	26	148

In simulation 1, it is assumed that one firm produces all canola used for biodiesel. All processors who are indifferent between buying conventional canola and buying nothing are denoted by $\hat{\theta}$; therefore, processors whose need is greater than $\hat{\theta}$ determine the demand for conventional canola. The demand for conventional canola is 50 percent (1-0.5) of total biodiesel production. In simulation 2, two firms compete on the production of conventional canola. This competition leads to a decrease in price of conventional canola, p_0, from \$0.10 in simulation 1 to \$0.07 in simulation 2. The decrease in price leads to an increase in processors purchasing conventional canola. The demand is now 67 percent (1-0.33) of total biodiesel production. Individual firm profit, π_0, in simulation 1 is \$69.7 million and \$31 million in simulation 2 (simulation 2 includes two firms, so total firms profit is \$62 million). Total processor surplus, s_0, is \$34.86 million in simulation 1 and 61.97 million in simulation 2. Total sector welfare is \$105 million in simulation 1 and \$124 million in simulation 2.

Release of a GM high-oil canola variety is assumed to be by one firm ($n_1 = 1$) that has a monopoly position with respect to the trait, and only one firm will provide the technology. In simulation 3 and 4, processors choose between conventional and GM high-oil variety. In this scenario, the production efficiency of high-oil canola is analogous to the increased oil output from the high-oil variety. Expectations are for a 3-20 percent increase in oil output from the conventional variety. Sensitivities were conducted on the production efficiency of the high-oil variety.

Simulations 3 and 4 illustrate the market equilibrium with two products: GM and conventional. It is not clear how output trait products will be priced. Here it is assumed they are priced as a fixed payment, plus a technology fee that varies with the amount of output produced, in this case \$/gallon. The total price of the GM output-trait product is p_1 (\$/lb.) plus p_L (license fee, \$/gal.), and p_0 is the price of the conventional processing input. Processors with the highest θ value or those with $\widetilde{\theta} < \theta < 1$ will adopt the GM output-trait input. Processors with a θ such that $\hat{\theta} < \theta < \tilde{\theta}$ will adopt conventional technology. Processors who decide to use neither technology choice have a θ such that $0 < \theta < \hat{\theta}$. In simulation 3, high-oil canola is adopted by 18 percent of processors. The conventional processing input is adopted by 41 percent of all processors, and 41 percent choose to adopt neither high-oil nor conventional canola. Those who adopt neither are choosing not to enter the market. In simulation 4, high-oil canola has a 14 percent adoption rate, 57 percent choose conventional adoption, and 29 percent adopt nothing.

Comparison of simulations 1 and 3 are used to evaluate the impact of the introduction of the new technology. The agbiotechnology firm sets a license price, p_L, of \$0.13/gal. for high-oil canola. The availability of the high-oil technology results in a price decrease from \$0.10/lb. to \$0.09/lb. for the conventional canola, p_0, a decrease of 10 percent, likely due to increased competition and lower prices. A large portion of the payoffs to conventional growers transfers to GM growers and the biotechnology provider. In simulation 1 to 3, conventional growers' profits decrease from \$69.7 million to \$47 million, a decrease of 33 percent. Profits for growers of high-oil canola are \$9.8 million, and profits for the biotechnology provider are \$15.2 million. Both processors who continue to use conventional technology and those that adopt GM technology gain surplus when the output-trait technology is introduced. From simulation 1 to 3, surplus for processors who use conventional canola increase from \$34.86 million to \$70.77 million. Introduction of high-oil canola result in a surplus of \$25.2 million for those who adopt GM technology. Total processor surplus increase due to more technology choices and lower prices. Total sector welfare increases from \$105 million to \$158 million, from simulations 1 to 3.

When comparing simulations 2 and 4 (when $n_0 = 2$), the agbiotechnology firm sets a lower license price, p_L, of $0.09/gal. to be competitive in the more competitive market. Due to the introduction of high-oil canola, conventional canola prices, p_0, decrease 14 percent, from $0.07/lb. to $0.06/lb. From simulations 2 to 4, conventional farmer profits decrease from $31 million to $22.8 million. Profits for growers of high-oil canola are $6.4 million, and profits for the biotechnology provider are $8.9 million. Processor surplus increases from $61.97 million to $68.3 million for those who use conventional canola, and surplus to those who adopt GM technology is $25.9 million. Total sector welfare increased from $124 million to $148 million. It is noted that there is a decrease in welfare comparing simulation 3 and 4. This is likely due to the decrease in profits of both conventional and GM growers.

Sensitivities are performed on key variables that are defined in the base case to illustrate the effects of these changes. Theses variables are important in determining likely results. If these variables are changed, the results would be affected. Interpreting these effects is important in determining the likely market outcomes. Sensitivities are conducted on key variables in the high-oil canola and high-fermentable corn scenarios. Results of sensitivities are given along with references to figures located in Appendix B.

Number of High-oil Canola Firms

In the base case, it was assumed that one seed or biotechnology firm holds the rights to all high-oil canola production. This is because of patent protection and patent holders' rights to protect their property rights. In the base case, the patent allows monopoly pricing of the trait. Patents offer protection for a number of years, after which other participants may enter the market. More than one firm may also provide traits with similar benefits to other output-traits. The number of seed/trait firms increased from 1 to 6, and results are shown in Appendix B (Figures 1 through 4).

As the number of firms increases, the price of high-oil canola decreases from \$0.065/lb to under \$0.03/lb. The price of conventional canola also decreases by less than \$0.01/lb. The adoption levels of GM canola increase by over 20 percent while the adoption level of conventional decreases by around 10 percent. The surplus of processors who adopt GM increases, and welfare is a net gain, but surplus to processors who adopt the conventional trait declines. While the profits to growers of both conventional and GM canola decline, the biotechnology firm profits increase greatly.

Production Efficiency of High-oil Canola

In the base case, it is assumed that high-oil canola has a per hundred weight (cwt.) increase in oil output of 3-20 percent higher than conventional lines. These expectations are based on early trials of high-oil varieties, and actual production efficiency may be far different from expectations. Biotechnology firms have worked to achieve desired levels of benefit gained based on today's expectations and technology. As technology and methods of extracting oil from canola improve, the value of it is expected to change.

The percent of benefit gain over the conventional variety was increased from 10 percent to 90 percent. As the production efficiency increases, the technology fee and the price of GM canola increase while conventional variety remains relatively flat. GM adoption increases, and conventional adoption decreases. The surplus of GM processors increases; the surplus of conventional processors decreases slightly; and welfare is a net increase. Profits of GM growers and the biotechnology firm increase by \$15 million and \$25 million, respectively. Results are illustrated in Figures 5-8 of Appendix B.

Marginal Cost of GM Production

In the base case, it is assumed that the marginal cost of producing both conventional and output-trait canola is equal and set at 0. In this analysis, it is also assumed that processors or consumers will pay the technology fee to biotech firms, as they will realize the benefit from the output-trait. Traditionally, technology fees have been charged to growers, but it is unknown how technology fees will be charged for output-traits. If the technology fee is charged to growers, the marginal cost of growing the GM variety will increase.

As the marginal cost of production increases, the price of GM and conventional canola increases. The increased cost of producing the GM variety forces biotechnology firms to lower their technology fee. Adoption level of GM increases, while conventional decreases. Profits received by conventional growers' increases, but profits received by growers of high-oil canola and the biotechnology firm reach negative levels. The level of surplus that goes to processors who adopt conventional decreases; processors who adopt GM have a decline. Overall sector welfare is a net loss. Results are illustrated in Figures 9-12 in Appendix B.

Market with Conventional and High-fermentable Corn

The ethanol market has been rapidly expanding over the past few years. This has led seed and biotech companies to develop varieties to aid in the production of ethanol. High-fermentable corn varieties yield a higher output of ethanol per bushel of corn (3-5 percent). Production efficiency of high-fermentable corn is assumed to be the potential ethanol benefit of GM over conventional varieties. The process used to compare the effects of the introduction of GM high-fermentable corn into a market where previously only conventional corn existed is the same as the process used for high-oil canola. Simulations 1b and 2b correspond to a market with only conventional corn, and simulations 5 and 6 correspond to a market with both conventional and GM corn available to processors. In all simulations for ethanol, the total number of gallons produced in the United States is 4,051 million gallons per year. All figures are in millions of dollars. Simulations 1b and 2b are shown alongside simulations 5 and 6 to illustrate key changes after the introduction of the GM variety (Table 5.2). Standard deviations of results are in Appendix B.

Table 5.2. Price Impact Model Results: Conventional and High-fermentable Corn

			p_0	p_1	p_L	Conv	GM	π_0	π_1	π_B	s_0	s_1	W
Sim.	Structure		----$ lb-----		$/gal.	Adopt	Adopt	------------ $ million --------------					
#1b	$n_0 = 1$	$n_1 = 0$	0.33			50%		749			375		1124
#2b	$n_0 = 2$	$n_1 = 0$	0.22			67%		333			666		1332
#5	$n_0 = 1$	$n_1 = 1$	0.28	0.12	0.18	41%	17%	515	91	138	772	258	1683
#6	$n_0 = 2$	$n_1 = 1$	0.19	0.09	0.12	58%	13%	251	54	74	752	256	1584

Simulations 1b and 2b represent the initial corn market used for ethanol production where only conventional corn is available. In this market, processors pay $0.33/lb for corn used in ethanol production, and the adoption rate is 50 percent of the total possible market. When there is increased competition ($n_0 = 2$) introduced into the market, the price of corn is reduced to $0.22/lb and adoption increases to 67 percent. These simulations are used to compare with the results after the GM trait is released.

Comparing simulations 1b and 5, the introduction of GM corn results in a 15 percent decrease in p_0 from $0.33/lb to $0.28/lb. The agbiotechnology firm sets a price of $0.18/gal. Given this price, 17 percent of ethanol processors with the highest willingness to pay for the GM variety (or, highest θ) adopt the GM variety. Processors who adopt conventional technology (such that $\hat{\theta} < \theta < \tilde{\theta}$) represent 41 percent of the total possible market, and 42 percent adopt neither technology choice. Similar to the canola case, much of the payoffs to growers of corn for ethanol shift from conventional growers and the biotechnology provider. From simulations 1b to 5, conventional grower profits decrease from $749 million to $515 million. Profits to growers of the GM variety are $91 million, and the biotechnology provider receives $138 million from technology fees. Again, both ethanol processors who use conventional technology and those who use GM technology gain surplus from more choices being available. Surplus to users of conventional technology rise from $375 million to $772 million as a direct result of lower prices, and surplus to those who adopt high-fermentable corn is $258 million. Total sector welfare rises by 49 percent due to more choices being available and lower price of conventional varieties.

Comparing simulations 2b and 6 (when $n_0 = 2$), the agbiotechnology firm sets a lower technology fee of $0.12/gal in the more competitive market. The conventional corn price, p_0, decreases by 14 percent from $0.22/lb to $0.19/lb. Again, processors benefit from more choices being available. Payoffs again shift from growers of conventional varieties to GM growers and biotechnology firms. Profits to conventional growers decrease from $333 million to $251 million. Growers of GM corn receive $54.4 million and the biotechnology firm receives $74 million. Once again, surplus is a net gain for all processors. Processors who adopt conventional technology gain surplus from $666 million to $752 million, and processors who adopt GM corn have surplus of $256 million. Total sector welfare has a net gain of 19 percent. It is noted that there is a decrease in welfare comparing simulation 5 and 6. This is likely due to the decrease in profits of both conventional and GM growers.

Sensitivities are performed on the market with Conventional and GM high-fermentable corn. Assumptions made are the same as the high-oil canola market. These results are described below and shown in Appendix B (Figures 13 through 24).

Number of High Ethanol Corn Firms

As the number of GM corn firms increases due to patent expiration or similar technology, the price of both technology choices will decrease by $0.05/lb. Adoption levels of GM technology is expected to increase, and conventional adoption is expected to decrease. Profits to growers of both technology choices are expected to decrease; biotechnology firm profits are expected to increase slightly. Surplus received by processors who adopt GM corn increases, conventional processors lose surplus, and welfare remains virtually constant. Results are illustrated in Figures 13-16 in Appendix B.

Production Efficiency of GM Corn

To show the effects of sensitivities of the production efficiency of GM corn, the level of production efficiency is increased from 1 percent to 10 percent gain over conventional varieties. The effects are much less dramatic than the high-oil canola market because the current rate of increase in corn is much less than that of canola. Prices of conventional, GM, and the technology fee for corn increase only slightly. Adoption levels of both conventional and GM varieties remain mostly constant. Again, profits received by all players, surplus gained by all processors, and total sector welfare remains virtually constant. Results are illustrated in Figures 17-20 in Appendix B.

Marginal Cost of GM Corn

To show the effects of sensitivities on the marginal cost of producing the GM variety, the marginal cost is increased from $1 to $6. As the marginal cost increases, the price of GM corn increases dramatically by over $0.10. The technology fee decreases dramatically, while price of conventional corn increases slightly. The adoption level of GM corn decreases, likely due to the higher prices, while conventional adoption increases. Profits received by growers of GM corn and the biotechnology firm decrease to near negative levels. Profits received by conventional growers' increases by over $50 million. Surplus received by adopters of conventional increases, while surplus for adopters of GM decreases. Overall sector welfare has a slight net gain. Results are illustrated in Figures 21-24 in Appendix B.

Conventional and Omega-3 Soybeans

Products rich in omega-3 have been shown to provide numerous health benefits. Soybeans with high levels of omega-3 can be used as functional foods and provide a direct benefit to consumers. Omega-3 soybean oil is much healthier than conventional soybean oil due to the stearidonic acid (SDA) content of the omega-3 oil. GM omega-3 has been shown to provide superior stability to fish oil, the current leading source of omega-3, and provides a superior taste rating (Monsanto, 2006). These characteristics provide consumer health benefits over conventional technologies. Because consumer traits are assumed to go directly to the consumer and will not undergo processing steps, the processing requirement variable (a_i) is not needed for a consumer trait and has been omitted from the analysis.

Production efficiency of GM omega-3 soybeans is assumed to be the potential omega-3 benefit of GM over conventional sources such as fish oil. Early tests show and 18-20% increase in quality and performance over conventional sources of omega-3 (Monsanto, 2006). Much less is known about the possibilities of benefits from GM omega-3, as well as the possible market size, because many of the products are still in the early stages of development. Monsanto (2005) has early trial data on possible benefits and expectations of potential acres that will be grown. This data will be used to estimate the effects of the introduction of the GM variety.

Omega-3 from conventional sources is assumed to be from fish oil or flax oil, while GM omega-3 is derived from the GM output trait in soybeans. Simulations 1c and 2c correspond to a market with only conventional sources of omega-3 available to consumers, and simulations 7 and 8 correspond to a market with both conventional omega-3 and omega-3 derived from GM soybeans. Simulations 1c and 2c are shown alongside simulations 7 and 8 to illustrate the market before and after the introduction of the GM variety (Table 5.3). Standard deviations of results are in Appendix B.

Table 5.3. Price Impact Model Results: Conventional and Omega-3 Soybeans

			p_0	p_1	p_L	Conv	GM	π_0	π_1	π_B	s_0	s_1	W
Sim.	Structure		------$ lb------			Adopt	Adopt	------------- $ million					---------------
#1c	$n_0 = 1$	$n_1 = 0$	0.50			50%		77			38		115
#2c	$n_0 = 2$	$n_1 = 0$	0.33			67%		34			68		136
#7	$n_0 = 1$	$n_1 = 1$	0.41	0.22	0.35	41%	18.4%	51	12.5	20	76	49	196
#8	$n_0 = 2$	$n_1 = 1$	0.28	0.19	0.27	56%	15.4%	24	8.7	13	73	43.5	178

Simulations 1c and 2c represent a market where only conventional sources of omega-3 are available to consumers. In this market, consumers pay \$0.50/unit for omega-3 and the adoption rate is 50% of the total possible market. When there is increased competition (2c), the price of omega-3 is reduced to \$0.33/unit and adoption increases to 67% likely due to lower prices. These simulations are used to compare with the results after the GM trait is released.

Comparing simulations 1c and 7, the introduction of GM leads to an 18 percent decrease in p_0, the conventional form of omega-3, from \$0.50/unit to \$0.41/unit. The biotechnology firm sets a license price of \$0.35. It is not clear how GM traits will be priced to consumers. Here it is assumed to be a premium paid for the GM source. From this price, 18.4 percent of consumers are expected to adopt the GM variety, 41 percent adopt conventional, and 41 percent choose neither form of omega-3. Profits of conventional sources decrease from \$77 million in simulation 1c to \$50.9 million in simulation 7. Profits to growers of GM omega-3 soybeans are \$12.5 million, and \$19.7 million in profits goes to the biotechnology firm. Consumers of conventional omega-3 gain \$38.12 million in surplus, and consumers of GM omega-3 have \$48.95 million in surplus. Total sector welfare has a net gain of 71 percent.

Comparing simulations 2c and 8 (when $n_0 = 2$), the conventional omega-3 price declines by 15 percent from \$0.33/unit to \$0.28/unit after the introduction of the GM variety. The biotechnology firm now sets a license price of \$0.27. GM adoption is 15.4 percent; conventional adoption is 56 percent; 29 percent adopt nothing. Profits to suppliers of the conventional source decrease from \$34 million to \$24.3 million. The surplus increases by $5 million for consumers who adopt conventional omega-3. Adopters of GM omega-3 receive $43.45 million in surplus. Total market welfare increases from $136 million to $177.7 million. It is noted that there is a decrease in welfare comparing simulation 7 and 8. This is likely due to the decrease in profits of both conventional and GM growers.

Sensitivities were also performed on the Omega-3 markets to show the effect of certain variables. Assumptions made are the same as the high-oil canola and high-ethanol corn markets. These results are described below and shown in Appendix B (Figures 25 through 32).

Number of Omega-3 Soybean Firms

As competition increases in the omega-3 market due to patent expiration or other firms entering the market with similar technology, the price of GM omega-3 and conventional sources is expected to decrease. Adoption levels of GM technology is expected to increase, and conventional adoption is expected to decrease. Profits to suppliers of both technology choices are expected to decrease; biotechnology firm profits are expected to increase slightly. Surplus received by consumers who adopt GM omega-3 increases, conventional processors lose surplus, and welfare remains virtually constant. Results are illustrated in Figures 25-28 in Appendix B.

Production Efficiency of Omega-3 Soybeans

In the base case, it is assumed that GM omega-3 soybeans has an 18-20% increase in quality and performance over conventional sources of omega-3. The percent of benefit gain was increased from 10 percent to 90 percent over conventional sources. As the production efficiency increases, the technology fee and the price of GM omega-3 increases while conventional remains relatively flat. GM adoption increases and conventional adoption decreases. Surplus of GM processors increases, surplus of conventional processors decreases slightly, and welfare is a net increase. Results are illustrated in Figures 29-32 in Appendix B.

Variations of Surplus

The variation of surplus measure was used by Lemarie and Marette (2003) and Huso and Wilson (2006) to analyze the distribution of surplus with the introduction of a new GM trait. This measure shows that because of the expected price decrease of the conventional technology, after the introduction of the GM variety, adopters of GM are not the only players to benefit. Processors whose willingness-to-pay did not previously allow them to adopt any technology choice and now adopt conventional have an increase in surplus. Also, processors who adopt the conventional variety in both scenarios benefit from the price decrease of the conventional technology. Finally, processors with the highest willingness-to-pay will adopt GM and will experience an increase in surplus from the new variety being available to them. The analysis is used to compare processor surplus as the market shifts from a conventional only market to a market with both conventional and GM output-trait products. Results are shown in Tables 5.4, 5.5, and 5.6.

Table 5.4. Canola Biodiesel Variations of Surplus ($ million)

Initial Sim.	***Final Sim.***	$\Delta S_{\phi\to 0}$	$\Delta S_{0\to 0}$	$\Delta S_{0\to 1}$	ΔS	$n_0 * \Delta\pi_0$	$\Delta\pi_1 + \Delta\pi_B$	ΔW
#1	#3	48.32	3.37	4.86	56.55	-22.54	25.0	59
#2	#4	23.11	3.48	2.17	28.76	-16.44	15.31	27.6

Table 5.5. High-fermentable Corn Variations of Surplus ($ million)

Initial Sim.	*Final Sim.*	$\Delta S_{\phi\to 0}$	$\Delta S_{0\to 0}$	$\Delta S_{0\to 1}$	ΔS	$n_0 * \Delta\pi_0$	$\Delta\pi_1 + \Delta\pi_B$	ΔW
#1b	#5	524.6	80.2	46.4	651.2	-234.13	229.25	646.34
#2b	#6	253.8	70.5	18.6	342.9	-82.13	128.24	388.98

Table 5.6. Omega-3 Soybean Variations of Surplus ($ million)

Initial Sim.	*Final Sim.*	$\Delta S_{\phi\to 0}$	$\Delta S_{0\to 0}$	$\Delta S_{0\to 1}$	ΔS	$n_0 * \Delta\pi_0$	$\Delta\pi_1 + \Delta\pi_B$	ΔW
#1c	#7	52.3	8.91	25.96	87.14	-25.59	32.19	93.74
#2c	#8	24.7	8.01	15.69	48.41	-9.66	21.24	59.99

The variation of surplus measure is used to measure the surplus for a particular group of processors who change their processing input choices after the GM technology is available. For example, from simulations 1 to 3, $\Delta S_{\phi\to 0}$ represents the surplus to those processors who adopt no technology choice in simulation 1 and adopt conventional in simulation 3. In simulation 1, 50 percent adopt no processing input, and 50 percent adopt conventional canola. In simulation 3, 41 percent adopt no technology choice, 41 percent adopt conventional, and 18 percent adopt GM high-oil canola for processing biodiesel. This implies 9 percent (0.5-0.41) move from nothing to conventional canola. The surplus received by those 9 percent is $48.32 million.

Processors adopt conventional canola in both simulations 1 and 3. The increase in surplus ($\Delta S_{0\to 0}$) to these processors is a direct result of the price decrease of the conventional canola. In simulation 1, 50 percent adopt conventional canola. In simulation 3, 41 percent adopt conventional canola and 18 percent adopt GM. This leaves 32 percent purchasing conventional canola in both scenarios. The surplus gained by these processors is \$3.37 million.

Processors with the highest willingness-to-pay for GM canola will adopt GM; this makes up 18 percent of the processors in simulation 3. The change in surplus to those 18 percent is the difference between the surplus they receive when only conventional canola is available and the added surplus they receive when GM canola is available to them. Surplus to these processors ($\Delta S_{0\to 1}$) increases by \$4.86 million.

Changes in adoption levels of processors and changes of prices of conventional canola lead to changes in profits to firms who produce each technology. The profits of conventional firms decrease by \$22.54 million due to the price decrease of conventional canola. This decrease in profits is offset by the increase of \$25 million in profits received by producers of GM canola and the biotechnology firm. Overall change in sector welfare is an increase of \$59 million. Interpretation of the remaining simulations in Tables 5.4, 5.5, and 5.6 are identical to the description given above.

Summary

The model is used to show the effects of the introduction of a new technology in a market where previously only conventional technology existed. Technology fees are charged as a way for the biotechnology firm to capture profits. The biotech firm sets the technology fee and, based on this, processors will decide how much to purchase, and farmers will choose how much to grow. In the case of input-traits, the benefit of the trait goes directly to the farmer, and they are charged technology fees on a per acre basis. In this case, because the benefit of output-traits is primarily received by processors or consumers, it is assumed that the processor or consumer will pay the tech fee on a per pound or per bushel basis.

Many issues are involved in the decisions of processors and biotechnology firms when a GM output-trait is made available in a market where only conventional was previously available. Adoption of GM varieties ranges from 13 percent to 18.5 percent. Depending on the situation, conventional adoption decreases by about 10 percent in each scenario after the GM trait is released. In each scenario, the price of the conventional canola decreases by 10 percent to 18 percent, depending on the market competition and the level of benefit gained by the GM product.

The base case made strict assumptions about the level of competition, the marginal cost of the technology choices, and the production efficiency of the GM variety. Sensitivities performed on these variables show their effect on the market. The key outcomes are highly dependent on each of these assumptions. In general, the overall market is better off from more technology choices being available and increased competition. The pricing and adoption of each technology choice is highly dependent on the technical efficiency of the GM variety, the number of seed or biotech firms that have the GM variety available, and the marginal cost of each variety.

The importance of the variation of surplus measure is to show that adopters of GM technology are not the only players in the market to benefit from the introduction. The decrease in price is a direct benefit to those who adopt conventional in both scenarios and those whose willingness-to-pay was previously too low for either technology. Firm profits are also affected, and overall sector welfare is better off because of lower prices and more technology choices.

Many challenges still exist in determining the pricing of GM output-traits. Many of the traits are in the beginning stages of development, and information on their possible benefits is still unknown. The traditional method of charging technology fees may not work well for output-traits, and the fee may be charged to the processor or consumer who realizes their benefits. This process and method of collecting fees may need to be better understood before output-traits can be accurately priced. Finally, changing market conditions due to the rapid development of the ethanol and biodiesel market may have a large impact on pricing output-traits.

CHAPTER 6
CONCLUSIONS

Problem

Agriculture biotechnology has revolutionized production agriculture. Since the first traits were commercialized in 1996, millions of acres of genetically modified (GM) crops have been planted by farmers. Nearly all of these acres involve input-traits such as herbicide tolerance (HT) or insect resistance (IR) that provide direct agronomic benefits to farmers. The next generation of GM crops contains output-traits that provide direct benefits to processors or consumers. These traits are expected to lower production and input costs of processors and consumers who adopt GM versus conventional varieties.

GM Traits in Crops

While the majority of the traits that are currently commercialized are input traits, output traits are beginning to emerge in production agriculture. Agbiotechnology companies are working on development of many traits, both input and output varieties. Some of the input-traits being developed include improved HT and IR varieties as well as drought tolerant and nitrogen utilizing varieties of many crops. Major areas of development in processor-preferred output-traits include improved oil varieties of soybeans and canola, improved ethanol output varieties of corn, and varieties of many crops with improved feed values. The major focus of output-traits directed towards consumers is improving the health benefits of many crops such as omega-3 soybeans and low-fat varieties. Some of these varieties are in the early stages of commercialization while others will not be released for the next few years if they are approved.

Price Impacts on Competing Technologies

Once a new output-trait variety is released, processors and consumers face a strategic decision of whether to adopt the GM variety or continue to use the conventional variety. This decision is based on the cost-benefit analysis of the GM versus the conventional variety. The release of the output-trait variety is expected to result in a decrease in price of the existing conventional technology choice as has been documented for GM input-trait varieties. This price decrease makes the conventional variety less costly when compared to the GM variety resulting in an increase in surplus for those processors who adopt the GM variety as well as those who adopt conventional varieties.

Objectives

There were two main objectives in this research. The first main objective is to develop a model reflective of technology competition to predict the optimal prices and strategies for market traits. In achieving this objective, the thesis 1) documented the changes from GM modifications and how they occurred in existing GM grains; 2) selected desirable traits that have promise for demand from the many traits that are being developed and nearing commercialization; 3) identified issues such as consumer acceptance, adoption, and potential release of the new products; and 4) identified changes in surplus as a result of the new product. The second main objective is to use the theoretical model developed in Chapter 3 to develop a method of pricing output-traits and to determine optimal strategies of the agbiotechnology firm, processors and consumers, and farmers when making decisions on commercialization, processing and consumption, and planting varieties.

This study provided an introduction into the development of output-traits in agbiotechnology including the direction and development of output traits, intellectual property rights, consumer acceptance, and pricing issues. Theoretical models of price impacts and pricing strategies are developed in Chapter 3. Empirical analysis was developed and reported in Chapters 4 and 5, respectively.

Procedures

Price Impact Model

A Cournot quantity competition model was developed to determine Nash equilibrium quantities of conventional and output-trait varieties of the crop in question. Market clearing prices of the respective varieties are then determined based on these quantities. The agbiotechnology firm determined a profit maximizing technology fee ($/gallon) for the output-trait. The market with the conventional variety only was compared to the market with conventional and the GM output-trait variety to determine the price decrease of the conventional variety as a result of the release of the GM variety into the market. Adoption and changes in processor/consumer surplus, tech firm payoffs, grower payoffs, and sector welfare was also analyzed.

Processors and consumers make their adoption decisions based on the technical efficiency of the two varieties. Processors and consumers with the highest willingness-to-pay adopt the GM variety, while the rest will adopt conventional or choose not to adopt either technology choice. High-oil canola is assumed to have 3-20% greater oil output than conventional varieties (M. Melani, personal communication, 2006). High-fermentable corn is expected to have a 3-5% increase in ethanol output over conventional corn varieties (Monsanto, 2005). Finally, omega-3 soybeans are expected to have about a 20% increase in omega-3 performance over traditional sources of omega-3 (Monsanto, 2005).

Results

Price Impact Model Base Case Results

The release of a high-oil canola variety for use in biodiesel processing would result in a price decrease of conventional canola of 14-18% the results suggest. Processors with a low willingness-to-pay for the GM variety realize cost savings in biodiesel processing as a direct result of this price decrease. Processors who adopt the GM variety benefit from the increase in oil content of the new variety. They experience an increase in surplus of nearly $5 million. Processors who continue to use the conventional variety in both scenarios realize an increase in surplus of over $3 million. Given market equilibrium quantities of the conventional and high-oil varieties, adoption rates were determined as 41% for no product adoption, 41% as conventional adoption, and 18% for high-oil canola adoption.

The release of a GM high-fermentable corn variety for use in ethanol production results in a 13-17% decrease in the price of conventional corn. Processors with a low willingness-to-pay for the GM variety again benefit from the price decrease of the conventional variety resulting in an increase in surplus of over $80 million. The increase in surplus for those processors who adopt the GM variety increases by over $46 million. Again, assuming market equilibrium quantities of the conventional and GM varieties, adoption rates were determined as 42% for no product adoption, 41% for conventional adoption, and 17% for GM adoption.

Similar to the previous two markets, the release of GM omega-3 soybeans would result in a 15-19% decrease in the price of conventional omega-3 sources. Surplus to those consumers who continue to adopt conventional variety and those who adopt GM increases by $9 million and $26 million, respectively. Given market equilibrium quantities of the conventional and GM varieties, adoption rates were determined as 41% for no product adoption, 41% as conventional adoption, and 18% for high-oil canola adoption. Introduction of the GM variety in all scenarios resulted in an increase in surplus to those who continued to use the conventional variety (due to the price decrease), processors and consumers who adopted GM, and the biotechnology firm.

Prices of the conventional variety decreased in all three scenarios. Processors and consumers who adopt the conventional variety benefit as a direct result of the price decrease. Those with a high willingness-to-pay for the GM variety benefit from the increase in output of the GM variety. Sector welfare of processors, growers of conventional and GM varieties, and agbiotechnology firms benefit from the introduction of the GM variety.

Price Impact Model Sensitivities

Data used in the base case was simulated to represent likely possible outcomes; however, changes in key variables result in changes in the equilibrium outcome. Sensitivities were conducted to illustrate the effects of changes in these variables. In the market with conventional crops only, an increase in the number of conventional firms' results in a decrease in price and increased adoption of the conventional variety. In all markets with conventional and GM, an increase in the number of firms producing the output-trait variety results in lower prices of the variety and increased GM adoption. A decrease in price of the conventional variety is also expected. This sensitivity represents patent expiration or more than one firm holding similar output-trait technology.

The model is highly sensitive to the technical efficiency of the GM variety. As the technical efficiency of the GM variety increases, the price of the GM variety and the technology fee increase. The price of the conventional variety falls slightly. GM adoption increases and conventional adoption decreases as the technical efficiency increases for each crop. Profits of the Biotech Company and grower of the GM variety also increase due to increases in the technical efficiency.

Marginal cost of production of the GM variety also has a large effect on outcomes. The marginal cost of producing the GM variety may increase over that of the conventional variety due to yield drag, technology fees, or segregation costs among other things. As the marginal cost increases, the price of the GM variety increases and the technology fee decreases. This causes GM adoption to increase and conventional adoption to decrease. Profits of GM growers and the biotechnology firm decrease as their costs increase and conventional growers increase profits.

Contributions and Implications

This study provided contributions in developing a model of price changes of current technologies as a result of the release of new competing output-trait technology. The price impact model is applied to three new output-trait technologies that are nearing commercialization to be released in the market. The model can also be applied to any of the many traits being researched in agbiotechnology. The results of the model show that the biotechnology firm is not the only player to benefit from commercialization of a new trait. Processors who adopt GM and those who adopt conventional benefit from more technology choices being available and lower prices of the conventional technology. The overall sector welfare also increases once the output-trait technology is released.

This study also provides a framework for pricing output-traits. Technology fees have historically been charged to growers of the crop as they have realized the benefit of the trait. Processors and consumers will be the direct beneficiaries of the benefits of output-traits and therefore the technology fee may be charged directly to them on a per unit processed basis. This analysis provides guidance for biotechnology companies on possible strategies to recoup research and development costs in the form of technology fees for these and possible upcoming output-traits.

Implications

There are many implications that arise from this analysis. First, the output-trait firm is not the only player in the model to benefit from the release of the output-trait variety. Surplus to all processors, not only those who adopt GM, increases once the GM variety is released. Processors with the highest willingness-to-pay for the GM variety benefit from the increase in output they receive from the GM variety over conventional. Also, processors who adopt conventional in both scenarios benefit directly from the price decrease of the conventional variety once the GM variety is released. The price decrease also allows some of the processors or consumers whose willingness-to-pay previously did not allow them to adopt any technology choice to enter the market and benefit from lower prices. Second, the decrease in price of the conventional variety leads to lower adoption rates of the GM variety than was initially expected. Some consumers and processors who would adopt GM do not because the conventional variety is now relatively cheaper. Therefore, the price decrease must be included when agbiotechnology firms consider possible adoption rates. Finally, the release of an output-trait variety leads to a decrease in payoffs to growers of conventional varieties but higher payoffs for growers of the output-trait variety and the biotechnology firm. Overall, surplus to processors and consumers, growers of each variety, and the biotechnology firm increases due to the release of the output-trait variety.

Limitations and Need for Further Research

Limitations

Because the output-trait varieties analyzed in this study have not been released, no historical data exists on their possible benefits. This study used discrete parameter values and random variable distributions based on biotechnology firm expectations to represent likely outcomes. If these expectations are to change, the results will be affected. The model also assumes no issues involving market acceptance of the GM variety. Some processors or consumers may be highly averse to GM foods leading to discounts of foods containing the GM variety. This would ultimately lead to higher adoption higher prices of conventional. This analysis also uses a partial equilibrium model. The partial equilibrium model looks at one sector of the economy separate, and not the economy as a whole. Incorporating the parameters that are excluded in the partial equilibrium may affect the outcomes.

Need for Further Research

Research on the impact of the release of a GM output-trait variety on the entire canola or corn market may also affect processors' adoption decisions. Incorporating the constraints of the entire crop market into a processor or consumer decision model may more accurately predict price changes and processor or consumer adoption rates. Many other output-traits such as low-linoleic soybeans, that reduce the fat content in soy oil, are being developed and could be analyzed to determine their price effects.

The mechanisms by which these prices and royalties will be charged and collected is speculative. Here we assumed that processors or consumers would be charged on a per-unit processed/consumed basis by the technology provider. Alternatives exist which may be more appropriate in output-trait pricing. These include contracts with processors or marketers, which may be exclusive or not; auctioning off the rights to the use of the output trait; charging a fixed fee or royalty for use of the technology, or, a per-unit fee. All these, amongst others, are alternatives that could be used and will no doubt be subject to much analysis in the future.

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APPENDIX A
RESOLUTION OF COURNOT-NASH EQUILIBRIA

Detailed Resolution of Market Equilibrium with One Product

The model is similar in structure to Huso and Wilson who applied the model to producer traits. In this case, the model is applied to processor traits and consumer traits. The former is similar to Huso and Wilson. However, the latter differs. For completeness, underlying fundamental relations and manipulations for each are shown, as well as the comparative statics.

A processor or consumer who is indifferent between buying the technology choice 0 and buying nothing is identified by the preference parameter $\hat{\theta}$. Because θ is uniformly distributed between 0 and 1, the total demand for the conventional processing input is

(A.1) $$Q_0 = Na_0(1-\hat{\theta}).$$

The preference parameter $\hat{\theta}$ can be determined by using the indirect utility function u_0, and assuming $u_0 = 0$:

(A.2) $$\hat{\theta} = \frac{a_0 p_0}{x_0}.$$

The demand function can be rewritten as

(A.3) $$Q_0 = Na_0(1-\frac{a_0 p_0}{x_0}).$$

The inverse demand function can be given as

(A.4) $$p_0(Q_0) = \frac{x_0}{Na_0^2}(Na_0 - Q_0).$$

The profit function for seller *k*, $\pi_{ok} = (p_0(Q_0) - c_0)q_{0k}$ is written as

(A.5) $$\pi_{ok} = (\frac{x_0}{Na_0^2}(Na_0 - Q_0) - c_0)q_{0k}.$$

Q_0 can be expressed as

(A.6) $$Q_0 = q_{0k} + \sum_{j=1}^{n_0 - 1} q_{0j}.$$

With q_{ok} being the quantity of seller *k* and q_{oj} being the quantity of seller *j*, for all *j*=1,2,3,...,($n_0 - 1$). The profit function is rewritten:

(A.7) $$\pi_0 = \left(\frac{x_0}{Na_0^2}\left[Na - 2q_{0k} - \sum_{j=1}^{n_0 - 1} q_{0j} \right] - c_0 \right) q_{0k}.$$

To determine the profit maximizing level of q_{ok}, the first order condition is

(A.8) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{Na_0^2}\left[Na - 2q_{0k} - \sum_{j=1}^{n_0 - 1} q_{0j} \right] - c_0 = 0.$$

With all other $n_0 - 1$ sellers being *j*=1,2,3,..., $n_0 - 1$. Solving for q_{ok} yields

(A.9) $$q_{0k} = \frac{1}{2}\left\{ \left[Na_0 - \frac{Na_0^2 c_0}{x_0} \right] - \sum_{j=1}^{n_0 - 1} q_{0j} \right\}.$$

Under a symmetric Cournot-Nash equilibrium, all sellers select the same strategy. In this case $q_{0k} = q_{0j}$, for all j. Substituting q_{0k} for q_{0j} gives the following equation:

(A.10) $$q_{0k} = \frac{1}{2}\left\{ \left[Na_0 - \frac{Na_0^2 c_0}{x_0} \right] - (n_0 - 1) q_{0k} \right\}.$$

Solving this equation for q_{0k} gives the equilibrium quantity for each seller:

(A.11) $$q_0^* = \frac{Na_0(x_0 - a_0 c_0)}{x_0(n_0 + 1)}.$$

The optimal market equilibrium total quantity is then $Q_0^* = q_0^* n_0$. or

(A.12) $$Q_0^* = \frac{Na_0(x_0 - a_0 c_0)}{x_0(n_0 + 1)}.$$

This total quantity can then be substituted into the inverse demand function:

(A.13) $$p_0(Q_0) = \frac{x_0}{Na_0^2}\left(Na_0 - \frac{Na_0(x_0 - a_0 c_0)n_0}{x_0(n_0 + 1)}\right).$$

Simplifying this expression yields the equilibrium market price:

(A.14) $$p_0^* = \frac{x_0 + a_0 c_0 n_0}{a_0(n_0 + 1)}.$$

Substituting q_0^* and p_0^* into the profit function and solving for optimal profit yields:

(A.15) $$\pi_0^* = \frac{N}{x_0}\left[\frac{x_0 - a_0 c_0}{n_0 + 1}\right]^2.$$

Total processor or consumer surplus from indirect utility is

(A.16) $$s_0^* = N\int_{\hat{\theta}^*}^{1} u_0 \cdot d\theta = N\int_{\hat{\theta}^*}^{1} \theta x_0 - a_0 p_0 * d\theta$$

Substituting p_0^* for p_0 and integrating the expression gives:

(A.17) $$s_0^* = N\int_{\hat{\theta}^*}^{1} u_0 \cdot d\theta = N\int_{\hat{\theta}^*}^{1} \theta x_0 - a_0\left(\frac{x_0 + n_0 a_0 c_0}{a_0(n_0 + 1)}\right) \text{Or}$$

(A.18) $$s_0^* = N\left[\left\{\frac{x_0}{2} - \frac{x_0 + n_0 a_0 c_0}{n_0 + 1}\right\} - \left\{\frac{\hat{\theta}^{*2} x_0}{2} - \frac{\hat{\theta}^*(x_0 + n_0 a_0 c_0)}{n_0 + 1}\right\}\right].$$

Total sector welfare is defined as

(A.19) $$W = n_0 \pi_0^* + s_0^*.$$

Detailed Resolution of Market Equilibrium with Two Products

Because $\widetilde{\theta}$ refers to a processor who is indifferent between the type *0* and the type *1* products, it is implied that , for this processor, $u_0 = u_1$. From this equality, $\widetilde{\theta}$ can be determined:

(A.20)
$$\widetilde{\theta} = \frac{a_1 p_1 + p_L - a_0 p_0}{x_1 - x_0}.$$

The demand functions for product type *0* and product type *1 are:*

(A.21)
$$Q_0 = Na_0(\widetilde{\theta} - \hat{\theta}) \text{ and } Q_1 = Na_1(1 - \widetilde{\theta}).$$

Substituting the derived expressions for $\hat{\theta}$ and $\widetilde{\theta}$ into the demand functions and assuming a given level of p_L gives

(A.22)
$$Q_0(p_0, p_1, p_L) = Na_0\left(\frac{a_1 p_1 + p_L - a_0 p_0}{x_1 - x_0} - \frac{a_0 p_0}{x_0}\right) \text{and}$$

(A.23)
$$Q_1(p_0, p_1, p_L) = Na_1\left(1 - \frac{a_1 p_1 + p_L - a_0 p_0}{x_1 - x_0}\right).$$

To determine the inverse demand functions, both demand functions can be simultaneously solved for prices, p_0 and p_1. Solving $Q_0(p_0, p_1, p_L)$ for p_0 and simplifying gives

(A.24)
$$p_0(Q_0, Q_1, p_L) = \frac{x_0}{a_0}\left(1 - \frac{Q_0}{Na_0} - \frac{Q_1}{Na_1}\right).$$

Solving $Q_1(p_0, p_1, p_L)$ is then

(A.25)
$$p_1(Q_0, Q_1, p_L) = \frac{x_1}{a_1}\left(1 - \frac{Q_0 x_0}{Na_0 x_1} - \frac{Q_1}{Na_1}\right) - p_L$$

Using $p_0(Q_0, Q_1, p_L)$ in the profit function for seller *k* of product type *0* yields

(A.26) $$\pi_{0k} = \frac{x_0}{a_0}\left(1 - \frac{\left(q_{0k} + \sum_{j=1}^{n_0-1} q_{0j}\right)}{Na_0} - \frac{n_1 q_1}{Na_1}\right) q_{0k} - c_0 q_{0k}.$$

Since all firms adopt the same strategy, $Q_1 = q_1 n_1$. Taking the partial derivative of π_{0k} with respect to q_{0k} to determine the profit maximizing level of q_{0k} is given as

(A.27) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{a_0}\left(1 - \frac{\left(q_{0k} + \sum_{j=1}^{n_0-1} q_{0j}\right)}{Na_0} - \frac{n_1 q_1}{Na_1}\right) - \frac{x_0 q_{0k}}{Na_0^2} - c_0 = 0.$$

Under a symmetric Cournot-Nash equilibrium, $q_{0k} = q_{0j}$ for any j, j=1,2,3,..., $(n_0 - 1)$, the first-order condition for profit maximization by the n_0 sellers is simplified to

(A.28) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{a_0}\left(1 - \frac{(n_0+1)q_0}{Na_0} - \frac{n_1 q_1}{Na_1}\right) - c_0 = 0$$

Using $p_1(Q_0, Q_1, p_L)$ in the profit function for seller r of product type 1 yields

(A.29) $$\pi_{1r} = \left[\frac{x_1}{a_1}\left(1 - \frac{n_0 q_0}{Na_0} * \frac{x_0}{x_1} - \frac{q_{1r} + \sum_{s=1}^{n_1-1} q_{1s}}{Na_1}\right) - p_L\right] q_{1r} - c_1 q_{1r}.$$

Taking a partial derivative of π_{1r} with respect to q_{1r} to determine the profit maximizing level of q_{1r} is given as

(A.30) $$\frac{\partial \pi_{1r}}{\partial q_{1r}} = \frac{x_1}{a_1}\left(1 - \frac{n_0 q_0}{Na_0} * \frac{x_0}{x_1} - \frac{q_{1r} + \sum_{s=1}^{n_1-1} q_{1s}}{Na_1}\right) - p_L - \frac{x_1 q_{1r}}{Na_1^2} - c_1 = 0.$$

Under a symmetric Cournot-Nash equilibrium, $q_{1r} = q_{1s}$ for any s, s=1,2,3,..., $(n_1 - 1)$, the first-order condition for profit maximization by the n_1 sellers is simplified to

(A.31) $$\frac{\partial \pi_{1k}}{\partial q_{1k}} = \frac{x_1}{a_1}\left(1 - \frac{n_0 q_0 x_0}{N a_0 x_1} - \frac{(n_1+1)q_1}{N a_1}\right) - p_L - c_1 = 0$$

Simultaneously solving the two first-order conditions.

(A.32) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{a_0}\left(1 - \frac{(n_0+1)q_0}{N a_0} - \frac{n_1 q_1}{N a_1}\right) - c_0 = 0 \text{ and}$$

(A.33) $$\frac{\partial \pi_{1k}}{\partial q_{1k}} = \frac{x_1}{a_1}\left(1 - \frac{n_0 q_0 x_0}{N a_0 x_1} - \frac{(n_1+1)q_1}{N a_1}\right) - p_L - c_1 = 0$$

The Cournot-Nash equilibrium quantities are

(A.34) $$q_0^*(p_L) = -N a_0 \cdot \frac{-a_0 c_0 x_1 + x_0 x_1 + a_1 c_1 x_0 n_1 + a_1 p_L x_0 n_1 - a_0 c_0 x_1 n_1}{x_0(-x_1 - x_1 n_0 - x_1 n_1 + x_0 n_0 n_1 - x_1 n_0 n_1)} \text{ and}$$

(A.35) $$q_1^*(p_L) = N a_1 \cdot \frac{-a_1 c_1 - a_1 p_L + x_1 + a_0 c_0 n_0 - a_1 c_1 n_0 - a_1 p_L n_0 - x_0 n_0 + x_1 n_0}{-x_1 - x_1 n_0 - x_1 n_1 + x_0 n_0 n_1 - x_1 n_0 n_1}$$

Now, $Q_0^* = q_0^* n_0$ and $Q_1^* = q_1^* n_1$. Substituting Q_0^* and Q_1^* into the inverse demand function and solving for prices yields

(A.36) $$p_0^*(p_L) = -\frac{a_1 n_1 x_0 (c_1 + p_L) + x_0 x_1 + a_0 c_0 n_0(-n_1 x_0 + x_1 + n_1 x_1)}{a_0(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)} \text{ and}$$

(A.37)

$$p_1^*(p_L) = \frac{-x_1(a_0 c_0 n_0 - n_0 x_0 + x_1 + n_0 x_1) + a_1((1+n_0)p_L x_1 + c_1 n_1(n_0 x_0 - x_1 - n_0 x_1))}{a_1(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)}$$

Equilibrium prices and quantities are used in the profit functions to determine firm profits:

(A.38) $$\pi_0^*(p_L) = \frac{N(a_1 n_1 x_0(c_1 + p_L) + (-a_0 c_0(1+n_1) + x_0)x_1)^2}{x_0(n_0(n_1(x_0 - x_1) - x_1) - (1+n_1)x_1)^2} \text{ and}$$

(A.39)
$$\pi_1^*(p_L) = \frac{Nx_1(a_0c_0n_0 - a_1(1+n_0)(c_1+p_L) - n_0x_0 + x_1 + n_0x_1)^2}{((1+n_1)x_1 + n_0(x_1 + n_1(-x_0 + x_1)))^2}$$

The profit function for the biotechnology seller is $\pi_B = n_1 q_1^*(p_L)p_L$. Profit maximization for the biotechnology seller with respect to p_L yields the equilibrium license price, p_L^*:

(A.40)
$$p_L^* = \frac{a_0c_0n_0 - a_1c_1(n_0+1) - n_0x_0 + x_1 + n_0x_1}{2a_1(n_0+1)}$$

The processors' surplus in the two product case is defined as:

(A.41)
$$s_0^* = N\int_{\hat{\theta}^*}^{\tilde{\theta}^*} u_0 d\theta \text{, and}$$

(A.42)
$$s_1^* = N\int_{\tilde{\theta}^*}^{1} u_1 d\theta.$$

where $u_0 = \theta x_0 a_0 p_0^*$ and $u_1 = \theta x_1 - a_1 p_1^* + p_L^*$. Integrating s_0^* gives the following expression

(A.43)
$$S_0^* = \frac{1}{2}\left(-\hat{\theta}^2 x_0 + \tilde{\theta}^2 x_0 - \frac{2(\hat{\theta} - \tilde{\theta})(a_1n_1(c_1+p_L)x_0 + x_0x_1 + a_0c_0n_0(-n_1x_0 + x_1 + n_1x_1))}{n_0n_1x_0 - (1+n_0)(1+n_1)x_1}\right)$$

Integrating s_1^* yields

(A.44)
$$S_1^* = \frac{1}{2}\left(\begin{array}{l} x_1 - \tilde{\theta}^2 x_1 + (1-\tilde{\theta})\left(-\dfrac{x_1 + n_0(a_0c_0 - x_0 + x_1)}{(1+n_0)}\right) + \\ \dfrac{-a_1c_1n_0n_1x_0 + a_1(1+n_0)(c_1(n_1-1) - 2p_L)x_1 + 2x_1(x_1 + n_0(a_0c_0 - x_0 + x_1))}{n_0n_1x_0 - (1+n_0)(1+n_1)x_1} \end{array}\right)$$

Sector welfare is then defined as:

(A.45)
$$W = n_0\pi_0^* + (n_1 - 1)\pi_1^* + \pi_B^* + s_0^* + s_1^*$$

Market Equilibrium with Two Products: Conventional and GM Consumer Traits

When the crop is considered to have a consumer benefit rather than a processor benefit such as omega-3 or low fat soybeans, there will not be a processing requirement, a_i, in the equations. In the consumer case the utility functions are then,

(A.46)
$$\begin{aligned} u_0 &= \theta x_0 - p_0 \\ u_1 &= \theta x_1 - p_1 - p_L \end{aligned}$$

Based on the condition $u_0 = u_1$ we find:

(A.47)
$$\tilde{\theta} = \frac{p_0 - p_1 - p_L}{x_0 - x_1}.$$

The demand functions for a given level of p_L for each of the two technology choices are then:

(A.48)
$$Q_1 = N\left[\left(\frac{p_1 + p_L - p_0}{x_1 - x_0}\right) - \left(\frac{p_0}{x_0}\right)\right]$$

(A.49)
$$Q_1 = N\left[1 - \left(\frac{p_1 + p_L - p_0}{x_1 - x_0}\right)\right]$$

The inverse demand functions can be found by simultaneously solving the demand functions for p_0 and p_1.

(A.50)
$$\begin{cases} p_0(Q_0, Q_1) = -x_0\left(\dfrac{Q_1 - N + Q_0}{N}\right) \\ p_1(Q_0, Q_1) = \dfrac{-(Q_0 x_0 + N p_L + Q_1 x_1 - N x_1)}{N} \end{cases}$$

Using $p_0(Q_0, Q_1)$ in the profit function for seller k of product type 0 yields

(A.51) $$\pi_{0k} = x_0 \cdot \left(1 - \left(\frac{q_{0k} + \sum_{j=1}^{n_0-1} q_{0j}}{N} \right) - \frac{n_1 q_1}{N} \right) q_{0k} - c_{0k} q_{0k}$$

Using $p_1(Q_0, Q_1, p_L)$ in the profit function for seller k of product type 1 yields

(A.52) $$\pi_{1k} = x_1 \left(1 - \left(\frac{n_0 q_0 x_0}{N x_1} \right) - \left(\frac{p_L}{x_1} \right) - \left(\frac{q_{1k} + \sum_{j=1}^{n_0-1} q_{1j}}{N} \right) \right) q_{1k} - c_1 q_{1k} .$$

Like the previous processor good case, the firms choose quantity to maximize profit in the symmetric Cournot-Nash equilibrium. The first order conditions are

(A.53) $$\frac{\partial \pi_{0k}}{\partial q_{0k}} = x_0 \cdot \left(1 - \frac{q_0 (n_0 + 1)}{N} - \frac{q_1 n_1}{N} \right) - c_0 = 0$$

(A.54) and $$\frac{\partial \pi_{0k}}{\partial q_{1k}} = x_1 - p_L - \left(\frac{n_0 q_0 x_0}{N} \right) - \left(\frac{q_1 x_1}{N} \right) - \left(\frac{n_1 q_1 x_1}{N} \right) - c_1 = 0$$

Simultaneously solving the first-order conditions for equilibrium quantities is then

(A.55) $$q_0^* = -\frac{N(c_1 n_1 x_0 + n_1 p_L x_0 - c_0 x_1 - c_0 n_1 x_1 + x_0 x_1)}{x_0 (n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1)}, \text{ and}$$

(A.56) $$q_1^* = \frac{N(c_1 - c_0 n_0 + c_1 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1}{n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1} .$$

Recall, $Q_0^* = q_0^* n_0$ and $Q_1^* = q_1^* n_0$. Substituting Q_0^* and Q_1^* into the inverse demand function and solving for p_0^* and p_1^* gives

(A.57) $$p_0^* = -\frac{c_1 n_1 x_0 + x_0 (n_1 p_L + x_1) + c_0 n_0 (-n_1 x_0 + x_1 + n_1 x_1)}{n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1}, \text{ and}$$

(A.58) $$p_1^* = \frac{c_1 n_1 (n_0 (x_0 - x_1) - x_1) + x_1(-c_0 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1)}{n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1}.$$

The profit maximizing technology fee is:

(A.59) $$p_L^* = \frac{c_0 n_0 - c_1(1 + n_0) - n_0 x_0 + x_1 + n_0 x_1}{2(1 + n_0)}.$$

The equilibrium profits of the sellers of each technology choice are then:

(A.60) $$\pi_0^* = \frac{N(c_1 n_1 x_0 + n_1 p_L x_0 - c_0 x_1 - c_0 n_1 x_1 + x_0 x_1)^2}{x_0 (n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1)^2}, \text{ and}$$

(A.61) $$\pi_B^* = \frac{N n_1 p_L (c_1 - c_0 n_0 + c_1 n_0 + p_L + n_0 p_L + n_0 x_0 - x_1 - n_0 x_1)}{n_0 (n_1 (x_0 - x_1) - x_1) - (1 + n_1) x_1}.$$

Similar to the processor case, total consumer surplus is defined over the ranges of adoption for each technology choice:

(A.62) $$s_0^* = N \int_{\hat{\theta}^*}^{\tilde{\theta}^*} u_0 d\theta, \text{ and}$$

(A.63) $$s_1^* = N \int_{\tilde{\theta}^*}^{1} u_1 d\theta.$$

In this case, $u_0 = \theta x_0 - p_0^*$ and $u_1 = \theta x_1 - p_1^* - p_L^*$. Substituting the equilibrium prices in to the indirect utility functions and integrating, the consumers' surplus is given by the following expressions

(A.64) $$s_0^* = \frac{1}{2}\left(-\hat{\theta}^2 x_0 + \tilde{\theta}^2 x_0 - \left(\frac{2(\hat{\theta} - \tilde{\theta})(n_1(c_1 - c_0 n_0 + p_L) x_0 + (c_0 n_0 (1 + n_1) + x_0) x_1)}{n_0 n_1 x_0 - (1 + n_0)(1 + n_1) x_1} \right) \right)$$

(A.65)

$$s_1^* = \frac{1}{2}\left(x_1 - \tilde{\theta}^2 x_1 + \frac{2(-1 + \tilde{\theta})((p_L + n_0(-c_0 + p_L + x_0 - x_1) - x_1) x_1 + c_1 n_1 (n_0 x_0 - (1 + n_0) x_1))}{n_0 n_1 x_0 - (1 + n_0)(1 + n_1) x_1} \right)$$

Sector welfare is then defined as $W = n_0\pi_0^* + n_1\pi_1^* + \pi_B^* + s_0^* + s_1^*$.

APPENDIX B
ILLUSTRATIONS

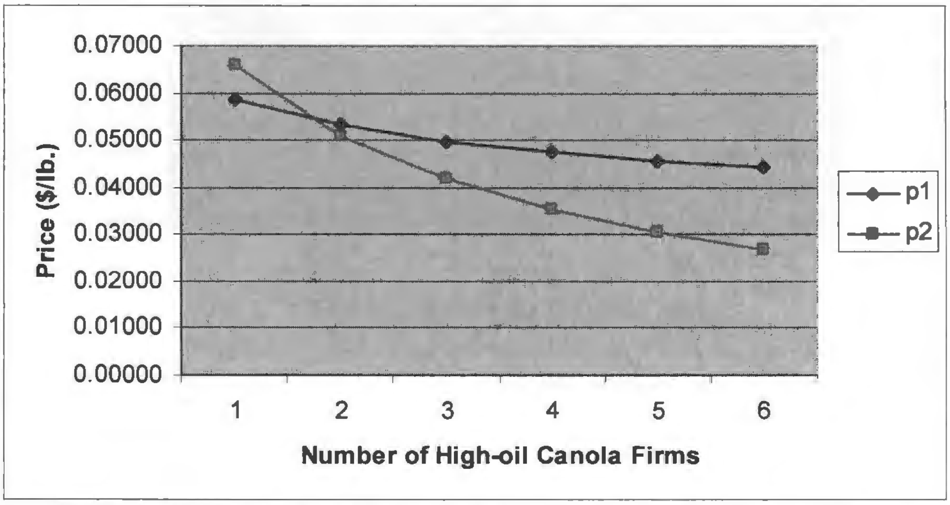

Figure 1. Impact of High-oil Canola Producing Firms on Technology Prices.

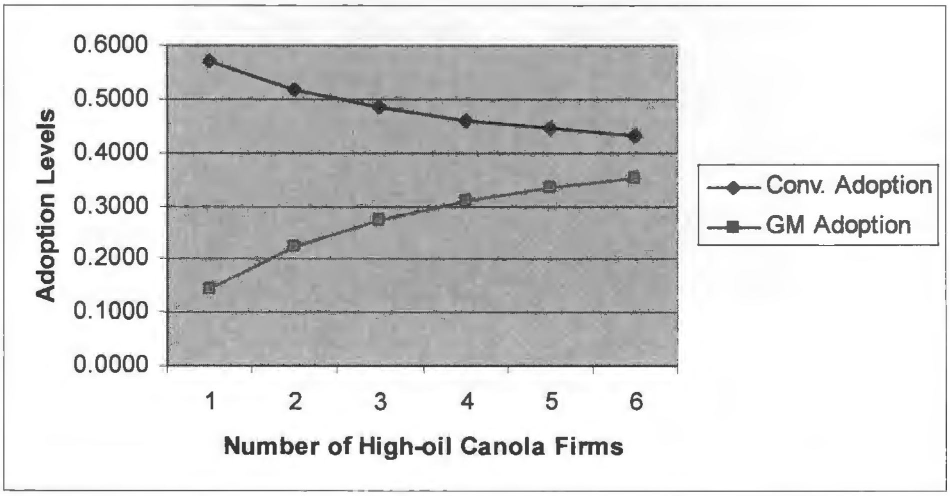

Figure 2. Impact of High-oil Canola Producing Firms on Adoption Levels.

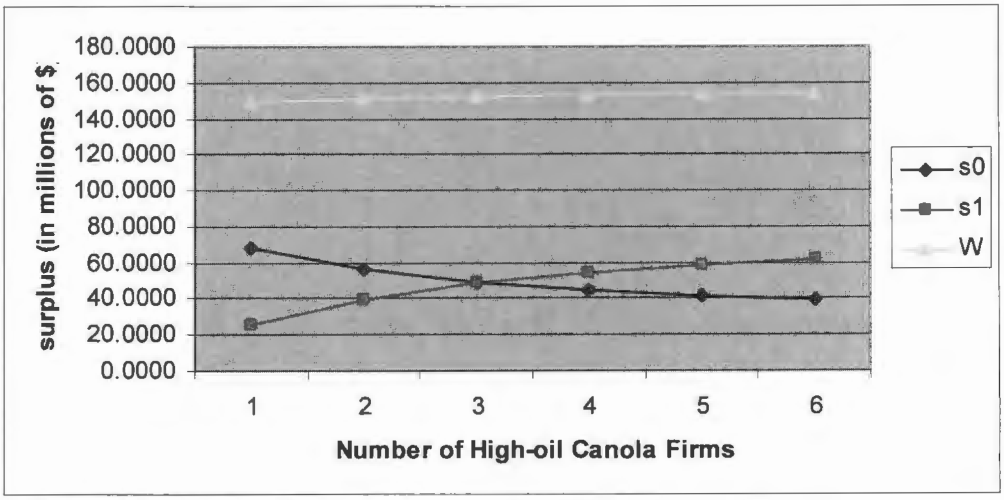

Figure 3. Impact of High-oil Canola Producing Firms on Surplus Levels.

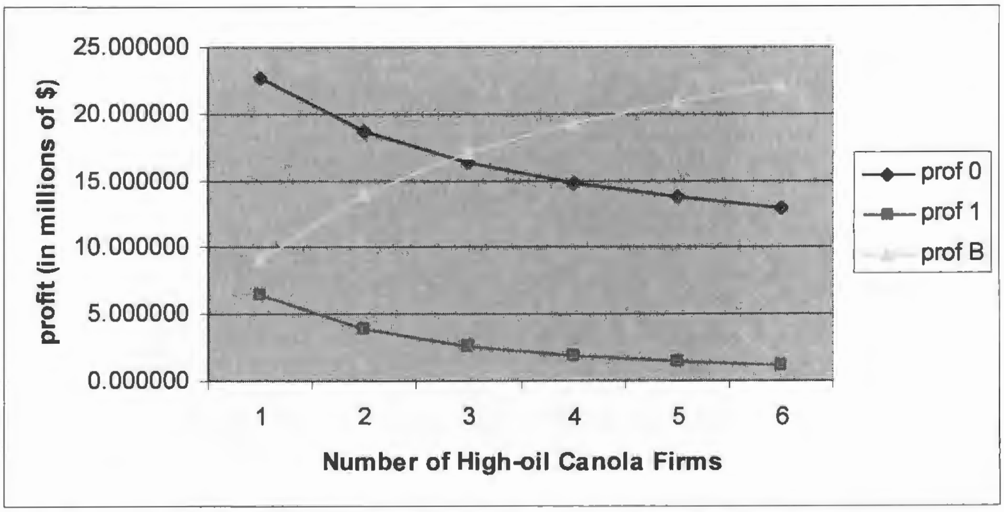

Figure 4. Impact of High-oil Canola Producing Firms on Firm Profits.

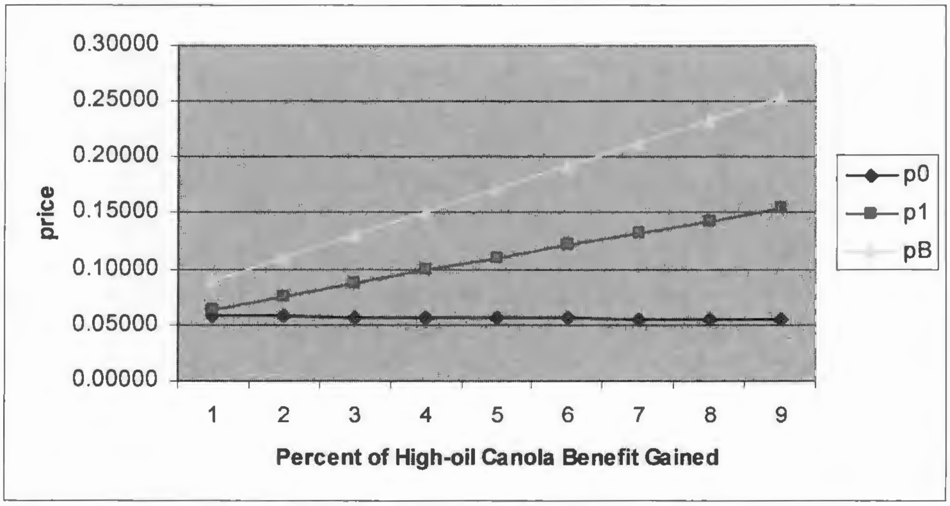

Figure 5. Impact of High-oil Canola Efficiency on Technology Prices.

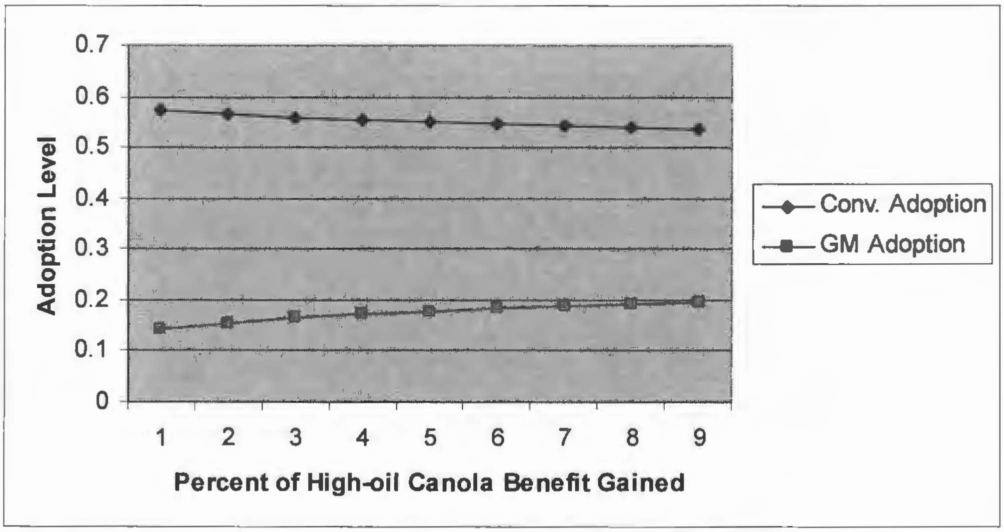

Figure 6. Impact of High-oil Canola Efficiency on Adoption Levels.

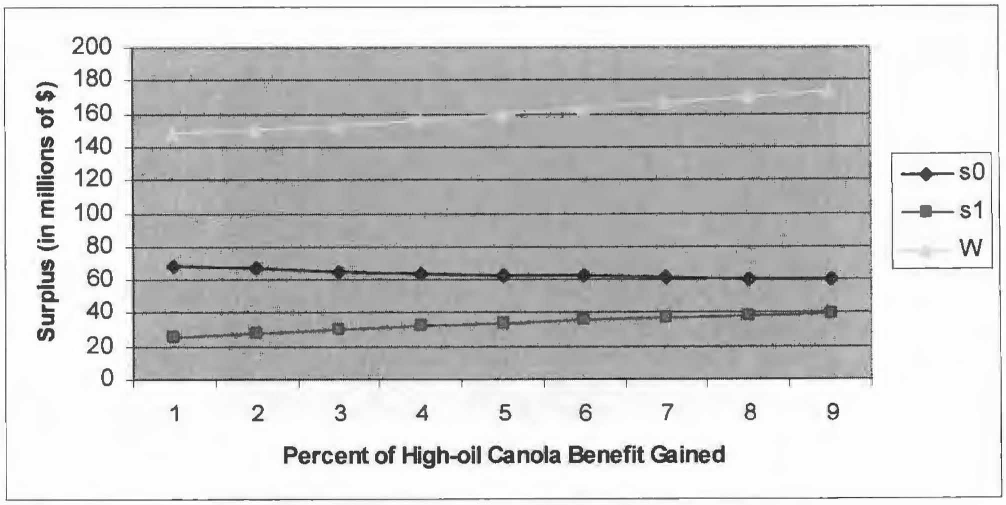

Figure 7. Impact of High-oil Canola Efficiency on Surplus Levels.

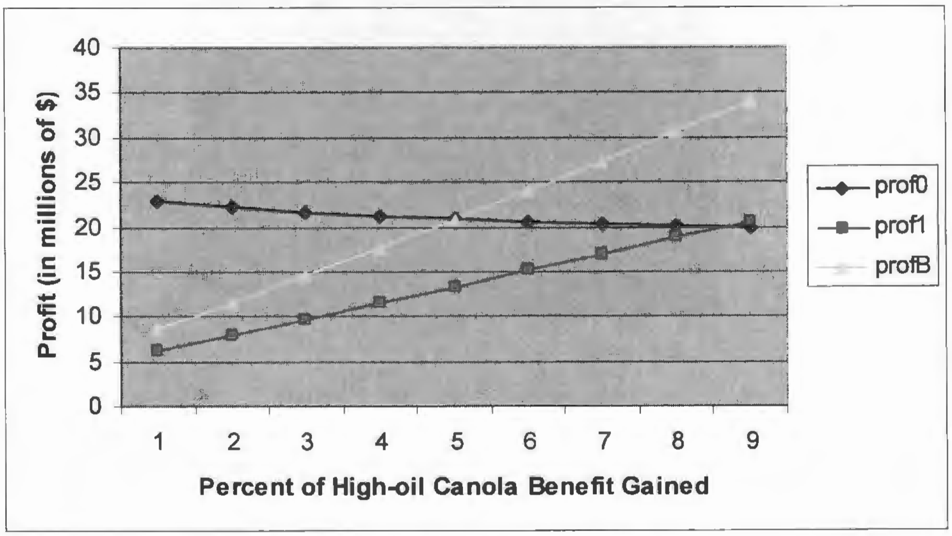

Figure 8. Impact of High-oil Canola Efficiency on Firm Profits.

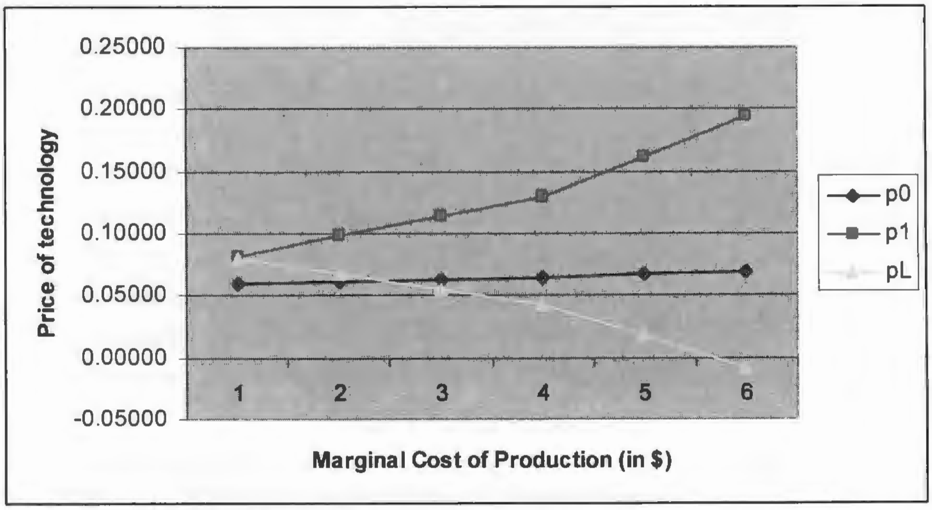

Figure 9. Impact of High-oil Canola Marginal Cost on Technology Prices.

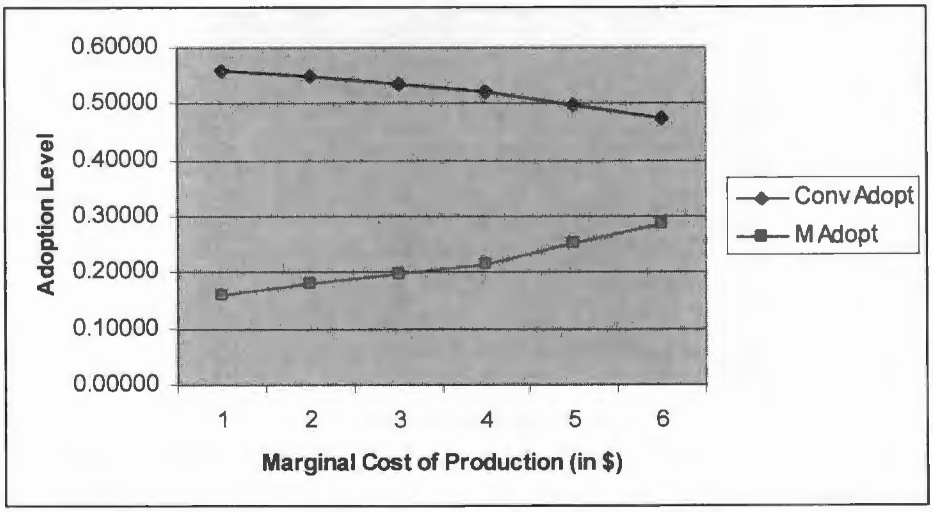

Figure 10. Impact of High-oil Canola Marginal Cost on Adoption Levels.

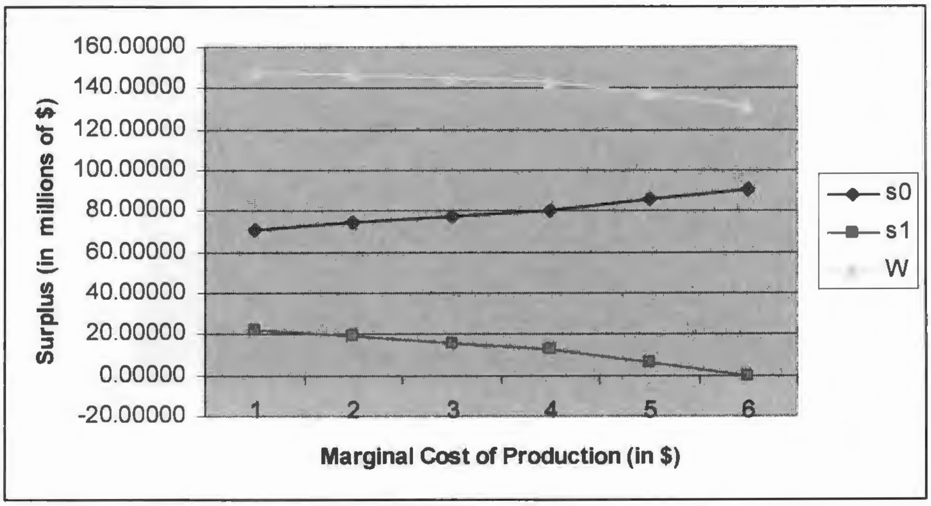

Figure 11. Impact of High-oil Canola Marginal Cost on Surplus Levels.

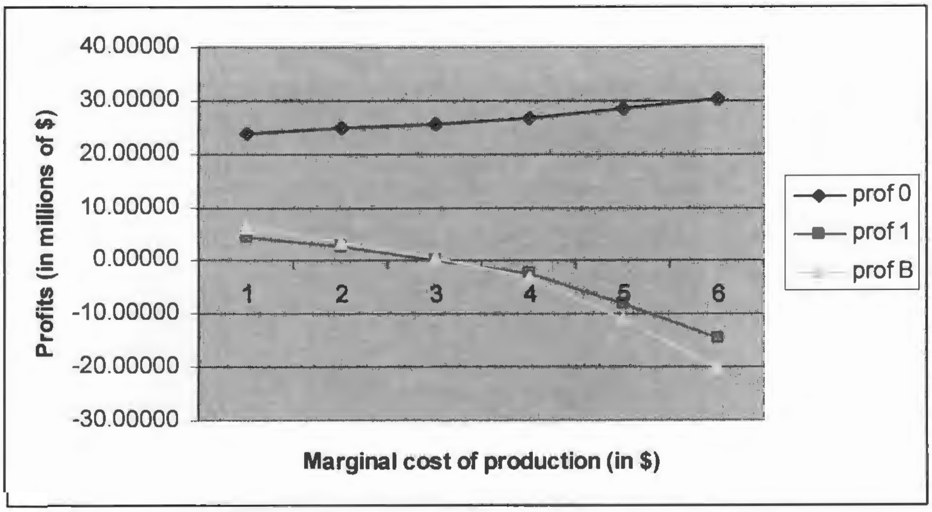

Figure 12. Impact of High-oil Canola Marginal Cost on Firm Profits.

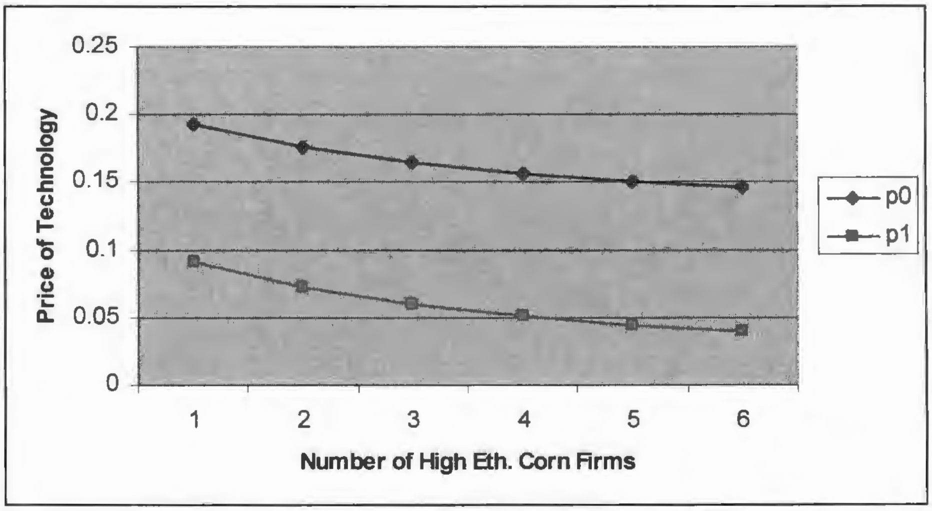

Figure 13. Impact of High-fermentable Corn Producing Firms on Technology Prices.

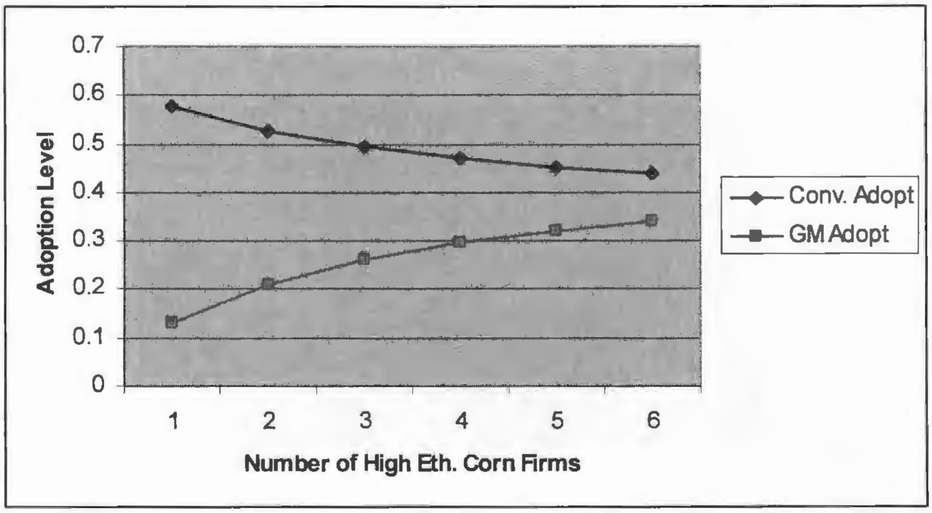

Figure 14. Impact of High-fermentable Corn Producing Firms on Adoption Levels.

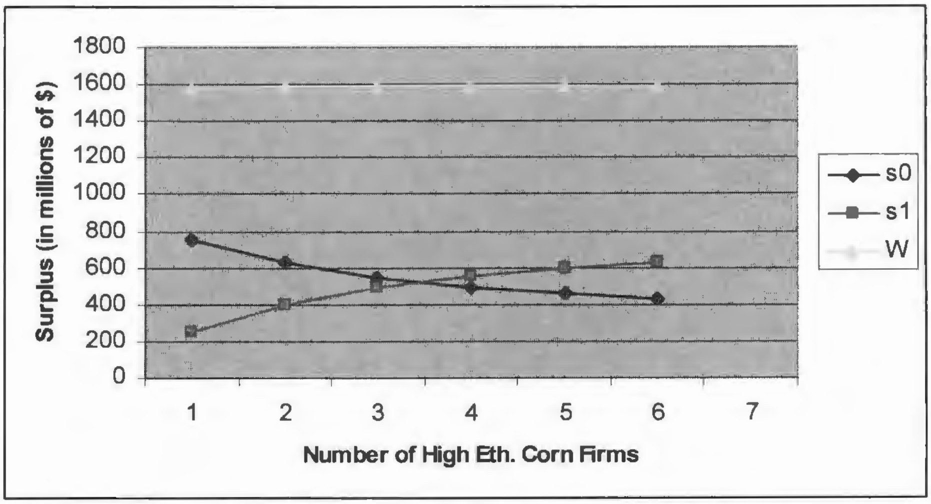

Figure 15. Impact of High-fermentable Corn Producing Firms on Surplus Levels.

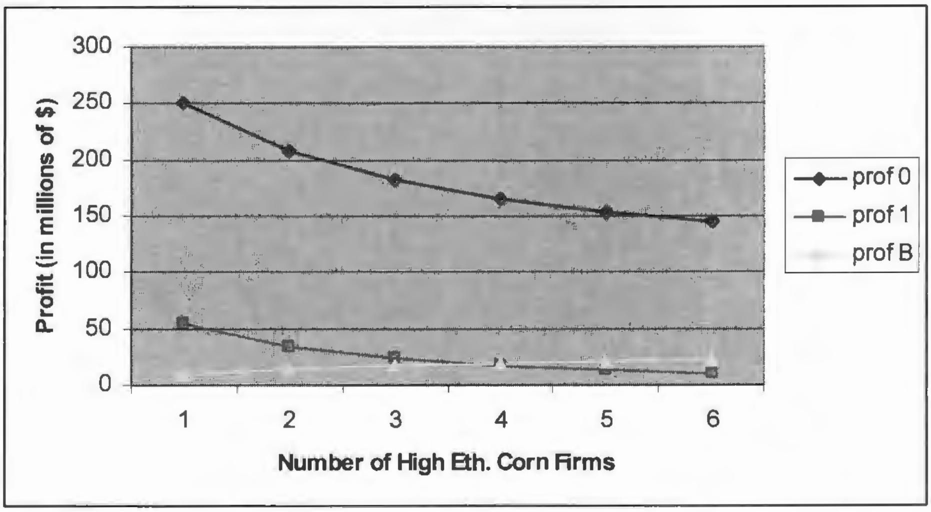

Figure 16. Impact of High-fermentable Corn Producing Firms on Firm Profits.

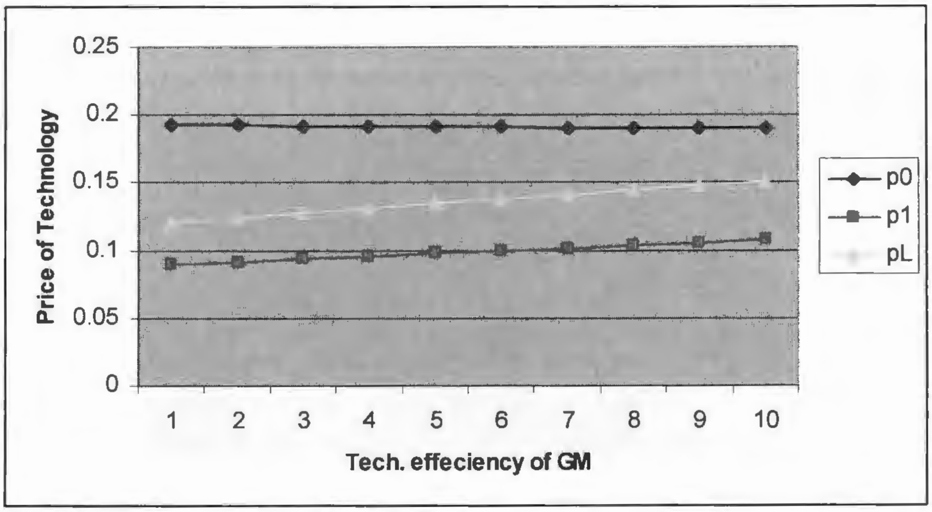

Figure 17. Impact of High-fermentable Corn Efficiency on Technology Prices.

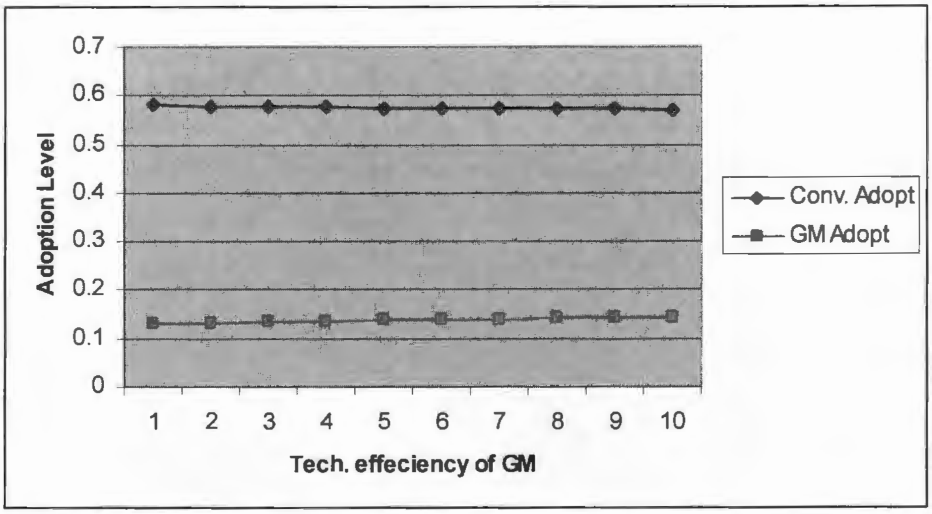

Figure 18. Impact of High-fermentable Corn Efficiency on Adoption Levels.

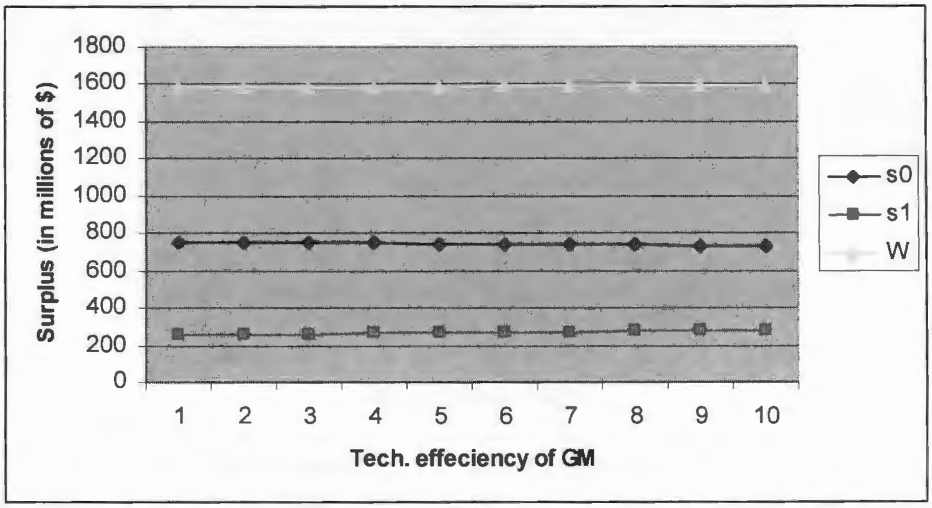

Figure 19. Impact of High-fermentable Corn Efficiency on Surplus Levels.

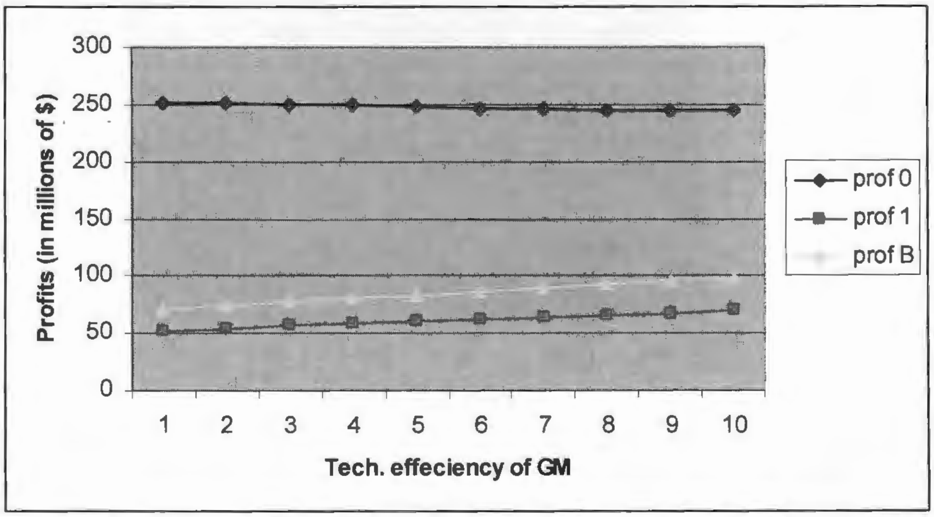

Figure 20. Impact of High-fermentable Corn Efficiency on Profit Levels.

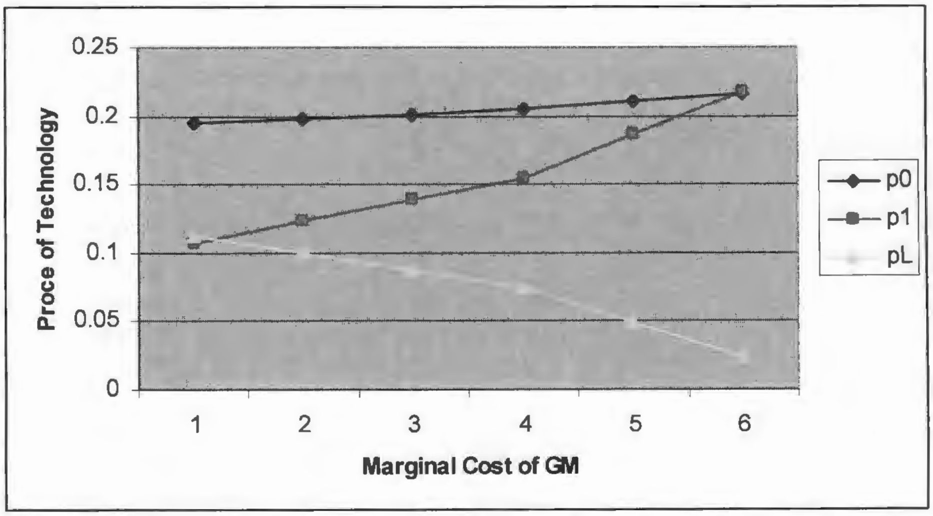

Figure 21. Impact of High-fermentable Corn Marginal Cost on Technology Prices.

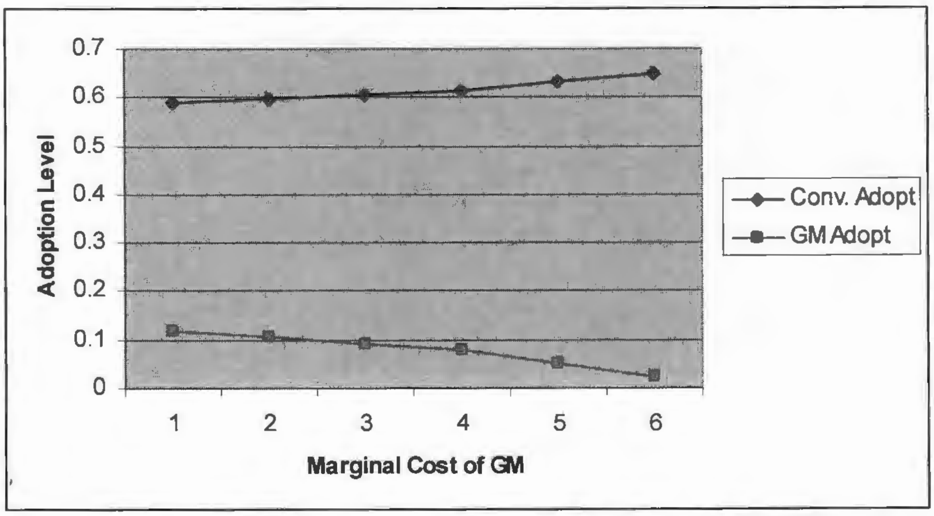

Figure 22. Impact of High-fermentable Corn Marginal Cost on Adoption Levels.

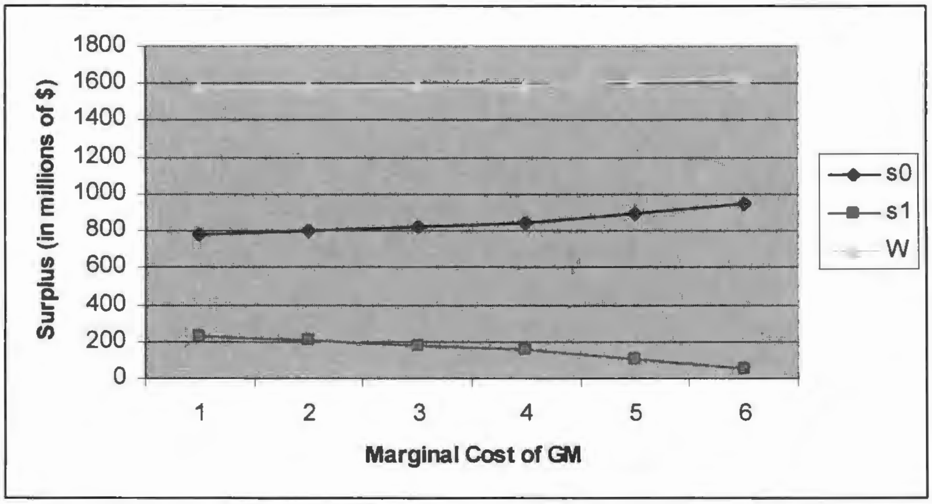

Figure 23. Impact of High-fermentable Corn Marginal Cost on Surplus Levels.

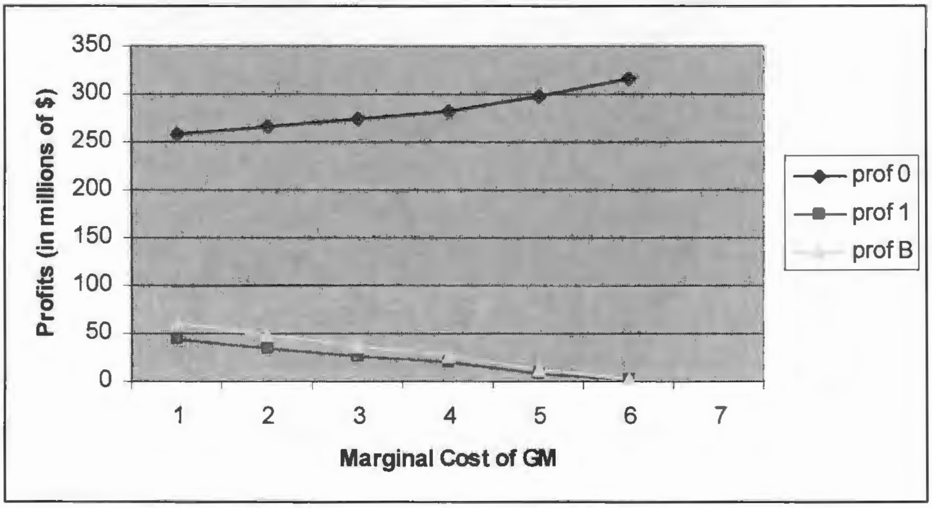

Figure 24. Impact of High-fermentable Corn Marginal Cost on Firm Profits.

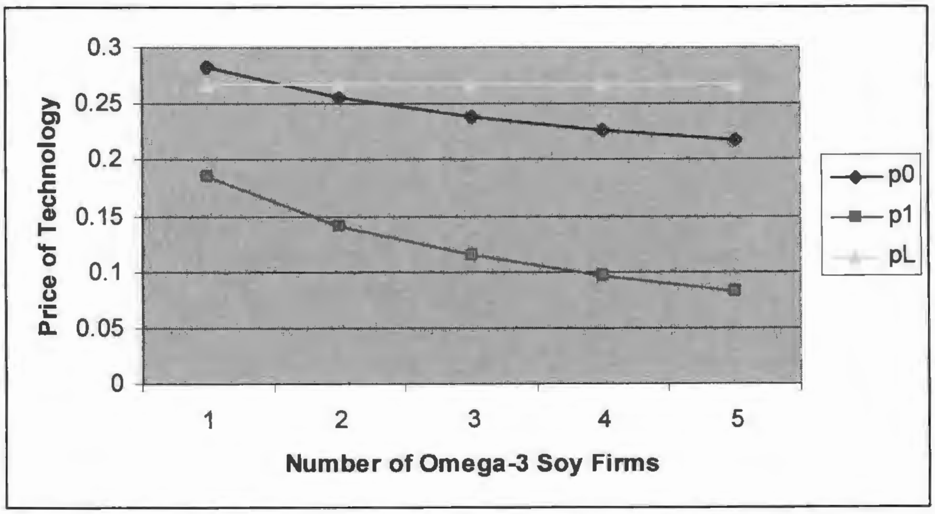

Figure 25. Impact of Number of Omega-3 Soy Firms on Technology Prices.

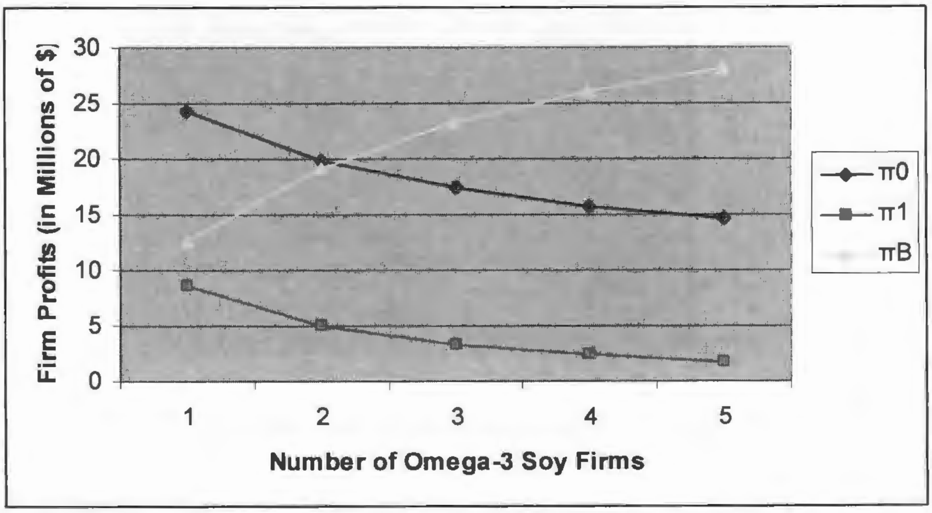

Figure 26. Impact of Number of Omega-3 Soy Firms on Firm Profits.

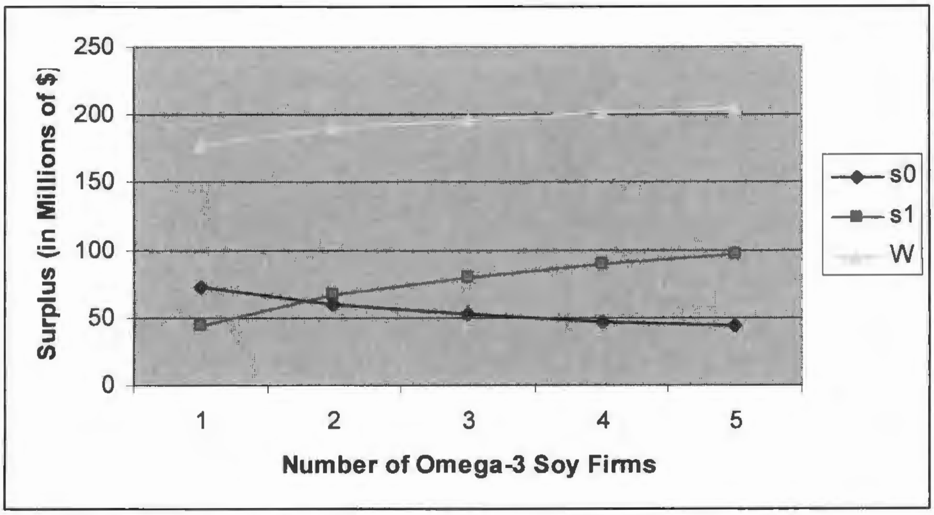

Figure 27. Impact of Number of Omega-3 Soy Firms on Firm Surplus.

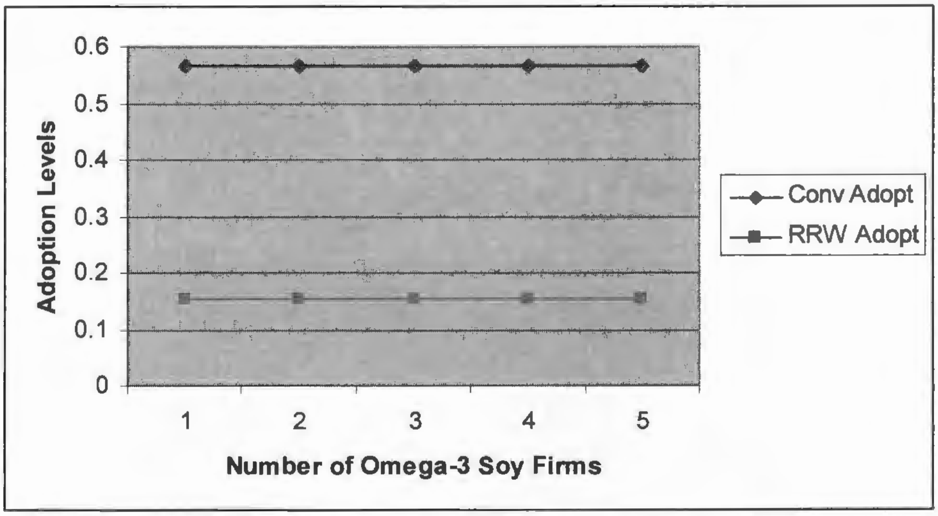

Figure 28. Impact of Number of Omega-3 Soy Firms on Adoption Rates.

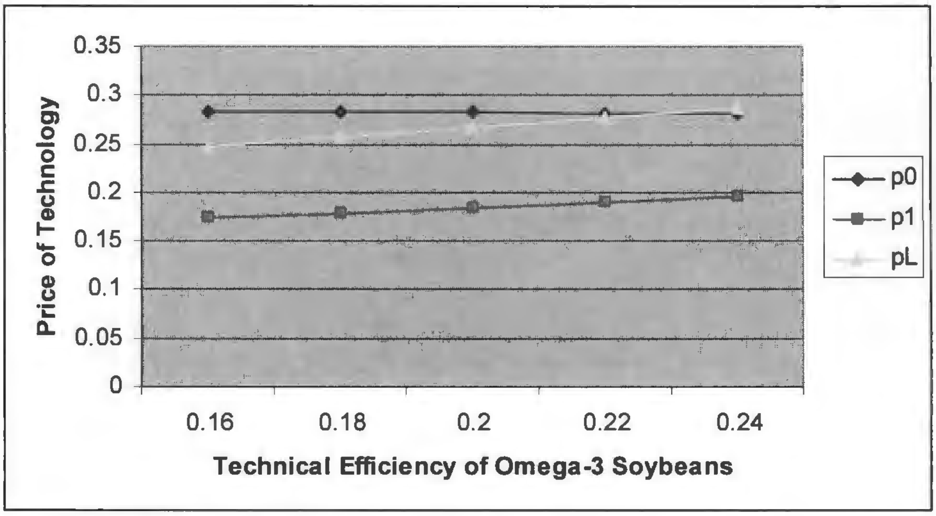

Figure 29. Impact of GM Omega-3 Efficiency on Technology Prices.

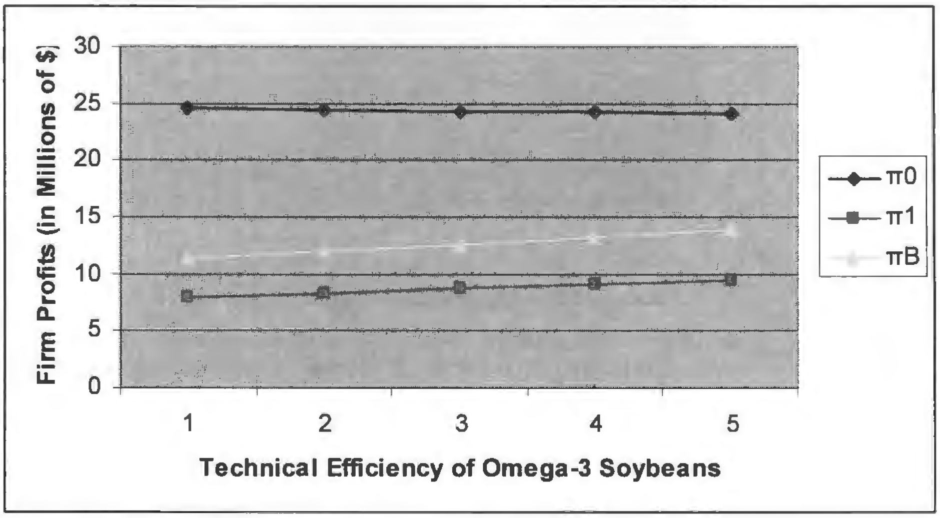

Figure 30. Impact of GM Omega-3 Efficiency on Firm Profits.

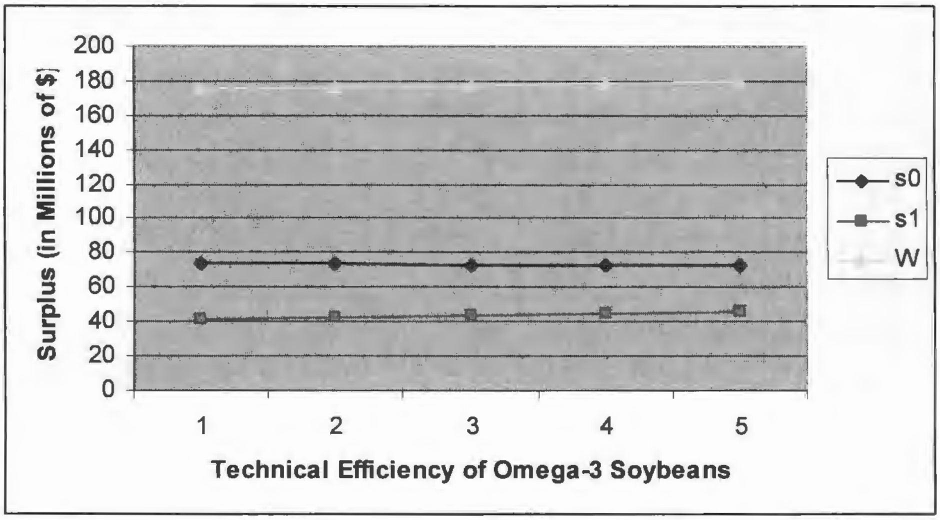

Figure 31. Impact of GM Omega-3 Efficiency on Surplus Levels.

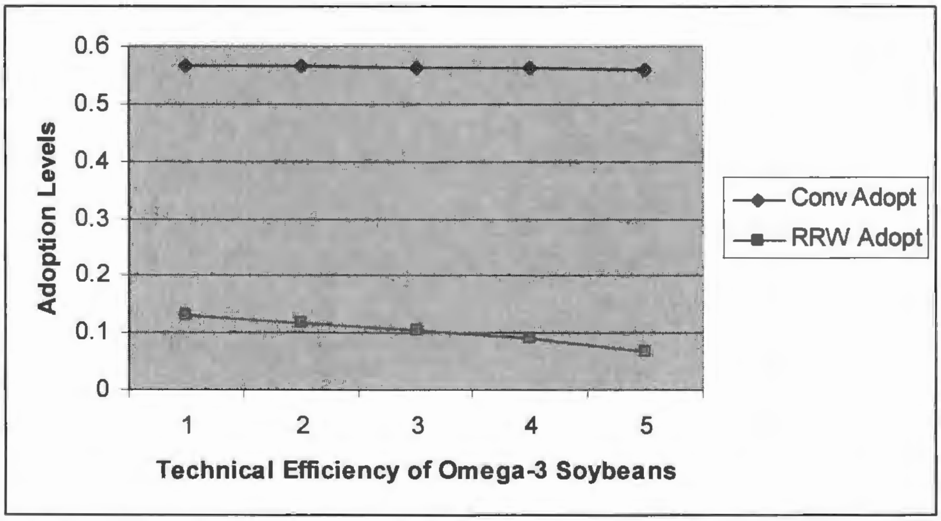

Figure 32. Impact of GM Omega-3 Efficiency on Adoption Levels.

Table B.1. Price Impact Model Results: Standard Deviation of Results

	p_0	p_1	p_L	Conv	GM	π_0	π_1	π_B	s_0	s_1	W
Sim.	-----$ lb-----		$/gal	*Adopt*	*Adopt*	------------------ $ million --------------					
#3	0.170	0.164	0.254	2.1E-03	4.1E-03	16.03	3.36	5.22	24.1	8.6	53.9
#4	0.118	0.132	0.186	2.3E-03	6.8E-03	7.74	2.20	3.10	23.2	8.8	50.6
#5	0.174	0.149	0.227	2.9E-04	5.8E-04	16.59	2.93	4.45	24.9	8.3	54.2
#6	0.121	0.115	0.157	3.2E-04	9.6E-04	8.08	1.75	2.38	24.2	8.3	51.0
#7	0.010	0.057	0.104	1.1E-03	2.1E-03	0.70	1.32	2.31	1.26	3.5	3.9
#8	0.009	0.062	0.104	1.1E-03	3.1E-03	0.47	1.30	2.08	1.63	3.9	3.4