UNIVERSITY OF CALGARY

Are Genetically Modified Foods Good?

The Welfare Implications of Agricultural Biotechnology

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS

DEPARTMENT OF ECONOMICS

CALGARY, ALBERTA

DECEMBER, 1999

Abstract

Agricultural biotechnology and genetically modified foods in particular, have been receiving increasing media attention as consumer awareness of the new technology spreads. Ethical concerns and fears over uncertain long-term health and environmental effects have been escalating. As a result of the uncertainty, some consumers are requesting informational labelling to provide them with the ability to choose between consuming genetically modified and non-genetically modified foods. This thesis looks at the effects of biotechnological innovation on the total welfare of society when consumers can and cannot distinguish between genetically modified and non-genetically modified foods. Since there is an adverse quality effect as well as a beneficial price effect, the overall effect on consumers and society as a whole is ambiguous in general and could be harmful.

Acknowledgements

I would like to thank Kelly and David for giving me the friendship and answers I needed to complete this degree. Thank you Jeff Gordon for giving me something to look forward to each week – Re use to L se. Thank you Greg Moore for making me proud to be Canadian and reminding how precious life is and to make the most every day we are given. Thank you Jacques Villeneuve for teaching me to push on through the days when the best option seems to be quitting. Thank you U2 for making the music that can relax yet energize me, excite yet soothe me. I would also like to thank my parents, Dianne and Marv, for giving me the foundation to be successful. Thank you my precious Connor for being so loveable. Thank you Dr. Gaisford for taking me in and helping me pursue the topic of my choice. Finally, thank you Dr. Kerr for giving me the confidence to believe I could come this far.

To my husband and best friend, Dale. Thank you for listening while I went on about this topic for what must have seemed like forever.

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Chapter 1 – Introduction

Are genetically modified foods good? The answer depends on the definition of "good". In the present analysis "good" is defined in the economic sense of the word. In economics an occurrence is good if the benefits to society are greater than the costs. In other words, genetically modified foods are good if the economic net benefit of the technological innovation is positive.

In recent years scientists have been able to develop new varieties of crops by manipulating their genetics and combining the desired traits of organisms to alter the characteristics of various crops. The new varieties have improved production characteristics and have the potential to provide consumption-specific attributes. Biotechnological innovation has introduced a whole new sector within agricultural production. While the introduction of genetically modified foods has the potential to radically transform agriculture, the benefits of productivity improvements must be weighed against public fears. Biotechnology gives rise to ethical issues and may have the potential to cause unforeseen long-term health and environmental problems.

Agriculture has been undergoing significant technological changes in the area of genetic engineering over the last decade. As adoption rates become more and more extensive, an understanding of the welfare implications of the technology grows in importance. Table 1 gives some insight into the adoption of agricultural biotechnology by producers.

Table 1. Acreage of Biotech Crops in Canada

Company	Product	Approval Date	Acreage 1996	1997	1998
AgrEvo Canada	Liberty Link canola	Mar-95	370,500	2,100,000	2,100,000
AgrEvo Canada	Liberty Link corn	Apr-97	n/c	n/c	300,000
Monsanto	Roundup Ready canola	Mar-95	50,000	450,000	2,000,000
Monsanto/Calgene	Laurate canola	Apr-96	5,000	5,000	5,000
Monsanto	Roundup Ready soybeans	Apr-96	n/c	6,000	150,000
Monsanto	YieldGard corn	Feb-97	n/c	60,000	700,000
Monsanto	NewLeaf Potato	Dec-95	1,500	5,000	10,000
Pioneer Hi-Bred	Pursuit Smart corn	Feb-96	n/c	10,000	20,000
Pioneer Hi-Bred	Pursuit Smart canola	Apr-95	n/c	1,600,000	2,100,000

n/c: not commercialized
Source: Sparks Companies

Genetically modified corn varieties covered just over one million acres in 1998, which is approximately 40 percent of the entire corn crop in Canada. The genetically modified canola varieties comprised about half of all canola acreage in Canada in 1998 (Sparks Companies, 1998). Similar adoption rates are found in the United States. In 1998 nearly 75 million acres of biotechnologically enhanced crops were planted, which is about 23 percent of the total acreage of all major crops. In the United States, cotton, soybeans, and corn are the most widely adopted genetically modified crops (Sparks Companies, 1998).

The early focus of biotech research on crops has been on input traits, particularly herbicide tolerance. Attention has recently expanded to output characteristics, with a wide variety of traits being pursued for human, livestock, and industrial markets.

However, input characteristics such as herbicide tolerance, disease and insect resistance, and stress tolerance still dominate research. Cost reducing or yield enhancing traits accounted for 87 percent of the field trials in 1997, with 51 percent of trials targeting herbicide tolerance (Sparks Companies, 1998).

This thesis considers how consumers' inability to distinguish between genetically modified organisms and non-genetically modified organisms affects the total welfare of society. A "pooling equilibrium" arises because the information structure will only sustain a single market for both types of products. Both a favorable price effect and an adverse quality effect arise under hidden information when genetically modified foods are introduced.[1] Some genetically modified foods can be produced at lower cost, resulting in a savings that can potentially be passed on to consumers, but depending on the preferences of consumers the perceived quality of goods available may fall. Depending on the relative magnitudes of the price and quality effects, biotechnological innovation can be good or bad. When the welfare of society increases as a result of the introduction of a genetically modified food it can be concluded that the genetically modified food is "good". In most cases, however, the analysis shows that biotechnological innovation affects total welfare ambiguously because of the competing price and quality effects, when asymmetric information persists. The technology is found to be welfare improving when consumers have no desire to differentiate genetically modified foods from non-genetically modified foods.

[1] The term "genetically modified food" refers to the final product consumed, while "genetically modified organism" refers to the genetically modified input to the final product. For example, canola oil is a genetically modified food, but the seed is a genetically modified organism.

A follow-up exploration looks at possible solutions to the consumers' information problem when genetically modified foods become available. Solutions include an identity preservation system, where firms label their products allowing consumers to choose between genetically modified foods and non-genetically modified foods accurately. In this case the available information sustains two separate markets and gives rise to a "separating equilibrium". When labelling is mandatory for genetically modified foods the analysis shows that if biotech innovation occurs it is welfare improving. The analysis also shows that no biotech innovation could be better for society than innovation with a policy of voluntarily labelling non-genetically modified foods.

The thesis is organized as follows; chapter 2 provides a general introduction to agricultural biotechnology. Chapter 3 describes the asymmetric information problem as it applies in the context of biotechnology and reviews the relevant literature on asymmetric information. Chapter 4 considers how asymmetric information at the consumer level affects the total welfare of society once genetically modified organisms become available commercially and a "pooling equilibrium" results. Chapter 5 follows with an examination of solutions to the asymmetric information problem that result in a separating equilibrium. Chapter 6 provides conclusions to the analysis and possibilities for future research.

Chapter 2 – What is Biotechnology?

Introduction

Biotechnology is the term used to describe various techniques employing the properties of living things, at the microorganism level, to make products or provide services (Grace, 1997). The use of 'living things' is not new. Dairy products, bread, wine, and antibiotics are examples of traditional products produced from biotechnology, but none of these would be considered biotechnology in the modern sense. Traditional biotechnology, which crossbreeds plants or animals to develop a new variety with a desired characteristic, has been used for thousands of years. With traditional breeding practices many generations of plants or animals must be grown to select for the desired characteristic. It can take up to 12 years to breed disease-resistant crop plant varieties (CFIA, 1997). Using the techniques of biotechnology, disease resistance can be introduced in 2-3 years (Kerr, 1999b).

What is new about modern biotechnology are the methods being used to derive the desired characteristics (Grace, 1997). Scientists are able to work more directly with genes to shorten the process of traditional breeding. Genetic engineering is one technique of biotechnology that allows scientists to transfer a specific gene from one organism into another, allowing the latter organism to manifest the new characteristic with more precise control over the potential effects than traditional breeding. Through the use of *transgenics*[1] it is also possible to introduce desirable traits from outside the

[1] Transgenics refers to genetic modification of an organism where the inserted gene originates from outside the species.

species, something that is not possible with traditional breeding techniques (CFIA, 1997).

Current Uses/Benefits of Biotechnology

For the moment the benefits of agricultural biotechnology are being seen at points in the food supply chain prior to consumption. The primary benefits are likely to accrue to biotechnology firms. Benefits to producers and processors are also likely to arise at least in the short term. Biotechnology firms benefit because they are the patent holders of the technology. Producers may receive a benefit from the products of biotechnology through a reduction in input costs required to produce high quality crops. Processors may receive a benefit because they have access to products that are more compatible with processing techniques.

Many genetic modifications have introduced herbicide tolerance to crops allowing farmers to control weeds more efficiently and at lower cost. Typically, farmers must use more than one herbicide, and possibly multiple applications, to fight a combination of broad-leaf and grassy weeds. Herbicide tolerance means one spray, and often only one application, is effective in killing most weed pests without harming crops. Consider the following example demonstrating the cost savings available with genetically modified canola:

> A producer chooses between seeding genetically modified or non-genetically modified canola. The producer who chooses genetically

> modified seed does not have to do any pre-seeding preparation of the field. However, the producer who chooses non-genetically modified seed must either till prior to seeding or spray with a non-selective herbicide if no-till farming is employed. Herbicides applied on non-genetically modified crops are more expensive than those used on genetically modified crops. The genetically modified seeds, however, are more expensive than non-genetically modified seeds. These two costs balance, therefore, the cost savings offered by genetically modified canola comes from not having the pre-seeding preparation involving till or spray (Horachek, 1999).

With genetically modified (GM) seeds farmers spend less time in the field, lowering fuel costs and reducing their exposure to chemicals. Herbicide tolerance, through reduced pesticide use, can benefit more than just farmers, it can also benefit the environment. Less herbicide use means less environmental damage.

Biotechnology has been used in other ways to reduce the environmental impact of current farming practices. For example, the bacterium, Bacillus thuringiensis (more commonly known as Bt) is responsible for producing insecticide. Using biotechnology techniques the Bt gene is inserted directly into commercial plant varieties, producing the toxin when activated. With Bt present in the plant, as particular insects attack the plant the bacteria is activated, killing the insect, leaving the crop unharmed. Introduction of the Bt bacteria removes the need to apply insecticides to crops that would otherwise be

susceptible to particular insect pests. Bt genes have been inserted into corn, cotton, tomatoes, and potatoes to produce pest-resistant varieties, eliminating pesticide use. Using fewer herbicides and insecticides in less powerful doses can, therefore, significantly reduce the impact of pesticides on the environment (Grace, 1997).

The world's population is expected to reach 8 billion by 2020 (FAO, 1999). Reducing the loss of crops due to insects and weeds also increases the productivity of land allowing more people to be fed while staying within the limits of the arable land available.

One of the first genetically engineered products available to farmers was recombinant bovine somatotropin (rBST), also referred to as bovine growth hormone (BGH), or simply BST. The hormone is produced naturally by cows to promote growth in calves and regulate milk production in dairy cows. The engineered version of the hormone is used to increase a cow's milk yield by up to twenty percent. It is manufactured using copies of bovine genes, so the product administered to the cow is essentially the same as that made by the cow herself. Nonetheless, the use of recombinant BST has been the subject of heated controversy (Grace, 1997).

Health Canada has been assessing the safety of rBST for some time and in 1998 made the decision not to approve the hormone for sale in Canada. Studies were done to assess the human and animal safety implications. The scientific review found no significant risk to human safety by consuming products from animals injected with the hormone. However, rBST was rejected based on the safety risk placed on the injected animals because increased risks of the occurrence of mastitis, infertility, and lameness

were found (Health Canada, 1998). The European Union (EU) has placed a moratorium on use of BST until 2000 and banned imports of milk from BST-treated cows. However, the reason for this reaction may have been the EU's oversupply of milk, rather than concerns about safety (Sparks Companies, 1998).

Biotechnology has played a vital role in cheese production. Traditionally, rennet (used to enhance the curdling of milk to produce cheese) had to be obtained from calves' stomachs. In the late 1980s researchers were able to transfer the DNA responsible for producing the enzyme chymosin, which performs the same function as rennet, into commercial microorgansims. These microorgansims provide cheese satisfying religious regulations and vegetarian needs (Grace, 1997). The Vegetarian Society, which rejects all other genetically modified foods, has given approval of the chymosin-based products (The Times, 1999).

Public Concerns

As quickly as biotechnology seems to have been introduced, public concerns have arisen. The concerns range from the environmental impact of biotechnology in agricultural production to long-term health effects. A key concern revolves around unknown long-term health effects, which include scientists' inability to predict the impact of biotechnology and the cumulative effects of consuming genetically modified foods (GMFs) over time (House of Lords, 1998). This is very much a fear of the unknown, a sense that "meddling" with the genetic make-up of foods is somehow unnatural and will lead to unintended side-effects in later years. The use of antibiotic

resistant marker genes[2] has given rise to concerns that this practice may contribute to the growth of antibiotic resistance in humans and animals (Citizens' Panel, 1999; House of Lords, 1998)

Individuals have expressed concern over the risks to humans and/or animals as a result of an increase in the allergenicity of foods that have been genetically modified (House of Lords, 1998). Individuals are not alone in their concern over potential allergens. The food industry and safety assessment bodies in North America and Europe are also concerned. In Canada, the potential for allergenic responses to genetically modified foods (GMFs) are considered by looking at the history of both the host and the donor organisms as well as the modification that has taken place (CFIA, 1998c). In the US, firms are not exploring the use of genetic material from foods commonly associated with allergies, like peanuts, because safety testing and regulatory hurdles are extensive. A benefit commonly overlooked is that biotechnology is beginning to be used to modify proteins to eliminate the triggers of allergic reactions (Center for Consumer Research, 1999).

Several environmental concerns have become evident. Individuals are worried about the effect genetically modified organisms (GMOs) could have on biodiversity. They are concerned that GMOs will reduce the size of the gene pool with unknown consequences. Other environmental concerns follow from the possibility of gene transfer where seeds from a genetically modified crop cross-pollinate with a non-genetically modified crop. Several studies have been conducted and most, though not

[2] Marker genes are used to track the presence of a modified gene.

all, have concluded that the probability of gene transfer is minimal (see Lefol et.al. (1996), Bing et. al. (1995), and Salisbury and Wratten (1997)). The UK government has requested that barriers between GM crops and non-GM crops be widened from 2 miles to 5 miles (Perdikis et al., 1999). Individuals are also concerned about the loss of traditional foods if gene transfer cannot be controlled. They question scientists' ability to preserve traditional products, wondering if non-genetically modified foods will exist as an alternative in the future.

There has been talk that the development of herbicide tolerant crops could create "superweeds". The concern is that weeds will become immune to herbicides, will be more difficult to control and, as a result, more herbicides will need to be applied. The basis for this concern has not been supported scientifically. Moreover, developers of pesticides have always had to deal with problems of resistance by regularly developing new chemicals (Hobbs and Plunkett, 1999).

Concern also arises from individuals who question the ethics of genetic engineering. They feel it is unethical for human beings to play God, or tamper with Mother Nature. Some are frightened that if the developers of the technology continue, and individuals follow their lead by purchasing these products, Mother Nature will react negatively. Most surveys have shown there are distinct ethical opinions among individuals regarding the application of biotechnology. Many are not willing to accept the genetic modification of animals or humans, but applying the technology to plants is far less controversial.

Individuals have shown concern that biotechnology involves risk-taking simply for commercial gain (FAO, 1999). The patenting of genes is another matter of interest because some individuals question whether human beings have the right to own life forms. The introduction of modern biotechnology highlights many moral and ethical concerns which are nearly impossible to resolve.

Some religious groups have questions about violating dietary bans. Some have suggested that eating pigs modified by human genes makes consumers cannibals. These concerns lose credibility because DNA is not species specific. Human beings already have genes in common with many other plants and animals – the very reason genes can be transferred between different organisms (Grace, 1997).

Recent Test Results; Is There a Scientific Basis for the Concerns?

Scientific evidence to support these consumer concerns is at best patchy and at worst contradictory. Genetic engineering introduces a protein to the food that previously did not exist in the product. The "new" protein is digested in the same way as any other protein. It is broken down into amino acids (which are the building blocks of proteins) and absorbed by the body. Whether the protein is from genetically modified soya, for example, or non-genetically modified soya is irrelevant because the amino acids are the same, therefore, no long-term health risks are expected (FBCN, 1999b).

In response to concerns over the effects of GMFs on biodiversity, a study of Monarch butterflies was conducted by scientists at Cornell University. The study found that when the Monarch butterflies' larvae was covered with pollen from genetically

modified (Bt) corn the butterfly experienced higher mortality rates than larvae coated with non-genetically modified pollen. Thus, Bt corn could threaten the existence of the Monarch butterfly. John Losely, one of the scientists who took part in the experiments with the Monarch butterfly admits his work does not condemn Bt technology, which he says has known benefits, but shows there are unexpected effects. However, Don Lafontaine, an entomologist with Agriculture and Agri-Food Canada, says it is unlikely that Bt pollen will seriously affect Monarch populations because of their large numbers and wide range covering almost all of eastern North America (Western Producer, 1999a).

In the summer of 1998, Arpad Pusztai, an expert on plant proteins, found, while working at the Rowatt Institute in Aberdeen, Scotland, that genetically modified potatoes can damage rats' vital organs and weaken the immune system. A review by Stanley Ewen, a pathologist at Aberdeen University's Medical School, supported Pusztai's conclusions (Western Producer, 1999b). However, in May 1999, a review by The Royal Society, which is an independent academy of British scientists, indicated that Pusztai's research was flawed in its design, execution, and analysis. Therefore, they concluded his results were irrelevant (Western Producer, 1999c).

Scientific studies have supported and rejected some of the concerns expressed by individuals. Many studies continue to be contradictory, compounding the confusion surrounding GMFs.

Public Attitudes

The attitudes expressed by consumers vary greatly across groups within countries, but most notably, attitudes vary between continents. Attitudes in North America and the European Union have been well documented relative to attitudes around the world. Therefore attitudes in North America and the EU will be the focus of discussion in this section.

Individuals in the European Union show a distrust of biotechnology, its applications, its developers, and its regulators. In Europe fears are understandable. According to the Economist (1999a), European governments have a record of suppressing "inconvenient" scientific data, and when that does not work, of simply lying about food safety. Several surveys have been conducted to clarify the attitudes and concerns consumers have regarding modern biotechnology. An EU funded three-year study published in 1998 suggests Europeans place more trust in consumer groups (33%) and environmental groups (24%) for information on biotechnology than industry or government. More than half the people surveyed (51.8%) felt current regulations are insufficient to protect people from health risks. In the UK, where knowledge is relatively high, GMFs are seen as being purely in the interest of producers and retailers, with a lack of consumer benefits (FBCN, 1999a).

A 1999 poll commissioned by Greenpeace in Scotland showed 59 percent of those surveyed believe genetically modified foods should be banned and 44 percent said they would vote for a parliamentary candidate if they campaigned for a ban on GMFs.

Moreover, 57 percent said they would not consume GMFs, but 31 percent said they would (Friends of the Earth, 1999).

In the UK, a MORI poll conducted in June 1998 for the Genetic Engineering Group revealed that 77 percent of those surveyed favoured a ban on growing GM crops and food, with a further 61 percent not wanting to eat GM foods. Other surveys over the past year have indicated a prevailing public backlash against GM foods with strong preferences among a majority of UK consumers for labelling food containing GM ingredients (Hobbs and Plunkett, 1999; Perdikis et al., 1999).

UK supermarkets have responded to concerns by announcing their intentions to remove all GM ingredients from their own-label product lines. Some food manufacturers have followed suit. Twenty-four of the top thirty UK food manufacturers including Cadbury's, Heinz, and Kellogg's have removed, or will be removing, genetically modified ingredients from their in-house brand products (Friends of the Earth, 1999).

As a result of newspaper articles referring to GMFs as "Frankenstein Foods" and recent food scares, public concerns are growing which is reflected in a few countries partially banning GMFs. Denmark, Britain, and France have called a partial halt to approvals of genetically modified organisms while Austria, Luxembourg, and France have banned new crop strains. These three countries, along with Greece, have declared an import and commercialization ban on GM corn and canola, despite the fact that the crops have received EU approval (Perdikis et. al., 1999).

Attitudes in North America are much more passive than in the EU, but concerns are growing. In an issue published early in 1999, The Economist gave four possible explanations for this:

> "First, Americans may simply feel more positive about technology in general, and thus more willing to accept its biological version. Second, because America keeps its agricultural heartland separate from its rural playgrounds, concerns about the environmental effect of GM food may be less intense. Third, Americans have a stronger economic incentive than Europeans, since it is often their companies that produce the stuff and their farmers who grow it. And fourth, Americans may already have made their peace with GM foods after debating their regulation in the early 1990s. Or Americans may simply be woefully ill informed about what is going on (The Economist, 1999a, p.20)."

The Economist seems to have omitted from its list the fact that Americans (and Canadians) generally trust their governments' ability to objectively assess the health and environmental effects of genetically modified organisms (GMOs) before being approved for commercial production.

In a survey commissioned by the Government of Canada in March of 1998, 90 percent of Canadians said that maintaining biodiversity was very important to them, only 12 percent felt the federal government was doing a poor job with respect to biotechnology, and most surveyed (87%) expressed some level of confidence in food safety regulations. In Canada, consumer groups, biotechnology companies, and environmental groups were found to be much less trustworthy than health care professionals and scientists (in industry, universities, and government) which differs

from the agencies held in high esteem by EU citizens as mentioned above (Industry Canada, 1998).

Genetically modified foods were the subject of discussion at a citizen's conference held in March 1999 at the University of Calgary. Many concerns were expressed at the conference including: genetic modification of animals, gene patenting, increased pest resistance, gene transfer of GMOs posing environmental risks, biodiversity being threatened, and the implications of genetic engineering not fully understood by the scientific community (Citizen's Panel, 1999).

Hoban (1997) reported that between two-thirds and three-quarters of US consumers support biotechnology and are willing to accept GMFs. In the survey, which included sixteen European countries and Japan, consumers in Canada and the US were found to have the highest willingness to buy foods modified to resist pests.

Canada's Regulatory System

The Federal Regulatory Framework for Biotechnology (1993) addresses Canada's international commitments under the United Nation's (UN) Commission on Sustainable Development and the UN's Convention on Biological Diversity (Industry Canada, 1998). The Regulatory Framework is intended to ensure that the benefits of biotechnology evolve while protecting health, safety, and the environment. The principles adopted include: protecting the health of Canadians and the environment; adapting existing laws and regulatory departments; providing a sound, scientific knowledge base to assess risk and evaluate products; and ensuring that development and

enforcement of Canadian biotechnology regulations are clear, include consultation, and are consistent with national priorities and international standards (Industry Canada, 1998).

This framework is the result of an agreement, between the agencies and departments responsible for regulation, on principles for an efficient and effective approach to regulating the products and processes of biotechnology. There are two federal regulatory bodies involved where GMOs are concerned, Health Canada and the Canadian Food Inspection Agency. The roles of each are described below.

Health Canada

Health Canada has primary responsibility for human health related issues and, as such, is the lead agency in assessing food safety. Health Canada sets standards for the safety of the food supply, including genetically modified foods. Specifically Health Canada:

- establishes health, safety, and quality standards for food processing facilities;
- evaluates the safety of additives, pesticides, animal drugs, and chemical residues;
- inspects, monitors, and tests to ensure products adhere to safety standards

(CFIA, 1997).

All food products, including products of biotechnology, must pass Health Canada's safety assessment procedures before becoming available commercially. Safety assessments of GMFs are carried out using information and criteria described in Health Canada's Guidelines for the Safety Assessment of Novel Foods (Volume II: GMOs and

Plants). These guidelines establish the requirements for the pre-market notification and safety assessment of GMFs. Safety assessments are based on a comparison of the modified food to its traditional counterpart in terms of molecular, compositional, toxicological, and nutritional data (CFIA, 1998a). Health Canada evaluates this information to "make a decision as to whether the food should be permitted for sale" (CFIA, 1998b).

Canadian Food Inspection Agency

In Canada, genetically engineered foods are regulated in the same manner as foods produced by traditional methods in order to protect human, animal, and environmental health. The Canadian Food Inspection Agency (CFIA) is the lead agency responsible for regulating products of biotechnology. Specifically, the CFIA is responsible for regulating the performance and environmental safety of the product in question as well as inspection and monitoring to ensure registered products continue to meet quality and safety standards after registration (CFIA, 1998b).

Among the duties of the CFIA are:

- inspection and registration of facilities, food, animals, and licensed fruit and vegetable dealers;
- monitoring quality, grade, packaging, and labelling practices according to national standards;

- designing and conducting laboratory testing programs to ensure agricultural products meet safety standards, and;
- certifying products for import or export

(CFIA, 1997).

U.S. Regulatory System

In the US GMFs are regulated by the Food and Drug Administration (FDA), Environmental Protection Agency (EPA), and the United States Department of Agriculture (USDA). The FDA has primary responsibility for regulating food additives and new foods, domestic or imported, except meat and poultry products which are regulated by the USDA. The FDA's authority comes from the Federal Food, Drug, and Cosmetic Act (FFDCA) (Biotechnology Information Series, 1999). The FFDCA places a legal duty on developers to ensure that the foods they present to consumers are safe (Maryanski, 1995).

The FDA uses a multi-disciplinary approach in its approval process. This approach relies on information pertaining to the agronomic and quality attributes of the plant, genetic analysis of the modification and stability of expected traits, evaluation of the toxicity and allergenicity of newly introduced proteins (USEU, 1999). The EPA regulates pesticides used in or on foods under the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) and the FFDCA. A common application of genetic engineering is the use of bacillus thuringiensis (Bt) to produce pest resistant crops, such as Bt corn and Bt potatoes. These crops fall under the jurisdiction of the EPA.

Regulations are used to ensure that there are no adverse effects on the environment or non-target organisms (IFIC, 1999). The USDA and one of its divisions, the Animal and Plant Health Inspection Service (APHIS), develop policy, regulations, and review all environmental releases (from field trials to commercial plantings) of genetically engineered microorganisms, animals and plants. Permits are issued by APHIS after scientific review of potential environmental impacts (Maryanski, 1995).

Labelling policies are similar in Canada and the United States. In the US labelling is required in situations where genes to which some people are allergic are transferred from one species to another. For example, if a gene from peanuts, a food that commonly causes allergic reactions, were inserted into corn, the corn would have to be labelled. The only way labelling can be avoided is if the corn is proven, to the satisfaction of the Food and Drug Administration (FDA), not to produce an allergic reaction (Biotechnology Information Series, 1999). The same policy is used in Canada.

The policy response to biotechnology has also been similar in Canada and the US. Their policies are based on similar principles which include:

- Focussing regulation on the product rather than the process. The safety of the new plant, animal, or product is examined rather than the mechanism by which it was developed (Biotechnology Information Series, 1999).
- GMFs are regulated in the same manner as food derived from conventional methods.
- Existing laws are being adapted to accommodate GMFs.
- Only if the GMF is significantly different from the non-GMFs already available commercially do the GMFs have to go through a safety assessment.

EU Regulatory Process

Policymakers in the EU have attempted to raise consumer confidence in their ability to provide a safe food supply as they formulate biotechnology policy. The EU has chosen to develop new legislation to regulate biotechnology separate from existing legislation because the risk associated with GMFs is assumed to differ from the risk associated with other food products. This action is different from that being carried out in North America where existing laws are being adapted to regulate biotechnology.

On 15 May 1997 the European Community's Novel Foods Regulation came into effect and introduced a mandatory pre-market approval system for novel foods (including GMFs) throughout the EU. The Novel Foods Regulation requires foods derived from genetically modified soya and corn be labelled as genetically modified, beginning 1 September 1998, if either protein or DNA resulting from genetic modification is present (House of Lords, 1998).

Before a GMO can be released into the environment, the manufacturer or importer must show that commercialization of the GMO poses no risk to human health or the environment. Approval of GMOs in the EU falls within the jurisdiction of the regulatory document, Deliberate Release into the Environment of Genetically Modified Organisms (90/220/EEC) (Engel et al., 1995). The document establishes the procedure for authorizing the commercialization of products containing GMOs which involve notifying the appropriate agency in the country where the product will be marketed for the first time. This agency carries out the environmental risk assessment. The applicant

must provide information on data and results obtained concerning any risks for human health and the environment. If the application is not rejected it is passed on to the EU Commission. The Commission is responsible for undertaking an EU-wide consultation (Engel et al., 1995). However, through legislative provision countries can refuse to accept GM crops already approved by the European Commission if they have new evidence of risk. Recently France, Austria, and Luxembourg exercised this right to reject some types of GM corn and canola (The Economist, 1999a).

Japan's Regulatory System

In Japan, the approval process for GM crops differs based on whether the crop is intended for human or animal consumption. In all cases, however, the first step in the process is a review by the Ministry of Agriculture to determine whether the product could have an impact on the environment. If the product is intended for animal consumption, the Ministry of Agriculture will then evaluate the safety of the product and its effects on livestock. After this review is complete, the Ministry of Agriculture will or will not approve the crop. If the product is intended for human consumption, the Ministry of Health and Welfare and the Council for Food Safety conduct the evaluation. The Ministry of Health and Welfare tests the product and gathers data related to human consumption (e.g., digestion, metabolic effects, and toxicity). Once the tests are complete, the Council for Food Safety evaluates the data and makes a recommendation to the Ministry of Health and Welfare, which has the final say in approving the product (Maryanski, 1995).

International Trade Issues

As a result of, and in addition to, food safety concerns and public attitudes, GMOs present a new dilemma in the international arena. Current international trade agreements do not deal with GMOs, allowing potentially unfair trade barriers to be erected with domestic food safety concerns as the justification. Barriers that are perceived as unfair often result in trade disputes. The World Trade Organization (WTO) governs international trade among most countries and is responsible for dispute settlement. Without international agreement on the treatment of GMOs, the WTO could have many disputes to settle with no guiding principles (Kerr, 1999a).

National standards for assessing the safety of GMOs tend to differ significantly across countries. These differences, in turn, lengthen the approval process proportionately, causing interruptions in trade. Once again, the lack of international standards means countries are free to set their own standards with the objective unclear. It may be that assessment procedures are formulated solely to ensure safety requirements are satisfied. More controversial though, national standards may be used as a non-tariff barrier to restrict imports, providing protection for domestic firms. The distinction between the two objectives is not obvious and proof of the intended objective is difficult, if not impossible. These conditions can lead to further trade disputes, testing the strength of the international agreements that do exist.

Several international agreements exist that are relevant to the international movement of GMOs. Each agreement has strengths and weaknesses as a governing body able to establish guidelines for trade in GMOs, though none are ideal. The

agreements to be discussed below include the Biosafety Protocol, the Codex Alimentarius, and the Agreement on Sanitary and Phytosanitary Measures.

Biosafety Protocol

The Biosafety Protocol, when finalized, will be an international agreement among the member countries of the UN's Convention on Biological Diversity. The purpose of the Convention on Biological Diversity, of which Canada is a member, was to affirm the international community's commitment to conserve and protect biodiversity. The member countries of the Convention on Biological Diversity are negotiating the Biosafety Protocol. The Biosafety Protocol will set rules for living modified organisms (LMOs) traded internationally which may negatively affect biodiversity (CFIA, 1998d). LMOs are a subset of GMOs that retain metabolic activity or are reproducible. For example, canola seeds can reproduce (i.e., they retain their metabolic activity), thus are categorized as LMOs. Canola oil, however, cannot produce more oil and is not considered an LMO, but a GMO.

Presently, 171 countries have signed the Convention on Biological Diversity and 134 countries have ratified it. One of the countries continuing to refuse ratification of the Convention is the United States (Isaac and Phillips, 1999). Until the United States agrees to the Convention on Biological Diversity the Biosafety Protocol may have difficulty being effective internationally.

In order to protect biodiversity, the initial scope of the Biosafety Protocol was to develop a set of legally binding rules for testing, import, export, deliberate release, and

commercial use of LMOs. The importing country would be responsible for the assessment. Upon completing the scientific risk assessment the importing country can choose to grant or deny importation of the LMO depending on the identified risk(s) to biodiversity (Isaac and Phillips, 1999). The governing process of the Protocol is to be Advance Informed Agreement (AIA).

> "AIA refers to the notion that a product or organism will only be transferred (shipped) after the agreement of the receiving country has been obtained. Any effective AIA system relies on the early transfer of quality information, thus allowing any potential receivers to make a fully informed decision on the acceptability of importing the product or organism concerned (Convention on Biological Diversity, 1997)."

AIA is supposed to allow countries to assess the potential for negative impacts on biodiversity of the initial import or export of LMOs. The principle of AIA allows for less rigorous criteria in regulating the international movement of agricultural products than the scientific basis required by the SPS agreement, to be discussed below.

The Working Group on Biosafety noted that there is not yet a comprehensive system for controlling the international movement of LMOs. As shown below, the Codex Alimentarius' coverage of LMOs is secondary to the main purpose of current international agreements. Therefore, the Working Group has the purpose of designing an agreement with the administrative capacity and membership of the more established agreements, as well as the specific focus on LMOs lacking in most of those agreements.

Negotiations during the development of the Protocol have shown that many of the negotiating parties have different ideas about the scope the Protocol should take. Some countries feel the Biosafety Protocol should focus on the risks to biodiversity of

international movement of LMOs. Others have suggested that the Protocol take a more comprehensive approach to include biodiversity, food safety, economic development, and moral, ethical, and religious concerns surrounding GMOs/LMOs. Once a final Biosafety Protocol is completed and signed, a minimum number of countries will have to ratify the Protocol before it takes effect, which could take several years (Isaac and Phillips, 1999).

Codex Alimentarius

The Codex Alimentarius is an internationally developed code of food standards. It was developed by the Codex Alimentarius Commission established in 1962 by the Food and Agriculture Organization of the UN and the World Health Organization. The purpose of the Codex is to establish and to harmonize definitions and requirements for food to facilitate international trade. The standards were set to raise the quality of the food supply and to provide consumers with healthy food products (Convention on Biological Diversity, 1997).

Membership in the Codex is not mandatory and member countries are not required to adhere to the standards developed. Standards are developed through consultation among, and information sharing with, Codex's 28 commodity specific committees, the Commission itself, member governments, and others including trade and consumer groups. The commodity specific committees draft standards and make recommendations to the Commission. The Commission then formulates standards to be reviewed by the member governments and others. The list of countries adopting the

standards is published so exporters are aware of the regulatory framework in potential markets (Convention on Biological Diversity, 1997).

The Codex has not yet begun to address biotechnology related issues on a regular basis, but may in the future. The mandate, however, is not expected to be broadened to include issues relating to the conservation and sustainable use of biodiversity (Convention on Biological Diversity, 1997).

Agreement on Sanitary and Phytosanitary Measures

One of the major achievements of the Uruguay Round was the agreement on Sanitary and Phytosanitary Measures (SPS). The SPS agreement codified for the first time the principle that such measures should be used only in response to legitimate health or scientific concerns. It states that phytosanitary trade barriers should be, applied only to the extent necessary to protect human, animal or plant life or health, based on scientific principles, and not maintained without sufficient scientific evidence (Kerr, 1999a). Other obligations of the SPS relevant to GMOs include the following: (i) sanitary and phytosanitary measures are to be based on an assessment of risk, and (ii) countries have committed to cooperation in designing international standards for food safety and sanitary and phytosanitary regulations. Each country does its own risk assessment and the acceptable level of risk is established by each country. This autonomy allows governments to incorporate their country's social and cultural concerns in determining the acceptable level of risk (Kerr, 1999b).

With the SPS agreement, it was intended that non-tariff barriers would no longer be used unpredictably to protect domestic industries (Kerr, 1999b). It was widely believed that this agreement would allow for an unbiased system of evaluating the scientific basis behind phytosanitary trade barriers. Import bans may still be imposed, but these countries leave themselves open to retaliation.

The picture was clouded considerably by the WTO's dispute settlement panel's recent ruling in the US/EU case over hormone treated beef. The panel restated that bans like the EU ban on hormones were allowable only if used for health reasons, not if they were implemented for trade reasons. It said that there must be a scientific basis for any food safety standards and found that the EU had not shown sufficient scientific justification for its ban, seemingly siding with the US and Canada in the dispute. However, it also agreed with the EU that member states could have the right to establish, on a scientific basis, levels of consumer protection that are higher than prevailing international health standards. There has not yet been a test case in the WTO over GMOs or similar agricultural biotech products, and it seems increasingly uncertain how the WTO would attempt to settle any such dispute (Sparks Companies, 1998).

Recently, the EU has suggested that the SPS be renegotiated to create a broader list of ways to judge the acceptability of food, including consumer acceptance and even ethical considerations. Canada says it will resist the EU's efforts to expand the definition of how to judge the safety of food products involved in trade (Western Producer, 1999a).

The Future of Biotechnology

The future of biotechnology is difficult to predict beyond an expectation that it will be pervasive in agriculture rather than peripheral. We can only guess what the possibilities are for this relatively new technology. One thing is certain, however. The emphasis of innovation will expand to include consumption characteristics in addition to production characteristics. The following are just a few of the changes expected in the future. Improvements in the quality of meat, milk, eggs, and wool, and an ability to produce healthier, faster-growing animals are expected. Reproductive technologies will allow farmers to get more offspring from select animals. Fine-tuning genetic control can provide such things as designer milk (custom-made for yogurt production or lactose-intolerant consumers) and engineered sheep growing wool ideal for carpet-making (Grace, 1997).

In Canada, scientists are testing genetically modified alfalfa, grapes, and winter barley for improved freezing tolerance. For example, researchers estimate that grape production in Ontario could double by developing grape varieties able to resist freezing at temperatures 2°C lower than current vines (Grace, 1997).

Soil quality is essential in influencing crop productivity. Modern intensive farming methods usually require large inputs of fertilizer to maintain the level of soil nutrients required by high yield crops. One of the most important benefits of biotechnology would be crops genetically engineered to fix their own nitrogen, a trick that legumes perform naturally. It may be easier to modify the crop to suit the soil rather than the soil to suit the crop. For example, researchers are studying ways to engineer

salt tolerance into crops. This could make it possible to expand farmland into marginal areas with poor soils, or even to irrigate fields with seawater. Within agriculture the ultimate goal of biotechnology research is to engineer plants ideal for every growing condition and market niche (Grace, 1997; The Times, 1999).

The future of biotechnology involves more than agricultural production. There is potential for food to provide more than just calories and essential nutrients. Biotechnological innovation has the ability to engineer foods to delay the onset of degenerative diseases and aging, and contribute to a healthier society (Kishore and Shewmaker, 1999).

Crops may be altered to contain higher levels of vitamins or chemicals to provide protection against heart disease and cancer; potatoes with lower starch levels absorbing less fat when fried; salad crops that remain crisper longer; and melons and raspberries that ripen more slowly keeping them in good condition longer. Nuts without the allergens and cotton with longer, stronger fibers, and *colour* may be developed (The Times, 1999).

> "Genetic engineering is also turning plants and animals into living factories for making drugs, industrial chemicals, fuels, plastics, medical products, and other materials. For example, altering the structure of fatty acids in oil-bearing plants, such as canola, flax, and soybeans, which can be used to manufacture anything from hydraulic fluids to nylon (Grace, 1997, p.125)."

Cornstarch is a versatile and abundant raw material, produced by plants at about the same cost per pound as crude petroleum. By manipulating the genes responsible for starch production, bioengineers can produce starches with different properties. Canadian

researchers have developed an edible plastic film from a combination of pea starch, pea protein, and canola oil. Products like this might one day be used to package foods such as noodles or soups, allowing the whole package to be dropped into the cooking water, and leaving less waste for disposal (Grace, 1997).

Transgenic plants can also be made to produce completely new products. Engineered canola, for example, is now a source of the blood anticoagulant hirudin, which is normally made by leeches. Hirudin is a clotting promoter that produces a very low rate of immune reactions in patients. It is a good example of the sort of high-value product that is economically worthwhile for biotechnology companies to develop. Leech genes that code for the protein are added to canola plants, which then produce hirudin. The hirudin molecules cluster around oil bodies in the plant cells, making it a fairly straightforward process to extract and purify them (Grace, 1997).

The future of biotechnology looks intriguing and, as this chapter has attempted to illustrate, the issues raised by biotechnology are complex. In identifying the challenges and characteristics that arise as a result of the introduction of biotechnology products from an economics perspective one fundamental issue stands out. There exist improved production and consumption characteristics from biotechnology. Production characteristics tend to be those that consumers are unable to identify. For example, consumers will not be able to determine whether the plant that produced the canola oil they use was genetically modified to be herbicide tolerant. Herbicide tolerance is a characteristic of the plant, not the oil. Consumption characteristics are those that appeal directly to consumers and, therefore, some consumers would like to be able to establish

the presence of the characteristic prior to or shortly after purchase. Examples of consumption characteristics include canned vegetables with higher than average vitamin content, or lettuce that remains crisp longer. Depending on whether the genetic modification has been done to improve a production or consumption characteristic, consumers may be able to distinguish between GMOs and non-GMOs. If there is a production characteristic, consumers are not likely to be able to distinguish between GMOs and non-GMOs. If there is a consumption characteristic, consumers are likely to be able to distinguish between GMOs and non-GMOs. The economic implications of the ability or lack of ability of consumers to distinguish between GMOs and non-GMOs will be discussed in the following chapters. There exists an extensive literature that addresses consumers' inability to determine quality prior to purchase. In the next chapter relevant elements of this literature will be reviewed.

Chapter 3 – The Asymmetric Information Problem and Literature Review

From an economics perspective the analysis surrounding the introduction of genetically modified foods presents an interesting application of a familiar problem. The commercial availability of GMOs and non-GMOs presents an asymmetric information problem when the seller has more information about the product than the buyer. In this case the information asymmetry results from consumers' inability to distinguish between genetically modified and non-genetically modified products.

To date, genetic engineering has resulted in changes to organisms benefiting production practices through a reduction in costs. The first wave of modifications has been tailored to appeal to producers, providing an incentive for them to adopt the new technology. Biotechnology companies realize that before consumers can have an opportunity to accept these new products, the producers must first choose to grow them rather than their non-genetically modified alternatives. The modifications emphasizing production characteristics, like pest resistance and herbicide tolerance, are more likely to result in asymmetric information than future modifications that are expected to have positive consumption characteristics. Consumers should be able to distinguish the consumption characteristics either before purchase or immediately after consumption, which is not possible with production characteristics. For example, a potato plant engineered to resist pests produces a potato that is difficult and may be impossible to distinguish from a non-modified potato, but a potato that is engineered to cook twice as fast as a conventional potato can be distinguished from the non-modified potato upon

cooking. Discussion in this chapter will be restricted to genetic modification of production characteristics unless stated otherwise.

The idea that goods are a bundle of characteristics is reminiscent of Lancaster's Theory of Characteristics first published in 1966. In his seminal article Lancaster describes a new approach to consumer theory. Utility does not derive from goods, but rather, utility derives from a combination of properties that characterize the good. "The good does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility (p.134)." Lancaster uses meals as an example. A meal, which is traditionally treated as a single good, has nutritional and aesthetic characteristics with different meals possessing these characteristics in different proportions. Thus, different meals provide different levels of utility, a concept not possible when a meal is treated as a single good. The utility derived from canola oil can vary considerably across consumers depending on how they value the genetically modified or non-genetically modified characteristic. It is not the oil itself that provides utility. Rather, utility arises from the combination of characteristics such as calories per serving, cholesterol, saturated fat levels, and whether the food is genetically modified or non-genetically modified.

A lack of symmetry in information regarding the genetically modified characteristic of products results in market failure because consumers are prevented from making fully informed decisions. This, in turn, causes an inefficiency in the market for products of biotechnology and their non-GM counterparts. However, closer inspection of the problem reveals the uniqueness of information asymmetry when

applied to GMOs and non-GMOs. Genetically modified foods are not directly amenable to the typical asymmetric information analysis.

In this chapter the asymmetric information problem with respect to GMOs will be discussed. Several peer-reviewed articles published over the past 30 years provide analyses, which are in part consistent with the analysis required in the case of GMOs versus non-GMOs. Each has an aspect that describes, or adapts well to modern biotechnology. However, none of them are ideal for the purpose of studying the introduction of biotechnology to agriculture from an asymmetric information and total welfare perspective. Throughout this chapter the analyses and conclusions of these papers will be discussed to demonstrate the unique features of the problem in the case of GMOs.

Information asymmetry exists throughout the initial stages of the supply chain because the seller may have more information about the true quality characteristics of the product than does the buyer. At some point this becomes, instead, a situation of incomplete information, where neither buyer nor seller have full information. For example, seed companies know which of their products are genetically modified when they sell them to producers. Presumably there is a strong commercial incentive to inform farmers as, in many cases, the seed was genetically modified to enhance certain desirable traits such as pest resistance, herbicide resistance, and yield improvements. This means that farmers should know which of their crops have been genetically modified when selling them to processors, but without further investigation processors have no way of knowing. This is the point at which information asymmetry sets in. As

food progresses down the supply chain, the level of further processing increases and the degree of information about the "GM characteristic" of the ingredients decreases. The term "GM characteristic" refers to whether or not the product is genetically modified or non-genetically modified and represents a quality characteristic. Non-genetically modified foods may be treated as high quality, while GMFs are treated as low quality.

At the retailer-consumer level, there is likely a situation of incomplete information with respect to the GM characteristic when (in the absence of regulatory or industry-driven solutions) neither party has full information about its presence or absence (Hobbs and Plunkett, 1999). Throughout the subsequent chapters the biotech firm or firms creating GMOs will be assumed to be vertically integrated to include production at the farm level. The vertically integrated firms will be is referred to as 'GMO producers'. The stylized supply chain, which excludes processors, distributors, and retailers will capture the essential features of the hidden quality problem. GMO or non-GMO producers will know whether their product is genetically modified, but consumers will not. The stylized supply chain will be discussed in detail in chapter 4.

Whenever asymmetric information occurs, an incentive may exist for one side to misrepresent the correct information. In this case, the seller may want to convince the buyer that the product is of higher quality than it really is. The seller may, on the other hand, want to reduce quality, given the buyers expectations, in order to reduce costs (Church and Ware, 1999).

Most asymmetric information analyses begin by classifying the good(s) being studied as search, experience, or credence goods. Nelson (1970) defines search goods to

be those whose quality can be determined by inspecting the product prior to purchase. It is the consumer that carries out the inspection. For some goods the search procedure will be inappropriate if the purchase price is low enough. In these cases, evaluation of quality is easier by purchase rather than search (Nelson, 1970). To rank brands of margarine, for example, the consumer would almost certainly purchase different brands for consumption and then determine the brand preferred from those purchased. Nelson (1970) first defined this information process as "experience". Simply put, experience goods are those whose quality is learned at minimal cost after purchase, upon consumption.

Credence goods are those with qualities that cannot be evaluated in normal use. Instead the assessment of quality requires additional costly information, even after purchase (Darby and Karni, 1973). A level of expertise, not held by most consumers, is required to ascertain quality. The existence of credence characteristics means the asymmetric information problem persists upon consumption of the good. The market for credence goods is characterized by high information costs.

It is difficult to categorize GMOs as search, experience, or credence goods. The current round of production-enhancing modifications produces GMOs that are neither search nor experience goods because the GM characteristic of these products cannot be determined before or soon after consumption. Credence good may best describe GMOs because credence goods require costly expertise to determine quality. Establishing the GM characteristic of a product, at a minimum, requires scientific testing, but in some cases may never be possible no matter what the level of expertise. Genetically modified

canola seeds and the oil derived from them provide an example. After crushing, the altered DNA exists only in the canola meal, it is not present in the oil. No test performed on the product and no level of expertise can detect whether the oil came from genetically modified seeds. Without the ability to verify the quality of the product there is no incentive for firms to provide the non-GMO if its production costs are higher. As will be shown in chapter 5, paying for quality certification may be an alternative to "expertise" for these credence goods.

The information literature shows a bias toward studying experience goods. For example, Akerlof (1970) looked at the market for used cars. In this case the buyer does not have the same information about the used car as the seller. The used car is an experience good because the buyer is able to determine if the car is a good car (a plum) or a bad car (a lemon) after purchase and does not require expertise in the area of used cars to make the determination. Akerlof's market for used cars is dominated by low quality used cars (lemons). High quality cars sell at the low quality price because consumers cannot distinguish the plums from the lemons. Lemons end up dominating the market because few if any high quality cars are offered for sale. The market for GMOs and non-GMOs has similar implications. Depending on the assumptions of the model this thesis will show that the market for non-GMOs is dominated by or can be driven out of existence by the presence of GMOs. Consumers expect a blended product, therefore, the willingness to pay is lower. As a result, less high quality is provided.

Shapiro (1983) provided another example in which experience goods are the focus. He assumes consumers cannot observe product quality before purchase. The

essence of the article is as follows: because the goods are experience goods firms have an incentive to reduce quality (and in turn production costs) to increase profits until consumers detect the low quality being produced and stop purchasing it. The loss of profits from the threat that consumers will terminate purchase of their products ensures that firms will produce the expected level of quality.

This type of firm behaviour based on reputation is less likely for farm-level producers that have the opportunity to employ biotechnology. GMO inputs entail lower production cost than non-GMOs. Therefore, farm-level producers using GMOs would be able to reduce cost and increase profits until consumers become aware that they have been consuming GMOs. Shapiro's analysis is not directly applicable to GMOs and non-GMOs because they are credence goods which means consumers may never know the product they have been consuming is not the quality expected. In Shapiro's framework firms choosing to produce GMOs or non-GMOs do not have the incentive to produce non-GMOs because consumers will not be able to evaluate the GM quality of the product without incurring significant cost.

Shapiro suggests that high quality goods must sell at a premium to stop firms from selling low quality products. This premium on high quality is treated as compensation for firms that have invested in establishing a reputation for selling high quality products. It seems sensible that if non-GMOs sold at a premium, firms would be less likely to cut quality and produce GMOs, but once again GMOs and non-GMOs are different because they are credence goods. The premium would be effective in ensuring only non-GMOs were produced by high quality producers if production of GMOs could

be detected upon consumption and would lead consumers to substitute away from the cheating firm's product. However, it may be prohibitively expensive for consumers to determine GM quality therefore, there may be no recourse to penalize cheating firms and no incentive to produce non-GMOs. The problem is that reputation is very costly to establish when the products for sale are credence goods. The assumption of experience goods limits the applicability of Shapiro's analysis.

Klein and Leffler (1981) explored the idea of repeat-purchase to ensure only high quality is produced. They suggested that repeat purchase is not enough, but loss of future sales must also be accompanied by the loss of a price premium to guarantee high quality. For Shapiro the price premium was explained as a return on reputation. For Klein and Leffler the price premium covers the sunk cost incurred to produce high quality over low quality. Once again the analysis assumes consumers can determine the quality of the product costlessly, which is not true for GMOs.

Darby and Karni (1973) introduced credence goods in their analysis. They showed that the existence of credence qualities provides an incentive for firms to deceive consumers regarding the quality of the product purchased. They use the example of automobile repair services. They find that, in the absence of government intervention, some level of deception (fraud) is profit maximizing because the cost of discovering the deception is high.

Signaling is a common theory used in addressing asymmetric information problems. Milgrom and Roberts (1986) consider price and advertising as signals of an experience good's quality. In asymmetric information analyses advertising does not

play an informational role. Milgrom and Roberts build on Nelson's (1974) idea that consumers can determine whether the good is high quality based on the firm's expenditure on advertising and the threat of losing repeat purchases. Nelson proposes that high quality producers will advertise to a greater extent than low quality producers because they know their high quality product will attract repeat purchases.

Milgrom and Roberts suggest that Nelson's argument can be interpreted so that price can signal quality and advertising is not necessary, assuming the firm is not a price taker. In fact, what Milgrom and Roberts find is that in equilibrium both price and advertising are used as signals. The combination of signals is required so that no low quality firm will find it profit maximizing to mimic the pricing or advertising efforts of the high quality firm. Milgrom and Roberts surmise that including price as a signal of quality, where Nelson only considered advertising, questions the intuition that a high quality producer will benefit more from attracting an initial sale. Therefore, price as a signal of quality provides the basis for the higher quality firm's willingness to advertise more.

According to Nelson, advertising signals quality because only the firms producing high quality find it profitable to invest in advertising. Advertising in this context, plays no informational role, but acts only as a signal of quality.[1] The investment in advertising is profitable for high quality firms because only high quality products will generate repeat purchases, offsetting the advertising cost. Advertising, as

[1] For informational purposes, advertising of low quality products may also be observed.

described by Nelson, does not work for GMOs/non-GMOs because the GM characteristic of the good cannot be determined upon consumption. It is too costly for consumers to discover whether the firm misrepresented its product. Thus, there is no incentive to advertise and produce high quality because the threat of losing repeat purchases does not exist.

Bagwell and Riordan (1991) find that high but declining prices signal a high quality product. They return to Klein and Leffler's (1981) and Shapiro's (1983) arguments that prices are the most efficient signal of quality because the loss of future sales will hurt low quality producers most. Bagwell and Riordan carry the analysis further to say that as the number of informed consumers increases (as the firm establishes a reputation) the need for prices to signal quality is reduced and prices start to fall. Shieh (1993) points out the complicating factor from the consumer's perspective that high price may signal higher production costs, not always higher quality. The high priced experience good may simply be the result of a less efficient production process. Sheih concludes that firms producing experience goods have less incentive to adopt new, cost reducing technologies because consumers may perceive the ability to supply at lower price to be a result of lower quality.

Reputation becomes important for consumers in decision making because it gives them another dimension on which to make a quality distinction. A firm with a reputation for supplying the desired quality is more likely to experience repeat purchases than a firm with no reputation or a reputation for low quality products. Reputation as a solution to asymmetric information may not be applicable in the case of GMOs and non-

GMOs because it would be extremely costly and sometimes impossible for consumers to verify the quality the firm has produced in the past and can be expected to produce in the future.

The common solutions to the asymmetric information problem discussed above break down because GMOs/non-GMOs are credence goods and the solutions are based on analyses of experience goods. It becomes apparent that credence goods may require government intervention to address the asymmetric information problem because the private incentives to do so are much weaker than with experience goods. As will be discussed in chapter 5, solutions to the asymmetric information problem in this analysis take the form of labelling. The welfare effects of labelling GMOs as a "product of biotechnology" and non-GMOs as "GMO-free" are considered when the market for GMOs or for non-GMOs bear the cost of the information.

The introduction of GMOs presents a challenging problem because the demand effects of this new genre of products are unknown. Typical analyses assume consumers agree over the preference ordering of goods. This is to say that they agree on what is high quality and what is low quality. In other words, vertical differentiation is usually assumed in the product space. This common assumption is not true in reality when the quality difference is GMO versus non-GMO. The type of differentiation that is most appropriate in this case is horizontal where the optimal choice (at equal prices) depends on the particular consumer (Tirole, 1988).

Each of the papers discussed above considers private solutions to the asymmetric information problem either through advertising, repeat purchase, or signaling. Most

require the assumption of experience goods and, therefore, are not easily adapted to the GMO/non-GMO situation. The common solutions discussed above reveal the uniqueness of the GM characteristic of products because the typical analyses do not adapt well to GMOs/non-GMOs. The unique nature of the asymmetric information problem as it applies to GMOs and non-GMOs follows from the credence properties of the goods.

In the following chapter a model is developed to study the asymmetric information problem related to GMOs and non-GMOs as credence goods as well as the effect of information asymmetry on total welfare before and after biotechnological innovation. Following the analysis of the asymmetric information problem, solutions to the problem are studied in chapter 5 along with their welfare implications.

Chapter 4 – Biotechnological Innovation with Pooling Equilibria

Introduction

As described in the previous chapter, the problem being addressed arises from a market failure on the demand side of the market for GMOs and non-GMOs. The market failure results from an asymmetric information problem where consumers cannot distinguish between GMOs and non-GMOs. The products' visual and taste characteristics provide no information about the GM characteristic of the product, either before or after consumption. The market is inefficient because consumers are not able to make fully informed decisions when choosing between GMOs and non-GMOs. Inefficiency in the market means consumer surplus is not maximized because the information necessary to distinguish the two products is inadequate. In this chapter it is assumed that no form of voluntary or mandatory identity preservation system exists to inform consumers regarding the GM characteristic. Chapter 5 will consider such solutions to the asymmetric information problem and the resulting separating equilibrium.

The typical supply chain for genetically modified products involves several stages of production. A "biotech firm" carries out the research and development necessary to bring the GMO to market and is the holder or the patent for the technology. The biotech firm then sells the GM seed to seed companies who, in turn, sell to growers. Alternatively, the biotech firm may sell seed directly to farm-level growers. Farm-level "growers" then produce the GM crop for commercialization. Once the GM crop has

been harvested it is transferred to "processors" who convert the GMO into GMFs. From the processor the GMF is handled by a "distributor" who distributes the GMFs among "retailers" offering the foods for sale to consumers. Non-GMOs may co-mingle at the processor, distributor, and consumer stages.

To clarify the key information issues, a highly stylized version of the typical supply chain is assumed in which the biotech firms vertically integrate to the commercial production stage. The biotech firm, the seed company, and growers are contained within the same firm. This vertically integrated firm is a "GMO producer". For simplicity, the analysis abstracts entirely from the processor, distributor, and retailer stages. GMO producers, along with any remaining fringe non-GMO suppliers, sell the final product directly to consumers. It is also assumed that there is a single GMO producer. The GMO producer may have market power depending on the nature of its cost advantage over fringe suppliers.

The assumption of vertical integration is made to simplify the analysis, but is not an extreme assumption. In reality the biotech firm with intellectual property rights has very tight control over production that uses GMO inputs. The growers of GMOs often acts much like an employees or partners of the biotech firm. Producer technology-use agreements provide an example of the close relationship that is typical between the biotech firm and the grower. These agreements require that the grower applies for the right to grow GM seed and that the application satisfies the biotech firm. Once the grower is granted the right to grow the GM seed that right can be terminated if the grower does not comply with the terms of the agreement (Monsanto, 1999).

In addressing this asymmetric information problem several cases are considered. Underlying each case is a two-stage game.[1] Stage-one is the entry/investment stage. In stage-one firms decide whether to invest in the research and development necessary to engineer a GMO. Stage-two is the production/exchange stage. In stage-two biotech firms integrate forward and choose the quantities of GMOs they will produce. Each game studied involves two goods. Good 1 is the non-GMO produced by a competitive fringe and good 2 is the GMO produced by the GMO producer.

Cases considered in detail are those where the GMO producer has chosen to innovate. The stage-two market is represented by the dominant-firm, competitive fringe framework common in industrial organization. This model provides a reasonable caricature of the actual market for GMOs and non-GMOs. In reality, there are a few large biotechnology firms that, through close relationships with farm-level growers compete with many small producers of non-GM products. In the model, it is assumed, for simplicity, that there is a single vertically integrated GMO producer that acts as a dominant firm or residual monopolist relative to the perfectly competitive fringe suppliers of non-GMOs. The GMO producer often has market power, which means it sets price above marginal cost. Perfectly competitive supply of non-GMOs means there are many price-taking firms supplying non-GMOs. The fringe takes its price equal to marginal cost.

The outcome of the game depends crucially on whether the genetically modified and non-genetically modified products are perceived by consumers as homogeneous or

[1] Two types of stages exist, stages of the production process and stages of the game.

heterogeneous goods. The outcome is also affected by the assumption of perfectly elastic supply versus imperfectly elastic supply and the magnitude of the dominant firm's marginal cost advantage which determines the its choice of output.

The terms homogeneous and heterogeneous goods are being used in an economic theory sense as opposed to a technological sense. It is assumed that homogeneous goods are perceived by consumers as perfect substitutes with symmetric quality, while heterogeneous goods are imperfect substitutes with asymmetric quality as perceived by consumers.[2] The heterogeneous goods cases depart from the homogeneous goods cases because consumers care about the difference between goods 1 and 2. Consumers who treat the goods as homogeneous cannot distinguish between the goods, nor do they care to. The difference between cases of homogeneous and heterogeneous goods is whether consumers want to distinguish between the two goods or not.

When consumers care about the difference between GMOs and non-GMOs it is assumed that their willingness to pay for GMOs is lower than for non-GMOs. Willingness to pay is lower for some consumers because long term uncertainty, health concerns, and other reasons discussed in chapter 2 imply that GMOs may not satisfy consumer preferences. For these consumers the perceived quality of GMOs is lower than for non-GMOs. Since it is assumed that the introduction of GMOs shifts demand to the left, this analysis is relevant only for first-round innovations where GMOs provide no direct consumer benefits. What this means is that GMOs and non-GMOs are

[2] If homogeneous and heterogeneous were defined in terms of technology we would say homogeneous goods are modified using the same technique and heterogeneous goods are modified using different techniques, but this is not the definition intended here.

functionally equivalent; neither one has characteristics that make it a superior functioning product at the consumer level. As an example, consider canola genetically modified with herbicide tolerance. Herbicide tolerance provides benefits to producers, not consumers, through reduced input costs and potentially higher yields. If the GMO had a direct consumer benefit such as improved fat composition the analysis being done here would be more complicated. Consumers would be choosing between a whole new bundle of characteristics, not simply between GMO and non-GMO. The change in demand resulting from the introduction of a GMO with additional consumption characteristics would not be directly attributable to the GMO/non-GMO characteristic. If genetic modification meant canola oil had a healthier fat composition the effect on demand of a choice between genetically modified and non-genetically modified canola oil could not be attributed solely to the choice between genetically modified and non-genetically modified, but will in part be a result of the improved quality attribute. This complicating factor is assumed away by considering innovation that provides benefits only in the production process with the only difference at the consumer level being whether or not the product has been genetically modified.

The two features of homogeneous goods, as they are defined here, are perfect substitutability between the goods and symmetric quality. The assumption of perfect substitutes provides for linear indifference curves and symmetry in quality ensures a one-to-one tradeoff between the goods (i.e., the marginal rate of substitution of good 2 for good 1 is equal to one, MRS=1). The symmetric quality assumption rules out the possibility that consumers will trade more or less than a single unit of a GMO for one

unit of a non-GMO. By contrast, when the goods are heterogeneous, quality is asymmetric and the products are imperfect substitutes. Thus, indifference curves are non-linear and the tradeoff between good 2 and good 1 is not one-for-one. Rather, the marginal rate of substitution of good 2 for good 1 is always greater than one.

Depending on the dominant firm's marginal cost there exist three ranges of quantity setting and three ranges of pricing options. The three levels of marginal cost are associated with each of the three segments of the dominant firm's marginal revenue curve. When the dominant firm chooses quantity such that price is set just below the minimum necessary to generate any fringe supply, the price is said to be set *pre-emptively* because the GMO producer gains all of the market by just undercutting the competitive fringe price. When the dominant firm chooses quantity where both good 1 and good 2 are produced, there is said to be *accommodating pricing* because both goods are supplied. When the dominant firm chooses quantity such that price is set significantly below the minimum supply price of the fringe and good 1 is driven out, the pricing option is referred to as *pure-monopoly* pricing. The cases of pure-monopoly pricing differ from pre-emptive pricing in that the monopoly price is much lower than the pre-emptive price. Each of these profit maximizing price setting options will be discussed in greater detail below in association with the monopolist's problem and along with a diagram.

The pre-emptive and pure-monopoly pricing cases give rise to an extreme equilibrium because the non-GMO product is driven out, as happens to high quality cars in the "market for lemons" (Akerlof, 1970). The accommodating pricing cases give rise

to a non-degenerate, pooling equilibrium where both goods are available and are not separated by the market.

The mathematical analysis will derive a general expression for the slope of residual demand, which has implications for the shape of the dominant firms's marginal revenue curve. Different assumptions about the level of marginal cost will affect the dominant firm's profit maximizing output. The output choice of the dominant firm then affects the proportion of non-GMOs and GMOs in the market further affecting the total welfare of society. The generalized form of the residual demand function will be adapted for several cases as they are characterized by homogeneous or heterogeneous goods, perfectly elastic or imperfectly elastic fringe supply, and pre-emptive, accommodating, or monopoly pricing. The mathematical analysis will be shown once for the general case, focussing on the GMO producing firm's optimal behaviour and the subsequent impact on society. Then, as each unique case is proposed, the generalized mathematical analysis will be made specific and will accompany the graphical analysis associated with that case.

Consumers

A quasilinear utility function is used to derive inverse demand from which the dominant firms's residual demand function is determined. Direct demand is also derived and used in the total surplus measures. Quasilinear utility allows marginal utility to be set equal to price because the marginal utility of income is equal to one (i.e.,

in the constrained optimization problem the Lagrangian multiplier is equal to one), simplifying the analysis without losing generalizability.

Each individual has the same quasilinear utility function:

$$U = U(q_1, q_2) + q_0$$

where q_0, the numeraire, is a composite of all other goods consumed, q_1 is the quantity of non-GMOs consumed, and q_2 is the quantity of GMOs consumed. Following from utility maximization,

$$U_1, U_2 > 0$$
$$U_{11}, U_{12} = U_{21}, U_{22} < 0 \qquad (C.1)$$

For now, asymmetric information persists and the equilibrium is a pooling equilibrium. The utility function associated with the pooling equilibrium is given by (1) below. With a pooled equilibrium the expected quantity of non-GMOs consumed is $Eq_1=\theta Q$ and the expected quantity of GMOs consumed is $Eq_2=(1-\theta)Q$ where θ is the probability that one unit of product consumed is good 1 and $(1-\theta)$ is the probability that one unit of product consumed is good 2. The total quantity of goods 1 and 2 consumed is $Q=q_1+q_2$. The probability of a unit of product being a non-GMO is:

$$\theta = \frac{q_1}{q_1 + q_2} \tag{C.2}$$

Thus,

$$(1-\theta) = \frac{q_2}{q_1 + q_2} \tag{C.3}$$

is the probability of a unit of product being a GMO.

Individual consumers take the probabilities as given – the probabilities are independent of the quantity of each good consumed. Consumers are assumed to know the probabilities based on publicly available seeded acreage statistics.

When θ is constant, $\theta = \bar{\theta}$ and,

$$\frac{\partial \bar{\theta}}{\partial q_1} = 0 \tag{C.4}$$

$$\frac{\partial \bar{\theta}}{\partial q_2} = 0 \tag{C.5}$$

The consumer's problem under asymmetric information is as follows,

$$\max_{\{Q\}} \; U = U(\theta Q, (1-\theta)Q) + q_0 \qquad \text{subject to} \quad q_0 + pQ = M$$

or

$$\max_{\{Q\}} \; U = U(\theta Q, (1-\theta)Q) + M - pQ \tag{1}$$

where M is income, and p is the price of the pooled good.

Before deriving the demand function it is important to note that there are demand side implications depending on whether the goods are homogeneous or heterogeneous. If good 1 and good 2 are homogeneous (i.e., goods 1 and 2 are perfect substitutes *and* quality is symmetric) the marginal utilities of each good are equal, which implies the second derivatives are also equal.

$$U_1 = U_2 \quad \text{or} \quad \text{MRS}_{21} = 1$$

$$\Rightarrow U_{11} = U_{22} = U_{12} = U_{21} \tag{C.6}$$

If good 1 and good 2 are heterogeneous (i.e., goods 1 and 2 are imperfect substitutes *and* quality is asymmetric) the utility from one more unit of good 1 is greater than the utility from one more unit of good 2.

$$U_1 - U_2 > 0 \quad \text{or} \quad \text{MRS}_{21} > 1 \tag{C.7}$$

Consequently, the non-GMO is the high quality good in this case.

With this in mind, taking the derivative of (1) with respect to Q, the inverse demand function is immediately obtained from the first order condition for utility maximization.

$$\frac{dU}{dQ} = \theta U_1(\theta Q, (1-\theta)Q) + (1-\theta)U_2(\theta Q, (1-\theta)Q) - p = 0 \tag{2}$$

$$\theta U_1(\theta Q,(1-\theta)Q)+(1-\theta)U_2(\theta Q,(1-\theta)Q)=p$$

There are three possible inverse demand curves associated with the heterogeneous goods cases depending on the proportion of good 1 and good 2 available. When $0<\theta<1$ both goods will be produced and the slope of the inverse demand curve is

$$\frac{dp}{dQ}=\theta^2U_{11}+2\theta(1-\theta)U_{12}+(1-\theta)^2U_{22}<0.$$

When $\theta=1$ good 2 is not produced. The slope of the inverse demand curve when consumers can purchase only good 1 is

$$\frac{dp}{dQ}=U_{11}<0.$$

When $\theta=0$ good 1 is not produced. The slope of the inverse demand curve when consumers can purchase only good 2 is

$$\frac{dp}{dQ}=U_{22}<0.$$

When the goods are homogeneous, demand is unchanged as good 2 enters the market. The slope of inverse demand is

$$\frac{dp}{dQ}=U_{11}=U_{22}<0.$$

Although it is common to use inverse demands to graph demand functions the direct demand functions are more useful in the total welfare analysis. The direct demand function is a function of price and probability,

$$Q = D(p, \theta) \tag{3}$$

Where the properties of direct demand are:

$$\frac{dQ}{dp} < 0$$

$$\frac{dQ}{d\theta} > 0. \tag{C.8}$$

Total quantity consumed of goods 1 and 2 decreases as price increases and increases as the probability of a unit of product being high quality increases. Proof of these properties is in appendix A.

Compensating variation is used to determine the welfare effect of innovation. Compensating variation and consumer surplus are equivalent when the utility function is quasilinear, therefore, in this analysis compensating variation is equal to the change in consumer surplus.[3] The convention is adopted that compensating variation, like the change in consumer surplus, is positive when there is a change that is beneficial to consumers. The change in consumer surplus in general is given by,

[3] Consumer surplus is the difference between what the consumer is willing to pay and what they actually pay. It is the net benefit that consumers receive above what they must pay for a good.

$$CV = \Delta CS = -\int_{p^0}^{\infty} (D(p,\theta^0) - D(p,\theta^1))dp + \int_{p^1}^{p^0} D(p,\theta^1)dp \qquad (4)$$

The complete derivation of this expression is found in appendix B. The first term is the change in consumer surplus due to a reduction in quality. This is a negative term referred to as the quality effect. The last term allows for a change in consumer surplus due to a reduction in price. This is a positive term referred to as the price effect. In each case the negative quality effect and positive price effects compete to determine the net effect on total welfare.

The Competitive Fringe

Supply by the fringe is assumed to be perfectly competitive with free entry and exit in the market for non-GMOs. Since the GMO producer chooses whether or not to enter, fringe producers of non-GMOs are assumed to have the same perogative. Thus, this is essentially a long run equilibrium. The supply function of the non-GMO producing fringe is

$$S(p) \equiv q_1. \qquad (C.9)$$

It is the nature of the pooling equilibrium that $p_1 = p_2 = p$, where p is the price of the pooled good. The shape of the fringe supply curve depends on whether imperfectly

elastic or perfectly elastic supply is assumed. Let p^k be defined as the vertical intercept of the fringe supply curve.

When supply is imperfectly elastic either $p>p^k$, $p=p^k$, or $p<p^k$. For $p>p^k$, supply and the reciprocal of the slope of supply are both strictly positive,

$$\begin{aligned} &S(p)>0 \\ &S'(p)>0 \end{aligned} \tag{C.10}$$

As p approaches p^k from above supply approaches zero while the inverse of the slope of supply is positive

$$\lim_{p \downarrow p^k} \begin{aligned} &S(p)=0 \\ &S'(p)>0 \end{aligned} \tag{C.11}$$

When supply is perfectly elastic, the output of good 1 can be anywhere from zero to infinity.

$$\lim_{p \downarrow p^k} \begin{aligned} &S(p) \in [0,\infty) \\ &S'(p) \to \infty \end{aligned} \tag{C.12}$$

Regardless of the elasticity of supply, output and the inverse of the slope of the supply curve are zero for $p< p^k$.

$$S(p) = 0 \qquad (C.13)$$
$$S'(p) = 0$$

In the long run, perfectly competitive supply is horizontal when non-GMO production is a constant cost industry. Long run supply is upward sloping when the industry is characterized by increasing costs. Increasing costs in the production of non-GMOs could result from factors used solely to produce non-GMOs, such as specific chemical inputs and seed, increasing in cost as the aggregate output of non-GMOs increases.

Introduction of GMOs by the dominant firm impacts total surplus through producer surplus as well as consumer surplus. Producer surplus is the difference between revenue and the social opportunity cost of production. Since each fringe firm earns zero long run profits and producer surplus, it should be emphasized that the entire "producer surplus" of the fringe accrues as rents on factors specific to GMO production. For the moment the focus is on the surplus of the competitive fringe only. Since individual fringe firms do not significantly affect the probability of consuming good 1 (i.e., θ) or good 2 (i.e., $1-\theta$), the producer surplus calculation remains conventional. The change in producer surplus is,

$$\Delta PS = \int_{p_1'}^{p_1^0} S(p)dp_1 \qquad (5)$$

Equation (5) says the change in producer surplus is the area under the supply curve between prices p_1^f and p_1°. The magnitude of producer surplus will depend on whether all of the non-GMOs are driven out of the market or not. When good 2 becomes available, if the commercial supply of good 1 is zero, then producer surplus is zero, and all of the former producer surplus is lost.

The Dominant Firm

Unlike the consumer and the competitive fringe, the dominant firm is able to influence the proportion of GMOs and non-GMOs available in the market. In choosing the quantity of GMOs to produce, the dominant firm must take into consideration the impact the change in probabilities will have on demand. This is in addition to the usual effects the dominant firm must account for in setting quantity which relate to the price of the marginal unit of output and the change in price affecting the inframarginal units of output.

It is widely acknowledged that GMOs can be produced at lower marginal cost than non-GMOs, but price is typically set above marginal cost because GMO producers are able to exert market power. Market power in this situation is most likely a result of the small number of GMO producers. As the vertically integrated firm's residual demand becomes more inelastic the firm's market power increases.

As the quantity of non-GMOs supplied increases (decreases) the probability of a unit of product consumed being a non-GMO increases (decreases).

$$\frac{\partial \theta}{\partial q_1} = \frac{1-\theta}{q_1+q_2} > 0 \qquad (C.14)$$

Not surprisingly, as the quantity of GMOs supplied increases (decreases) the probability of a unit of product consumed being a non-GMO decreases (increases).

$$\frac{\partial \theta}{\partial q_2} = \frac{-\theta}{q_1+q_2} < 0 \qquad (C.15)$$

Using the relationships defined in equations (*C*.2), (*C*.3), and (*C*.9) we solve (2) as a function of q_2 to find residual demand.

$$\frac{S(p)}{S(p)+q_2} U_1(S(p),q_2) + \frac{q_2}{S(p)+q_2} U_2(S(p),q_2) = p \quad \text{or} \quad p = P(q_2) \qquad (6)$$

For simplicity the residual demand function facing the dominant firm is written in explicit rather than implicit form.

Residual demand ($P(q_2)$), or net demand as it is also called, is the demand curve the GMO producing firm faces. In general, the shape of residual demand is similar to the D^r curve shown in figure 4.0 on the following page.

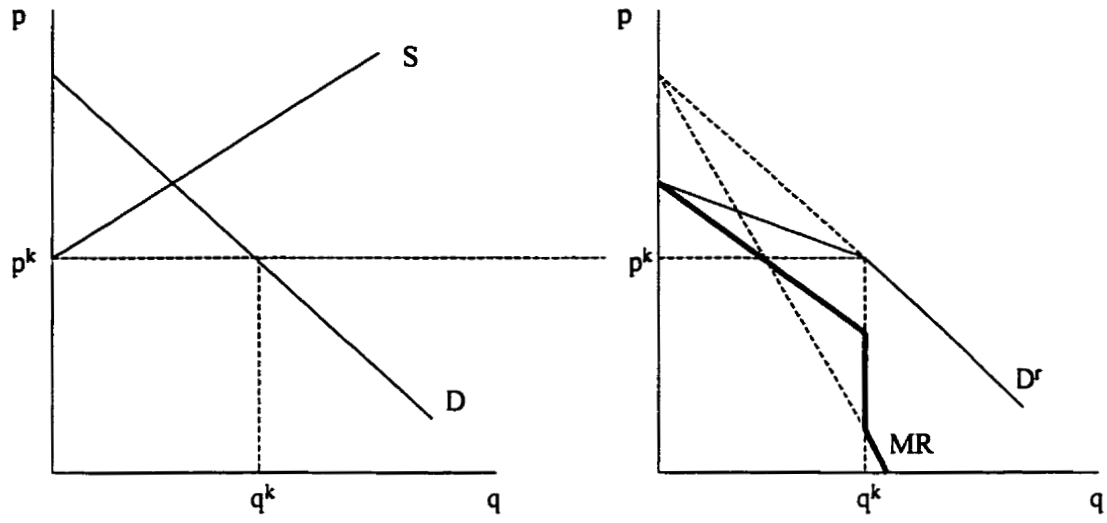

Figure 4.0: Residual Demand and Marginal Revenue

The net quantity demanded for the pooled good is the horizontal difference between quantity demanded and quantity supplied by the non-GMO producing competitive fringe, D–S in figure 4.0. At price p^k, where supply of good 1 goes to zero, residual demand has a kink. The curve in bold, labelled MR, is the dominant firm's marginal revenue drawn against the residual demand curve.

The residual demand, equation (6), can be written as:

$$P(q_2) - \frac{S(p)}{S(p)+q_2} U_1(S(p),q_2) - \frac{q_2}{S(p)+q_2} U_2(S(p),q_2) = 0 \qquad (6')$$

By totally differentiating (6') and rearranging, the slope of the residual demand function, $P'(q_2)$, is:

$$\frac{dp}{dq_2} = \frac{\theta U_{12} + (1-\theta)U_{22} + (U_1 - U_2)\dfrac{-\theta}{q_1 + q_2}}{1 - (\theta U_{11} + (1-\theta)U_{21})S'(p) - (U_1 - U_2)S'(p)\dfrac{1-\theta}{q_1 + q_2}}. \tag{7}$$

Equation (7) is the generalized slope of residual demand. Using conditions (*C*.1), (*C*.7), (*C*.10), (*C*.14), and (*C*.15) the sign of (7) is ambiguous.

$$\frac{dp}{dq_2} = \frac{(-)}{(+)-(+)}$$

The slope of the residual demand curve depends on the sign of the denominator. The slope of residual demand will be determined for each case studied below because the slope depends on the specific factors of each case.

The monopolist's revenue function is:

$$r(q_2) = P(q_2)q_2. \tag{8}$$

Marginal revenue is given by:

$$r'(q_2) = P'(q_2)q_2 + P(q_2). \tag{9}$$

Marginal revenue (see figure 4.0) shows how revenue changes with a change in output. When output equals zero, the marginal revenue from selling the inital unit of output is just the price. When output is greater than zero, the marginal revenue from selling an extra unit of output must be less than the price since the only way to sell the additional output is to reduce price of all units (Varian, 1992). Therefore, the marginal revenue curve lies below the residual demand curve as long as the residual demand curve is downward sloping. The marginal revenue curve will have a vertical portion resulting from the kink in the corresponding residual demand curve. Note that this marginal revenue curve (9) will have discontinuities in it depending on the shape of residual demand.

In this analysis it is the relative slope of residual demand above and below p^k that is critical. When the upper portion of residual demand is flatter than the lower portion, as is usually the case, marginal revenue drops at the kink since price falls more rapidly below the kink. Marginal revenue steps up when the upper portion of residual demand is steeper than the lower portion.

The dominant firm's profit function ($\Pi(q_2)$) is:

$$\Pi(q_2) = r(q_2) - c(q_2) \tag{10}$$

Here $r(q_2)$ is the dominant firm's revenue function and $c(q_2)$ is the cost function. Equation (10) implies the profit maximizing condition,

$$r'(q_2) = c'(q_2) \qquad (C.16)$$

which is, of course, marginal revenue equal to marginal cost.

As mentioned at the beginning of this chapter, the three pricing options available to the dominant firm are, pre-emptive, accommodating, and pure-monopoly pricing. The three options arise because the marginal revenue curve has three segments. Each of these pricing options is depicted in figure 4.1 below. In each case the dominant firm is maximizing profit by choosing quantity such that marginal revenue equals marginal cost. Given the profit maximizing quantity, the dominant firm then sets price according to the residual demand curve.

Marginal cost intersecting marginal revenue in the upper portion of marginal revenue gives rise to accommodating pricing where both goods are provided. Accommodating pricing allows for the existence of a competitive fringe supply of non-GMOs. Marginal cost intersecting marginal revenue in the vertical portion of marginal revenue gives rise to pre-emptive pricing where only good 2 is produced. With pre-emptive pricing price is set as high as possible consistent with eliminating the fringe. Marginal cost intersecting marginal revenue in the lower portion of marginal revenue gives rise to pure-monopoly pricing and, once again only good 2 is supplied. Under pure-monopoly pricing there is no fringe supply of non-GMOs and price is set strictly lower than required to eliminate the fringe. In all cases, of course, the GMO producer is maximizing profit.

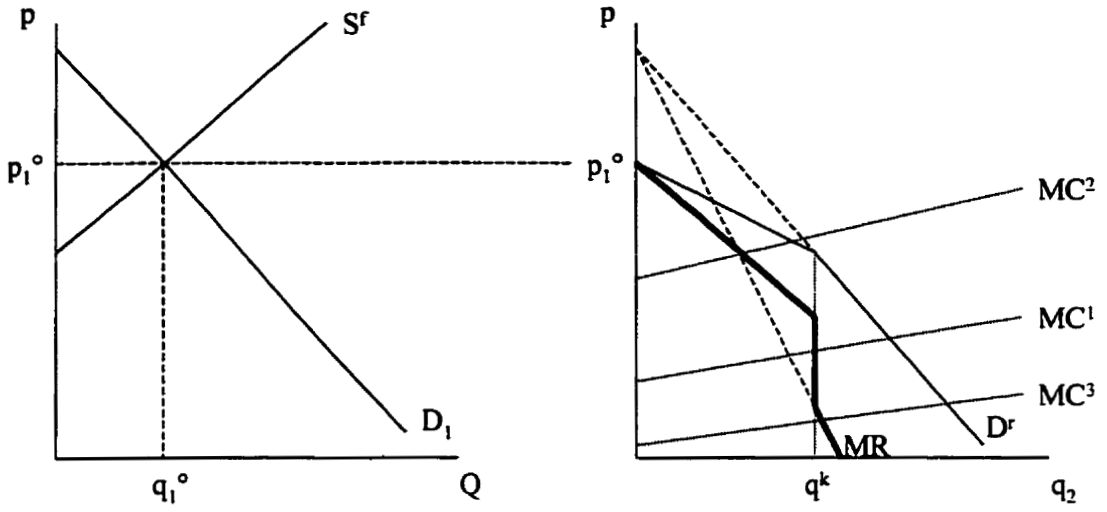

Figure 4.1: Pre-emptive, Accommodating, and Pure Monopoly Pricing

Stage-two profits of the GMO producer are equal to revenue minus production cost. Stage-two profits are defined to exclude the sunk costs incurred in stage-one (Church and Ware, 1999). The overall profit of the GMO producing firm is equal to stage-two profits minus the sunk research and development cost incurred in stage-one. Examples of sunk costs include expenditures on research and development and regulatory compliance. Positive overall profits (i.e., stage-two profit minus research and development cost greater than zero) for the monopolist are a signal to other potential entrants.

This signal will tend to result in entry with the overall profit being dissipated. Although it is not done here, the model could be generalized to allow for monopolistic competition or an open-entry Cournot oligopoly among rival GMO producers.

Total Surplus

The purpose of the analysis is to make a statement about the impact of innovation on total welfare. The change in total welfare or surplus is measured by summing the change in producer surplus, the change in consumer surplus (compensating variation), and any overall economic profits made by the innovating firm. Once the shape of residual demand and marginal revenue is established and an assumption is made about the level of the dominant firm's marginal cost, the welfare analysis of the impact of biotechnological innovation on society can be carried out. The change in total welfare is the sum of the changes in consumer surplus (CS) and producer surplus (PS), plus stage-two profits (Π) minus sunk costs (F) incurred by the innovating firm.

$$\Delta TS = \Delta CS + \Delta PS + \Pi - F$$

If the change in total welfare is less than (greater than) zero, innovation has a net negative (positive) effect on society. The changes in consumer surplus and producer surplus as well as monopoly profits are described graphically for each unique case examined below.

Recall that stage-one is the innovation or entry stage where biotechnology firms may choose to undertake costly research and development leading to a genetically modified product. Stage-two is the production stage where this analysis assumes just one biotechnology firm has made the stage-one decision to innovate.

Due to the potential for entry, stage-two profits significantly in excess of sunk costs are unlikely to persist. The situation where there is only one GMO producer is a full equilibrium only if there is no incentive for rival biotech firms to engage in research and development and then production. There will in fact be no incentive for further entry into the GMO side of the market if the first firm earns overall profits that are equal to zero or at least sufficiently close to zero that a second firm would earn overall negative profits. To avoid the complexity of modelling an open-entry oligopoly among rival GMO producers yet remain consistent with the principle that entry will have strong tendency to dissipate profits, special attention will be focussed on the situation where the first GMO-producing firm earns zero overall profits (i.e., $\Pi - F = 0$). Consequently, the change in total surplus excluding the stage-two monopolist's profit and the sunk research and development cost from stage-one are also examined and represented as ΔTS^*.

$$\Delta TS^* = \Delta CS + \Delta PS$$

Innovation Does Not Occur

In this two stage game no firm chooses to invest in biotechnological research and development. Beginning in stage-two and solving recursively, for this type of outcome to occur, the sunk cost of research and development in stage-one must be greater than profit earned in stage-two. The optimal amount of investment in research and development in stage-one is zero. Essentially this is the market equilibrium before

genetically modified foods are commercially available. The market is represented in figure 4.2.

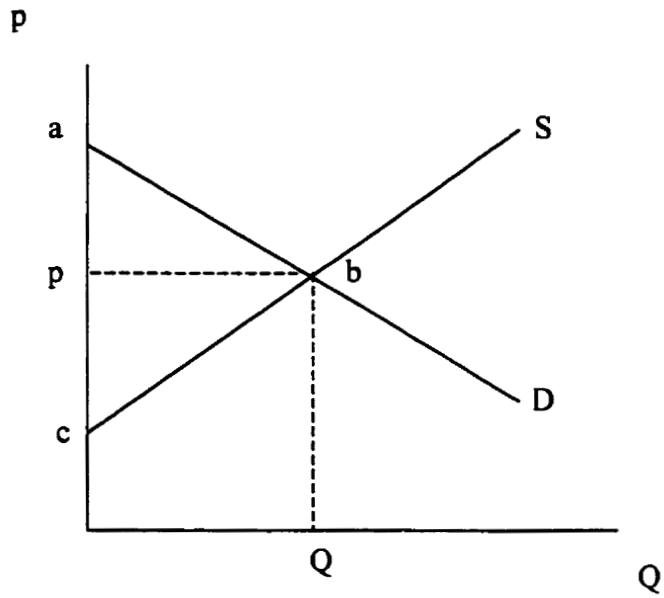

Figure 4.2: Innovation Does Not Occur

The market for non-GMOs is assumed to be perfectly competitive. In this no innovation case, q_2=0 and q_1>0. Consumer surplus is represented by area abp and producer surplus by area pbc in figure 4.2. Total surplus is the sum of the two areas and, thus, is equal to abc.

Innovation Occurs

In the following cases a single GMO producer chooses to invest in research and development. Therefore, GMOs are in production and available commercially. For a firm to choose to produce GMOs the sunk cost of research and development incurred in stage-one must be less than or equal to the expected profit gained in stage-two. If sunk costs exceeded expected profit no firm would choose to innovate.[4]

In all cases, three different demand curves for the pooled good are possible. They are shown in figure 4.3. The demand for good 1, the non-GMO, when only good 1 is available, is represented by D_1. The D_1 curve reflects consumers' willingness to pay for non-GMOs when no GMOs are available commercially. The demand for good 2, the GMO, when only good 2 is available is represented by D_2. The D_2 curve reflects consumers' willingness to pay for GMOs when no non-GMOs are available commercially. The demand for an average good when both goods are available and pooled together is represented by D_a. The D_a curve reflects consumers' willingness to pay for an average good given the probability with which a unit of product is likely to be a non-GMO versus a GMO. As the proportion of GMOs in the market increases from 0 to 1, demand shifts to the left, reflecting consumer perception of decreasing quality.

[4] Here actual and expected profits are equal since we abstract from uncertainty over both the cost and outcome of research and development and demand.

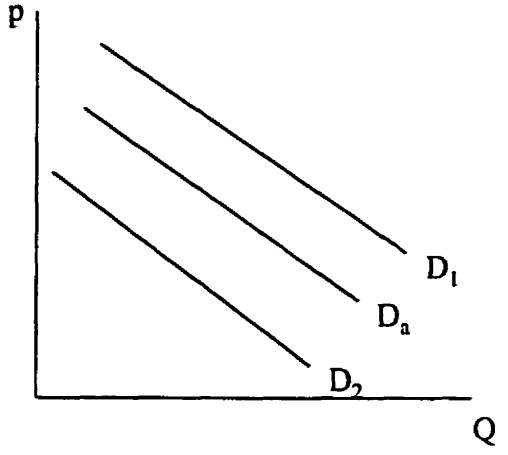

Figure 4.3: Possible Demand Curves

Each case determines the shape of residual demand and its associated marginal revenue given a combination of the following features; (i) heterogeneous vs. homogeneous, (ii) perfectly elastic supply vs. imperfectly elastic supply, and (iii) accommodating, pre-emptive, or monopoly pricing. In each case the change in total welfare attributable to innovation is measured.

I. Homogeneous Goods with Perfectly Elastic Supply

When supply is perfectly elastic, for all $p>p^k$, there is an infinite supply of good 1. Here the competitive fringe is a constant cost industry, which explains the perfectly elastic supply curve, *S*, shown in figure 4.4a. Goods 1 and 2 are homogeneous which means consumers treat the two products as perfect substitutes and are willing to trade them one for one. Since consumers do not perceive a quality difference between the two goods there is no differential in willingness to pay across the two goods. Thus, demand

does not change upon introduction of good 2, the GMO. In the following six diagrams, the appropriate demand curve, $D_{I=2}$, reflects the fact that demand is the same before and after the introduction of GMOs. The asymmetric information problem persists in this situation because consumers cannot distinguish between GMOs and non-GMOs, but they do not care that the difference exists. When the goods are homogeneous consumers *choose* not to differentiate the two products. It is consumers' perception of the goods that is important–whether the goods are technologically unique is irrelevant.

For $p=p^k$ conditions (*C*.1), (*C*.6), (*C*.12), (*C*.14), and (*C*.15) hold and the slope of residual demand given by equation (7) becomes,

$$\frac{dp}{dq_2} = 0$$

For $p<p^k$, therefore, $\theta=0$, conditions (*C*.1), (*C*.4), (*C*.5), (*C*.6), and (*C*.13) and (7) becomes,

$$\frac{dp}{dq_2} = U_{22} < 0$$

It follows that the slope of residual demand is zero at p^k and is downward sloping below p^k. Residual demand, as it applies in figures 4.4a, 4.4b, and 4.4c, is the same as the fringe supply curve along $p=p^k$ until the point where S and $D_{I=2}$ intersect. Below $p=p^k$ residual demand coincides with $D_{I=2}$. The marginal revenue associated with residual demand for $p=p^k$ is equal to price and coincides with residual demand until the kink in

residual demand where marginal revenue falls vertically to the marginal revenue curve associated with the portion of the residual demand curve coinciding with $D_{1=2}$.

A. Pre-emptive Pricing

In this case, shown in figure 4.4a, the GMO and non-GMO are assumed to be homogeneous goods. The dominant firm's marginal cost is assumed to be at a level where the profit maximizing condition (MR=MC) dictates an optimal output of q_2^f. Following the optimal output up to the residual demand curve, the dominant firm's optimal price is p^k. The price set is just low enough to drive all the non-GMOs out of the market. Therefore, the price set is referred to as pre-emptive.

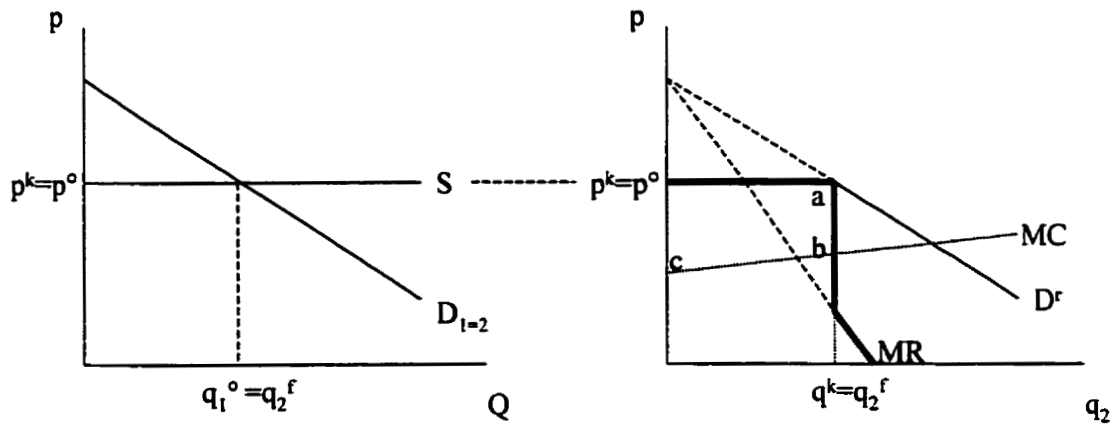

Figure 4.4a: Homogeneous Goods with Perfectly Elastic Supply - Pre-emptive Pricing

There is no loss in consumer surplus because perceived quality remains unchanged, but the gain from a lower price is infinitesimal because the dominant firm just undercuts p^k. There is a gain of stage-two profits shown as area p^kabc in figure 4.4a and producer surplus is zero when supply by the fringe is perfectly elastic. Since we assume no fixed or quasi-fixed costs in stage two, the dominant firm's stage-two profit coincides with its producer surplus. More formally, the cost function for stage two is assumed to be continuous with the cost equal to zero when output is equal to zero. With $\Delta PS = 0$, $\Delta CS \approx 0$, and given $\Pi - F \geq 0$ for innovation to occur, the change in total surplus is

$$\Delta TS = \Delta CS + \Pi - F \geq 0.$$

In the situation where there is no incentive for further entry by rival biotech firms because overall profits are equal to zero (i.e., $\Pi = F$), the change in total surplus is approximately equal to zero.

$$\Delta TS^* = \Delta CS \approx 0$$

Thus, the change in total welfare is non-negative when, (i) consumers perceive the goods as homogeneous, (ii) non-GMO supply is perfectly elastic, and (iii) the GMO producer prices pre-emptively.

B. Accommodating Pricing

In this case, goods 1 and 2 are homogeneous and supply is perfectly elastic. The dominant firm chooses quantity according to the profit maximizing condition, marginal revenue equal to marginal cost. The dominant firm's optimal quantity dictates the optimal price, p^f. The optimal price is set such that both GMOs and non-GMOs are supplied. Therefore, the price is referred to as accommodating.

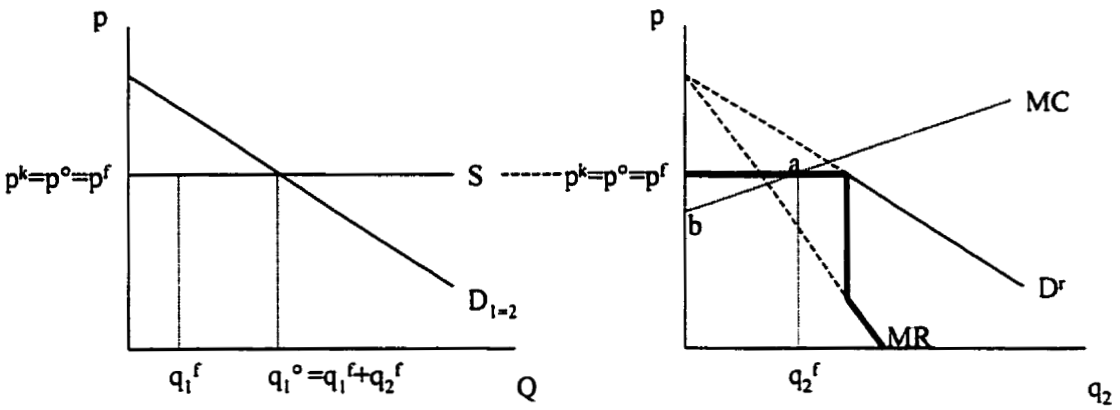

Figure 4.4b: Homogeneous Goods with
Perfectly Elastic Supply -
Accommodating Pricing

The quantity of the non-genetically modified good produced by the competitive fringe after innovation is q_1^f and stage-two profits are area p^kab in figure 4.4b. Consumer surplus does not change because the price set by the dominant firm is equal to the previous competitive price, a result caused by supply being perfectly elastic.

Perceived quality is also unchanged. Again, producer surplus is zero. Since $\Delta CS = 0$ and $\Pi - F \geq 0$, the change in total surplus for innovation to occur is:

$$\Delta TS = \Pi - F \geq 0$$

In the situation where the dominant firm's overall profits are equal to zero (i.e., $\Pi = F$) and there is no incentive for rival GMO firms to enter the market, the change in welfare is equal to zero.

$$\Delta TS^* = \Delta CS = 0$$

Thus, the change in total welfare is also non-negative when, (i) the goods are homogeneous, (ii) supply is perfectly elastic, and (iii) pricing is accommodating.

C. Monopoly Pricing

Again goods 1 and 2 are homogeneous and supply is perfectly elastic. The marginal cost of the innovating firm is low, giving rise to the profit maximizing quantity, q_2^f, as shown in figure 4.4c. The dominant firm's profit maximizing price, p^f, is set such that all of the non-GMOs are driven out of the market and is referred to as a pure-monopoly price. The pure-monopoly price differs from the pre-emptive price because of the difference in levels of marginal cost. The pure-monopoly price is associated with a lower level of marginal cost than pre-emptive pricing.

Here an increase in welfare is expected. Consumer surplus increases by the area $p^k abp^f$ due to the favourable price effect. Perceived quality is unchanged. Again producer surplus is zero, as always when supply is perfectly elastic. Stage-two profits are represented by area $p^f cde$. The change in total surplus given $\Pi - F \geq 0$ is,

$$\Delta TS = \Delta CS + \Pi - F > 0$$

If there is no incentive for rival biotech firms to enter because the GMO producer's overall profit is equal to zero (i.e., $\Pi = F$), the change in welfare remains strictly positive.

$$\Delta TS^* = \Delta CS > 0$$

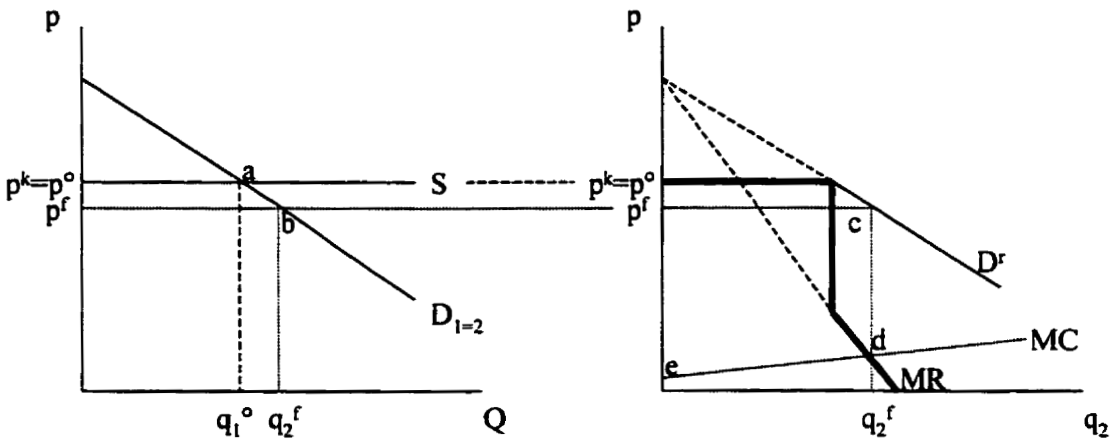

Figure 4.4c: Homogeneous Goods with Perfectly Elastic Supply - Pure Monopoly Pricing

Welfare increases unambiguously when (i) the goods are homogeneous, (ii) supply is perfectly elastic, and (iii) the GMO producer sets a pure monopolist price.

II. Homogeneous Goods with Imperfectly Elastic Supply

To determine the shape of residual demand when the goods are homogeneous and fringe supply of non-GMOs is imperfectly elastic the relative slope of residual demand for $p>p^k$ and $p<p^k$ must be established. Conditions (*C*.1), (*C*.6), (*C*.14), and (*C*.15) hold.

For $p>p^k$ (*C*.10) holds as well and (7) becomes,

$$P'(q_2)=\frac{U_{22}}{1-U_{21}S'(p)}<0 \tag{15}$$

For $p<p^k$ (*C*.13) holds and (7) becomes,

$$P'(q_2)=U_{22}<0 \tag{16}$$

The dominant firm's residual demand curve (D') is flatter above p^k than below because,

$$\left|\frac{U_{22}}{1-U_{21}S'(p)}\right|<\left|U_{22}\right| \tag{17}$$

Residual demand, as depicted in figures 4.5a, 4.5b, and 4.5c, is the horizontal difference between $D_{1=2}$ and S. At $p=p^{\circ}$ residual demand is zero, between p° and p^{k} residual demand is $D_{1=2}-S$, and when $p<p^{k}$ residual demand coincides with $D_{1=2}$. The upper segment of marginal revenue is the marginal revenue associated with the upper portion of residual demand. At the kink in residual demand marginal revenue falls to the marginal revenue associated with $D_{1=2}$.

A. Pre-emptive Pricing

Discussion of this case is based on figure 4.5a. Here consumers are assumed to be indifferent between GMOs and non-GMOs. The relevant demand curve is $D_{1=2}$ because the goods are perceived as homogeneous which means willingness to pay does not change when the proportion of GMOs/non-GMOs available changes.

The dominant firm's optimal quantity choice, q_2, occurs where marginal revenue equals marginal cost (MR=MC). The price charged by the dominant firm, p_2 or p^{f}, is determined diagrammatically by tracing q_2 up to the residual demand curve. The pricing strategy of the GMO producer depends on their level of marginal cost. Here we consider the situation where the marginal cost curve intersects marginal revenue at some point in the vertical portion of the marginal revenue curve resulting in an output of $q_2=q^{k}$. At this output, the marginal cost of the dominant firm is below the price taken by the competitive fringe because the dominant firm is assumed to have an advantage resulting from lower production costs once the new technology is adopted. Price is then set at a price of $p^{f}=p^{k}$ which is just consistent with driving all fringe producers from the

market. The dominant firm steals all of the market when it sets price pre-emptively and only the GMO is provided as depicted in figure 4.5a.

Consumer surplus increases unambiguously by area $p^{\circ}abp^{f}$ in figure 4.5a. This is due to the presence of a favourable price effect and the absence of an adverse quality effect. Producer surplus decreases by area $p^{\circ}ap^{f}$, but this is just a direct transfer to consumers leaving area $p^{f}ab$ as the net increase in surplus. Area $p^{f}cde$ represents the dominant firm's stage-two profit.

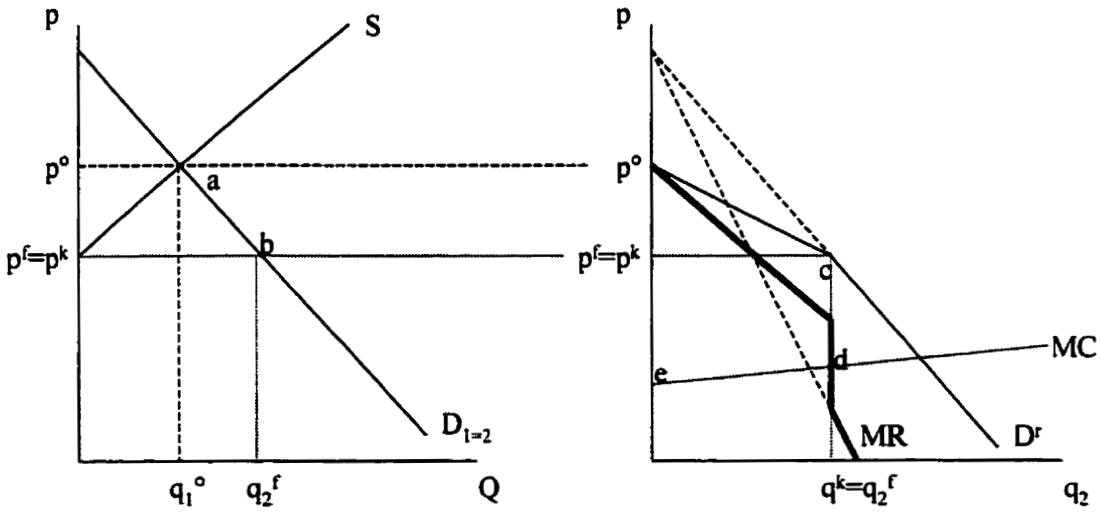

Figure 4.5a: Homogeneous Goods with Imperfectly Elastic Supply - Pre-emptive Pricing

The change in producer surplus is negative but less than the increase in consumer surplus, therefore, $\Delta CS - \Delta PS > 0$. Given that $\Pi - F \geq 0$ for innovation to occur, the change in total surplus is

$$\Delta TS = \Delta CS - \Delta PS + \Pi - F > 0.$$

Even if the GMO producer earns zero overall profits (i.e., $\Pi = F$) and there is no incentive for rival firms to enter, the change in welfare remains strictly positive

$$\Delta TS^* = \Delta CS - \Delta PS > 0.$$

Therefore, innovation will raise total welfare when, (i) goods 1 and 2 are homogeneous, (ii) supply is upward sloping, and (iii) the dominant firm prices pre-emptively.

B. Accommodating Pricing

This case is shown graphically in figure 4.5b on the following page. Consumers perceive the goods as homogeneous so $D_{1=2}$ is the appropriate demand curve. The dominant firm's marginal cost is at a level where the dominant firm chooses output such that price is accommodating. Both good 1 and good 2 are produced though supply of good 1 decreases as good 2 enters the market as shown in the figure.

The unambiguous increase in consumer surplus of area $p^{\circ}abp^{f}$ comes about due to the presence of a favourable price effect and the absence of a harmful quality effect. The change in producer surplus is negative shown as area $p^{\circ}acp^{f}$. Nevertheless, the

consumers gain more than the producers lose, leaving a net increase in surplus of area abc, (i.e., $\Delta CS - \Delta PS = abc > 0$). Stage-two profits are area $p^f def$ as shown in figure 4.5b. With the net increase in surplus of area abc and $\Pi - F \geq 0$ for innovation to occur, the change in total surplus is

$$\Delta TS = \Delta CS - \Delta PS + \Pi - F > 0.$$

Once again, the change in welfare remains strictly positive even if the GMO producer's overall profits are equal to zero (i.e., $\Pi = F$) so that there is no incentive for entry.

$$\Delta TS^* = \Delta CS - \Delta PS > 0$$

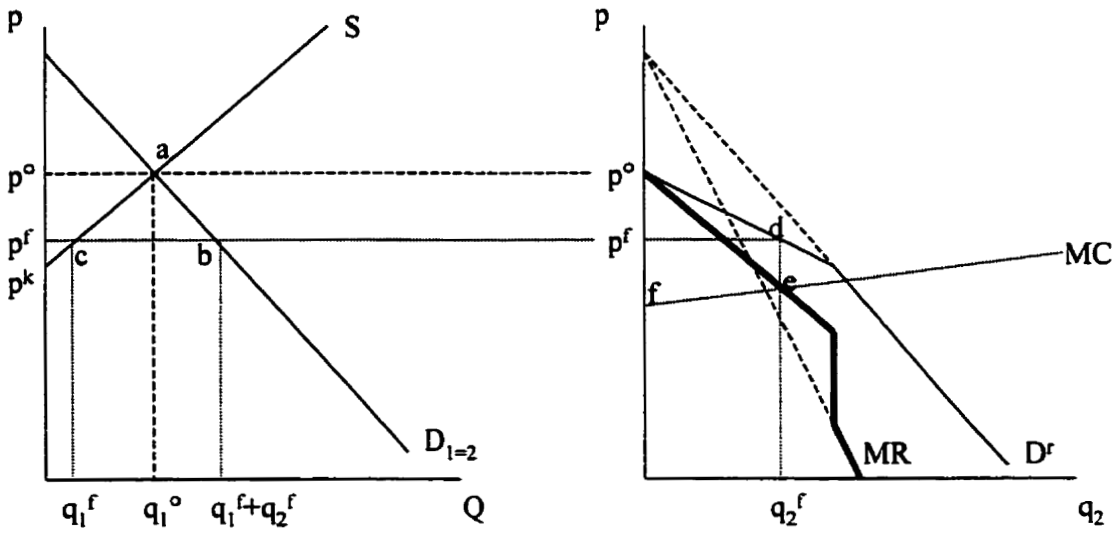

Figure 4.5b: Homogeneous Goods with Imperfectly Elastic Supply - Accommodating Pricing

When the goods are (i) homogeneous, (ii) supply is imperfectly elastic, and (iii) price is accommodating, total welfare increases unambiguously.

C. Monopoly Pricing

In this case, goods are homogeneous, pricing is monopolistic, and non-GMO fringe supply is upward sloping. All of the non-genetically modified product is driven out of the market and only GMOs are available commercially. Consumers gain from lower prices and o not suffer any adverse quality effects. Area $p^{o}ap^{k}$ (see figure 4.5c) is the loss in producer surplus transferred to consumers as part of area $p^{o}abp^{f}$, which is the increase in consumer surplus. This leaves a net increase in surplus equal to area $p^{k}abp^{f}$. Area $p^{f}cde$ is the dominant firms's profit in stage-two.

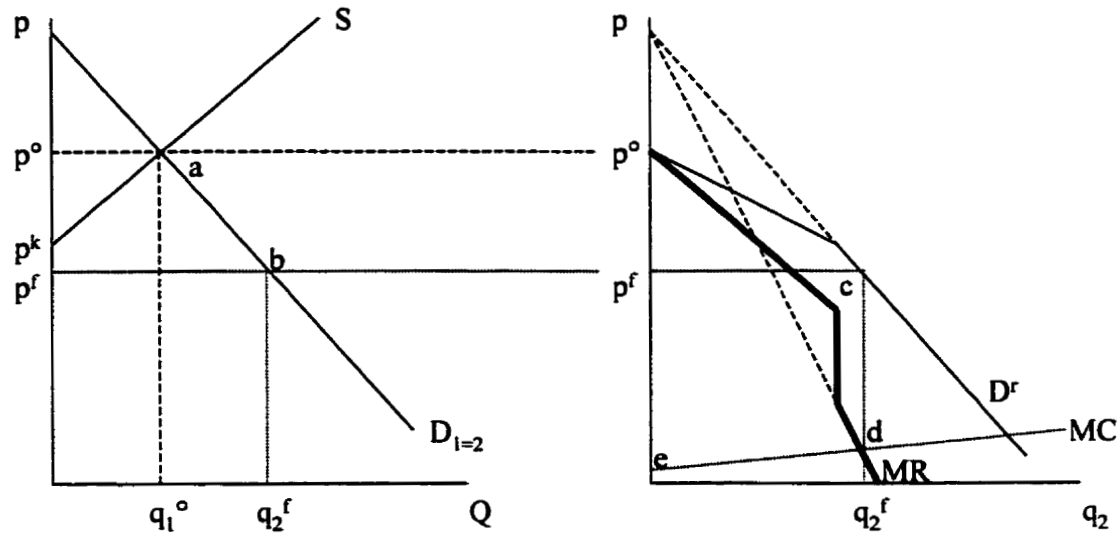

Figure 4.5c: Homogeneous Goods with Imperfectly Elastic Supply - Pure Monopoly Pricing

The change in producer surplus is negative, but $\Delta CS + \Delta PS > 0$ so the change in total surplus is given by

$$\Delta TS = \Delta CS - \Delta PS + \Pi - F > 0,$$

where $\Pi - F \geq 0$ for innovation to occur. As in the other homogeneous goods situations where fringe supply is not perfectly elastic, the unambiguous welfare gain to society does not depend on positive profits for the dominant firm. Even if overall profits were equal to zero (i.e., $\Pi = F$) so that there is no incentive for further entry, the welfare gain remains.

$$\Delta TS^* = \Delta CS - \Delta PS > 0$$

Biotechnological innovation has a positive effect on total welfare when the model is characterized by, (i) homogeneous goods, (ii) imperfectly elastic supply, and (iii) pure-monopoly pricing.

III. Heterogeneous Goods with Perfectly Elastic Supply

With the heterogeneous goods, consumers perceive a quality difference and are willing to pay less for the GMO. Consequently, in figures 4.6a, 4.6b, and4.6c, D_2, the demand curve that prevails when only GMOs are produced, lies below D_1, the demand curve that applies when only non-GMOs are produced. The heterogeneous versus

homogeneous goods characteristic does not impact the shape of residual demand when supply is perfectly elastic which means the relative slope of residual demand in this case is the same as in case II. Residual demand is perfectly elastic along p^k then negatively sloped when price falls below p^k.

Residual demand, as it applies in figures 4.6a, 4.6b, and 4.6c, is the same as the fringe supply curve along $p=p^k$ until the point where S and D_2 intersect. Below $p=p^k$ residual demand coincides with D_2. The marginal revenue associated with residual demand for $p=p^k$ is the same as residual demand until the kink where marginal revenue falls vertically to the marginal revenue curve associated with the portion of the residual demand curve coinciding with D_2.

A. Pre-emptive Pricing

Here supply by the fringe is perfectly elastic and the goods are heterogeneous. The dominant firm chooses quantity where marginal revenue equals marginal cost, $q_2=q^k$. Price is set pre-emptively so the GMO producer gains all of the market for GMOs and non-GMOs. Quantity demanded after innovation is q_2^f and quantity supplied consists entirely of the genetically modified product.

Consumer surplus increases slightly because of the infinitesimal fall in price, but decreases significantly because of the perceived quality reduction caused by the shift from D_1 to D_2. This decrease in consumer surplus is given by area abcd in figure 4.6a below. There will be a gain from stage-two profits shown as area p°efg and producer surplus is zero because supply by the fringe is perfectly elastic.

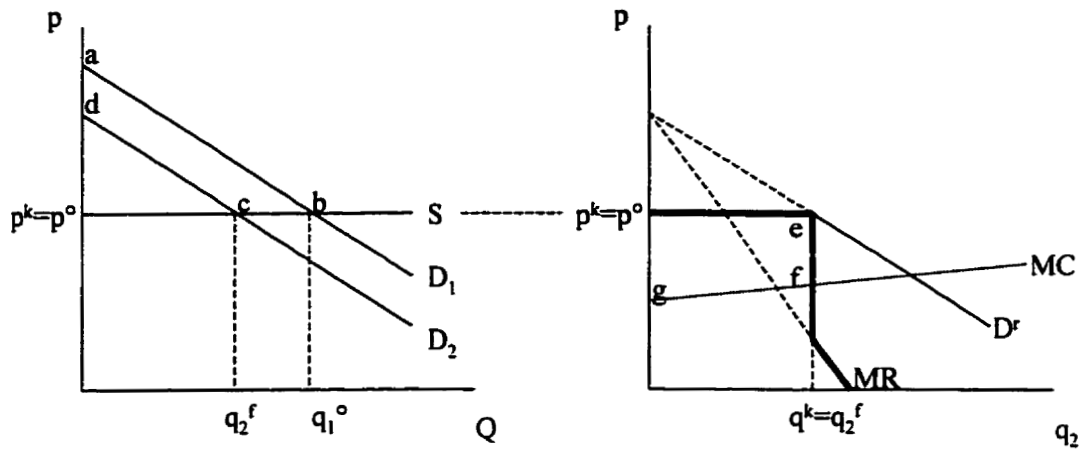

Figure 4.6a: Heterogeneous Goods with Perfectly Elastic Supply - Pre-emptive Pricing

The change in total surplus is ambiguous and depends on the relative magnitudes of the consumer loss and any overall profit of the dominant firm.

$$\Delta TS = \Delta CS + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

In the situation where the dominant firm's overall profits are equal to zero (i.e., $\Pi = F$) and there is a full equilibrium because there is no incentive for rival biotech firms to enter, the change in welfare is unambiguously negative.

$$\Delta TS^* = \Delta CS < 0$$

The adverse quality effect acts alone in this situation.

When, (i) consumers perceive GMOs and non-GMOs as heterogeneous, (ii) supply by the fringe is perfectly elastic, and (iii) the monopolist prices pre-emptively, the change in total welfare is, at best, ambiguous with the introduction of GMOs.

B. Accommodating Pricing

In this case, the two goods are heterogeneous, which means, as in all heterogeneous goods cases, that these consumers are willing to pay less when GMOs enter the market and are pooled with non-GMOs. The introduction of GMOs shifts the demand curve down from D_1 to D_a in figure 4.6b. Since some non-GMOs remain in the market, the demand curve does not shift down all the way to D_2.

Supply is perfectly elastic and price is accommodating such that $p^f = p^k$. In the absence of any price reduction, consumer surplus falls by area abcd due to the adverse quality effect. Stage-two profits are area p°ef and producer surplus of the fringe is zero. When $\Pi - F > \Delta CS$ the change in total surplus is positive. In general, however, the change in total surplus is ambiguous.

$$\Delta TS = \Delta CS + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Total welfare would definitely decline if the overall profits of the dominant firm were equal to zero so that there was no incentive for further entry.

$$\Delta TS^* = \Delta CS < 0$$

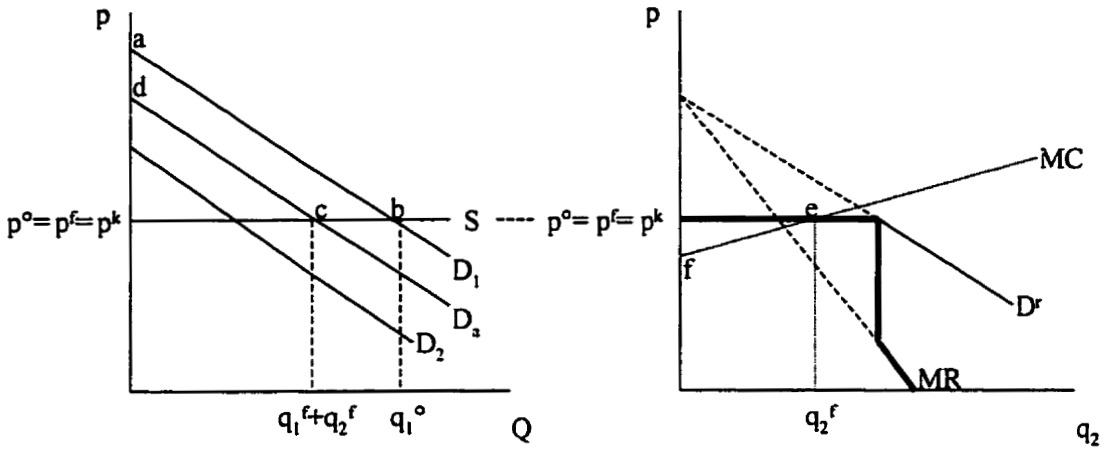

Figure 4.6b: Heterogeneous Goods with Perfectly Elastic Supply - Accommodating Pricing

When, (i) the goods are heterogeneous, (ii) supply is perfectly elastic, and (iii) price is accommodating the change in total surplus is negative in the absence of overall profits for the dominant firm. If stage-two profits exceed sunk costs, the change in total surplus is ambiguous.

C. Monopoly Pricing

In this case the goods are heterogeneous, supply is perfectly elastic, and pricing is purely monopolistic. The effect on welfare is, once again, ambiguous. There is a loss in consumer surplus resulting from the change in demand due to the perceived reduction in quality, but there is also a gain in consumer surplus attributable to the fall in price.

The negative quality effect is area abcd in figure 4.6c on the following page, while the positive price effect is area $p^k cep^f$. Producer surplus is zero and stage-two monopoly profits are area $p^f fgh$. The change in total surplus given $\Pi - F \geq 0$ is ambiguous because the change in consumer surplus is ambiguous due to the competing price and quality effects.

$$\Delta TS = \Delta CS + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

When stage-two profits are equal to sunk costs and there is no incentive for further entry, the change in total surplus is positive (negative) if the beneficial price effect is of greater magnitude than the harmful quality effect.

$$\Delta TS^* = \Delta CS \begin{matrix} > \\ = \\ < \end{matrix} 0$$

The farther left is D_2 the larger the loss in consumer surplus. The effect of D_2 being further to the left of D_1 is reinforced by the effect on residual demand. As D_2 moves left and residual demand moves left, the quality reduction increases and the benefit due to lower price decreases.

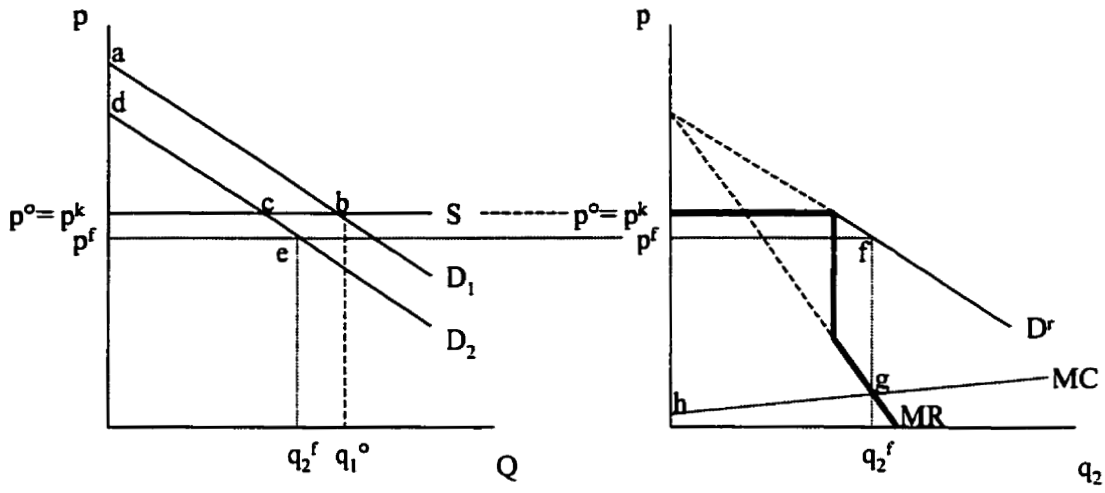

Figure 4.6c: Heterogeneous Goods with Perfectly Elastic Supply - Pure Monopoly Pricing

IV. Heterogeneous Goods with Imperfectly Elastic Supply

To determine the shape of residual demand when the goods are heterogeneous and supply is imperfectly elastic the relative slope of residual demand for $p>p^k$ and $p<p^k$ must be established. Conditions (*C*.1), (*C*.7), (*C*.14), and (*C*.15) hold.

For $p>p^k$ (*C*.10) holds as well and (7) is unchanged.

$$\frac{dp}{dq_2} = \frac{\theta U_{12} + (1-\theta)U_{22} + (U_1 - U_2)\dfrac{-\theta}{q_1 + q_2}}{1 - (\theta U_{11} + (1-\theta)U_{21})S'(p) - (U_1 - U_2)S'(p)\dfrac{1-\theta}{q_1 + q_2}} \tag{7}$$

For $p<p^k$ (C.13) holds and (7) becomes,

$$P'(q_2) = U_{22} < 0 \tag{17}$$

Comparing equations (7) and (17),

$$\begin{matrix} > \\ U_{22} = \\ < \end{matrix} \frac{\theta U_{12} + (1-\theta)U_{22} + (U_1 - U_2)\dfrac{-\theta}{q_1+q_2}}{1-(\theta U_{11} + (1-\theta)U_{12})S'(p) - (U_1 - U_2)S'(p)\dfrac{1-\theta}{q_1+q_2}}$$

There is no simplification for the right hand side to make determination of the inequality easier. The limit of the right hand side can be taken, which is the same as (7), to make some inferences about the slope of residual demand as p approaches p^k from above.

$$\lim_{p \downarrow p^k} \theta = 0$$

Therefore, the slope of the upper portion of residual demand is,

$$\lim_{p \downarrow p^k} P'(q_2) = \frac{U_{22}}{1 - U_{21}S'(p) - (U_1 - U_2)S'(p)\dfrac{1}{q_1+q_2}}$$

When

$$U_{21} + \frac{U_1 - U_2}{q_1 + q_2} < 0$$

the upper portion of residual demand is flatter than the lower portion and marginal revenue is well behaved as shown in figure 4.7a.

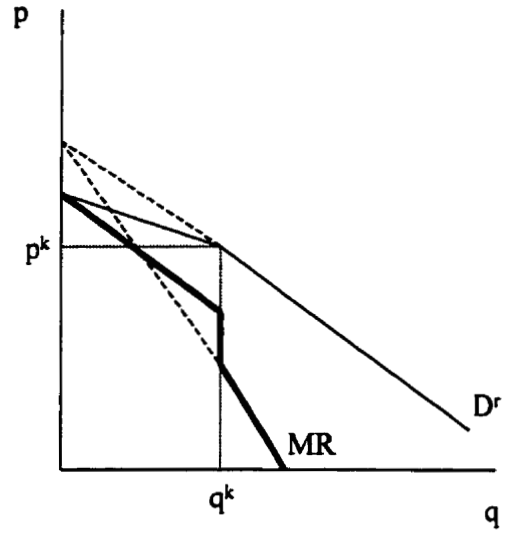

Figure 4.7a

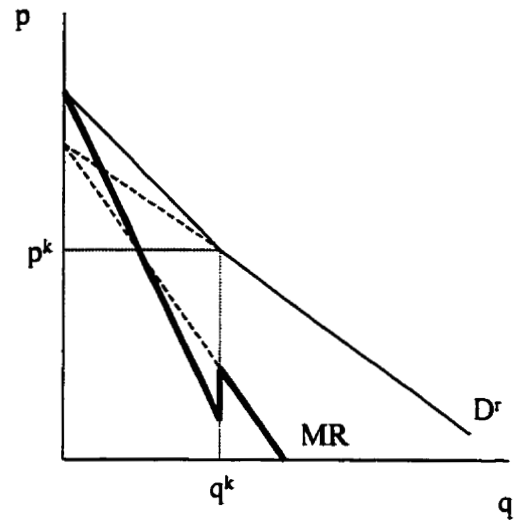

Figure 4.7b

An alternate case occurs when,

$$\frac{1}{S'(p)} > U_{21} + \frac{U_1 - U_2}{q_1 + q_2} > 0$$

When this condition holds, the upper portion of residual demand is steeper than the lower portion, though still negatively sloped. The associated marginal revenue curve is shown in figure 4.7b. This marginal revenue curve is rather unusual because the curve steps up. As shown in equation (9), marginal revenue is a function of the slope of residual demand. In figure 4.7b, residual demand is steep to the left and flat to the right, causing the step up rather than down. This implies that the marginal cost curve could

cut the marginal revenue curve three times. In such a case two quantities exist where profits achieve a local maximum and the profit curve has two peaks. In this situation pre-emptive pricing will not occur because it is a local minimum.

Two other possibilities exist for the shape of residual demand. The curve may have no kink, which is the intermediate case between the two discussed above. It is also possible for the residual demand curve to have backward bending segments. For positively sloped residual demand to occur the following condition must hold,

$$U_{21} + \frac{U_1 - U_2}{q_1 + q_2} > \frac{1}{S'(p)}$$

The possibility of residual demand having positive segments is not considered explicitly because these curves introduce complications without altering the essential conclusions of the analysis.

The residual demand curve shown in figures 4.8a, 4.8b, and 4.8c for cases with heterogeneous goods and imperfectly elastic supply is different from previous cases with imperfectly elastic supply because the goods are heterogeneous. At $p=p^{\circ}$, which is the intersection of D_1 and S, residual demand is zero. Between $p=p^{\circ}$ and $p=p^{k}$, where $S > 0$, residual demand is downward sloping. Below $p=p^{k}$ residual demand coincides with D_2. The upper segment of marginal revenue is the marginal revenue relative to the upper portion of residual demand down to the kink where marginal revenue falls vertically to the point where it becomes the marginal revenue associated with the lower portion of residual demand.

A. Pre-emptive Pricing

This case is depicted in figure 4.8a on the following page. Consumers treat the genetically modified and non-genetically modified products as heterogeneous. Supply by the fringe is positively sloped. Marginal cost of the dominant firm intersects the vertical portion of the marginal revenue curve. Price is set just low enough to take all of the market for good 1 away from the competitive fringe. Once again the dominant firm is pricing pre-emptively.

Total welfare is affected ambiguously. Stage-two profits are area $p^k ghi$. Consumer surplus increases by area $p^o cfp^k$, which is the benefit from the decrease in price, but consumer surplus also decreases by area abcd, which is the loss due to the change in quality.

$$\Delta CS = p^0 cfp^k - abcd$$

Area $p^o bp^k$ is the loss in producer surplus.

$$\Delta PS = -p^0 bp^k$$

Consider, for a moment, the impact of the price decline on consumers and fringe producers. The (positive or negative) net gain from the price decline is $p^f ef - cbe$. To

assess the full impact on consumers and fringe producers, the adverse quality effect must be included.

$$\Delta TS^* = \Delta CS + \Delta PS = p^k ef - abed \begin{matrix} > \\ = 0 \\ < \end{matrix}$$

$$p^k ef > abed \Rightarrow \Delta CS + \Delta PS > 0$$

$$p^k ef < abed \Rightarrow \Delta CS + \Delta PS < 0$$

Of course, ΔTS^* would reflect the change in welfare if the overall profits of the dominant firm were equal to zero and there was no incentive for further entry (i.e., $\Pi=F$).

The impact on total welfare remains ambiguous when the overall profits of the dominant firm exceed zero ($\Pi - F \geq 0$)

$$\Delta TS = \Delta CS + \Delta PS + \Pi - F \begin{matrix} > \\ = 0 \\ < \end{matrix}$$

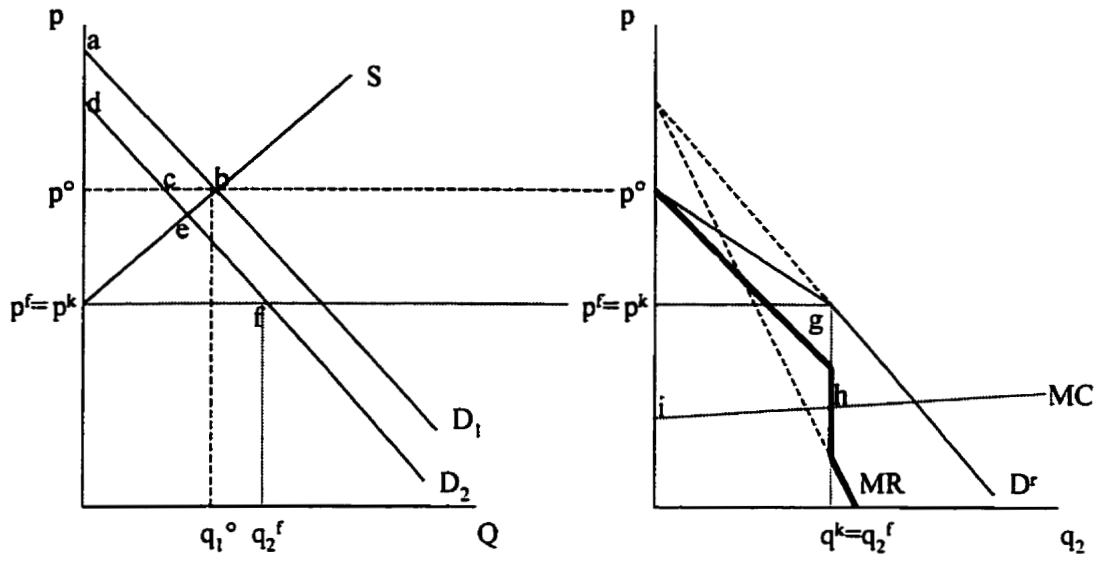

Figure 4.8a: Heterogeneous Goods with
Imperfectly Elastic Supply - Pre-emptive Pricing

When, (i) the goods are heterogeneous, (ii) supply is imperfectly elastic, and (iii) price is pre-emptive the change in total surplus is ambiguous.

B. Accommodating Pricing

This case is depicted in figure 4.8b on the following page. The demand curve, D_a, is a pooled curve representing demand for an average good when consumers are aware that both the GMO and non-GMO are available and are perceived as heterogeneous. The new demand curve, D_a, says there exists a probability, θ, that the good purchased is a non-GMO. It follows then that $(1-\theta)$ is the probability of purchasing a GMO. It is assumed that consumers are able to costlessly obtain

information about the proportion of GMOs to non-GMOs available in the market. The blended demand curve reflects consumers' willingness to pay for the good knowing the probability distribution.

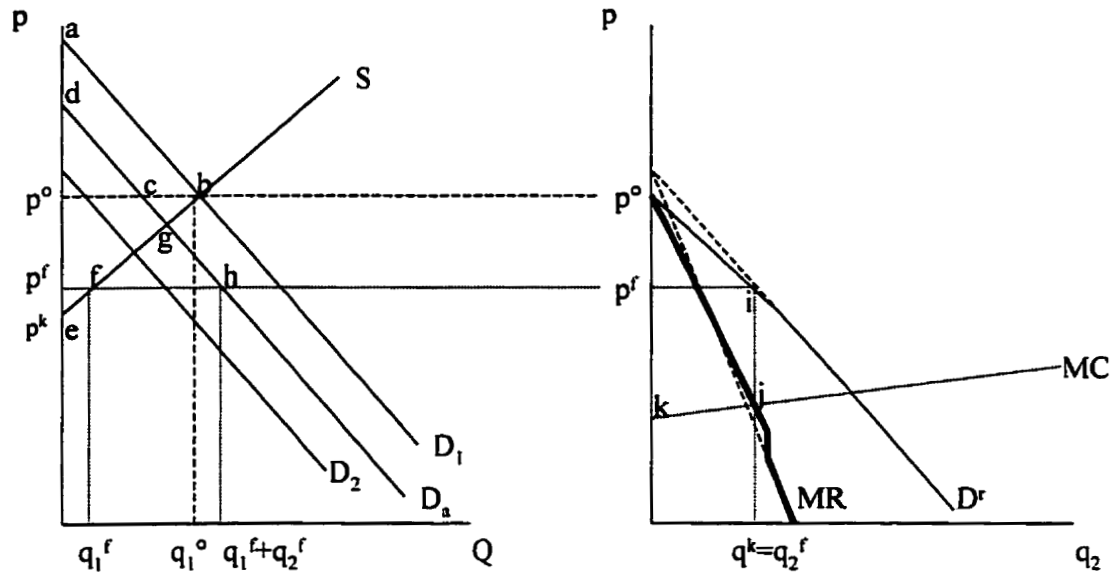

Figure 4.8b: Heterogeneous Goods with Imperfectly Elastic Supply - Accommodating Pricing

The larger the probability of a GMO or the smaller consumers' willingness to pay for GMOs the farther left of D_l, D_a will be. Given the level of marginal cost shown in figure 4.8b the dominant firm sets an accommodating price of p^f.

The total welfare change is ambiguous. Consumers lose are abcd from the decline in quality, but they gain $p°chp^f$ from the reduction in price.

$\Delta CS = p^{\circ}chp^{f} - abcd$

Producer surplus falls by area $p^{\circ}bfp^{f}$.

$\Delta PS = -p^{\circ}bfp^{f}$

Thus, the (positive or negative) net gain to consumers and fringe producers from the price reduction is fgh – cbg. Including the adverse quality effect on consumers yields:

$$\Delta TS^{*} = \Delta CS + \Delta PS = fgh - abgd \begin{matrix} > \\ = \\ < \end{matrix} 0$$

$fgh > abgd \Rightarrow \Delta CS + \Delta PS > 0$

$fgh < abgd \Rightarrow \Delta CS + \Delta PS < 0$

Once again, ΔTS^{*} reflects the change in welfare for society when there is no incentive for additional biotech firms to enter because overall profit is equal to zero. The change in welfare remains ambiguous even if the overall profits of the dominant firm are positive.

$$\Delta TS = \Delta CS + \Delta PS + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Stage-two profits are given by area $p^f ijk$. When (i) the goods are heterogeneous, (ii) supply is imperfectly elastic, and (iii) price is accommodating, the impact of biotech innovation is ambiguous.

C. Monopoly Pricing

Suppose that the goods are heterogeneous, supply is upward sloping, and monopoly pricing occurs. This case is depicted in figure 4.8c. All of good 1 is driven out of the market so the D_2 demand curve applies. Recall the D_2 curve is consumers' willingness to pay for GMOs when no non-GMOs are in production. The change in welfare is, one again, ambiguous. Area $p^\circ cfp^f$ is the increase in consumer surplus due to the price effect and area abcd is the decrease in consumer surplus due to the quality effect when GMOs enter the market.

$$\Delta CS = p^\circ cfp^f - abcd$$

Producer surplus falls by area $p^\circ bp^k$.

$$\Delta PS = -p^\circ bp^f$$

The (positive or negative) net effect of the price reduction on consumers and producers combined is $p^k efp^f - ceb$. Including the quality effect on consumers yields:

$$\Delta TS^* = \Delta CS + \Delta PS = p^k efp^f - abed \begin{matrix} > \\ = \\ < \end{matrix} 0$$

When the dominant firm's overall profits are equal to zero (i.e., $\Pi = F$) and there is no incentive for additional biotech firms to enter the market, ΔTS^* indicates the change in welfare for society.

Allowing the possibility of positive overall profits for the dominant firm (i.e., $\Pi \geq F$), still yields an ambiguous effect on welfare.

$$\Delta TS = \Delta CS + \Delta PS + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Area $p^f ghi$ is stage-two monopoly profit.

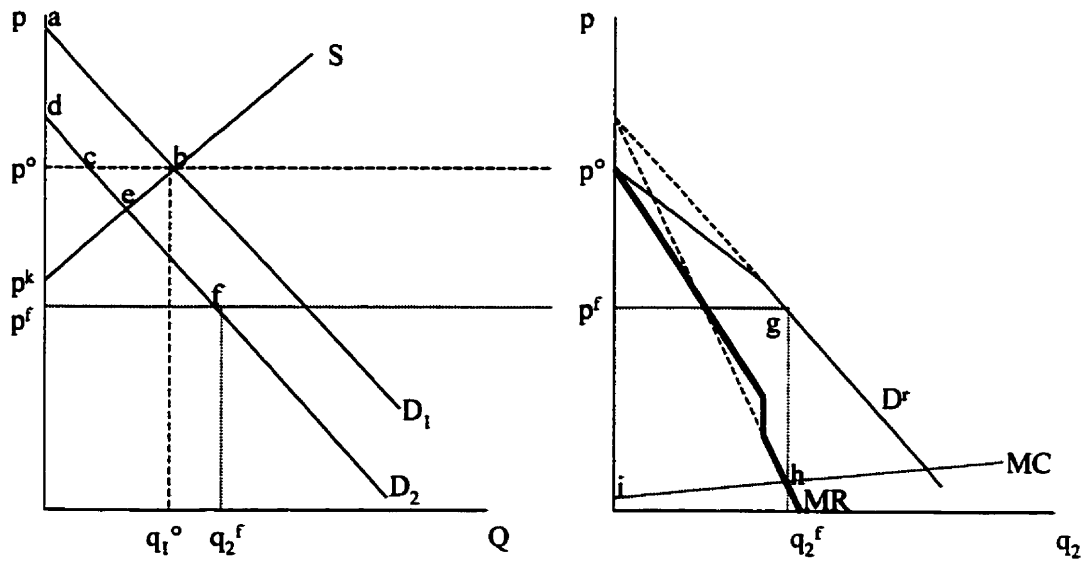

Figure 4.8c: Heterogeneous Goods with Imperfectly Elastic Supply - Pure Monopoly Pricing

When, (i) the goods are heterogeneous, (ii) supply is imperfectly elastic, and (iii) price is a pure monopolist price, the change in total surplus is ambiguous whether the GMO producer earns positive overall profits or not.

Discussion

Even when consumers cannot differentiate between GMOs and non-GMOs biotechnological innovation has an unambiguously positive, or at least non-negative, effect on society when consumers perceive the goods as homogeneous. Therefore, the change in total surplus is greater than or equal to zero with certainty when the asymmetric information problem is inconsequential for consumers.

For all cases involving heterogeneous goods, innovation has at best an ambiguous effect on total surplus and at worst a net negative effect. Heterogeneous goods cause ambiguity in the total surplus measure because of the competing price and quality effects. The favourable price effect tends to be larger the lower is the GMO producer's marginal cost. In the case involving accommodating pricing, the price effect also increases as fringe supply becomes more inelastic. The adverse quality effect is always larger the greater the relative distaste for GMOs rather than non-GMOs. For accommodating pricing, the negative quality effect is larger the lower is the GMO producer's marginal cost because the quality of the pooled good falls as GMO output increases. The magnitude of the perceived quality effect does not depend on the position of the marginal cost curve under pre-emptive and pure-monopoly pricing since

one hundred percent of the output is low quality GMO. The positive price effect and negative quality effect cause the impact of biotechnological innovation on society to be ambiguous when GMOs and non-GMOs are pooled, but some consumers perceive GMOs as lower quality.

In the next chapter the welfare effects of biotechnological innovation are considered when consumers are fully informed and a separating equilibrium results. The analysis under full information is simpler and the results less ambiguous.

Chapter 5 – Biotechnological Innovation with Separating Equilibria

Introduction

Uncertainty on the scientific front and the nature of consumer concerns has suggested there may be a need for some type of labelling of the products of biotechnology (Hadfield and Thomson, 1998). With labelling as a signal for quality, the market failure caused by asymmetric information can potentially be corrected with little of the government involvement that is often required when goods with credence qualities are involved. Labels transform credence (as well as experience) characteristics into search attributes making it possible for consumers to judge quality where they previously could not (OECD, 1997).

This chapter conducts a welfare analysis of the markets for GMOs and non-GMOs when consumers are fully informed about the GM characteristic of products available. Thus, the asymmetric information problem is corrected. The solution is provided in one of three ways. The first is a benchmark case where consumers have the ability to costlessly determine quality. The second is where a voluntary identity preservation system exists and is reflected in non-GMOs being labelled. The third is a mandatory identity preservation system where GMOs are required to be labelled. Voluntary labelling of non-GMOs would be something like "GMO-free" for example. Mandatory labelling of GMOs would be something like "product of biotechnology".

Identity preservation of a non-GMO can be considered successful when the non-GMO is prevented from co-mingling with GMOs in the food supply chain. To preserve

the identity of a non-genetically modified product, documentation must be available to prove that all ingredients used in production were non-genetically modified and that the product never came into contact with any GMO. Here identity preservation is assumed to be a necessary prerequisite to labelling. No product can be labelled as containing or not containing genetically modified ingredients, in whole or in part, unless the product has been segregated throughout the entire food supply chain. Labels that do not require identification of the GM characteristic with certainty such as, "may contain genetically modified organisms", will not require identity preservation. The information provided by the label however, is less valuable. If a consumer is to make a *fully* informed decision they must be able to establish the GM characteristic of goods with certainty, therefore, labelling options not requiring identity preservation are excluded from this analysis.

The key difference in this chapter from the last is that consumers are able to distinguish between GMOs and non-GMOs, providing for a separating equilibrium. The markets for good 1 and good 2 are separable because the GM characteristic of the two goods can be determined, therefore, the two goods can be segregated at the consumer point of purchase. Consumers' perception of the goods as homogeneous or heterogeneous is no longer critical as in the previous chapter because consumers have full information regarding the GM characteristic of competing products.

Firms whose food products do not contain GMOs may see this as an opportunity to differentiate their product in the eyes of consumers with a "GMO-free" label. Despite the fact that GMOs and non-GMOs may be functionally identical, when consumers

perceive a difference, or for ethical reasons do not wish to consume GMOs, a market premium may be available for a "GMO-free" labelled product. The transaction costs of proving the validity of this claim, however, are likely to be non-trivial. This may include thorough testing of all food products to determine the presence of GMOs. It is not at all clear that the technology currently exists to do this on a commercial scale. Alternatively, it will involve identifying upstream firms throughout the supply chain who use non-GMO inputs, monitoring their production practices, and probably establishing identity preserved supply chains to ensure only non-GM ingredients enter the food supply chain. This will likely put those firms wishing to include a "GMO-free" label on their products at a commercial disadvantage since it will be more costly to substantiate the absence rather than the presence of GMOs (Hobbs and Plunkett, 1999).

In reality, firms may have the incentive to mislead consumers by labelling their genetically modified product as a non-GMO to appropriate any non-GMO premium that may exist. The firms' profit from cheating may exceed their profit from not cheating. This behaviour on the part of firms may alter the monitoring/enforcement costs of either labelling policy. However, in this analysis labels are assumed to be accurate with no false labelling.

Under the conditions of a separating equilibrium this chapter looks at the consumer's problem, the competitive fringe's problem, and the GMO producers' problem, then measures the change in total welfare to society of biotechnological innovation. Cases considered are those where non-GMO fringe supply is perfectly or imperfectly elastic, and where information is costless or costly. The costly information

cases are associated with voluntary or mandatory labelling. Voluntary labelling is assumed to be provided by the non-GMO producing fringe and the cost of labelling is borne by the market for non-GMOs. Mandatory labelling is assumed to be provided by the vertically integrated GMO producer and the cost of labelling and verification that the GMO product does not escape into the non-GMO supply chain is borne by the market for GMOs. Costless information provides a benchmark analysis, it is the outcome when, in the limit, mandatory or voluntary labelling is costless.

Consumers

Consumers maximize utility subject to their budget constraint. The utility function is quasilinear as in chapter 4. The consumer's problem is as follows,

$$\max_{\{q_1, q_2, q_0\}} U = U(q_1, q_2) + q_0 \qquad \text{subject to } q_0 = M - p_1 q_1 + p_2 q_2$$

or

$$\max_{\{q_1, q_2\}} U = U(q_1, q_2) + M - p_1 q_1 + p_2 q_2$$

The variables M, p_1, p_2, and q_0 are income, the prices of good 1 and 2, and the quantity of a composite numeraire good. Consumers are assumed to be price takers. The consumer choice variables are q_1 and q_2 which represent the quantity consumed of non-GMOs and GMOs. The first order conditions for utility maximization are the inverse demand functions for good 1 and 2, respectively,

$$p_1 = U_1(q_1, q_2)$$

$$p_2 = U_2(q_1, q_2)$$

The properties of the inverse demand functions follow from the first order conditions,

$$\frac{\partial p_1}{\partial q_1} = U_{11} < 0$$

$$\frac{\partial p_1}{\partial q_2} = \frac{\partial p_2}{\partial q_1} = U_{12} = U_{21} < 0$$

$$\frac{\partial p_2}{\partial q_2} = U_{22} < 0$$

As expected, an increase in quantity reduces the product's own price and reduces the cross price when the goods are substitutes as they are here. The cross partial derivatives are equal by Young's theorem (Chiang, 1984). The direct demand functions for good 1 and 2 are given by,

$$q_1 = D_1(p_1, p_2) \tag{1}$$

$$q_2 = D_2(p_1, p_2) \tag{2}$$

The direct demand functions have the expected properties,

$$\frac{dq_1}{dp_1} = D_{11} < 0$$

$$\frac{dq_1}{dp_2} = \frac{dq_2}{dp_1} = D_{12} = D_{21} > 0$$

$$\frac{dq_2}{dp_2} = D_{22} < 0$$

See appendix C for proof of the properties of the direct demand functions. These direct demand functions will be referred to as ordinary or cross-price-contingent demands throughout this chapter.

The ordinary demand functions are used in the welfare analysis of biotechnological innovation. On the consumer's side, compensating variation is used as an exact measure of the change in consumer welfare.

$$\begin{aligned} CV = \Delta CS_1 + \Delta CS_2 &= \int_{p_1^f}^{p_1^0} D_1(p_1, p_2)dp_1 + \int_{p_2^f}^{p_2^0} D_2(p_1, p_2)dp_2 \\ &= \int_{p_1^f}^{p_1^0} D_1(p_1, p_2^0)dp_1 + \int_{p_2^f}^{p_2^0} D_2(p_1^f, p_2)dp_2 \end{aligned} \tag{3}$$

Since tastes are quasilinear, the compensating variation is equal to the overall change in consumer surplus.[1] The convention adopted for evaluating this line integral is to assess the change in consumer surplus on the non-GMO market (i.e., market one) before the GMO market (i.e., market two). Thus, the price of the GMO is held at its initial level, p_2^0, which is effectively infinite, while the change in consumer surplus for

[1] Since tastes are quasilinear and the cross-price effects on demand are symmetric, the solution to the line integral problem is path independent, or independent of the order of integration.

the non-GMO market is evaluated. Then the price of the non-GMO, having already moved to its final level, is held at p_1^f, as consumer surplus is evaluated on the GMF market.

Innovation that creates the market for good 2 generates a new source of consumer surplus. The increase in consumer surplus is a direct result of innovation because the availability of the new product creates consumer surplus where it previously did not exist.

The Competitive Fringe

The fringe producers of non-GMOs are assumed to be perfectly competitive as in chapter 4. The supply function differs only because the markets are separated. In chapter 4 supply was a function of the pooled price, here supply of good 1 depends only on the price of good 1. The supply function of the competitive fringe is,

$$S(p_1) = q_1 \tag{4}$$

The shape of the fringe supply curve depends on whether imperfectly elastic or perfectly elastic supply is assumed. In the long run, perfectly competitive supply is horizontal when production of non-GMOs is a constant cost industry. Long run supply is upward sloping when the industry is characterized by increasing costs.

The non-GMO firms' supply function is used to measure the change in producer surplus resulting from biotechnological innovation. The change in producer surplus is

$$\Delta PS = \int_{p_1'}^{p_1^0} S(p_1)dp_1. \tag{5}$$

The change in producer surplus is the area under the supply function between the initial and final prices of good 1.

The Dominant Firm

The dominant firm is now a monopolist producer of the GMO (i.e., good 2). For the dominant firm, however, the usual monopoly problem for the GMO product is compounded by the presence of the substitute non-GMO product. The market equilibrium conditions for the non-GMO and GMO products are:

$$D_1(p_1, p_2) = S_1(p_1)$$

and

$$D_2(p_1, p_2) = q_2.$$

When the dominant firm chooses its output q_2, this determines the price of the non-GMO as well as that of the GMO. The reduced-form or solution equations for the product prices are:

$$p_1 = P_1(q_2) \tag{6}$$

and

$$p_2 = P_2(q_2) \tag{7}$$

Appendix D provides further details on the derivation of equation (7). Equation (7) is referred to as the reduced-form (inverse) demand function or the (inverse) demand function facing the dominant firm. This reduced-form demand function takes account of how the dominant form's choice of output affects the price of the GMO directly and indirectly through the influence on the price of the non-GMO. Thus, the reduced-form (inverse) demand function, $p_2 = P_2(q_2)$, is distinct from the ordinary cross-price-contingent demand function $q_2 = D_2(p_1, p_2)$. While the ordinary demand function is central to the calculation of changes in consumer surplus on market 2, the reduced-form demand function is essential for the analysis of the dominant firm's pricing decision for its GMO product.

Appendix D contains the proof showing that the slope of the reduced-form demand function that faces the dominant firm is greater than or equal to the slope of the ordinary demand function which is contingent on p_1.

$$\left|P_2'(q_2)\right| = \left|\frac{1}{D_{22} + \dfrac{D_{12}D_{21}}{S'(p_1) - D_{11}}}\right| \geq \left|\frac{1}{D_{22}}\right| = \left|\frac{dp_2}{dq_2}\right|_{dp_1=0}$$

The slope of the reduced-form demand curve is greater in absolute value than the slope of the ordinary demand curve. Therefore, the reduced-form demand curve facing the

dominant firm is more inelastic than the ordinary cross-price-contingent demand curve for good 2.

If the dominant firm reduces its output, there is an immediate or direct effect where the price of the GMO rises even if the price of the non-GMO remains constant. The price of the non-GMO, however, will not necessarily remain constant. The higher price for the GMO will lead to excess demand for the substitute non-GMO unless the fringe supply is perfectly elastic. Thus, there is an induced increase in the price of the non-GMO in turn creates additional excess demand for the GMO. Thus, there is a further indirect increase in the price of the GMO resulting from the interaction with the substitute market. The reduced-form demand function takes the indirect as well as the direct effect on the GMO price into account. Thus, the reduced-form demand function for the GMO will coincide with the ordinary cross-price-contingent demand function if the fringe supply is perfectly elastic, and it will be steeper than the ordinary demand function otherwise.

Profits may arise because of the innovating firm's ability to exert market power in the development and production of the genetically modified product. Stage-two profits are simply revenue minus cost. Revenue of the dominant firm given (1) is

$$r_2 = p_2 q_2 = P_2(q_2) q_2 .$$

As in chapter 4, the dominant firm's stage-two cost function, which is defined to exclude stage-one sunk costs, is

$c_2 = c(q_2)$.

Stage-two profits are

$\Pi = r_2 - c_2$.

Profit maximization requires marginal revenue equal marginal cost,

$$P_2 + q_2 \frac{\partial p_2}{\partial q_2} = c'(q_2)$$

Total Surplus

Total surplus, in general, is the sum of consumer surplus in both markets, plus producer surplus in the market for the GMO, plus the stage-two profits of the GMO producer minus stage-one sunk costs.

$$\Delta TS = \Delta CS_1 + \Delta PS + \Delta CS_2 + \Pi - F$$

Here Π is the dominant firm's stage-two profit from good 2 and F is the sunk research and development cost incurred to develop good 2. Therefore, $\Pi - F \geq 0$ for innovation to occur. If the inequality did not hold, no firm would invest in the research and development necessary to develop a GMO. If the model were generalized to allow for entry into production of genetically modified substitutes, then overall profits would be dissipated. In other words, the situation with a single GMO producer is a full

equilibrium only if overall profit is equal to zero (i.e., $\Pi = F$). In such a situation total surplus is:

$$\Delta TS^* = \Delta CS_1 + \Delta PS + \Delta CS_2.$$

The remainder of this chapter looks at the welfare effect of innovation in six cases where supply of non-GMOs is perfectly or imperfectly elastic, and information correcting the asymmetric information problem is either costless, costly with voluntary labelling, or costly with mandatory labelling. Each case is discussed in association with diagrams representing the markets for good 1 and good 2. The change in total surplus as a result of biotechnological innovation is derived.

I. Perfectly Elastic Fringe Supply

The following three cases involve competitive fringe supply of non-GMOs that is perfectly elastic. As in chapter 4, perfectly elastic supply arises in the long run when the non-genetically modified industry is characterized by free entry with constant costs.

A. Costless Information

Costless information occurs when GMOs and non-GMOs can be distinguished by the consumer at no cost to either the firm offering the good or the consumer purchasing it. The markets for good 1, the non-GMO, and good 2, the GMO, under costless information and perfectly elastic fringe supply are represented by figure 5.1 and

5.2, respectively. In the market for good 1, S_1 is the supply curve of the non-GMO producing fringe. There are two demand curves, D_1° is the initial demand for good 1 prior to good 2 being available, which means q_2=0 and the initial price of good 2 approaches infinity. The second demand curve, D_1^f represents demand for good 1 after good 2 becomes available. Demand shifts left because some consumers will substitute away from good 1 into good 2, thus reducing demand for good 1. The D_1^f curve is the final demand for good 1 when the price of good 2 is held constant at its final level, p_2^f.

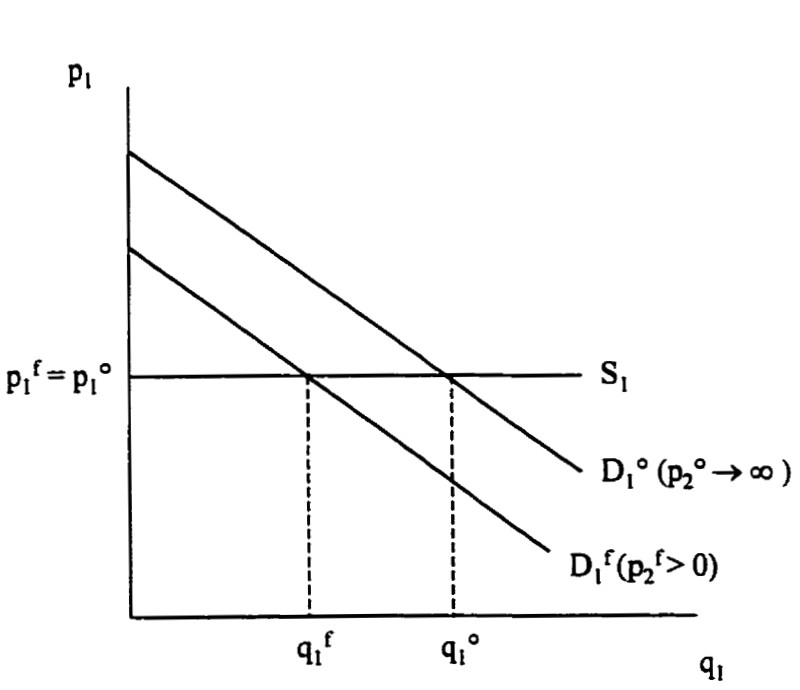

Figure 5.1: Costless Information with Perfectly Elastic Fringe Supply

Figure 5.2 shows the market for good 2 when information is costless and supply of good 1 is perfectly elastic. The reduced-form demand curve the dominant firm faces is $P_2(q_2)$. This demand curve allows for the potential variability of the price of good 1. Notice, however, that the price of good 1 is in fact constant in this particular case because supply is perfectly elastic. When fringe supply is perfectly elastic the dominant firm's demand curve, P_2, is the same as the ordinary demand curve, D_2.

Market for Good 2

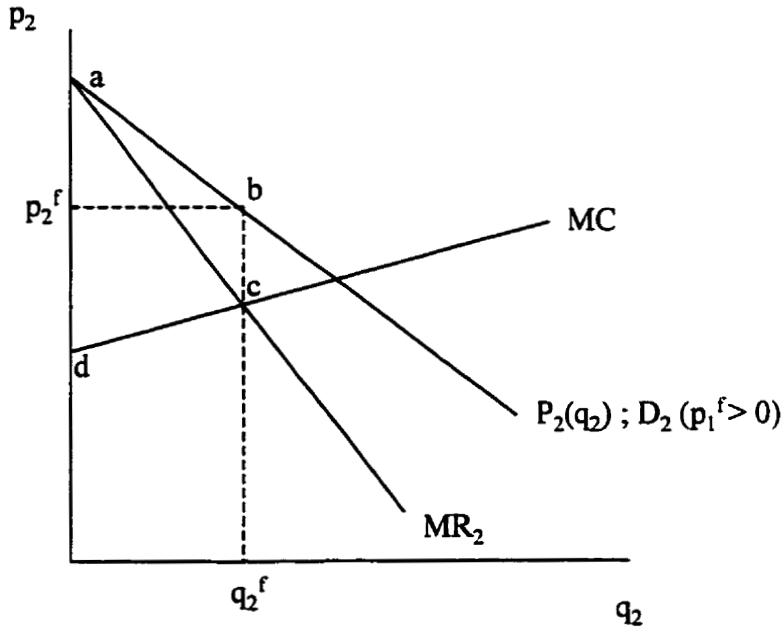

Figure 5.2: Costless Information with
Perfectly Elastic Fringe Supply

Marginal revenue of the dominant firm is derived from the reduced-form demand curve, $P_2(q_2)$. The profit maximizing quantity occurs, as usual, where marginal revenue

equals marginal cost and price is established by the demand curve facing the dominant firm.

Changes in consumer surplus are evaluated in accordance with equation (3). Recall that the convention adopted is to assess the change in consumer surplus on the non-GMO market before the GMO market. Thus, the price of the GMO is held at its initial level $p_2°$, which is effectively infinity and the change in consumer surplus on the non-GMO market is assessed against the initial demand curve $D_1°(p_2°\rightarrow\infty)$. Since the price of the GMO has not yet been changed, the final demand curve for the non-GMO, $D_2^f(p_2^f>0)$, is not relevant to the calculation of the change in consumer surplus in market one. In this case where the fringe supply is perfectly elastic, the change in consumer surplus in the non-GMO market is equal to zero because the price of the non-GMO does not change. It should be emphasized that there is no negative quality effect as in chapter 4 because the goods are not pooled. Therefore, introduction of GMOs does not reduce quality as perceived by consumers who have a preference for non-GMOs. The change in producer surplus is also zero in the market for good 1 because supply is perfectly elastic.

The change in consumer surplus in the market for good 2 is area abp_2^f in figure 5.2. The dominant firm's stage-two profit is shown as area p_2^fbcd.[2] The change in total surplus is,

$$\Delta TS = \Delta CS_2 + \Pi - F > 0$$

[2] In all cases subscripts refer to the good and superscripts refer to initial or final values.

where $\Pi - F$ is the monopolist's stage-two profit net of stage-one (sunk) costs. If overall profits are equal to zero (i.e., $\Pi = F$) so that there is no incentive for further entry, the change in welfare remains positive.

$$\Delta TS^* = \Delta CS_2 > 0$$

The change in total surplus resulting from biotechnological innovation is unambiguously positive when non-GMO supply is perfectly elastic and information is costless. Society is made better off by innovation because innovation creates consumer surplus in the market for good 2 that did not exist prior to innovation.

B. Voluntary Labelling

One solution to the problem of asymmetric information is voluntary labelling of food products not containing GMOs. This satisfies the consumer's "right to know" and allows market forces to signal consumer preferences to firms. Consumers with a safety or ethical objection to GM foods can signal their preferences by avoiding foods that do not display a non-GMO label (Hobbs and Plunkett, 1999).

The markets for good 1 and good 2, when non-GMO supply is perfectly elastic and voluntary labelling of non-GMOs is costly, are shown in figures 5.3 and 5.2, respectively. Labelling may impose significant costs on an industry related to segregating products and verification of the segregation (Caswell, 1998). This increase in cost is reflected in the upward shift of the fringe supply curve from S_1° to S_1^f. As

figure 5.3 shows, the cost of voluntary labelling is borne entirely by the consumers of good 1 while the market for good 2 is analogous to the costless information case. In figure 5.3 demand shifts to the left because some consumers substitute away from good 1 into good 2 when the market for good 2 is created.

Market for Good 1

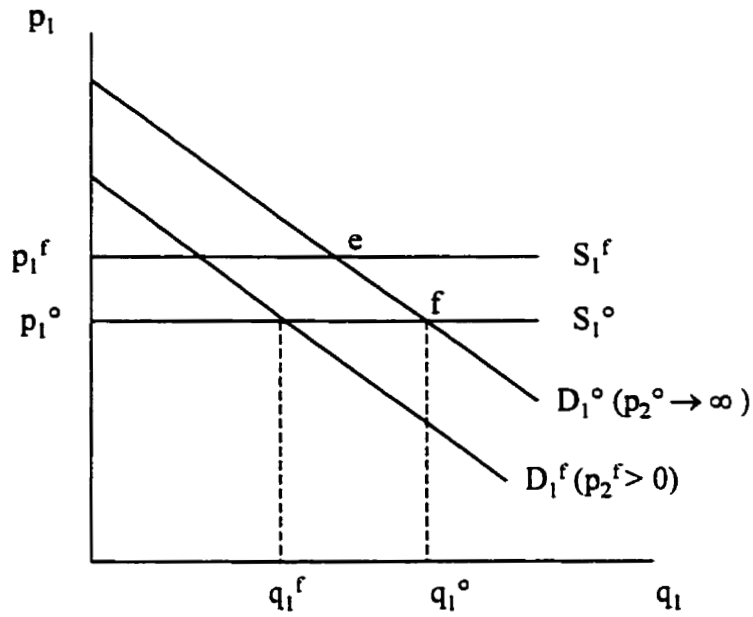

Figure 5.3: Costly Information with Perfectly Elastic Fringe Supply – Voluntary Labelling

Once again, the change in consumer surplus in the non-GMO market is assessed holding the price of the GMO at its initial infinite level. Since the relevant non-GMO demand curve is $D_1^\circ(p_2^\circ \rightarrow \infty)$, the change in consumer surplus, in the market for good 1

is represented by the loss of area $p_1^f efp_1^\circ$ in figure 5.3. The loss in consumer surplus results from the increase in price of good 1 arising from the identity preservation/labelling costs. The change in producer surplus is zero because supply is perfectly elastic, which also means producers are able to shift all of the labelling cost onto consumers. Having already changed the price of the non-GMO to its final level, p_1^f, the demand curve D_2 (p_1^f) is relevant to the consumer surplus calculation in the GMO market. Thus, the change in consumer surplus in market 2 is area abp_2^f in figure 5.2 as it was in the costless information case and stage-two profit is area $p_2^f bcd$. The change in total surplus is,

$$\Delta TS = \overset{(-)}{\Delta CS_1} + \overset{(+)}{\Delta CS_2} + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Biotechnological innovation will be welfare reducing when the costs of voluntary labelling are high and the loss in consumer surplus due in the non-GMO market is large. When overall profits are equal to zero and there is no incentive for entry, the change in total surplus remains ambiguous.

$$\Delta TS^* = \overset{(-)}{\Delta CS_1} + \overset{(+)}{\Delta CS_2} \begin{matrix} > \\ = \\ < \end{matrix} 0$$

If the gain in consumer surplus from the introduction of good 2 is greater than the loss in consumer surplus because of the price increase of good 1 due to labelling, the change in total surplus is positive.

C. Mandatory Labelling

A number of possible public policy solutions exist for correcting information asymmetry. If the presence or absence of a GMO is an important characteristic in the consumer's purchase decision but firms do not have the incentive to label voluntarily, regulators may choose to make those labels mandatory.[3] Welfare may be improved if the market failure caused by information asymmetry is corrected by government intervention.

While compulsory labelling may be a solution to information asymmetry, it is likely an expensive one. As with voluntary labelling, it requires that firms either thoroughly test all products to ensure the accuracy of a label, or incur transaction costs in monitoring all parties upstream in the supply chain to determine whether GMOs are present. This reduces the number of occasional spot market transactions which could impose high transaction costs on firms. Switching suppliers in an effort to reduce production costs may occur less frequently as the cost of monitoring the alternative inputs increases. As the costs of organizing transactions by means of exchange on the

[3] This is the approach favoured by the EU (Caswell, 1999). For example, in early 1999, the UK government announced regulations requiring all restaurants and food retailing establishments notify customers if the food they sell contains GM soya or corn. Foods that are derived from GM crops but no longer contain the genetically modified protein are excluded (Hobbs and Plunkett, 1999).

open market rise, closer forms of vertical coordination emerge (Williamson, 1979). Strategic alliances, contractual arrangements, and full vertical integration may result giving firms more control over, and more information about, the production practices of suppliers (Hobbs and Plunkett, 1999).

In this study mandatory labelling is imposed on the market for good 2. A mandatory label would be something such as, "a product of biotechnology". This type of label, as opposed to "may contain genetically modified ingredients," requires firms to label their products if they contain GMOs. The implication is that any product not labelled as "a product of biotechnology" is non-genetically modified. This is an assumption that may not hold in reality, but further research could investigate compliance. The latter label, "may contain genetically modified ingredients," provides no assurance to consumers of the GM characteristic of the product they are considering purchasing. The effect of a mandatory labelling policy is to increase the marginal cost of the dominant firm producing GMOs.

Under costly mandatory labelling with perfectly elastic non-GMO supply the markets for good 1 and good 2 are shown in figures 5.1 and 5.4, respectively. The market for good 1 is analogous to the costless information case, therefore, the change in consumer and producer surplus for good 1 remain zero.

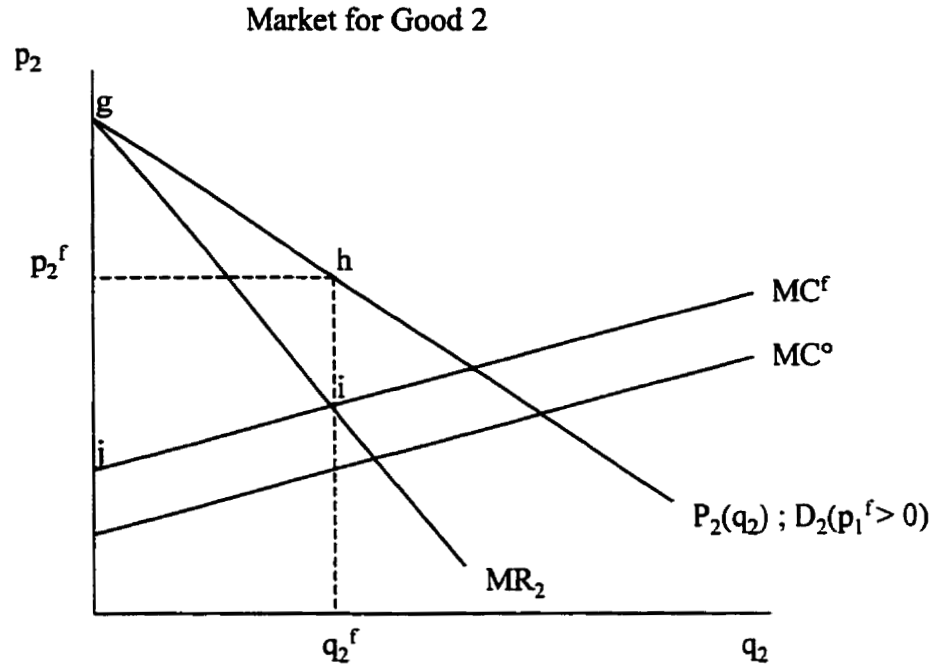

Figure 5.4: Costly Information with Perfectly Elastic Fringe Supply – Mandatory Labelling

Labelling of genetically modified products increases the price of good 2 and decreases the amount produced as well as stage-two profits. The change in consumer surplus in the market for good 2 is area ghp_2^f in figure 5.4, which is less than the change in consumer surplus in the costless and voluntary labelling cases, area abp_2^f, shown in figure 5.2 because the final price in figure 5.4 is higher than the final price in figure 5.2. Stage-two profits are area p_2^fhij.

The change in total surplus is,

$$\Delta TS = \Delta CS_2 + \Pi - F > 0$$

which is unambiguously positive. Even in the case where the GMO producers' overall profits are equal to zero (i.e., $\Pi = F$) and there is no incentive for further entry, the welfare gain remains.

$$\Delta TS^* = \Delta CS_2 > 0$$

The change in total surplus is unambiguously positive when non-GMO supply is perfectly elastic and mandatory labelling is costly. This contrasts with voluntary non-GM labelling where the change in total surplus is ambiguous.

The fact that the change in total surplus for mandatory labelling is unambiguously positive and the change in total surplus for voluntary labelling is ambiguous seems counterintuitive. The expectation was that mandatory labelling would be more likely to reduce total surplus than voluntary labelling. In the voluntary labelling case there is an ambiguous effect on total surplus due to the increase in the price of good 1 caused by good 2 being offered for sale and good 1 simultaneously requiring a label it previously did not. The increase in total surplus with mandatory labelling is unambiguous because as good 2 becomes available it must be labelled, simply reducing the consumer surplus generated by the new market. All else equal, voluntary labelling causes a loss in consumer surplus in market 1 while mandatory labelling only causes a smaller gain in market 2. Therefore, mandatory GM labelling cannot reduce total welfare whereas non-GM voluntary labelling can potentially reduce welfare.

II. Imperfectly Elastic Fringe Supply

For imperfectly elastic supply of non-GMOs the following three cases relax the assumption of perfectly elastic fringe supply. Perfectly competitive fringe supply is upward sloping because the industry exhibits increasing costs.

A. Costless Information

Figures 5.5. and 5.6 show the markets for good 1 and good 2 when supply is imperfectly elastic and information is costless. The market for good 1 is the same as it was for costless information and perfectly elastic supply with the exception that fringe supply is upward sloping. The market for good 2, however, is more complicated $P_2(q_2)$, the reduced-form demand curve facing the dominant firm, becomes more inelastic than $D_2(p_1^f > 0)$, the ordinary cross-price-contingent demand curve. As discussed earlier, these two curves have different slopes because $D_2(p_1^f > 0)$ holds the price of good 1 constant, while $P_2(q_2)$ allows the price of good 1 to vary.

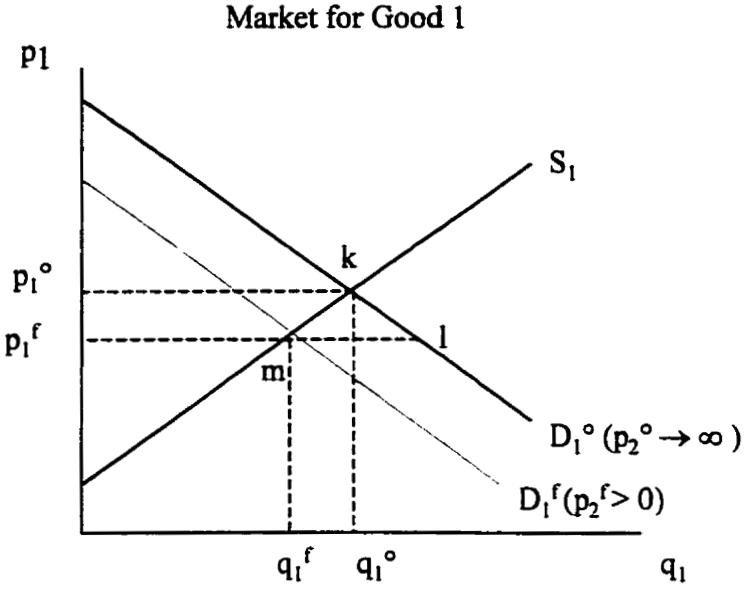

Figure 5.5: Costless Information with
Imperfectly Elastic Fringe Supply

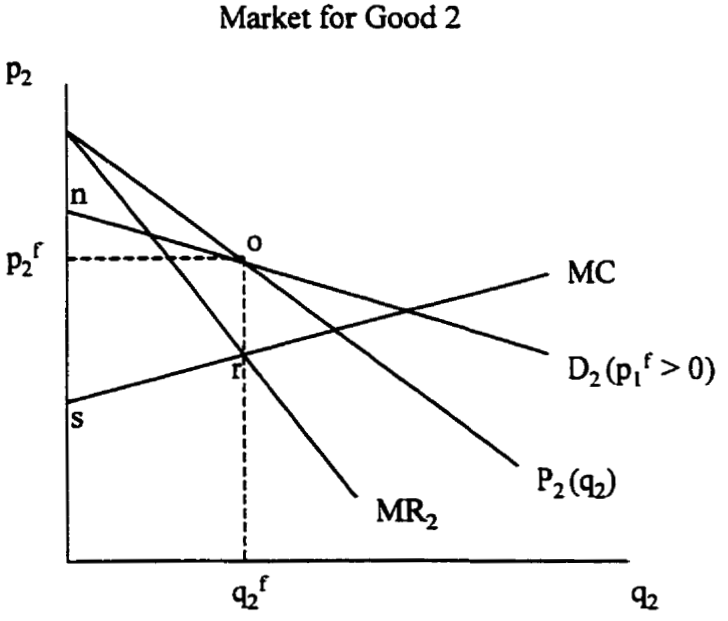

Figure 5.6: Costless Information with
Imperfectly Elastic Fringe Supply

Once again, the change in consumer surplus in the non-GMO market is assessed first using the $D_1(p_2^f > 0)$ demand curve. Consequently, the change in consumer surplus in the market for good 1 is a gain of area $p_1^{\circ}klp_1^f$ in figure 5.5. This increase in consumer surplus arises due to the fall in the price of good 1 made possible because fringe supply is upward sloping. The change in producer surplus in the market for good 1 is area $p_1^{\circ}kmp_1^f$, which is a direct transfer to consumers leaving a net increase in surplus in the market for good 1 equal to area klm.

The change in consumer surplus in market two is measured against the consumer demand curve, $D_2(p_1^f > 0)$. The change in consumer surplus in market 2 is area nop_2^f in figure 5.6. Stage-two profits are given by area p_2^fors. The change in total surplus is

$$\Delta TS = \Delta CS_1 - \Delta PS + \Delta CS_2 + \Pi - F > 0$$

and when stage-two monopoly profits are equal to stage-one sunk costs, the change in total surplus becomes

$$\Delta TS^* = \Delta CS_1 - \Delta PS + \Delta CS_2 > 0$$

which is unambiguously positive. Innovation continues to be beneficial to society even if overall profits are equal to zero (i.e., $\Pi = F$) and there is no incentive for rival biotech firms to enter.

B. Voluntary Labelling

Voluntary labelling applies to the labelling of non-GMOs. Therefore, the cost of the information provided by the label is borne by the market for good 1 and reflected in the upward shift of fringe supply in figure 5.7. The more elastic is fringe supply the greater the share of the labelling cost paid by consumers. There exist three possible shifts in supply such that, (i) $p_1^f < p_1^\circ$, (ii) $p_1^f = p_1^\circ$, and (iii) $p_1^f > p_1^\circ$. Looking at the case where $p_1^f = p_1^\circ$, the effect of a price change on surplus in the market for good 1 is neutralized. For $p_1^f = p_1^\circ$, the change in consumer surplus is zero in the non-GMO market because the consumer price is unchanged. There is, however, a decrease in producer surplus equal to area $p_1^\circ uvp_1^{sf}$ because the price received by the fringe net of labelling costs falls to p_1^{sf}. The farther S_1 shifts to the left the greater is the loss in surplus in market 1.

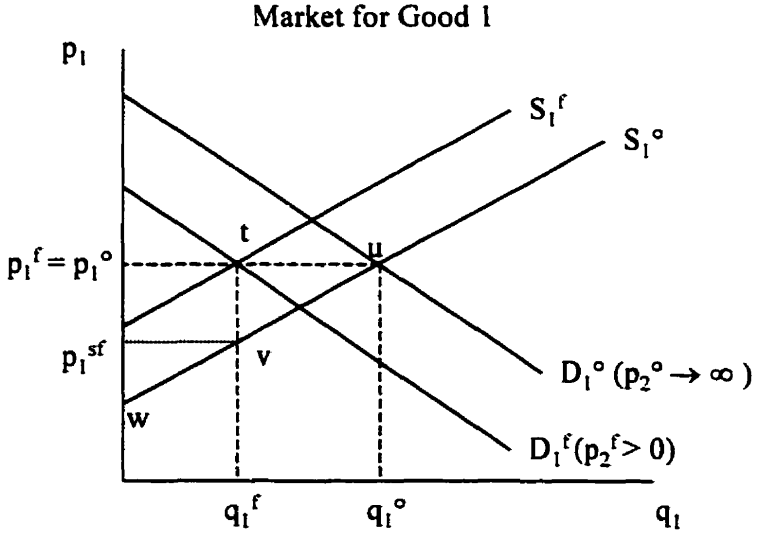

Figure 5.7: Costly Information with Imperfectly Elastic Fringe Supply – Voluntary Labelling

The market for good 2 continues to be shown by figure 5.6. The change in consumer surplus is area nop_2^f and stage-two profits are area $p_2^f ors$. The change in total surplus is ambiguous, given $\Delta CS_1 = 0$.

$$\Delta TS = \overset{(-)}{\Delta PS} + \overset{(+)}{\Delta CS_2} + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Generalizing to allow price changes in market one does not change the fact that welfare may either rise or fall.

$$\Delta TS = \Delta CS_1 + \Delta PS + \Delta CS_2 + \Pi - F \begin{matrix} > \\ = \\ < \end{matrix} 0$$

Similarly, the effect on welfare remains ambiguous if overall profits are equal to zero and there is no incentive for rival GMO producers to enter the market.

$$\Delta TS^* = \overset{(?)}{\Delta CS_1} + \overset{(-)}{\Delta PS} + \overset{(+)}{\Delta CS_2} \begin{matrix} > \\ = \\ < \end{matrix} 0$$

The effect of biotechnological innovation on total surplus is ambiguous when labelling is voluntary and non-GMO supply is imperfectly elastic. When the change in consumer surplus in market 1 is zero, the change in total surplus can be negative if the labelling cost offsets the consumer surplus gain in the market for good 2. The change in total surplus will be positive if the loss in producer surplus due to labelling cost is less

than the gain in consumer surplus from the introduction of good 2. When the change in total surplus is negative innovation is "bad" even though labelling is voluntary.

C. Mandatory Labelling

The markets for good 1 and good 2, when fringe supply is imperfectly elastic and labelling of good 2 is mandatory, are shown in figures 5.5. and 5.8, respectively. The market for good 1 are analogous to the costless information case. Therefore, the change in consumer surplus is the positive area $p_1{}^{\circ}klp_1{}^{f}$ in figure 5.5. The loss in producer surplus is area $p_1{}^{\circ}kmp_1{}^{f}$ in figure 5.5, which is transferred directly to consumers. Therefore, the net increase in surplus for market 1 is area klm.

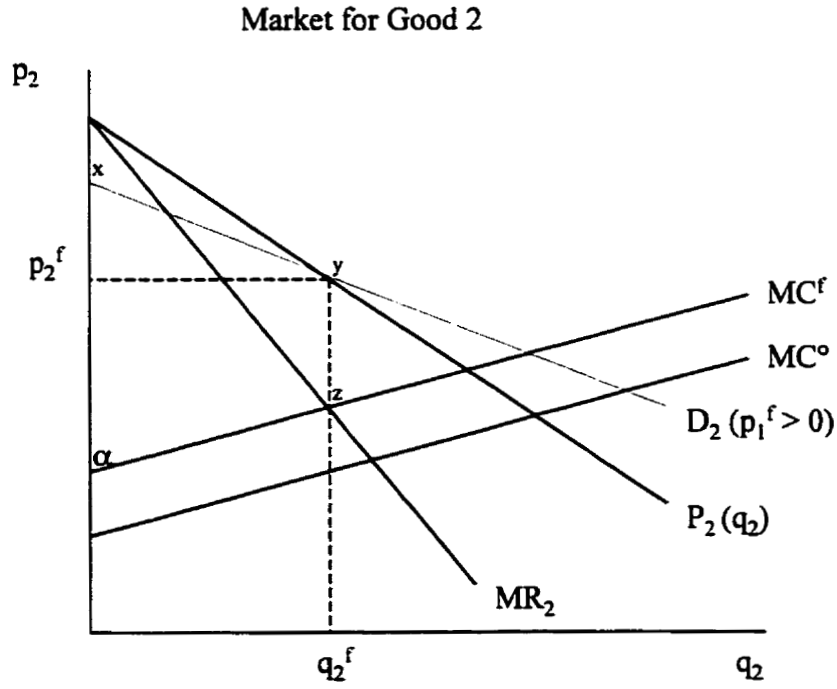

Figure 5.8: Costly Information with Imperfectly Elastic Fringe Supply – Mandatory Labelling

Figure 5.8 differs from figure 5.4 because the $D_2(p_1^f > 0)$ and $P_2(q_2)$ demand curves do not coincide in figure 5.8. Imperfectly elastic fringe supply means that the reduced-form demand curve facing the dominant firm is steeper than the ordinary cross-price-contingent demand curve for the GMO. It follows from figure 5.8 that the change in consumer surplus is xyp_2^f and stage-two profit is $p_2^f yz\alpha$. Since $\Delta CS_1 - \Delta PS > 0$, the change in total surplus is unambiguously positive.

$$\Delta TS = \Delta CS_1 - \Delta PS + \Delta CS_2 + \Pi - F > 0$$

The change in welfare is still unambiguously positive if overall profit is equal to zero and there is no incentive for rival GMO producers to enter.

$$\Delta TS^* = \Delta CS_1 - \Delta PS + \Delta CS_2 > 0$$

Similar to the results under the assumption of perfectly elastic fringe supply, the change in total surplus is unambiguously positive under mandatory labelling. Nevertheless, favourable innovations may not occur if identity preservation/labelling costs are too high.

Discussion

In this analysis, it is assumed that only non-GMO producing firms have the incentive to voluntarily label their products with a "GMO-free" type label, but is there

an incentive for GMO producing firms to adopt a voluntary labelling policy? That will depend on their assessment of consumer preferences. If firms are aware that their products contain GMOs but fear a consumer backlash, they will not have an incentive to disclose this information voluntarily--market failure occurs and GM foods will not be voluntarily labelled (Hobbs and Plunkett, 1999). Thus, it was assumed throughout this analysis that the dominant firm producing GMOs does not have the incentive to label its product as containing GMOs and the only way this food will be labelled is if it is mandatory.

In the case of genetically modified products with credible and valued benefits for consumers, firms may have an incentive to identify the GM characteristic of the product. The extent to which this would counter-act individual concerns over the "safety" and desirability of GM foods requires further investigation on a case-by-case basis.

The information provided by a label is valuable if total welfare increases as a result of the label. The value to consumers of a GM label that provides no additional useful information about the known safety or nutritional value of a product has been questioned in part because preliminary consumer research suggests confusion over the meaning of the term "genetically modified" (Kenny, 1999). Under the principle of "substantive equivalence"[4], GM and non-GM foods should have the same level of known safety. Critics of the mandatory labelling approach charge that GM labels could

[4] The principle of "substantive equivalence" means that when GM foods are tested using the same procedures as conventional foods, the modification is not significant or there is a high degree of similarity to the traditional product (Health Canada, 1994).

mislead consumers, implying that there is a difference in quality and safety between GM and non-GM foods. As such, adding GM labels may serve to complicate the issue, diluting the validity of the scientifically proven nutritional information (Kenny, 1999; Hobbs and Plunkett, 1999).

The welfare analysis presented here finds that GM innovation under a regime of mandatory labelling of GMOs has a positive effect, but GM innovation with voluntary labelling of non-GM products has an ambiguous impact. This analysis implicitly assumes that the value of a GM or non-GM label is equal. Demands for labelling are coming from consumers who want to avoid consuming GMOs. The purpose of the label is to change the credence characteristic of these goods into search characteristics. Search costs may, in fact, be lower for these consumers if non-GM labels are used rather than GM labels. With lower search costs the value of a non-GM label is likely to be higher for consumers who desire the information contained in the label.

Whether it is GMOs or non-GMOs that are labelled, at the heart of the problem is information. Consumers desire more information but most food supply chains, as they are currently structured, fail to provide this information. This suggests a growing role for the provision of credible product information and/or the auditing of product characteristics by third party private market players. Whereas in the past, a label or a firm's reputation alone was sufficient to satisfy consumers, increasingly, firms will have to demonstrate that they are adhering to certain principles and practices in line with claims of producing non-GMOs or GMOs. This suggests an increased role for

information technology in the agri-food chain to enhance traceability and improve information flows (Hobbs and Plunkett, 1999).

Identity preservation of products within the food supply chain may now be necessary to proceed with further biotechnology based innovations. As customized varieties involving particular transgenic modifications are developed to meet specific industrial or food-use requirements, greater segregation will have to be used to ensure that food processors receive the customized variety they have contracted. Under such commercial demand, these sectors may be required to move away from bulk distribution and handling into niche oriented contracting of specific-use agri-food products. Therefore, the long term strategic commercial interests may make identity preservation systems increasingly necessary (Isaac and Phillips, 1999). The costs of such market-driven segregation, however, are likely to be reflected in the prices of such customized varieties.

Chapter 6 – Conclusion

The title of this thesis asks if genetically modified foods are "good". Defining "good" to mean benefits greater than costs, the present analysis finds that genetically modified foods are good in some cases, but not in others. Table 6.1 provides a summary of the results found in chapter 4 when the asymmetric information problem persists.

Table 6.1 Summary of Pooling Equilibrium Results

		Pre-emptive Pricing	Accommodating Pricing	Pure Monopoly Pricing
Homogeneous Goods	Perfectly Elastic Non-GMO Supply	ΔTS positive ΔTS^* positive	ΔTS positive ΔTS^* positive	ΔTS positive ΔTS^* positive
	Imperfectly Elastic Non-GMO Supply	ΔTS positive ΔTS^* positive	ΔTS positive ΔTS^* positive	ΔTS positive ΔTS^* positive
Heterogeneous Goods	Perfectly Elastic Non-GMO Supply	ΔTS ambiguous ΔTS^* negative	ΔTS ambiguous ΔTS^* negative	ΔTS ambiguous ΔTS^* ambiguous
	Imperfectly Elastic Non-GMO Supply	ΔTS ambiguous ΔTS^* ambiguous	ΔTS ambiguous ΔTS^* ambiguous	ΔTS ambiguous ΔTS^* ambiguous

ΔTS includes stage-two dominant firm profits and stage-one sunk costs
ΔTS^* has stage-two dominant firm profits equal to stage-one sunk costs

In chapter 4 genetically modified and non-genetically modified organisms were assumed to be either homogeneous or heterogeneous. Although the homogeneous goods cases have an unambiguously positive, or at least non-negative, effect on welfare, the heterogeneous goods cases are a better reflection of reality. To assume consumers do not care about the GM characteristic of the foods they consume is an assumption that

does not hold for all consumers. In addition, increasing consumer concerns, as evidenced in chapter 2, suggest that the proportion of consumers perceiving the goods as heterogeneous is on the rise. When GMOs and non-GMOs are assumed heterogeneous, the impact on welfare is at best ambiguous and at worst negative, implying that consumers' inability to determine the GM characteristic of the foods they consume may significantly reduce welfare.

Consumers' desire to choose between genetically modified and non-genetically modified foods along with the ambiguous effect of biotechnological innovation on total surplus under asymmetric information implies that a solution to the information problem could increase total welfare. The asymmetric information problem means the market cannot function efficiently. As a result, there is a market failure and welfare is not maximized. Therefore, welfare could potentially be improved if consumers were fully informed. Addressing the market failure by providing product quality information to separate the markets for GMOs and non-GMOs allows consumers to make fully informed decisions that may improve efficiency, and consequently welfare, if the information costs are not too high. Table 6.2 provides a summary of the results found in chapter 5 when the asymmetric information problem has been corrected.

Chapter 5 considered options for solving the asymmetric information problem. Initially consumers were assumed to be able to costlessly distinguish between GMOs and non-GMOs. The costless information cases provided an ideal benchmark. However, the costless information cases themselves are not very useful in drawing

conclusions because credible information is always costly, particularly in attempting to distinguish non-GMOs from GMOs.

Table 6.2 Summary of Separating Equilibrium Results

	Voluntary Labelling	Mandatory Labelling
Perfectly Elastic Non-GMO Supply	ΔTS ambiguous ΔTS^* ambiguous	ΔTS positive ΔTS^* positive
Imperfectly Elastic Non-GMO Supply	ΔTS ambiguous ΔTS^* ambiguous	ΔTS positive ΔTS^* positive

The solutions to the asymmetric information problem considered were voluntary labelling of non-GMOs and mandatory labelling of GMOs. Any model must abstract from reality to be manageable. The model considered here is no different. It follows that opting for the most realistic assumptions within the model, the only situation in which biotechnological innovation is certain to be good (i.e., to yield unambiguously positive net benefits) is when mandatory labelling is required on genetically modified foods. Although it seems reasonable that those consumers who desire information ought to be the consumers who bear the cost of the information, the welfare analysis suggests just the opposite. With voluntary labelling of non-GMOs, consumers wanting to avoid GMOs are made worse off by biotechnological innovation while consumers who are indifferent between GMOs and non-GMOs are made better off. With mandatory GMO

labelling any biotechnological innovations that proceed will have positive expected net benefits. Consumers of GMOs benefit from innovation because of a fall in price.

It could be argued that labelling costs would raise the price of GMOs, offsetting any gain in consumer surplus. If this were true the innovation would not occur because it would not be profit maximizing for firms to innovate. With this arises one of the problems associated with mandatory labelling of GMOs. If labelling and sorting costs are too high, innovation that would otherwise be welfare improving, will not occur.

Mandatory labelling could also be problematic if providing a genetically modified label is less costly than ensuring products do not contain GMOs. This is a problem that could result in all foods being labelled as genetically modified, reducing the value of the label to consumers who have a preference for non-genetically modified foods. Further, in the conclusion to chapter 5, it was argued that the information contained in labelling non-GMOs may have greater value than the information in a GMO label suggesting that voluntary labelling may be the more effective policy.

In contrast to the theme of chapter 5, a voluntary labelling project was announced for foods derived from biotechnology on 17 September 1999 by the Canadian Food Inspection Agency (CFIA). The Canadian Council of Grocery Distributors (CCGD) and the Canadian General Standards Board (CGSB) are launching the project to develop a Canadian standard for the voluntary labelling of foods derived from biotechnology. The CGSB is an organization accredited by the Standards Council of Canada as a standards development and registration organization (CFIA, 1999). The labelling standard is to provide consistency in codes of practice for voluntary labelling

to give consumers information to choose between products that are or are not products of biotechnology. The voluntary labelling standard is to be developed with participation from consumer groups, food companies, producers, interest groups, and government, through a standards committee (CFIA, 1999).

The welfare analysis suggests implications for international trade. Taking the European Union as an example, many consumers there perceive GMOs and non-GMOs as heterogeneous goods. In the heterogeneous goods cases, biotechnological innovation affects welfare ambiguously and in some cases is welfare reducing, regardless of whether profit maximization implies the GMO-producer sets a pre-emptive, accommodating, or pure monopoly price. Trade agreements have not been adapted to handle GMOs, which means international standards have not been established. In the absence of international rules countries have been able to react to GMOs however they see fit. The European Union's response has been to impose import restrictions. The results of the welfare analysis carried out here imply that, in the absence of informative labelling or segregation of GMOs from non-GMOs, the European Union's import restrictions may be justifiable.

There are several opportunities for further research related to this topic. Rival biotech firms could be modeled formally. Collection of data to estimate demand functions for GMOs and non-GMOs would be valuable to clarify how much demand changes as the proportion of foods available become increasingly genetically modified. An estimation of the cost of identity preservation and, in turn, accurate labelling would

also be useful. Further research will want to consider the costs involved in enforcing mandatory GMO labelling versus voluntary non-GMO labelling.

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Appendix A – Properties of Direct Demand

Deriving the properties of the direct demand functions. Beginning with the consumer's unconstrained utility maximization problem,

$$U(\theta Q,(1-\theta)Q) + M - pQ \tag{1}$$

Taking the derivative of (1) with respect to Q,

$$p = \theta U_1(\theta Q,(1-\theta)Q) + (1-\theta)U_2(\theta Q,(1-\theta)Q) \tag{2}$$

Totally differentiating (2),

$$dp = \left[\theta^2 U_{11} + 2\theta(1-\theta)U_{12} + (1-\theta)^2 U_{22}\right]dQ$$

$$+\left[U_1 - U_2 + \theta Q(U_{11} - U_{12}) + (1-\theta)Q(U_{21} - U_{22})\right]d\theta.$$

Simplifying,

$$dp = \left[\theta^2 U_{11} + 2\theta(1-\theta)U_{12} + (1-\theta)^2 U_{22}\right]dQ$$

$$+\left[U_1 - U_2 + \theta Q(U_{11} - 2U_{12} + U_{22}) + Q(U_{21} - U_{22})\right]d\theta.$$

The inverse of the slope of the demand curve has the expected sign

$$\frac{dQ}{dp} = \frac{1}{\underset{(-)}{\theta^2 U_{11}} + \underset{(-)}{2\theta(1-\theta)U_{12}} + \underset{(-)}{(1-\theta)^2 U_{22}}} < 0 \tag{3}$$

As price increases total quantity consumed decreases.

As the probability of a unit of product being good 1 increases the total quantity consumed increases as shown in (4).

$$\frac{dQ}{d\theta} = -\frac{\overset{(+)}{U_1 - U_2} + \overset{(-)}{\theta Q(U_{11} - 2U_{12} + U_{22})} + \overset{(+)}{Q(U_{21} - U_{22})}}{\underset{(-)}{\theta^2 U_{11}} + \underset{(-)}{2\theta(1-\theta)U_{12}} + \underset{(-)}{(1-\theta)^2 U_{22}}} > 0 \tag{4}$$

In other words, as the proportion of non-GMOs (GMOs) increases quantity consumed increases (decreases). The numerator in equation (4) is positive because the second term in the numerator is never larger than the first term.

$$U_1 = U_1(\theta Q, (1-\theta)Q) \qquad U_2 = U_2(\theta Q, (1-\theta)Q)$$

$$\frac{dU_1}{d\theta} = (U_{11} - U_{12})Q \qquad \frac{dU_2}{d\theta} = (U_{21} - U_{22})Q$$

Further,

$$U_1 > U_2,$$

$$U_1 + \frac{dU_1}{d\theta} > U_2 + \frac{dU_2}{d\theta} \qquad \forall Q, \theta$$

Therefore,

$$U_1 + (U_{11} - U_{12})Q > U_2 + (U_{21} - U_{22})Q$$

Simplifying,

$$U_1 - U_2 + (U_{11} - 2U_{21} + U_{22})Q > 0.$$

It follows because θ>0,

$$U_1 - U_2 + (U_{11} - U_{21} + U_{22})\theta Q > 0.$$

Appendix B – Change in Consumer Surplus

The next task is the derivation of the change in consumer surplus.

$$CV = e(p^f, \theta^f, U^f) - e(p^f, \theta^f, U^\circ)$$

Add and subtract $e(p^\circ, \theta^\circ, U^\circ)$ and $e(p^f, \theta^\circ, U^\circ)$.

$$CV = e(p^f, \theta^f, U^f) - e(p^\circ, \theta^\circ, U^\circ) - e(p^f, \theta^f, U^\circ) + e(p^f, \theta^\circ, U^\circ)$$

$$- e(p^f, \theta^\circ, U^\circ) + e(p^\circ, \theta^\circ, U^\circ)$$

Initial and final income are equal, therefore, the first two terms cancel each other out.

$$CV = e(p^f, \theta^\circ, U^\circ) - e(p^f, \theta^f, U^\circ) + \int_{p^f}^{p^\circ} h(p, \theta^\circ, U^\circ) dp$$

Here h(.) is the Hicksian or compensating demand function. Note that

$$\lim_{p \to \infty} Q = 0, \quad e(p, \theta^\circ, U^\circ) = e(p, \theta^f, U^\circ)$$

In words, as price approaches infinity, expenditure on the pooled good is independent of θ. Subtract $e(p, \theta^\circ, U^\circ)$ and add $e(p, \theta^f, U^\circ)$.

$$CV = e(p^f, \theta^\circ, U^\circ) - e(\infty, \theta^\circ, U^\circ) + e(\infty, \theta^f, U^\circ) - e(p^f, \theta^f, U^\circ) + \int_{p^f}^{p^\circ} h(p, \theta^\circ, U^\circ) dp$$

Since tastes are quasilinear the change in consumer surplus is exactly equal to the compensating variation, therefore, Hicksian and Marshallian demands are equal and $h(.)$ can be replaced by $D(.)$.

$$\mathrm{CV} = \Delta\mathrm{CS} = -\int_{p^f}^{\infty} D(p,\theta^0)dp + \int_{p^f}^{\infty} D(p,\theta^f)dp + \int_{p^f}^{p^0} D(p,\theta^0)dp$$

Appendix C – Properties of the Consumer Demand Functions

The following is a proof of the properties of the direct, consumer demand functions. To determine the properties of the consumer demand functions, $q_1 = D_1(p_1, p_2)$ and $q_2 = D_2(p_1, p_2)$, starting with the indirect demand functions for good 1 and good 2 and totally differentiate.

$$p_1 = U_1(q_1, q_2)$$

$$dp_1 = U_{11}dq_1 + U_{12}dq_2$$

$$p_2 = U_2(q_1, q_2)$$

$$dp_2 = U_{21}dq_1 + U_{22}dq_2$$

Using Cramer's Rule to solve the total differential equations and derive the properties of the consumer demand functions.

$$\begin{bmatrix} U_{11} & U_{12} \\ U_{21} & U_{22} \end{bmatrix} \begin{bmatrix} dq_1 \\ dq_2 \end{bmatrix} = \begin{bmatrix} dp_1 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ dp_2 \end{bmatrix}$$

The determinant of the 2×2 matrix,

$$U_{11}U_{22} - U_{21}U_{12} > 0,$$

is positive because the goods are imperfect substitutes which means the direct effects are larger than the indirect effects.

$$D_{11} = \frac{dq_1}{dp_1} = \frac{U_{22}}{U_{11}U_{22} - U_{21}U_{12}} < 0 \qquad \begin{matrix}(-)\\(+)\end{matrix}$$

$$D_{12} = \frac{dq_1}{dp_2} = \frac{-U_{12}}{U_{11}U_{22} - U_{21}U_{12}} > 0 \qquad \begin{matrix}(+)\\(+)\end{matrix}$$

$$D_{21} = \frac{dq_2}{dp_1} = \frac{-U_{21}}{U_{11}U_{22} - U_{21}U_{12}} > 0 \qquad \begin{matrix}(+)\\(+)\end{matrix}$$

$$D_{22} = \frac{dq_2}{dp_2} = \frac{U_{11}}{U_{11}U_{22} - U_{21}U_{12}} < 0 \qquad \begin{matrix}(-)\\(+)\end{matrix}$$

The properties of the consumer demand functions are as expected.

Appendix D – Properties of the Demand Curve the Dominant Firm Faces

The following analysis shows that the slope of the demand curve the monopolist faces with variable p_1 is greater than the slope of the demand curve the monopolist faces when p_1 is held constant.

Starting with the consumer demand function for good 2,

$$q_2 = D_2(p_1, p_2), \tag{1}$$

the inverse slope of demand with fixed p_1 is simply the partial derivative of p_2 with respect to q_2,

$$\frac{\partial p_2}{\partial q_2} = \frac{1}{D_{22}} < 0 \tag{2}$$

The equilibrium condition for good 1 is,

$$S(p_1) = D_1(p_1, p_2),$$

where

$$(S'(p_1) - D_{11})dp_1 = D_{12}dp_2.$$

Thus, the price of good 1 depends positively on the price of the substitute, good 2.

$$p_1 = f(p_2),$$

where

$$f'(p_2) = \frac{D_{12}}{S'(p_1) - D_{11}} \geq 0.$$

Substituting into the direct demand function for good 2 yields,

$$q_2 = D_2(f(p_2), p_2),$$

where

$$dq_2 = (D_{22} + D_{21} f'(p_2))dp_2.$$

Consequently, the inverse demand function facing the monopolist can be written as,

$$p_2 = P_2(q_2),$$

where

$$P_2'(q_2) = \frac{1}{D_{22} + \frac{D_{12}D_{21}}{S'(q_2) - D_{11}}} \leq \frac{1}{D_{22}} = \left.\frac{dp_2}{dq_2}\right|_{dp_1=0}.$$

The slope of the monopolist's demand curve is a negative number that is of larger magnitude than the slope of the consumer's demand curve. Taking the absolute value of the slopes,

$$P_2'(q_2) = \left|\frac{1}{D_{22} + \frac{D_{12}D_{21}}{S'(q_2) - D_{11}}}\right| \geq \left|\frac{1}{D_{22}}\right| = \left.\frac{dp_2}{dq_2}\right|_{dp_1=0}$$

The monopolist's demand function is more inelastic than the consumer's demand function for good 2.