A nonlinear multicountry multicommodity spatial equilibrium model

with an application

by

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A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Economics

Major: Agricultural Economics

Iowa State University
Ames, Iowa

1988

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ABSTRACT

Food irradiation has now been legalized in the United States and in many other countries, including Australia and Japan. As yet, irradiated foods cannot be legally traded on world markets. Should this occur, the shelf life of meat will be extended long enough to eliminate the need for freezing during shipping. Freezing reduces the palatability and, consequently, the market price of meat. This quality discount in price can be regarded as equivalent to a transportation cost. The commercial acceptance of irradiation technology will reduce the quality discount and increase the quantity of meat traded on world markets but may decrease the trade in feedgrains. This is because countries such as Australia and Argentina can feed livestock more efficiently with grass than the United States and Japan can with feedgrains. The purpose of this study is to develop a model that is capable of analyzing the beef and feedgrain trade-offs when the quality discount is eliminated. The large impact of irradiation technology motivates the use of iso-elastic demand and supply systems. A new nonlinear multicountry, multicommodity model was developed and applied. This model is easy to work with and can be solved by commercially available software. The general model could also be applied to evaluate the impact of trade concessions on consumers and producers in both exporting and importing countries or to examine the cross-commodity effects of trade liberalization.

The results indicate that irradiation will not cause a large reduction in the price of feedgrains in the United States. This is because U.S. beef producers respond to the additional export market by demanding more feedgrains, and other countries do not have enough excess capacity to displace U.S. feedgrains. As with all models of this type, the numerical results depend on the elasticities used.

CHAPTER I. INTRODUCTION

Food irradiation is receiving renewed attention by scientists, policy makers, agricultural producer groups, public health officials, and consumers. Interest in the benefits of food irradiation and its limitations has been piqued by recent concerns over the safety of chemical fumigants and preservatives, and also because of the interest in reducing the incidence of food-borne diseases. Individuals concerned with food shortage problems in developing countries are eager to see whether irradiation can be used to eliminate high spoilage losses in those countries. In addition, food processors and retailers are continuously looking for less costly preservation methods and are always exploring new techniques to achieve desirable qualities in fresh and processed food.

Food irradiation techniques have been in the research and development stages in the United States for over thirty years. Canada, the Netherlands, and the Soviet Union accepted irradiation of certain food items in the 1950s. Currently 25 countries use the technology for one or more food items (Cessna and Rae, 1987). By employing ionizing energy, irradiation treats food by exposing it to gamma rays, X-rays, or accelerated electrons for a specific amount of time. Food irradiation is comparable to heating and freezing in its effect on the food and has potential as an innovative advantageous method for food preservation.

The thesis investigates the impact of beef irradiation on patterns of world trade in beef and feedgrains. With current technology the time required to ship fresh meat by ocean to Japan is too long for the meat to maintain edible qualities. Therefore, United States beef exporters must freeze the meat to ship it to Japan, causing severe quality deterioration. In addition, Japanese consumers favor frozen beef significantly less than fresh beef. Since irradiation makes it technically possible to ship chilled fresh beef to Japan from the other beef exporting countries, it is likely to change the current patterns of beef and feedgrains trade dramatically. If Japan accepts irradiated beef from any of the beef exporting countries, the United States, Australia, and Argentina, the quality discount due to freezing will be eliminated, since the chilled irradiated beef is assumed to be comparable in quality to chilled fresh beef. The quality discount due to freezing is reflected in the price that consumers are willing to pay for frozen beef. This price is lower than that of chilled fresh beef. Therefore, the irradiation process may be viewed as a way to eliminate the quality deterioration price differential due to freezing, thereby making imported beef more competitive with domestic beef in Japan. The lower beef price will also reduce domestic beef consumption in Japan, thereby reducing feedgrain demand in Japan. In turn, this reduces feedgrain imports into Japan. The overall impact on feedgrain prices in the different countries is ambiguous, since the country that exports the irradiated beef demands more feedgrains, while the beef industry in Japan demands less.

For policy purposes, the relevant question is whether the United States should encourage the use of the process both domestically and in food-importing countries. The purpose of this paper is to develop a methodology for answering this question and then to implement this methodology to measure how food irradiation will influence U.S. food exports should Japan accept irradiated meat.

Because meat irradiation has recently been legalized in the United States, and since Japan is the single most importer of U.S. beef, the results of this thesis are of high interest to agricultural policy makers. As of yet, however, beef irradiation has not been legalized in the international trade arena.

The thesis reviews the literature on spatial equilibrium models in Chapter II and summarizes developments in food irradiation in Chapter III. In Chapter IV the assumptions underlying the model and the data required to implement the model to the world trade in beef and feedgrains are presented. The theoretical model is developed and outlined in Chapter V. The theoretical model is a general nonlinear multicountry multicommodity spatial equilibrium model capable of handling relationships between different commodities by using a nonlinear complementarity algorithm. To the author his knowledge no such model has previously been developed. The model incorporates iso-elastic demand and supply curves, allowing the user to forecast the impact of various economic shocks on trade relationships. The development of the theoretical model is followed by an application of the model to the international beef and feedgrain trade between the United States, Australia, Argentina and Japan. The impact that beef irradiation has on the patterns of trade between these countries is investigated in Chapter VI. The results of the study are presented in Chapter VII. The results show a dramatic change in the patterns of beef and feedgrains trade, and therefore a large change in benefits to producers and consumers, should beef irradiation be allowed internationally. Chapter VIII summarizes the major results of the thesis and provides suggestions for further use of the model.

CHAPTER II. LITERATURE REVIEW

International agricultural trade models include two-region models, multiple region models, trade flow or market share models, and spatial equilibrium models. Two-region models divide countries into two groups: the group of interest, and all others. In principle, such models are domestic agricultural sector models that have been extended to include a foreign sector component. The two-region models do not specify the source and destination of the trade flows, but do specify the net trade between the country of interest and the rest of the world.

The multiple region models of agricultural trade divide the countries that constitute the aggregate rest of the world in the two region models into two or more trading regions, thus emphasizing the interrelationship between all trading regions.

In the investigation of the international trade of agricultural commodities, Thompson (1981) finds that spatial equilibrium models are the most popular. Spatial equilibrium models are structured such that prices are consistent between regions that trade with each other.

The development of trade flow models and market share models is motivated by the failure of spatial price equilibrium models to recognize the existence of more than one price in world agricultural markets and by the inability of spatial price equilibrium models to account for trade flows. Trade flow models may take into account the heterogeneity of commodities, or they may assume that importers differentiate goods subjectively by country of origin on for example historical or political grounds. The modeling techniques that are used include mechanical procedures that transform trade flows from one year to the next without regard for price, econometric techniques, and modifications of spatial equilibrium techniques.

The simple one-commodity model of perfect competition in spatial markets has been most widely applied in analyzing international agricultural trade. The seminal work in this area was done by Samuelson (1952), who first pointed out that an objective function exists whose maximization guarantees fulfillment of the conditions of a competitive market. Similar formulations were provided by Enke (1951), whose ideas were further developed by Takayama and Judge (1971), who showed that a competitive spatial equilibrium can be found by maximizing a quadratic objective function subject to a set of linear constraints. Other iterative linear programming procedures have been proposed by Fox (1953), Judge and Wallace (1958), Schrader and King (1962), King and Schrader (1963), Tramel and Seale (1959), and Yaron (1967).

Spatial equilibrium studies in the literature almost always model a single commodity, although some multi-commodity models have been developed. In the case of meat and feedgrains many spatial equilibrium models have been constructed for both commodities individually, but few have made the linkage between the two goods. However, to analyze the relationships between the meat and feedgrains markets, a multi-commodity model should be used (McCalla and Josling, 1985). Examples of one commodity spatial equilibrium models are provided by Shei and Thompson (1977) for wheat, who focus on spatial price determination in importing and exporting countries under alternative trade restrictions and policies, and Martin and Zwart (1975), who solve a similar quadratic programming model for pork. Examples of multi-commodity models are described by Martin (1981), and Takayama and Judge (1971, p. 267), both of which use linear demand and supply curves.

one multi commodity

Usually spatial equilibrium models assume linear demand and supply curves, although Rodriguez (1978) incorporates constant elasticity demand curves by using separable programming techniques. Since even such single commodity models can be large, linear demand and supply curves are often converted into excess demand and excess supply

linear

curves, thus reducing the number of curves by half. Linear demand and supply curves also give linear equilibrium conditions which can be solved by quadratic programming or linear complementarity algorithms. In general, spatial equilibrium models are nonlinear complementarity problems, where the nonlinearity comes from nonlinear demand and supply curves.

Since empirical evidence on the structure of meat and feedgrains markets is not clear, mathematical programming models assume either a perfectly competitive market or a monopoly market. For example, perfect competition and monopoly are discussed by Takayama and Judge (1971), Weinschenk, Heinrichsmeyer and Aldinger (1969), McCarl and Spreen (1980), and Norton and Schiefer (1980). However, oligopoly market structures have also been used in spatial equilibrium models. Imperfect competition has been recognized by Takayama and Judge (1971), McCarl and Spreen (1980), and in further developments have been published by Nelson and McCarl (1984). However, except for these studies, market distortions have not widely been implemented, even though market distortions present no computational difficulties (Paris, 1979; Kolstad and Burris, 1986).

The assumption underlying spatial equilibrium models have been relaxed in several ways. Fajardo, McCarl and Thompson (1981) constructed a multicommodity model for a single country with linear demand and supply curves. Holland (1985) allows nonlinear excess demand and excess supply curves for a single commodity. Governmental policies which lead to distortions have been endogenized either by assuming that policies are politically determined outside of markets (Rausser, Lichtenberg and Lattimore, 1982; Sarris and Freebairn, 1983; and Meilke and Griffith, 1983), or by assuming that policies coordinate consumers and producers within a country to jointly exercise oligopoly or oligopsony power (McCalla, 1966; Alaouze, Watson and Sturgess, 1978; Carter and Schmitz, 1979; Abbott, 1979; Karp and McCalla, 1983; Paarlberg and Abbott, 1986;

Kolstad and Burris, 1986). Kolstad and Burris develop the theory for a multicommodity, linear trade model, but only solve a single commodity linear model by adding oligopoly/oligopsony behavior to the model of Shei and Thompson (1977).

For the meat and feedgrains markets, the data readily available for most countries include prices, quantities consumed, quantities produced, and domestic demand and supply elasticities. Since irradiation has a rather large effect on transportation costs, the use of linear demand and supply curves may lead to corner solutions and therefore significantly change the elasticities used. An appropriate way to construct the model would be to use iso-elastic demand and supply systems which would allow commodities to be substitutes or complements in consumption and production. The model should calculate an equilibrium with total quantities consumed throughout the world matched by total quantities produced, and with prices in importing countries equal to the marginal costs of production in exporting countries plus the marginal costs of transportation and the implicit cost of any market distortions. In addition the model should consider complementarity conditions which arise at corner solutions where an importer begins exporting, or an exporter begins importing, or a country becomes isolated from world trade and produces only for domestic consumption.

To date, no multicommodity, multicountry, nonlinear spatial equilibrium model that utilized a nonlinear complementarity algorithm has been developed. In this thesis such a model is developed and applied to measure the impact of irradiation technology on the meat and feedgrain markets. In the model market distortions are quantified as tariff equivalents. These tariff equivalents remain constant throughout the policy experiments under the assumption that the degree of protection does not change during the period under study. Otherwise, in a multicommodity model, the conjectures by an oligopolist or oligopsonist about reactions to its policies must consider retaliation in any and all markets (Varian, 1984). Appropriate hypotheses about market structure would need to be developed and tested as McCalla (1966); Alaouze, Watson and Sturgess (1978); Carter and Schmitz (1979); and Kolstad and Burris (1986) have done for wheat.

CHAPTER III. GENERAL OVERVIEW OF FOOD IRRADIATION

Introduction

In this chapter the technical process of irradiation and its applications to food preservation is described. In addition, a summary of historical developments in food irradiation and some of the controversy surrounding the topic of food irradiation is presented.

Food irradiation is a process in which food products are exposed to high energy electromagnetic waves, thereby killing or rendering sterile pathogenic organisms, insects, and spoilage bacteria. The electromagnetic energy levels used are sufficient to break certain molecules into ionized or electrically charged particles. The irradiation process disrupts certain bonds in the molecules of DNA, thereby making cell reproduction impossible.

The electromagnetic energy that is used to irradiate the food is of the same type as radio waves, sunlight, or microwaves. However, because the energy waves need to penetrate the food, high levels of energy are needed for penetration. This requires that the beam must have a shorter wavelength than any of the aforementioned types of electromagnetic energy. This requirement limits the available sources to those that produce wavelengths in the X-ray to gamma range of the spectrum.

In the International System of Units irradiation is measured in Gray. This measurement replaces the rad, which is defined as 100 ergs of energy absorbed per gram of absorber. One kiloGray (kGy) equals 1000 Gy, which equals 100 kilorads.

The effects of the irradiation on food depend on the amount of energy absorbed. At lower doses of 0.05 to 1 kGy, insects and microbial organisms are sexually sterilized by damaging their genetic material and forming substances toxic to the organisms. In fruits and vegetables low irradiation doses cause chemical and physiological changes that may delay ripening and sprouting, whereas in meats low irradiation levels sexually sterilize food-borne parasites such as trichinae in pork. Medium doses of 1 to 10 kGy reduce the number of spoilage and pathogenic micro-organisms that contaminate foods. Very high doses of irradiation in the range of 23 to 57 kGy in combination with heating, can completely sterilize the food. However, the very high irradiation levels are generally considered impractical for food irradiation (Morrison and Roberts, 1985, p. II-1).

In the United States the use of food irradiation is regulated by the Food and Drug Administration (FDA). The FDA defines food irradiation as an additive to the food, because irradiation affects food chemically. Internationally, the International Joint Expert Committee on Food Irradiation (IJECFI), an impartial group of scientists, views irradiation as a "...physical process for treating foods and as such it is comparable to the heating or freezing of foods for preservation..." (Diehl, 1978). Defining food irradiation as a food additive is much more restricting than defining it as a process, because additives must not only pass more rigid testing standards for safety, but they must be declared on the food label (Wedekind, 1983).

Scientific evidence attesting to the safety and wholesomeness of irradiated food products has led to a limited acceptance of the process. The FDA currently approves the use of medium to high levels of irradiation to disinfect dried spices and seasonings (Dobkin and Blair, 1985). In addition, the FDA now allows low-dose irradiation to fresh fruits and vegetables to disinfest and to prevent spoilage. Although the concept of using irradiation as a processing technique has not yet been generally accepted, in July 1985 the FDA approved medium level irradiation for control of the Trichinella spiralis bacteria in fresh pork (LaBell, 1986).

High doses of meat irradiation can cause off-flavors, undesirable odors and nutritional deficiencies. However, Urbain (1978) finds that even irradiation sterilized meats have superior texture and nutritional content at a level comparable to conventional canned foods. To minimize off-flavors, undesirable odors and nutritional losses resulting from exposure to necessary high irradiation doses, foods can be vacuum sealed and irradiated at low temperatures. With the irradiation levels that are currently legal in the United States, no detectable increase in temperature occurs during the process. Moreover, the medium level irradiation process itself causes almost no noticeable change to the foods for which the process has been legalized, since the changes to the DNA molecules caused by the irradiation become important only if the cell begins to reproduce. The absence of noticeable change has led to certain difficulties in detecting whether food has been irradiated or not, but this problem has to some extent been resolved by attaching strips of material to the food containers, that change color when exposed to irradiation. However, to maintain acceptable qualities, meat should be at refrigeration temperature during the irradiation process and during the subsequent storing and shipping time.

Two different methods can be used to provide the energy that is required to penetrate the target material. The first, and until recently the only viable, method involves utilizing the radioactive isotopes of Cesium and Cobalt. Cesium-137 is produced as a by-product of the nuclear weapons industry. Small quantities of this isotope are available for purposes of irradiation. Cobalt-60 is manufactured specifically for the irradiation process by a Crown Corporation in Canada. Some advantages of these isotopes are that they are relatively cheap (Cesium-137 is free to certain installations), they are reliable, involve no moving parts, and the gamma rays produced have deep-penetrating power. The principal disadvantage of isotopes is the danger that is involved with handling them. Since the isotopes emit energy constantly, they must be lowered into water when the emitted energy is not required for the irradiation of the food, thereby making the water radioactive. Also, since the energy is emitted in a spherical pattern, the food must be exposed to the energy source for a longer period. Since the energy source is hot, it is difficult to keep the meat chilled. In addition, disadvantages of the use of the isotopes include their association with the nuclear power industry. This is especially true for Cesium because of its link to the nuclear weapons program.

The second possible source of energy is the electron accelerator. These machines accelerate electrons to high speeds. When the electrons collide with the nuclei of the cells of the target material, electromagnetic radiation is emitted that is of a suitable energy for irradiation. Until recently it had been impossible to consistently produce energy with sufficient penetrating power for meat irradiation. This situation has recently changed with the development of the induction linear accelerator (LINAC) that uses electric fields supported by magnetic induction for electron acceleration (Ch2M Hill, 1988). This machine has considerable advantages over isotope sources. It can be switched on and off and uses regular electric power. The LINAC beam can be focused on a target; hence, only a brief exposure time is required. The principal disadvantage of the machine-generated source is the high cost of the machines themselves, which varies from $2 million to $5 million, excluding buildings (Ch2M Hill, 1988).

Despite the endorsements of the relevant domestic and international scientific and regulatory agencies, the future of the irradiation process in the United States is in some doubt. Although several hundred studies have demonstrated that the use of the isotopes as energy sources has no effect on the wholesomeness of the food (CAST, 1986), the controversy surrounding the use of nuclear material has been a deterrent for corporations to consider the adoption of the process. Companies are reluctant to risk having their brand names associated with an issue as controversial as food irradiation.

The task of educating consumers about the process seems too risky and too expensive for one industry or company. Although both isotopic and machine sources have identical impacts on foods, it seems likely that consumers will react more favorably to machine generation, given the similarities between this process and that used in microwave ovens. Anti-nuclear groups have threatened to draw attention to the perceived dangers of the process if Cesium is used (NCSFI, 1987). Use of machine-generated energy should mitigate the opposition to the use of food irradiation. In addition, the difficulties with storing and transporting nuclear waste are avoided.

Currently, no commercial electron-beam meat irradiation facilities exist in the United States. A LINAC facility is currently under construction by the Meat Export Research Center at Iowa State University and should be operational by the end of 1989. This is one of six facilities the Department of Energy is sponsoring. The others are in Florida, Alaska, Hawaii, Oklahoma, and the state of Washington.

The process is more firmly established internationally. Commercial meat irradiation facilities exist in France and The Netherlands. Countries where meat or fish irradiation has been legalized include Australia, Brazil, Hungary, Israel, and South Africa. Consumers in The Netherlands and France have accepted the process as a method for ensuring the wholesomeness of shrimp and poultry (Hayes and Molins, 1988).

History of Food Irradiation

Discoveries involving the use of the radiation processing have been recorded since the beginning of this century. British and American patents were awarded as early as 1905 to individuals who were suggesting that ionizing radiation could be used to preserve food (Josephson, 1983). Later, in 1908 a technique using X-rays was developed for killing tobacco pests, and in 1920 a French scientist discovered that ionizing radiation could be used to preserve food (Lecos, 1985, pp. 253-255). However, formal food irradiation studies in the U.S. did not begin until 1943 when scientists at the Massachusetts Institute of Technology demonstrated that ground beef could be preserved by exposure to X-rays (Josephson, 1983). The U.S. government became aware of the process and enlisted the Natick Army Base to continue pursuing possible uses for irradiation (Dobkin, 1984; Tilley and Falk, 1987). Radiation sources and processing equipment were not developed until the early 1950s. In the U.S. a curtailment of studies and growth in the area of food irradiation occurred in 1958 when an amendment to the Food, Drug and Cosmetic Act defined irradiation as a food additive (Meister, 1982), but interest was renewed in the 1960s when the IJECFI pronounced its acceptance of several irradiated foods, including wheat and potatoes irradiated within prescribed limits (Diehl, 1978). The large number of recent international irradiation clearances may be attributed to the conclusions and recommendations of the IJECFI, sponsored by the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA), which state that "the irradiation of any food commodity up to an overall average dose of 1000 krads presents no toxicological hazard" (WHO, 1981). This position received considerable support after the Codex Alimentarius Commission adopted the IJECFI's recommendations (the Codex is a voluntary association of 122 member countries that sets global food standards). Organizations that have recently indicated their support for the process include the United States Department of Agriculture, the Food and Drug Administration, the American Medical Association, the World Health Organization, and the Food and Agriculture Organization of the United Nations (Swientek, 1985).

Uses and Applications of Irradiation

The primary motivation for the widespread approval of food irradiation has been the benefits that would result in terms of public health and reduced food spoilage should irradiation become widely accepted. Benefits are for example the displacement of chemical additives used to preserve food (Dobkin and Blair, 1985), to replace highly toxic fumigants (Kadar, 1986), to sterilize foods for patients whose immune system has been rendered fatally vulnerable to otherwise benign organisms found in everyday foods (Aker, 1984), and to eliminate the need for freezing food during storage (LaBell, 1986).

Irradiation of beef offers potential health protection benefits. For example, at medium irradiation levels of 2.5 to 5 kGy, beef contaminations by Salmonella and Clostridium perfringens, which cause stomach flu-like symptoms, are greatly reduced. While most of these pathogens are destroyed by thorough cooking, rare or raw meats may still contain them. Some pathogens that have heat-resistant strains, such as Clostridium perfringens, may remain, unless the meat is cooked under pressure.

Estimates of food losses during transportation, wholesaling, and retailing are about five percent for beef (Morrison and Roberts, 1985, p.III-5). To the extent that those losses are caused by spoilage, irradiation could potentially reduce such losses. However, fresh meats and produce also suffer from cutting and trimming losses, and losses caused by improper temperature and moisture control, as well as improper handling and ineffective management, which may not be reduced by irradiation.

Moreover, irradiation can be used to extend the shelf life of fresh meats by reducing spoilage loss. The dominant spoilage organism in fresh meat, poultry, and fish, Pseudomonas, is generally sensitive to irradiation. However, to maintain acceptable organoleptic qualities, the meats should be at refrigeration temperature when irradiated and shipped and stored under refrigeration (Morrison and Roberts, 1985).

The increased shelf life due to the irradiation process may have secondary effects that have received little attention. Current irradiation technology makes it theoretically possible to ship chilled irradiated meat across oceans, eliminating the need for freezing (Hayes and Molins, 1988). Adoption of the aforementioned IJECFI standard would greatly ease international trade restrictions on irradiated foods. Should irradiation become practically applicable, it would accommodate a well-documented consumer bias against frozen meat, especially in some east Asian countries. As a result, it would reduce shipping costs, since fresh meat would no longer have to be transported by air, but instead could be transported by land and ocean.

The aforementioned secondary effects of irradiation may have a considerable impact on patterns of world trade. Presently, the United States produces both feedgrains and meat. However, due in part to the problems with transporting meat, most of the excess food production in the United States is exported in the form of feedgrains. These feedgrains are then fed to livestock in feed-importing countries. Argentina and Australia, on the other hand, have significant quantities of surplus grass. This grass cannot be exported directly and must consequently be exported in the form of frozen meat. Even though Australia can technically ship chilled fresh beef to Japan, Japan requires its beef imports from Australia to be frozen in order to maintain a domestic buffer stock of beef. Any development that significantly reduces the transportation costs of meat relative to those for feedgrains will influence these patterns of trade. The net effect on the value of U.S. exports will be positive if food-importing countries increase the value of their imports of meat from the United States by more than they reduce the value of their feedgrain imports. On the other hand, the value of U.S. food exports will decrease if the process allows Australia and Argentina to utilize their comparative advantage in beef production at the expense of U.S. feedgrain exports.

CHAPTER IV. ASSUMPTIONS AND DATA

Introduction

In this Chapter the assumptions and the data that underlie the model and the results of the thesis are presented.

One consequence of the 1985 farm bill was a reduction in U.S. beef production costs. This reduction did not occur in the European Community, where grain producers are protected by variable import levies, or in Australia and Argentina, where cattle are fattened on grass. With the recent decline in the dollar, it now seems possible that the United States has a comparative advantage in meat production. In the period January to October 1987 the values of beef and pork exports were 22% and 50% greater, respectively, than during the same period in 1986 (*National Provisioner, 1988*). The United States is now the largest exporter of high quality beef and is expected to export more than 200,000 tons in 1987 (*National Provisioner, 1988*). More than half of these exports go to Japan, with Canada a distant second. The Japanese currently consume less than one-fifth as much beef per capita as do Americans. However, Japan has a large potential beef consumption, since the income elasticity of beef in Japan is quite high (Wahl et al., 1987).

Two barriers to U.S. beef exports to Japan exist. First, the Japanese currently maintain an import quota to protect their domestic beef industry. However, in the summer of 1988 Japan agreed to gradually remove its beef import quota over three years, replacing it with a tariff which will decline from 70 percent in 1991 to 50 percent in 1993. Second, the Japanese consumer has a strong preference for fresh or chilled meat over frozen meat. On March 4, 1988, the wholesale price in Tokyo for chilled U.S. strip loin was $9.76/lb versus $6.98/lb for the otherwise identical frozen U.S. strip loin (Tanaka, 1988). This chilled beef is flown to Japan from the United

States at air freights of more than \$3.00/lb, while the frozen beef is shipped via ocean freight for around \$0.22/lb. Generally, relatively small quantities of meat are flown to Japan by air, resulting in a high transportation cost. However, relatively large (over 3,000 lbs) container shipments can be transported relatively cheaper at \$1.80/lb, but only takes place for higher quality meat. Freezing is required to avoid spoilage during the voyage and during storage while held in government price stabilization stocks. As mentioned previously, one of the positive effects of irradiation is that the shelf life of beef, pork, or poultry can be extended to the point where these meats can be shipped from the United States to Japan and stored there while awaiting sale in chilled rather than frozen form. Japan built the first commercial irradiator in the world--to prevent sprout inhibition in potatoes destined for domestic consumption--but does not currently allow the importation of irradiated foods.

The barriers against Australian beef exports to Japan are much the same as against U.S. beef. There is a third barrier, however, against Argentine beef. The presence of foot-and-mouth disease in South America and mainland Europe limits the Argentine export market to Japan. Argentina has enough grassland to greatly increase production. If the threat of foot-and-mouth disease could be eliminated, Argentine beef might displace U.S. and Australian beef exports to Japan, since the costs of producing beef in Argentina are among the lowest in the world (Simpson and Farris, 1982). However, since the dose of irradiation that is required to kill the virus responsible for foot-and-mouth disease is not within currently acceptable limits, it is not likely that meat irradiation by itself will change current importation regulations on meat produced in a country where this disease exists. In general, viruses are not affected by low to medium levels of irradiation (Morrison and Roberts, 1985, p. II-13). However, if foot-and-mouth disease can be eradicated, Argentina will be a major potential beef exporter.

Table 1. Average 1984, 1985, 1986 Feedgrain Production, Consumption and Trade (in 1000 metric tons) (FAPRI, 1988a,b)

country	production	imports	exports	domestic use
Japan				
coursegr.	398	17,579	-	17,977
wheat	23	119	-	142
total	421	17,698	-	18,119
United States				
coursegr.	168,121	-	33,532	134,589
wheat	39,121	-	9,042	29,971
total	207,134	-	42,574	164,560
Australia				
coursegr.	6,185	-	3,988	2,197
wheat	5,104	-	4,255	849
total	11,289	-	8,243	3,046
Argentina				
coursegr.	14,764	-	8,198	6,566
wheat	-	-	-	-
total	14,764	-	8,198	6,566

Feedgrains Production, Consumption, and Trade

The grains that are considered for animal feeding purposes in this study are wheat and course grains, where the latter include corn, barley, sorghum, oats, rye, millet, and mixed grains. Table 1 lists the production, consumption and trade of feedgrains. In this table, feedgrains are divided into course grains and wheat. The data in this table are averages of 1984, 1985 and 1986. For Argentina wheat is not included, since in that country wheat production for the sole purpose of feeding animals does not take place. In general, sources do not discriminate between grains used for food and grains for direct human consumption, with the exception of domestic consumption data (FAPRI, 1988a,b). Therefore, in this thesis it is assumed that the ratio feed to food purposes

Table 2. Coursegrain Prices (FAPRI 1988a,b; Japanese Ministry of Agriculture 1985, 1986, 1987)

country	1985	year 1986	1987	1985-'87 average	weights for each grain	weighted feedgrain price
Japan						
barley	132	104	104	113	10.54	
corn	134	84	84	101	90.95	
oats	129	121	121	124	0.78	102
sorghum	-	-	-	-	-	
wheat	168	125	125	139	1.09	
United States						
barley	91	72	72	78	4.49	
corn	94	59	59	71	58.06	
oats	85	80	80	82	3.18	76
sorghum	90	54	54	66	5.67	
wheat	116	86	86	96	17.48	
Australia						
barley	85	85	93	88	36.30	
corn	111	87	96	98	5.05	
oats	69	70	76	72	29.17	95
sorghum	101	84	92	92	12.04	
wheat	121	122	133	125	34.84	
Argentina						
barley	42	28	13	28	0.59	
corn	76	52	52	60	39.24	
oats	43	29	14	29	0.97	54
sorghum	55	38	38	44	12.82	
wheat	78	62	62	67	-	

for export or import is equal to that of the domestic consumption for all the countries included in the study. In addition, it is assumed that total production is equal to the sum of domestic use and net exports for the grain exporting countries (United States, Australia and Argentina), and the difference between domestic use and net imports for the grain importing country (Japan). In this way annual feedgrain stocks are assumed to be zero.

Feedgrain Prices

The feedgrain prices for the feed exporting countries are producer prices (FAPRI, 1988a,b). However, since the Japanese producer price is heavily subsidized to a level of up to tenfold that of the other countries, the feedgrain price used is the import value of feedgrains.

Feedgrain prices were obtained by taking a weighted average of the individual feedgrains. The weights are used according to the quantity of grains used for feeding purposes in a particular country. As above, wheat was not included for Argentina. Since no price data on sorghum could be obtained for Japan, the price of sorghum was omitted in calculating the weighted feedgrain price. In Table 2 the prices of barley, corn, oats, sorghum and wheat are listed for the years 1985, 1986 and 1987 and the average price over these years. Since there are no data available on Japan for the years 1986 and 1987, the feedgrain prices for that country are adjusted according to US price changes for 1986 and 1987. This same method was used to obtain corn and sorghum prices for Argentina for the years 1986 and 1987.

Feedgrain Transportation Costs

Reliable data on freight rates are difficult to find. Most studies have taken a cavalier attitude towards the importance of these data and have employed very crude approximations. Many studies that include transportation costs assume a constant freight per weight and per distance measure on all routes, and base their rates solely on distance between ports. Binkley and Harrer (1981) have demonstrated that this assumption is not supported by the data. Therefore, in this thesis an attempt is made to calculate transportation rates for most of the routes of interest for both feedgrains and beef, based on industry sources.

Grain transportation costs from Iowa to Japan are approximately $32.00 per metric ton (mton). This rate consists of an over land section from Sioux City to Seattle of around $20.00 per mton (Burlington Northern Railroad Company, 1987) and an ocean section from Seattle to ports in Japan of approximately $12.00 per mton (*Journal of Commerce and Commercial*, 1987). The domestic rates are based on 54 railroad cars per transport with each car containing 190,000 lbs. of grain in bulk. The transportation rates by ocean are based on shipments of 52,000 mtons heavy grains.

The feedgrain transportation cost from Argentina to Japan of $48.00 per mton includes only the ocean transportation cost (*Journal of Commerce and Commercial*, 1987), and the cost of shipping feedgrains from Australia to Japan is the difference between the export price in Australia and the import price in Japan. The feedgrain prices are included in Table 4.

Beef Quantities

The beef quantities, given in Table 3, have all been adjusted to retail weight. In coherence with the USDA method, a retail to wholesale conversion factor of 0.74 for beef was used (USDA, 1988a). The U.S. data are averages of the annual 1984, 1985, and 1986 data (USDA, 1988a,b). For the United States, imports have been included in the total supply resulting in gross values for exports. This is a necessary and valid assumption for making the spatial equilibrium model useful for this study, since in reality the United States is a net exporter of high quality beef to Japan. The supply data for Australian beef are the total production data for Australia. Beef exports include veal, since a breakdown was not available. The beef data are averages of annual data of 1984, 1985, and 1986 (AMLC, 1987). All the data in Table 3 on Argentina were obtained from GATT (1986) and are averages from 1983, 1984, and 1985. The supply of beef includes only beef but exports include veal resulting in some veal for the quantity demanded. The data on Japan are averages of 1983, 1984, and 1985 (GATT, 1986).

Beef Prices

Prices of beef are listed in table 4. The U.S. beef price is an estimated weighted average of BLS prices of retail cuts from Choice Yield Grade 3 carcasses, averaged over 1985, 1986, and 1987. The beef price for Japan is an averages of 1983, 1984, and 1985 of Tokyo retail prices. The price of beef concerns medium quality dairy steer meat and all Japanese prices are based on an exchange rate of Y130 for U.S. $1 (Japanese Ministry of Agriculture, Forestry and Fisheries, 1985; 1986; and 1987).

Since Brisbane is the major Australian port of loading for meat export to Japan, this city was chosen to represent meat prices in that country. Similarly, Buenos Aires was chosen to represent Argentine beef prices. In this way the overland transportation cost has been incorporated in the price so that the transportation cost to Japan only involves the transport by ocean. In coherence with GATT methods, the average retail price for beef comprises rump steak data of 1984, 1985, and 1986 (AMLC, 1986; and GATT, 1986).

Meat Transportation Costs

Two different ways to transport beef from the United States, Australia, and Argentina to Japan were taken into consideration: frozen and chilled beef by ocean. For the United States, Sioux City was chosen as the point of origin from Iowa, with

Table 3. Domestic Quantities Demanded and Supplied with the United States Shipping Feedgrains and Frozen Beef to Japan and Australia and Argentina Shipping Frozen Beef to Japan (USDA, 1988a,b; AMLC, 1986; GATT, 1986)

Country	Commodity	Quantity demanded[a]	Quantity supplied[a]
Japan	Beef	544,000	390,000
	Feedgrains	18,119,000	421,000
United States	Beef	8,720,000	8,852,000
	Feedgrains	164,560,000	207,134,000
Australia	Beef	526,000	967,000
	Feedgrains	3,046,000	11,289,000
Argentina	Beef	1,647,000	1,801,000
	Feedgrains	6,566,000	14,764,000
ROW[b]	Beef	573,000	0
	Feedgrains	41,317,000	0

[a]Quantities are in metric tons.
[b]Represents the rest of the world.

Table 4. Domestic Prices and Quality Discounts, Transportation Costs, and Tariff Equivalents of Shipping Feedgrains and Frozen Beef from the United States to Japan and Frozen Beef from Australia and Argentina to Japan (FAPRI, 1988a,b; Japanese Ministry of Agriculture, 1985; *Journal of Commerce and Commercial*, 1987)

Country	Commodity	Domestic price[a]	Quality discount[a,b]	Transportation costs[a]	Tariff equivalents[a]
Japan	Beef	11,522			
	Feedgrains	102.0			
U.S.	Beef	5,182	4,033	431	1,876
	Feedgrains	76.0	0	26	0
Australia	Beef	3,055	4,033	255	4,179
	Feedgrains	95.0	0	7	0
Argentina	Beef	2,315	4,033	332	4,842
	Feedgrains	54.0	0	48	0

[a]Prices and costs are in U.S. dollars per metric ton.
[b]Quality discounts are 35 percent off the Japanese domestic price.

Long Beach, California, as the ocean harbor.

The cost of transporting both chilled and frozen beef from Sioux City to Long Beach is $99.73/mt of beef. This rate is based on a cost of $1.18/mt per 43,000 lb of meat and a distance of 1,650 miles. With an additional unloading charge of $55/mt, the total rail freight cost of shipping either chilled or frozen meat from Sioux City to Long Beach is $154.73/mt (Burlington Northern Railroad Company, 1987).

The cost of transporting beef from Long Beach to Japan by ocean depends on whether the beef is chilled or frozen. The ocean freight rates are $276/mt when frozen and $604/mt when chilled for beef in the form of outside skirt, hanging tender, short plate, and skirt plate. These transportation costs are calculated per metric ton based on a full 40-foot container load (45,000 lb or 20.43 mt). All rates have been uniformly adjusted to the CFS (container freight terminal stuffs) receiving charge, as opposed to the CY (container, stuff yourself) receiving charge. The rates for CFS are:

$24.00/revenue mt

$435.00/20-ft container

$480.00/40-ft container

All rates include a 25% currency adjustment factor (CAF) based on the freight rate for Japan effective November 1, 1987. The ocean transportation time from Long Beach to Japan is approximately 13 to 14 days (Strachan Shipping Company, 1987). A summary of these transportation costs is given in Table 5.

Since Brisbane is the largest port of loading for chilled and frozen beef with destination to Japan, this city was used as port of origin for Australia. In addition, since the retail market price of Brisbane was used as the price for Australian meat, the rail or truck transportation cost by land is incorporated in this price so that only the cost to move beef from Brisbane to Tokyo must be considered as total transportation cost. Based on an exchange rate of Australian \$1.40 = U.S. \$1, this transportation cost is U.S. \$255.24. This rate is based on a full 20-ft container of hung carcasses with high utilization. Both rates include the wharfage charge for Brisbane, bunker adjustment factor, and currency adjustment factor and are as of October 1987 (Mitsui O.S.K. Lines, America, Inc., 1987)

Since Buenos Aires is the only major port of loading for beef export, this city was used as port of origin for Argentina. As with Australia, the overland transportation cost has been incorporated in the Buenos Aires meat retail prices so that only the transportation cost needs to be taken into account. No rates were available for beef and pork since these meats were prohibited from importation from Argentina by Japanese regulations. Therefore, the chicken transportation cost of U.S. \$332.01/ton based on a full 20-foot container with high utilization was chosen as an alternative cost of beef transportation from Argentina to Japan. This rate includes container rental and bunker adjustment factor changes. These rates and regulations were in effect as of October 1987 (Themoline, New York, 1987). The transportation costs for frozen beef are listed in Table 4. The transportation costs for chilled beef are listed in Table 8 for the US, Table 10 for Australia, Table 12 for Argentina, and Table 14 for all three beef exporting countries.

In this study it is assumed that the aforementioned price differential between U.S. frozen strip loin and U.S. chilled strip loin of around 35 percent, is due to a quality difference caused by freezing the beef (Tanaka, 1988). It will therefore be assumed that the quality discount is 35 percent for beef from each country that exports frozen beef to Japan. A quality discount only occurs if beef is shipped in frozen form to Japan. No quality discount takes place if fresh irradiated meat is shipped to Japan, since the chilled irradiated beef is assumed to be comparable in quality to chilled

Table 5. Transportation Costs of Beef from Long Beach to Japan as of September 1987 in Dollars per Metric Ton in Various Units of Shipment (Mitsui O.S.K. Lines, America, Inc, 1987; Strachan Shipping Company, 1987; Themoline, New York, 1987)

	Frozen Shipments			Chilled Shipments		
	Per metric ton	20-ft container	40-ft container	Per metric ton	20-ft container	40-ft container
Beef offals (edible)	143	-	276	311	-	604
Beef outside skirt, hanging tender, short plate, shirt plate, etc.	141	-	276	541	-	604
Beef primal cuts and carcasses	168	375	-	-	-	-

Table 6. Domestic Demand and Supply of Beef and Feedgrains for Japan, the United States, Australia, and Argentina (Regier, 1978)

		Demand Price Elasticities		Supply Price Elasticities	
Country	Quantity	Beef	Feedgrains	Beef	Feedgrains
Japan	Beef	-1.20	0	0.50	-0.30
	Feedgrains	0.50	-0.60	0	0.25
U.S.	Beef	-0.70	0	0.30	-0.20
	Feedgrains	0.22	-0.40	0	0.30[a]
Australia	Beef	-0.50	0	0.40	-0.20
	Feedgrains	0.30	-0.30	0	0.25[a]
Argentina	Beef	-0.40	0	0.50	-0.20
	Feedgrains	0.30	-0.30	0	0.25[a]

[a]Assumed elasticity.

fresh beef. This assumption is reflected in Table 4; Tables 8, 10, and 12; and Table 14, in which none of the exporting countries ship fresh irradiated beef to Japan; only one of the exporting country ships irradiated beef to Japan; and all exporting countries ship fresh irradiated beef to Japan, respectively. Although the transportation cost of chilled versus frozen beef increases, the result is a net decrease in the price of beef in Japan and an increase in Japanese beef consumption. Alternatively, the irradiation process may be viewed as a way of avoiding the quality deterioration caused by freezing, thereby making imported beef more competitive with domestic beef in Japan. The lower beef price will also reduce domestic Japanese beef production, thereby reducing feedgrain demand in Japan. This reduces feedgrain imports from the feedgrain exporting countries. The overall impact on feedgrain prices in the different countries is ambiguous since the country that exports the irradiated beef demands more feedgrains while the Japanese beef industry demands less.

Elasticities

In Table 6 the own and cross price elasticities of beef and grains are given. All the elasticities have been obtained from Regier (1978), except for the own feedgrain supply elasticity of the U.S., Australia, and Argentina, which are given to be 0.10, 0.15, and 0.15, respectively. The reason for the admittedly arbitrary rejection of only some elasticities from one consistent source, is that the model used in this study assumes iso-elastic demand and supply curves which do not intersect with small elasticities. Since the model is more sensitive to changes in the elasticities when they are small, the most obvious elasticities to replace with alternative parameters are the smallest elasticities. Alternatively, however, other elasticities could have been chosen to be replaced. The cross price demand elasticity of beef and feedgrains for Japan, Australia and Argentina, and the cross price supply elasticity for Australia and Argentina could not be obtained from Regier (1978). Instead the ones for pork are used.

CHAPTER V. THEORETICAL MODEL

There are two possible approaches for constructing a multicommodity, nonlinear spatial equilibrium model. The first would be a nonlinear application of the method of Takayama and Judge (1971). An objective function would be specified as consumers' total willingness to pay less producers' total variable costs and total transportation costs, giving consumer plus producer surpluses. A mathematical programming algorithm would maximize surpluses subject to market-clearing conditions for quantities, in effect, by differentiating to satisfy nonlinear equilibrium conditions. For a multicommodity model with cross-price elasticities, specifying such an objective is difficult. The alternative is to specify the equilibrium conditions directly and to solve them by using a nonlinear complementarity algorithm. This is the method used below.

Consider m countries trading n commodities. Assume that a domestic demand curve may be written

$$D_{ij} = \alpha_{ij} \prod_{k=1}^{n} P_{ik}^{\beta_{ijk}} \qquad \text{for } i = 1, \ldots, m; \quad j = 1, \ldots, n; \quad k = 1, \ldots, n; \tag{1}$$

where D_{ij} is the quantity demanded in country i of commodity j;

P_{ik} is the price in country i of commodity k;

α_{ij} is a demand shifter that includes income effects in country i for commodity j;

β_{ijk} is the Marshallian elasticity in country i of price of commodity k on the quantity of commodity j.

The demand system for country i may be rewritten in price-dependent, logarithmic form.

$$\begin{bmatrix} \ln P_{i1} \\ \cdot \\ \cdot \\ \cdot \\ \ln P_{in} \end{bmatrix} = \begin{bmatrix} \beta_{i11} & \cdots & \beta_{i1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \beta_{in1} & \cdots & \beta_{inn} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \ln D_{i1} - \ln\alpha_{i1} \\ \cdot \\ \cdot \\ \cdot \\ \ln D_{in} - \ln\alpha_{in} \end{bmatrix} \quad \text{for } i = 1, \ldots, m \qquad (2)$$

Thus, for a single commodity, the inverse demand curve is

$$P_{ij} = a_{ij} \prod_{k=1}^{n} D_{ik}^{\,b_{ijk}} \quad \text{for } i = 1, \ldots, m; \; j = 1, \ldots, n; \; k = 1, \ldots, n; \qquad (3)$$

where b_{ijk} is the jk^{th} element of the $n * n$ inverse of the own-price and cross-price elasticity matrix for country i and

$$a_{ij} = \prod_{k=1}^{n} \alpha_{ik}^{\,-b_{ijk}} \; .$$

Assume that a domestic supply (marginal cost) curve may be written

$$S_{ij} = \gamma_{ij} \prod_{k=1}^{n} P_{ik}^{\,\delta_{ijk}} \quad \text{for } i = 1, \ldots, m; \; j = 1, \ldots, n; \qquad (4)$$

where S_{ij} is the domestic quantity supplied in country i of commodity j;

γ_{ij} is a shifter in country i for commodity j;

δ_{ijk} is the price elasticity in country i of price of commodity k on the quantity of commodity j.

As with demand, an inverse supply equation is

$$P_{ij} = c_{ij} \prod_{k=1}^{n} S_{ik}^{d_{ijk}} \qquad \text{for } i = 1, \ldots, m; \quad j = 1, \ldots, n; \tag{5}$$

where d_{ijk} is the jk^{th} element of the $n * n$ inverse of the own-price and cross-price supply elasticity matrix

$$\begin{bmatrix} \delta_{i11} & \cdots & \delta_{i1n} \\ \vdots & & \vdots \\ \delta_{in1} & \cdots & \delta_{inn} \end{bmatrix}^{-1}$$

and

$$c_{ij} = \prod_{k=1}^{n} \gamma_{ik}^{-d_{ijk}}.$$

Equilibrium conditions include a set of price linkages and a set of quantity linkages between countries. The price linkages use complementarity conditions to allow for corner solutions.

$$a_{ij} \prod_{k=1}^{n} D_{ik}^{b_{ijk}} + u_{eij} = c_{ej} \prod_{k=1}^{n} S_{ek}^{d_{ejk}} + q_{eij} + t_{eij} + T_{eij};$$

$$X_{eij} u_{eij} = 0; \tag{6}$$

$$X_{eij} \geq 0;\ u_{eij} \geq 0; \qquad \text{for } e = 1, \ldots, m; \quad i = 1, \ldots, m; \quad j = 1, \ldots, n;$$

where subscript e denotes a potential exporting country;

subscript i denotes a potential importing country;

q_{eij} is the component (if any) of transportation costs per unit attributable to quality deterioration during transit of commodity j;

t_{eij} is the actual cost of shipping a unit of commodity j;

T_{eij} is the implicit tariff equivalent per unit (if any) of trade restrictions for commodity j;

X_{eij} is the quantity of commodity j traded between country e and country i;

u_{eij} is the slack variable associated with commodity j traded between countries e and i.

If the marginal costs of producing and transporting a commodity plus the tariff equivalent and the quality deterioration factor exceed the price that will be received in the importing country, the slack variable, u_{eij}, will be positive and, by complementarity, the quantity traded, X_{eij}, must be zero. Only if marginal costs plus the tariff equivalent, the transportation cost, and the quality deterioration factor equal the price received will a commodity be traded. As a special case, the price-linkage equation is a simple price equals marginal cost equation if exporting country e is the same as importing country i, with zero marginal transportation costs, tariff equivalent, and quality deterioration factor.

Two quantity linkages equate the quantity demanded by a country to the total quantity imported and equate the quantity supplied to the total quantity exported.

$$D_{ij} = \sum_{e=1}^{m} X_{eij}; \qquad \text{for } i = 1, \ldots, m; \quad j = 1, \ldots, n; \tag{7}$$

$$S_{ej} = \sum_{i=1}^{m} X_{eij}; \qquad \text{for } e = 1, \ldots, m; \quad j = 1, \ldots, n.$$

For country e equal to country i, the quantity traded, X_{eij}, is produced and consumed domestically.

Equilibrium conditions (6) and (7) contain not only linkages from currently exporting to importing countries but also potential linkages in the reverse direction from currently importing to exporting countries. These potential linkages may become binding if a policy shock causes a corner solution, but to replicate the current trade situation, potential linkages from importing to exporting countries are not needed. If the countries are segregated into those currently exporting and those currently importing, the binding price linkages for the current trade situation can be simplified to

$$a_{ij} \prod_{k=1}^{n} D_{ik}^{b_{ijk}} = c_{ej} \prod_{k=1}^{n} S_{ek}^{d_{ejk}} + q_{eij} + t_{eij} + T_{eij};$$

$$\text{for } e = 1, \ldots, m; \quad i = 1, \ldots, m; \quad j = 1, \ldots, n. \tag{8}$$

Further, the quantity linkages can be combined into one global linkage equating world demand with world supply.

$$\sum_{i=1}^{m} D_{ij} = \sum_{i=1}^{m} S_{ij} \qquad \text{for } j = 1, \ldots, n. \tag{9}$$

Equilibrium conditions (8) and (9) may also hold for incremental policy changes. Even if a policy shock does force a corner solution, only one or two price linkages may be invalidated. Rather than to specify all potential linkages as complementarity conditions, it may be easier to replicate the current trade situation with only the binding price linkages, simulate a policy by changing parameters of interest in the model, and respecify the invalidated price linkages, if any.

CHAPTER VI. APPLYING THE MODEL TO BEEF AND FEEDGRAINS TRADE

To investigate the potential impact of the adoption of the irradiation technology on the beef industry, the general model outlined in Chapter V has been specified as a model with three exporting countries--the United States, Australia, and Argentina; and with two commodities--beef and feedgrains, which are produced by all of the countries. This specified model has been outlined below.

Demand and Supply Equations

The domestic demand curve in (1) and supply curve in (4) with i = 1, 2, 3, 4 respectively representing Japan, the United States, Australia, and Argentina and with j = 1, 2 respectively representing beef and feedgrains, can be specified as follows.

Demand Supply

Japan

$$D_{11} = \alpha_{11} P_{11}^{\beta_{111}} \qquad S_{11} = \gamma_{11} P_{11}^{\delta_{111}} P_{12}^{\delta_{112}} \qquad (10)$$

$$D_{12} = \alpha_{12} P_{11}^{\beta_{121}} P_{12}^{\beta_{122}} \qquad S_{12} = \gamma_{12} P_{12}^{\delta_{122}}$$

United States

$$D_{21} = \alpha_{21} P_{21}^{\beta_{211}} \qquad S_{21} = \gamma_{21} P_{21}^{\delta_{211}} P_{22}^{\delta_{212}} \qquad (11)$$

$$D_{22} = \alpha_{22} P_{21}^{\beta_{221}} P_{22}^{\beta_{222}} \qquad S_{22} = \gamma_{22} P_{22}^{\delta_{222}}$$

Australia

$$D_{31} = \alpha_{31} P_{31}^{\beta_{311}} \qquad S_{31} = \gamma_{31} P_{31}^{\delta_{311}} P_{32}^{\delta_{312}} \qquad (12)$$

$$D_{32} = \alpha_{32} P_{31}^{\beta_{321}} P_{32}^{\beta_{322}} \qquad S_{32} = \gamma_{32} P_{32}^{\delta_{322}}$$

Argentina

$$D_{41} = \alpha_{41} P_{41}^{\beta_{411}} \qquad S_{41} = \gamma_{41} P_{41}^{\delta_{411}} P_{42}^{\delta_{412}} \qquad (13)$$

$$D_{42} = \alpha_{42} P_{41}^{\beta_{421}} P_{42}^{\beta_{422}} \qquad S_{42} = \gamma_{42} P_{42}^{\delta_{422}}$$

Inverse Demand and Supply Equations

The inverse demand curve (3) and the inverse supply curve (5) may be specified in the following way.

Inverse Demand	Inverse Supply	
Japan		
$P_{11} = a_{11}D_{11}^{b_{111}}$	$P_{11} = c_{11}S_{11}^{d_{111}}S_{12}^{d_{112}}$	(14)
$P_{12} = a_{12}D_{11}^{b_{121}}D_{12}^{b_{122}}$	$P_{12} = c_{12}S_{12}^{d_{122}}$	
United States		
$P_{21} = a_{21}D_{21}^{b_{211}}$	$P_{21} = c_{21}S_{21}^{d_{211}}S_{22}^{d_{212}}$	(15)
$P_{22} = a_{22}D_{21}^{b_{221}}D_{22}^{b_{222}}$	$P_{22} = c_{22}S_{22}^{d_{222}}$	
Australia		
$P_{31} = a_{31}D_{31}^{b_{311}}$	$P_{31} = c_{31}S_{31}^{d_{311}}S_{32}^{d_{312}}$	(16)
$P_{32} = a_{32}D_{31}^{b_{321}}D_{32}^{b_{322}}$	$P_{32} = c_{32}S_{32}^{d_{322}}$	
Argentina		
$P_{41} = a_{41}D_{41}^{b_{411}}$	$P_{41} = c_{41}S_{41}^{d_{411}}S_{42}^{d_{412}}$	(17)
$P_{42} = a_{42}D_{41}^{b_{421}}D_{42}^{b_{422}}$	$P_{42} = c_{42}S_{42}^{d_{422}}$	

Price Linkages

Domestically, price equals the marginal costs for both beef and feedgrains in all four countries; internationally, the equilibrium prices of beef and feedgrains in Japan equals the marginal costs in each of the three exporting countries plus the respective marginal transportation costs, quality-deterioration factors, and tariff equivalents. Thus, (8) may be rewritten as follows.

Domestic Linkages

Japan

$$
\begin{aligned}
a_{11}D_{11}{}^{b_{111}} &= c_{11}S_{11}{}^{d_{111}}S_{12}{}^{d_{112}} \\
a_{12}D_{11}{}^{b_{121}}D_{12}{}^{b_{122}} &= c_{12}S_{12}{}^{d_{122}}
\end{aligned}
\qquad (18)
$$

United States

$$
\begin{aligned}
a_{21}D_{21}{}^{b_{211}} &= c_{21}S_{21}{}^{d_{211}}S_{22}{}^{d_{212}} \\
a_{22}D_{21}{}^{b_{221}}D_{22}{}^{b_{222}} &= c_{22}S_{22}{}^{d_{222}}
\end{aligned}
\qquad (19)
$$

Australia

$$
\begin{aligned}
a_{31}D_{31}{}^{b_{311}} &= c_{31}S_{31}{}^{d_{311}}S_{32}{}^{d_{312}} \\
a_{32}D_{31}{}^{b_{321}}D_{32}{}^{b_{322}} &= c_{32}S_{32}{}^{d_{322}}
\end{aligned}
\qquad (20)
$$

Argentina

$$
\begin{aligned}
a_{41}D_{41}{}^{b_{411}} &= c_{41}S_{41}{}^{d_{411}}S_{42}{}^{d_{412}} \\
a_{42}D_{41}{}^{b_{421}}D_{42}{}^{b_{422}} &= c_{42}S_{42}{}^{d_{422}}
\end{aligned}
\qquad (21)
$$

Trade Linkages

Japan-United States

$$
\begin{aligned}
a_{11}D_{11}{}^{b_{111}} &= c_{21}S_{21}{}^{d_{211}}S_{22}{}^{d_{212}} + q_{21} + t_{21} + T_{21} \\
a_{12}D_{11}{}^{b_{121}}D_{12}{}^{b_{122}} &= c_{22}S_{22}{}^{d_{222}} + t_{22} + T_{22}
\end{aligned}
\qquad (22)
$$

Japan-Australia

$$
\begin{aligned}
a_{11}D_{11}{}^{b_{111}} &= c_{31}S_{31}{}^{d_{311}}S_{32}{}^{d_{312}} + q_{31} + t_{31} + T_{31} \\
a_{12}D_{11}{}^{b_{121}}D_{12}{}^{b_{122}} &= c_{32}S_{32}{}^{d_{322}} + t_{32} + T_{32}
\end{aligned}
\qquad (23)
$$

Japan-Argentina

$$
\begin{aligned}
a_{11}D_{11}{}^{b_{111}} &= c_{41}S_{41}{}^{d_{411}}S_{42}{}^{d_{412}} + q_{41} + t_{41} + T_{41} \\
a_{12}D_{11}{}^{b_{121}}D_{12}{}^{b_{122}} &= c_{42}S_{42}{}^{d_{422}} + t_{42} + T_{42}
\end{aligned}
\qquad (24)
$$

where q_{ij} are quality discounts for commodity j exported from country i;

t_{ij} are transportation costs for commodity j exported from country i; and

T_{ij} are tariff equivalents for commodity j exported from country i.

Quantity Linkages

Market-clearing conditions must also hold for the quantities traded. Thus, (9) is specified in the following manner.

$$\text{Beef} \quad D_{11} + D_{21} + D_{31} + D_{41} = S_{11} + S_{21} + S_{31} + S_{41} - (D_{ROW1} - S_{ROW1})$$

(25)

$$\text{Feedgrains} \quad D_{12} + D_{22} + D_{32} + D_{42} = S_{12} + S_{22} + S_{32} + S_{42} - (D_{ROW2} - S_{ROW2})$$

where ROW represents the rest of the world.

The price and quantity linkages in (18) through (25) are poorly scaled with the data provided in Chapter IV, since they consist of numerically large quantities demanded and supplied juxtaposed against numerically small elasticities. The scaling problem can be overcome by logarithmic transformations. Demand and supply variables can be replaced by variables that equal the natural logarithms of demand and supply and the linkages modified accordingly. The transformed model was solved by the recently developed software, GINO (Liebman et al. 1986). An example of model as it is solved by GINO, is provided in the appendix. The demand and supply shift parameters in (10) through (13) were calibrated from the data in Tables 3, 4 and 6. This was done by substituting the data of the Tables into the model.

The model was used to simulate five different scenarios, respectively representing the current situation, three situations in which only one exporting country plus Japan adopt beef irradiation, and the final case in which all four countries adopt beef irradiation. In each case that Japan accepts irradiated beef from any of the exporting countries, the quality discount due to freezing will be eliminated since the chilled irradiated beef is assumed to be comparable in quality to chilled fresh meat.

CHAPTER VII. RESULTS

The results of the four scenarios are presented in Tables 7 through 15. In the first scenario of Tables 7 and 8, the United States and Japan are the only countries to adopt the irradiation process. United States beef exporters incur higher shipping costs because of the need to more closely monitor chilled versus frozen beef. Yet as expected, U.S. beef exports increase significantly due to the lower quality discount for beef that is transported from the United States to Japan. The lower beef price in Japan causes the domestic Japanese beef production to decrease which in turn decreases the demand for feedgrains in Japan, resulting in less feedgrain imports from the United States. Despite the reduction in feedgrain exports to Japan, U.S. feedgrain production and prices are higher because the U.S. beef industry demands more feedgrains to meet the additional beef export demand. The strong demand for U.S. beef by Japan increases the U.S. beef price which results in a smaller quantity demanded domestically. In both Australia and Argentina, the price of beef falls as the U.S. increases its market share in Japan. Beef production in Australia and Argentina falls and domestic consumption rises.

Although Argentina produces large quantities of beef, it currently consumes a surprisingly large portion of its output. Consequently, when beef prices fall slightly, domestic consumption increases and production decreases to a point where Argentina ceases to export. The demand for feedgrains in Argentina drops, but the higher world demand for feedgrains increases feedgrain prices, resulting in increased feedgrain production. These same effects occur in Australia, although that country does not lose its beef export market completely. Argentina's total loss of beef export markets might induce the Argentine government to reduce its currently existing beef export tax. This would alter the magnitude, but not the direction of change.

In the second scenario, described in the Tables 9 and 10, Australia and Japan are the only countries to accept irradiation. It was assumed that the Japanese discount frozen Australian beef by the same amount as frozen U.S. beef. Transportation costs do increase due to the need to more closely monitor the containers containing chilled meat, but not as much as for the United States in the first scenario. Australian beef production and exports increase dramatically, as do Japanese beef imports. However, the Australian beef industry is small relative to the potential Japanese demand; consequently, the beef price in Japan does not decrease by as much as it did for the adoption of beef irradiation by the United States. The United States ceases beef exports, thus reducing feedgrain demand. The increase in Australian feedgrain demand is not strong enough to prevent a decline in world feedgrain prices caused by a smaller feedgrain demand in the United States.

Similar results are true for scenario 3 of Tables 11 and 12, where Argentina and Japan are the only countries to adopt the process. The increase in Argentine beef production causes Japan to increase its beef imports by about as much as it did in scenario 2. Again, the resulting higher demand for Argentine feedgrains cannot offset the smaller feedgrain demand in the United States, Australia, and Japan. This results in lower world feedgrain prices, which in turn decreases feedgrain supply in all countries.

In scenario 4 of Tables 13 and 14, all four countries adopt the process. Japanese beef prices fall, and Japanese beef consumption increases dramatically. This increase in Japanese beef demand is such that beef exports from the United States, Australia, and Argentina all increase. Beef prices are higher and domestic consumption lower in beef exporting countries. On balance, beef consumption increases significantly, but feedgrain prices and production decline, as beef production shifts away from Japan where beef diets use more feedgrains.

The results of the study have been summarized in Table 15, in which dollar values are calculated. From this Table, it becomes clear that beef producers always benefit if their country adopts the technology. U.S. feedgrain producers can also benefit from the technology adoption, but the Australian and Argentine feedgrain producers do not. In nominal terms, the sum of the benefits to beef and feedgrain producers is always positive for those countries that adopt the technology. Japanese consumers benefit, irrespective of which exporting country adopts beef irradiation, but especially if all the exporting countries do.

In all scenarios, it was assumed that the Japanese maintain the tariff equivalents estimated from the base case. This gives the United States an advantage which is maintained throughout the estimation. If this tariff were applied equally to all countries, it would significantly influence the results in the fourth scenario. Although it would be relatively easy to perform policy experiments with an equal tariff, this was not attempted as it would shift the focus from irradiation to political economy. In addition, it could be argued that the tariff equivalent of the quota is greater for Australia than for the United States because of quality differences or because of a Japanese preference for reducing its trade deficit with the United States.

Scenario 1: The United States Adopts the Technology

Table 7. Domestic Quantities Demanded and Supplied with the United States Shipping Feedgrains and Irradiated Beef to Japan and Australia and Argentina Shipping Frozen Beef to Japan

Country	Commodity	Quantity demanded[a]	Quantity supplied[a]
Japan	Beef	556,530	386,017
	Feedgrains	17,920,178	421,271
United States	Beef	8,563,900	8,914,667
	Feedgrains	165,268,733	207,349,012
Australia	Beef	545,703	938,449
	Feedgrains	2,977,061	11,296,809
Argentina	Beef	1,713,009	1,713,009
	Feedgrains	6,366,045	14,781,924

[a]Quantities are in metric tons.

Table 8. Domestic Prices and Quality Discounts, Transportation Costs, and Tariff Equivalents of Shipping Feedgrains and Irradiated Beef from the United States to Japan and Frozen Beef from Australia and Argentina to Japan

Country	Commodity	Domestic price[a]	Quality discount[a,b]	Transportation costs[a]	Tariff equivalents[a]
Japan	Beef	11,305			
	Feedgrains	102.3			
U.S.	Beef	5,317	0	759	1,876
	Feedgrains	76.3	0	26	0
Australia	Beef	2,838	4,033	255	4,179
	Feedgrains	95.3	0	7	0
Argentina	Beef	2,098	4,033	332	4,842
	Feedgrains	54.3	0	48	0

[a]Prices and costs are in U.S. dollars per metric ton.

[b]Discounts for Australia and Argentina are the same as in Table 1. The discount for the United States is set to zero.

Scenario 2: Australia Adopts the Technology

Table 9. Domestic Quantities Demanded and Supplied with the United States Shipping Feedgrains and Frozen Beef to Japan, Australia Shipping Irradiated Beef to Japan, and Argentina Shipping Frozen Beef to Japan

Country	Commodity	Quantity demanded[a]	Quantity supplied[a]
Japan	Beef	548,575	388,887
	Feedgrains	18,078,845	420,777
United States	Beef	8,815,725	8,815,725
	Feedgrains	164,183,364	206,957,576
Australia	Beef	454,773	1,086,871
	Feedgrains	3,326,146	11,282,586
Argentina	Beef	1,670,378	1,770,968
	Feedgrains	6,504,789	14,749,205

[a]Quantities are in metric tons.

Table 10. Domestic Prices and Quality Discounts, Transportation Costs, and Tariff Equivalents of Shipping Feedgrains and Frozen Beef from the United States to Japan, Irradiated Beef from Australia to Japan, and Frozen Beef From Argentina to Japan

Country	Commodity	Domestic price[a]	Quality discount[a,b]	Transportation costs[a]	Tariff equivalents[a]
Japan	Beef	11,442			
	Feedgrains	101.8			
U.S.	Beef	5,102	4,033	431	1,876
	Feedgrains	75.8	0	26	0
Australia	Beef	4,087	0	499	4,179
	Feedgrains	94.8	0	7	0
Argentina	Beef	2,235	4,033	332	4,842
	Feedgrains	53.8	0	48	0

[a]Prices and costs are in U.S. dollars per metric ton.

[b]Discounts for the United States and Argentina are the same as in Table 1. The discount for Australia is set to zero.

Scenario 3: Argentina Adopts the Technology

Table 11. Domestic Quantities Demanded and Supplied with the United States Shipping Feedgrains and Frozen Beef to Japan, Australia Shipping Frozen Beef to Japan, and Argentina Shipping Irradiated Beef to Japan

Country	Commodity	Quantity demanded[a]	Quantity supplied[a]
Japan	Beef	548,591	388,906
	Feedgrains	18,080,846	420,756
United States	Beef	8,816,065	8,816,065
	Feedgrains	164,199,454	206,940,486
Australia	Beef	533,065	957,213
	Feedgrains	3,023,977	11,281,965
Argentina	Beef	1,584,043	1,892,580
	Feedgrains	6,769,704	14,747,775

[a]Quantities are in metric tons.

Table 12. Domestic Prices and Quality Discounts, Transportation Costs, and Tariff Equivalents of Shipping Feedgrains and Frozen Beef from the United States to Japan, Frozen Beef from Australia to Japan, and Irradiated Beef From Argentina to Japan

Country	Commodity	Domestic price[a]	Quality discount[a,b]	Transportation costs[a]	Tariff equivalents[a]
Japan	Beef	11,442			
	Feedgrains	101.8			
U.S.	Beef	5,102	4,033	431	1,876
	Feedgrains	75.8	0	26	0
Australia	Beef	2,975	4,033	255	4,179
	Feedgrains	94.8	0	7	0
Argentina	Beef	2,552	0	567	4,842
	Feedgrains	53.8	0	48	0

[a]Prices and costs are in U.S. dollars per metric ton.

[b]Discounts for Australia and the United States are the same as in Table 1. The discount for Argentina is set to zero.

Scenario 4: All Three Countries Adopt the Technology

Table 13. Domestic Quantities Demanded and Supplied with the United States Shipping Feedgrains and Irradiated Beef to Japan and Australia and Argentina Shipping Irradiated Beef to Japan

Country	Commodity	Quantity demanded[a]	Quantity supplied[a]
Japan	Beef	853,011	324,415
	Feedgrains	15,121,907	419,842
United States	Beef	8,600,624	8,930,903
	Feedgrains	166,257,044	206,215,785
Australia	Beef	510,598	992,615
	Feedgrains	3,111,831	11,255,658
Argentina	Beef	1,594,294	1,883,594
	Feedgrains	6,770,501	14,686,998

[a]Quantities are in metric tons.

Table 14. Domestic Prices and Quality Discounts, Transportation Costs, and Tariff Equivalents of Shipping Feedgrains and Irradiated Beef from the United States to Japan and Irradiated Beef from Australia and Argentina to Japan

Country	Commodity	Domestic price[a]	Quality discount[a,b]	Transportation costs[a]	Tariff equivalents[a]
Japan	Beef	7,920			
	Feedgrains	100.9			
U.S.	Beef	5,285	0	759	1,876
	Feedgrains	74.9	0	26	0
Australia	Beef	3,242	0	499	4,179
	Feedgrains	93.9	0	7	0
Argentina	Beef	2,511	0	567	4,842
	Feedgrains	52.9	0	48	0

[a]Prices and costs are in U.S. dollars per metric ton.
[b]Discounts on all exporting countries are set to zero.

Table 15. Estimated Impact of Irradiation on Several Economic Variables (in millions of U.S. dollars)

	Base scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Japan					
1. Value beef imports	1,774	1,928	1,827	1,827	4,187
2. Value beef consumption	6,268	6,292	6,277	6,277	6,756
3. Value feed imports	1,805	1,789	1,797	1,797	1,483
4. Value feed usage	1,848	1,833	1,840	1,840	1,526
5. Total value of beef & feed imports (1 + 3)	3,580	3,717	3,624	3,624	5,670
6. Total value beef & feed consumption (2 + 4)	8,116	8,124	8,117	8,117	8,281
United States					
7. Value beef exports	684	1,865	0	0	1,746
8. Value beef production	45,871	47,404	44,977	44,976	47,201
9. Value feedgr. exports	3,236	3,209	3,242	3,238	2,992
10. Value feedgrain production	15,742	15,813	15,684	15,679	15,442
11. Total value beef & feed exports (7 + 9)	3,920	5,074	3,242	3,238	4,738
12. Value beef & feedgrain production (8 + 10)	61,613	63,217	60,661	60,654	62,643
Australia					
13. Value beef exports	1,347	1,115	2,583	1,262	1,563
14. Value beef production	2,954	2,664	4,442	2,847	3,218
15. Value feedgrain exports	783	793	754	783	765
16. Value feedgrain production	1,072	1,076	1,069	1,069	1,057
17. Total value beef & feed exports (13 + 15)	2,130	1,907	3,337	2,044	2,327
18. Total value beef & feed production (14 + 16)	4,027	3,740	5,511	3,916	4,275
Argentina					
19. Value beef exports	357	0	225	787	726
20. Value beef production	4,169	3,595	3,958	4,830	4,730
21. Value feedgrain exports	443	457	443	429	419
22. Value feedgr. production	797	802	793	793	777
23. Total value beef & feed exports (19 + 21)	797	457	668	1,216	1,145
24. Total value beef & feed production (20 + 21)	4,967	4,397	4,751	5,623	5,507

CHAPTER VIII. SUMMARY AND CONCLUSIONS

The results of this study should not be taken as numerically accurate projections of what would actually happen to prices and quantities if the beef irradiation process is adopted, but they give an indication of the direction of the trade patterns that will undoubtedly take place. A general, and valid, criticism on mathematical spatial equilibrium models is that the price elasticities of the respective supply and demand curves determine to a large extent the magnitude of the shocks to the system. However, even though the demand and supply elasticities utilized may appear to have been utilized in a crude fashion, they have been taken from one extensive study, eliminating the need for further econometric evidence. The extent of the impact is somewhat overestimated because the model represents a part of the world beef and feedgrains trade. The inclusion of only one importing country seems to have a strong effect on the world feedgrain market, as is clear from scenario 4. The true impacts will also depend on negotiations to reduce trade protection. In addition, neither feedgrains nor beef are far from perfectly homogeneous commodities as assumed in the model.

Nevertheless, some useful conclusions can be drawn. First, little trade-off exists from the feedgrain producer's standpoint. A technology that increases meat exports from the United States will increase domestic demand for feedgrains that will offset the reduction in export demand. Second, Australia and Argentina can exploit their comparative advantages to remove the United States from its beef export markets only if the United States would not adopt the irradiation technology when one of the other beef exporting countries would adopt the technology. Third, meat irradiation will dramatically alter patterns of world trade in meat and feedgrains if other barriers to meat trade are reduced. If the United States alone adopts the process, U.S. meat exports might increase dramatically. If other food-exporting countries adopt the process and the United States does not, the United States may lose its export markets for beef.

The spatial equilibrium model that has been developed in this thesis can also be applied to various other trade issues. A second application of the model is presently in the development stages. This application relates to the recent trade agreements between the United States and Japan which will lead to a liberalization of the Japanese beef market. Under the agreement the Japanese import quota will increase by 60,000 tons of beef per year through 1990 after which the quota system will be replaced by a temporary import tariff that will be reduced in increments of 10% from 70% in 1991 to 50% in 1993. To forecast the implications of the agreements, the model has been modified to forecast the implications of these trade agreements. In addition, the model could be modified to investigate impacts on international trade relationships due to currency exchange changes.

To utilize the framework of the model in a more general manner, the model may be developed into a more user friendly software package to investigate the results of a change in technology or policy on the trade relationships between different regions. A more accessible software package for the model would also enable the user to investigate the impact of changes in the parameters of the model on the results, thus facilitating the investigation of a larger span of scenarios. Consequently, the model may then be used for more dynamic types of analyses.

REFERENCES

Abbott, P.C. "Modeling International Grain Trade with Government Controlled Markets." *American Journal of Agricultural Economics* 61 (1979):22-31.

Aker, S. N. "On the Cutting Edge of Dietetic Science." *Nutrition Today* 4 (1984):24-27.

Alaouze, G.M., A.S. Watson, and N.H. Sturgess. "Oligopoly Pricing in the World Wheat Market." *American Journal of Agricultural Economics* 60 (1978):173-185.

Australian Meat and Livestock Corporation (AMLC). *Statistical Review of Livestock and Meat Industries for the Year Ended 30 June 1987*. AMLC, Sydney, 1986.

Binkley, J.K., and B. Harrer. "Major Determinants of Ocean Freight Rates for Grain: An Econometric Analysis." *American Journal of Agricultural Economics* 63 (1981): 47-57.

Burlington Northern Railroad Company. Telephone conversations. October 26, and November 13, 1987.

Carter, C., and A. Schmitz. "Import Tariffs and Price Formation in the World Wheat Market." *American Journal of Agricultural Economics* 61 (1979):517-527.

CAST. "Ionizing Energy in Food Processing and Pest Control: I. Wholesomeness of Food Treated with Ionizing Energy." Report No. 109. Council for Agricultural Science and Technology, Ames, IA, 1986.

Cessna, Mary Ann, and Connie R. Rae. "Food Irradiation Technology: How Safe is it?" *Home Economics Forum* 1 (Spring 1987):18-21.

Ch2M Hill. *Options Analysis--Machine Sources for Food Irradiation*. U.S. Department of Energy Advanced Radiation Technology Programs, Washington, DC, 1988.

Diehl, J. F. "Food Irradiation--Worldwide Activity." *Food Engineering* 11 (1978):82-84.

Dobkin, B. "Lobster after thirty days on the shelf." *News Release of Council on Radiation Applications*. Atomic Industrial Forum, Inc., and Nuclear Energy Women, Bethesda, MD, 1984.

Dobkin, B., and N. Blair. "Food Irradiation: The Rip Van Winkle of Food Processing". *News Release of Council of Radiation Applications*. Atomic Industrial Forum, Inc., and Nuclear Energy Women, Bethesda, MD, 1985.

Enke, Stephen. "Equilibrium Among Spatially Separated Markets: Solutions by Electric Analogue." *Econometrica* 19 (1951):40-47.

Fajardo, Daniel, Bruce A. McCarl, and Robert L. Thompson. "A Multicommodity Analysis of Trade Policy Effects: The Case of Nicaraguan Agriculture." *American Journal of Agricultural Economics* 63 (1981):23-31.

Food and Agricultural Policy Research Institute (FAPRI). Trade Statistics. Department of Economics, Ames, Iowa, May, 1988a.

Food and Agricultural Policy Research Institute. FAPRI Staff Report #1-88. Department of Economics, Ames, Iowa, March, 1988b.

Fox, Karl A. "A Spatial Equilibrium Model of the Livestock Feed Economy in the U.S." *Econometrica* 21 (1953):547-566.

General Agreement on Tariffs and Trade (GATT). *The International Markets for Meat 1985*. Geneva, Switzerland. January, 1986.

Hayes, Dermot J., and R.A. Molins. "The Potential Use for Irradiation Technology in the U.S. Pork Processing Industry." *Pork Technical Reference Manual*. Forthcoming, 1988.

Holland, Forrest D. *ETP: A Microcomputer Model for the Spatial Equilibrium Model.* United States Department of Agriculture, Economic Research Service, International Economics Division, Washington DC, 1985.

Japanese Ministry of Agriculture, Forestry and Fisheries. *Statistical Yearbook 1984-1985*, 1985.

Japanese Ministry of Agriculture, Forestry and Fisheries. *Statistical Yearbook 1985-1986*, 1986.

Japanese Ministry of Agriculture, Forestry and Fisheries. *Monthly Statistics of Agriculture, Forestry and Fisheries*. Statistics and Information Department, December, 1987.

Josephson, E.S. "An Historical Overview of Food Irradiation". *Journal of Food Safety* 5 (1983):161-190.

Journal of Commerce and Commercial. "Shipment Fixtures Breakdown." *Journal of Commerce*, Various issues. November and December, 1987.

Judge G.G. and T.D. Wallace. "Estimation of Spatial Price Equilibrium Models." *Journal of Farm Economics* 40 (1958):801-820.

Kadar, A.A. "Potential Applications of Ionizing Irradiation in Postharvest Handling of Fresh Fruits and Vegetables". *Food Technology* 46 (1986):117-121.

Karp, L.S., and A.F. McCalla. "Dynamic Games and International Trade: An Application to the World Corn Market." *American Journal of Agricultural Economics* 65 (1983):641-656.

King, G.A. and Lee F. Schrader. "Regional Location of Cattle Feeding: A Spatial Equilibrium Analysis." *Hilgardia* 34 (1963):331-416.

Kolstad, Charles D., and Anthony E. Burris. "Imperfect Competitive Equilibria in International Commodity Markets." *American Journal of Agricultural Economics* 68 (1986):27-36.

LaBell, F. "Irradiation Facilities Geared to Process Pork". *Food Processing* 7 (1986):64-65.

Lecos, C. "Irradiation Proposed to Treat Food." *Nutrition and Health, New Concepts and Issues*. New York: Morton Publishing Co., 1985.

Liebman, Judith, Leon Lasdon, Linus Schrage, and Allen Waren. *Modeling and Optimization with GINO*. Palo Alto, California: The Scientific Press, 1986.

Martin, L.J. "Quadratic Single and Multi-Commodity Models of Spatial Equilibrium: A Simplified Exposition." *Canadian Journal of Agricultural Economics* 29 (1981):21-48.

Martin, L., and A.C. Zwart. "A Spatial and Temporal Model for the North American Pork Sector for the Evaluation of Policy Alternatives." *American Journal of Agricultural Economics* 57 (1975):55-66.

McCalla, A.F. "A Duopoly Model of World Wheat Pricing." *Journal of Farm Economics* 48 (1966):711-727.

McCalla, Alex F., and Timothy E. Josling. *Agriculture Policies and World Markets*. Chapter 3. New York: Macmillan Publishing Co., 1985.

McCarl, B. A., and T. H. Spreen. "Price Endogenous Mathematical Programming as a Tool for Sector Analysis." *American Journal of Agricultural Economics* 60 (1980):88-102.

Meilke K.D. and G.R. Griffith. "Incorporating Policy Variables in a Model of the World Soybean/Rapeseed Market." *American Journal of Agricultural Economics* 65 (1983):65-73.

Meister, S. Irradiated Foods. New York: The American Council on Science and Health, 1982.

Mitsui O.S.K. Lines, America, Inc. *Transportation Information Rates*. Mitsui: New York: Mitsui, October 1987.

Morrison, Rosanna Mentzer, and Tanya Roberts. *Food Irradiation: New Perspectives on a Controversial Technology*. U.S. Department of Commerce, National Technical Information Service, 1985.

National Coalition to Stop Food Irradiation (NCSFI). "Food Irradiation Alert." NCSFI Newsletter 2 (1987): 7.

National Provisioner. "Outlook for meat, by-product exports for 1988--Part 1." *National Provisioner 127* (April 9, 1988):10-20.

Nelson, C.H., and B.A. McCarl. "Including Imperfect Competition in Spatial Equilibrium Models." *Canadian Journal of Agricultural Economics* 32 (1984):55-70.

Norton, R.D., and G.W. Schiefer. "Agricultural Sector Programming Models: A Review." *European Review of Agricultural Economics* 7 (1980):229-64.

Paarlberg P.L., and P.C. Abbott. "Oligopolistic Behavior by Public Agencies in International Trade: The World Wheat Market." *American Journal of Agricultural Economics* 68 (1986):528-548.

Paris, Quirino. "New Interpretations of Linear Complementarity Problems." *Southern Economic Journal* 46 (1979):568-579.

Rausser, G.C., E. Lichtenberg, and R. Lattimore. "Developments in Theory and Empirical Applications of Endogenous Government Behavior." *New Directions in Econometric Modeling and Forecasting in U.S. Agriculture.* Edited by G.C. Rausser. Chapter 18. Amsterdam: North Holland Publishing Co., 1982.

Regier, Donald W. *Livestock and Derived Feed Demand in the World G.O.L. Model.* U.S. Department of Agricultural Economics, Statistics, and Cooperative Service. Foreign Agricultural Service Economic Report 152, 1978.

Rodriguez, G.R. "The Consideration of Risk in Agricultural Policies: The Phillippine Experience." Ph.D. Thesis, Purdue University, 1978

Samuelson, Paul A. "Spatial Equilibrium and Linear Programming." *American Economic Review* 42 (1952):283-303.

Sarris, Alexander H., and John Freebairn. "Endogenous Price Policies and International Wheat Prices." *American Journal of Agricultural Economics* 65 (1983):214-224.

Schrader, Lee F. and G.A. King. "Regional Location of Beef Cattle Feeding." *Journal of Farm Economics* 44 (1962):64-81.

Shei, S.Y., and R.L. Thompson. "The Impact of Trade Restrictions on Price Stability in the World Wheat Market." *American Journal of Agricultural Economics* 59 (1977):628-638.

Simpson, James R., and Donald E. Farris. *The World's Beef Business.* Ames, Iowa: Iowa State University Press, 1982.

Strachan Shipping Co., Transpacific Westbound Rate Agreement Tariff. Transportation Information Rates. New York, October 1987.

Swientek, R. J. "Food Irradiation Update". *Food Processing* 6 (1985):82-90.

Takayama, T., and G. Judge. *Spatial and Temporal Price and Allocation Models.* Amsterdam: North Holland Publishing Co., 1971.

Tanaka, Toshi. Fax Message to the Meat Export Center from the U.S. Meat Export Federation Tokyo office, March 4, 1988.

Themoline New York, New York. Transportation Information Rates. New York, October, 1987.

Thompson, Robert L. "A Survey of Recent U.S. Developments in International Agricultural Trade Models." Washington, D.C.: USDA,ERS Report No. 21, 1981.

Tilley, D. S., and C. L. Falk. "Food Irradiation: A proposed Economic Research Agenda and Implications for Agribusiness". *Agribusiness International Journal* 3 (1987): 339-347.

Tramel, Thomas E. and A.D. Seale, Jr. "Reactive Programming of Supply and Demand Relations--Applications to Fresh Vegetables." *Journal of Farm Economics* 41(1959): 1012-1022.

United Airlines. Telephone conversations. October 1987 - August 1988. Des Moines.

United States Department of Agriculture, Economic Research Service. *Livestock and Poultry, Situation and Outlook.* Washington, DC, February, 1988a.

United States Department of Agriculture, Economic Research Service. *Feed Situation and Outlook Yearbook.* FdS-305. Washington, DC, February, 1988b.

Urbain, Walter M. "Radurization and Radicidation: Meat and Poultry." in *Preservation of Food Ionizing Radiation*, Vol. III, ed. Edward S. Josephson and Martin S. Peterson, pp.2-11. Boca Raton, Florida: CRC Press, 1983.

Urbain, Walter M. "Food Irradiation." *Advances in Food Research* 24 (1978):155-227.

Varian, Hal R. *Microeconomic Analysis.* Second Edition. New York: Norton & Co., Inc., 1984.

Wahl, Thomas I., Dermot J. Hayes, and Gary W. Williams. "Japanese Beef Policy and Gatt Negotiations: An Analysis of Reducing Assistance to Beef Producers." International Agricultural Trade Research Consortium Working Paper #87-7, November 24, 1987.

Wedekind, L. *Food Preservation by Irradiation: A Fresh New Look.* Background Information Newsletter. Atomic Industrial Forum, Bethesda, MD, October 1983.

Weinschenk, G., W. Heinrichsmeyer, and F. Aldinger. "The Theory of Spatial Equilibrium and Optimal Location in Agriculture: A Survey." *Review of Marketing and Agricultural Economics* 37 (1969):3-71.

World Health Organization (WHO). "Wholesomeness of Irradiated Food". *Report of a Joint FAO/IAEA/WHO Expert Committee.* WHO Technical Report Series, number 659. WHO, Geneva, Switzerland, 1981.

Yaron, Dan. "Incorporation of Income Effects in Mathematical Programming Models." *Metroeconomica* 19 (1967):141-164.

ACKNOWLEDGEMENTS

I would like to take a few lines to thank some of the people involved in writing this thesis. First, I must thank my major professor, Dr. Dermot Hayes, for his support and helpful guidance throughout this research. I am very much indebted to Dr. Greg Hertzler, without whom the model of the thesis could not have been developed. Further appreciation goes to my committee members, Dr. Arne Hallam and Dr. Vincent Sposito, for providing useful comments. A major contribution was also provided by Rashid Hassan. A special thanks also goes to Dr. Lee Fletcher, who first enabled me to stay at Iowa State University by providing generous support.

I especially thank my wife, Marylka, for her special mental support to write the thesis. A special thanks also goes to my parents for their courage to let me pursue this seemingly endless school life. I would like to thank Roxie Clemens for typing a large part of the thesis.

Finally, I am also thankful to the Iowa Soybean Promotion Board for funding this study.

APPENDIX. THE EQUATIONS USED IN THE GINO ALGORITHM

In this appendix an example of the equilibrium conditions as it is solved by the GINO algorithm is provided. Each individual equation is numbered in the GINO model. Equations 1) through 8) in the GINO model correspond with equations (18) through (21) in Chapter VI of the thesis. Equations 9) through 14) in the GINO model correspond with equations (22) through (24) in Chapter VI, while equations 15) and 16) correspond with equation (25) in Chapter VI.

Due to scaling problems, the GINO model has been re-scaled by writing equations (18) through (25) in logarithmic form. Consequently, antilogs must be taken before the solution can be interpreted. Antilogs are taken in equations 17) through 32) in the GINO model to re-scale the quantities. Equations 33) through 40) in the GINO model calculate prices, described as a function of the quantities demanded or quantities supplied.

In each equation the parameters appear in a sequence that is identical to the sequence that is followed in Chapter VI. In the first line of the GINO model, for example, 20.357... corresponds with $\ln(a_{11})$ in equation (18); -0.833... corresponds with b_{111} in equation (18); LD11 corresponds with $\ln(D_{11})$ in equation (18); -47.476... corresponds with $\ln(c_{11})$ in equation (18); 2 corresponds with d_{111} in equation (18); LS11 corresponds with $\ln(S_{11})$ in equation (18); 2.4 corresponds with d_{112} in Equation (18); and LS12 corresponds with $\ln(S_{12})$ in equation (18).

In addition, the number 4033 in equations 9), 11), and 13) is the quality deterioration factor due to freezing the beef, q_{21}, q_{31}, and q_{41} in equations (22) through (24) of Chapter VI; the numbers 431, 255, and 332 in equation 9), 11), and 13) reflect the beef transportation costs t_{21}, t_{31}, and t_{41}, respectively in equations (22) through (24) of Chapter VI; the numbers 1876, 4179, and 4842 in equations 9), 11), and

13) reflect the tariff equivalents of the quota for the United States, Australia and Argentina, respectively. Similarly, the tariff equivalents and transportation costs of the feedgrains are listed in equations 10), 12), and 14) of the GINO model.

The equilibrium conditions appear as follows in the GINO algorithm:

```
MODEL:
  1) 20.357600635 - 0.83333333 * LD11 = - 47.476721976 + 2 * LS11 + 2.4 *
     LS12 ;
  2) 41.650414850 - .6944444 * LD11 - 1.666667 * LD12 = - 47.176579637 + 4
     * LS12 ;
  3) 31.383131784 - 1.428571 * LD21 = - 172.426743470 + 3.333333 * LS21 +
     6.6666667 * LS22 ;
  4) 64.184299831 - 0.7857143 * LD21 - 2.5 * LD22 = - 187.15803151 + 1 *
     LS22 ;
  5) 34.370647855 - 2 * LD31 = - 80.561480759 + 2.5 * LS31 + 3.333333 *
     LS32 ;
  6) 80.664455916 - 2 * LD31 - 3.333333 * LD32 = - 103.70838549 + 6.666667
     * LS32 ;
  7) 43.533329989 - 2.5 * LD41 = - 65.081079863 + 2 * LS41 + 2.666667 *
     LS42 ;
  8) 92.099866993 - 2.5 * LD41 - 3.333333 * LD42 = - 106.0623649 +
     6.666667 * LS42 ;
  9) 20.357600635 - 0.83333333 * LD11 = LOG( EXP( 31.383131784 - 1.428571
     * LD21 ) + 4033 + 431 + 1876 ) ;
 10) 41.650414850 - 0.6944444 * LD11 - 1.666667 * LD12 = LOG( EXP(
     64.184299831 - 0.7857143 * LD21 - 2.5 * LD22 ) + 26 ) ;
 11) 20.357600635 - 0.83333333 * LD11 = LOG( EXP( 34.370647855 - 2 * LD31
     ) + 4033 + 255 + 4179 ) ;
 12) 41.650414850 - 0.6944444 * LD11 - 1.666667 * LD12 = LOG( EXP(
     80.664455916 - 2 * LD31 - 3.333333 * LD32 ) + 7 ) ;
 13) 20.357600635 - 0.83333333 * LD11 = LOG( EXP( 43.533329989 - 2.5 *
     LD41 ) + 4033 + 332 + 4842 ) ;
 14) 41.650414850 - 0.6944444 * LD11 - 1.666667 * LD12 = LOG( EXP(
     92.099866993 - 2.5 * LD41 - 3.333333 * LD42 ) + 48 ) ;
 15) EXP( LD11 ) + EXP( LD21 ) + EXP( LD31 ) + EXP( LD41 ) + 573000 = EXP(
     LS11 ) + EXP( LS21 ) + EXP( LS31 ) + EXP( LS41 ) ;
 16) EXP( LD12 ) + EXP( LD22 ) + EXP( LD32 ) + EXP( LD42 ) + 41317000 =
     EXP( LS12 ) + EXP( LS22 ) + EXP( LS32 ) + EXP( LS42 ) ;
 17) D11 = EXP( LD11 ) ;
 18) D12 = EXP( LD12 ) ;
 19) S11 = EXP( LS11 ) ;
 20) S12 = EXP( LS12 ) ;
 21) D21 = EXP( LD21 ) ;
 22) D22 = EXP( LD22 ) ;
 23) S21 = EXP( LS21 ) ;
 24) S22 = EXP( LS22 ) ;
 25) D31 = EXP( LD31 ) ;
```

```
  26) D32 = EXP( LD32 ) ;
  27) S31 = EXP( LS31 ) ;
  28) S32 = EXP( LS32 ) ;
  29) D41 = EXP( LD41 ) ;
  30) D42 = EXP( LD42 ) ;
  31) S41 = EXP( LS41 ) ;
  32) S42 = EXP( LS42 ) ;
  33) P11 = 6.937350 * 10 ^ 8 * D11 ^ - 0.8333333 ;
  34) P12 = ( 3.246921 * 10 ^ - 21 ) * S12 ^ 4 ;
  35) P21 = 4.261092 * 10 ^ 13 * D21 ^ - 1.428571 ;
  36) P22 = ( 5.227568 * 10 ^ - 82 ) * S22 ;
  37) P31 = 8.452452 * 10 ^ 14 * D31 ^ - 2 ;
  38) P32 = ( 9.120538 * 10 ^ - 46 ) * S32 ^ 6.666667 ;
  39) P41 = 8.059071 * 10 ^ 18 * D41 ^ - 2.5 ;
  40) P42 = ( 8.663636 * 10 ^ - 47 ) * S42 ^ 6.666667 ;
END
```

The above described example of the model reflects the base Scenario. To simulate Scenario 1, the quality deterioration factor of $4033 in equation 9) must be eliminated, and the transportation cost of beef of $431 must be increased to $759. Similarly, in Scenario 2 for Australia, and in Scenario 3 for Argentina, the quality deterioration factors must be eliminated, and the transportation costs must be increased to $499 and $567, respectively. For Scenario 4, all quality deterioration factors must be eliminated, and all beef transportation costs must be increased.