Chapter 1. Introduction

1.1 Background and Motivation

The cattle and beef industry is a major component of the Australian agricultural sector. Farm-gate earnings are at about $4 billion per annum. About two-thirds of its output is exported, earning almost $3 billion per annum, or about one-third of all farm export revenue (ABARE 1998). In recent years, the beef industry has faced more competition both domestically and internationally. On the domestic market, chicken and pork have gained an increased share of meat consumption at the expense of beef (ABARE 1998). Overseas, liberalisation of some Asian markets has provided more opportunities for the industry, but the recent Asian economic crisis has also imposed challenges. While the beef import quota in the United States has been terminated, some South American exporters have achieved foot-and-mouth free status and are seeking a greater share of the United States market. In such a competitive and rapidly changing environment, it is vital that the scarce research and development (R&D) and market promotion funds available to the beef industry be used in the most efficient way to enhance industry competitiveness.

A successful investment in agricultural R&D leads to the production of knowledge and the creation of technology. Adoption of new technology increases productivity in the sense that more output can be produced for a given cost of inputs, or less input cost is needed to produce a given quantity of output. In the context of the Australian beef industry, R&D investments can be aimed at different sectors along the beef production and marketing chain. They can be on-farm investments targeting farm productivity, or they can be off-farm R&D investments improving the efficiency in feedlotting, processing, or domestic or export marketing sectors.

Promotion includes activities aiming to enhance the image of a product in the minds of potential buyers. It can take different forms, ranging from advertisement to activities such as trade displays, conveyance of technical information and in-store displays (Piggott 1998). There has been controversy regarding how to represent the effects of promotion in economic models, but, conventionally, the direct impact of a successful promotion can be considered to be an increase in consumers' "willingness-to-pay" for a given quantity of product. In other words, it can be represented as an increase in the quantity demanded for a given level of price. Promotion of Australian beef is carried out both domestically and in various overseas markets.

The initial impact of a research or promotion investment may occur in a particular sector of the industry. However, as all sectors are related through demand and supply interrelationships, this impact will eventually flow through to the whole value chain of the industry. For example, when a research-induced technology is adopted in the beef processing sector, not only the abattoirs themselves but also the cattle producers, the feedlots and the domestic and overseas consumers will all be affected.

Total annual expenditure on R&D and promotion for the beef and sheep meat industries has reached $100 million in recent years (MRC 1996/97, AMLC 1996/97). In the early 1990's, the majority of the R&D and promotion funds were spent on promotion. For example, only 34% of the total funds were invested in R&D in 1990/91. This percentage was increased to 40% in 1996/97 and to 49% in 1998/99 (MLA 1998/99). Of the total promotion expenditure for red meat, almost two-thirds were spent on promotion in overseas markets during 1990/91 and 1998/99 (AMLC 1996/97; MLA 1998/99). The splits of R&D expenditure among different types of R&D investments were not available before 1997/98. In 1998/99, of the 49% of the MLA expenditure spent on R&D, 21.4% was spent on producer R&D in the farm and feedlot sectors, 8.7% was spent on processor R&D in the processing sector under contract, and the remaining 18.9% was spent on joint R&D programs which address issues affecting all sectors of the industry.

Like most agricultural industries in Australia, in the cattle and beef industry, producers, feedlotters, processors and exporters pay levies to fund R&D programs, advisory and extension programs, and promotion and market development programs. Producer funds for R&D are also matched by government contributions on a dollar-for-dollar basis up to 0.5% of the gross industry value. In March 1997, the Federal Government announced a historic restructure of the Australian red meat industry's statutory organisation, which came into effect on 1 July 1998. The new structure has seen the formation of a primarily producer-funded body, Meat and Livestock Australia (MLA), which replaces the former Australian Meat and Livestock Corporation (AMLC) and the Meat Research Corporation (MRC). It has also seen the emergence of meat processors and exporters' and live exporters' own companies, the Australian Meat Processor Corporation (AMPC) and the Australian Livestock Exporter Corporation (Livecorp), respectively.

The restructure has resulted in new arrangements in the funding and management of R&D and promotion activities (MLA 1998). Before the restructuring, the AMLC was responsible for red meat promotion and the MRC was responsible for R&D programs. These funds came from various statutory levies and export charges from producers, feedlotters, processors and exporters, as well as government matching funds. Since July 1998, both the R&D and promotional programs have been managed by the same organisation, MLA. There are also significant changes in the funding of MLA. Now the majority of MLA funds are from compulsory producer and feedlot levies and government matching grants, but processors and live exporters no longer pay compulsory levies. AMPC and Livecorp collect non-statutory levies from their own members and contract MLA to deliver on research and promotion. Consequently, the contributions from processors and live exporters are significantly reduced. For 1997/98, processors and live exporters were estimated to have contributed $51 million under the statutory levy arrangement. For 1998/99 these two sectors' contributions to MLA, through contracted projects, are $12.9 million for AMPC and $0.9 million for Livecorp.

As the industry faces tougher market situations and governments tighten budgets, both producers and governments are concerned that the R&D and promotion investment dollars are allocated most efficiently to ensure the highest returns. In Australia, the woolgrowers and the red meat producers have both been asking questions regarding the value they receive for their levies (Piggott 1998). In the United States, farmers and processors have also been vocal in recent years about accountability for their levy dollars (Piggott 1998).

Knowledge about the returns from alternative investments across different sectors of the beef production and marketing chain is useful in that it facilitates efficient allocation of funds. Other important information is the distribution of gross returns across various industry groups -- producers, feedlotters, processors, exporters, retailers, and domestic and export consumers -- so that better decisions can be made about who should fund these investments. This is particularly relevant in today's economic climate where research resources are limited. The relevant questions are: How should the dollars be invested, particularly in relation to the balance of expenditures between R&D versus promotion, domestic promotion versus overseas promotion, R&D into grass-finishing cattle versus grain-finishing cattle, and traditional on-farm R&D versus off-farm R&D in sectors such as feedlot, processing and marketing? Who will benefit? Who should pay?

Primary producers contributed about 60% of the total MLA funds in 1998/99 (MLA 1998). However, as pointed out by Piggott (1998, p8.), the burden of producers' levies is also shared indirectly by consumers. Introduction of a levy causes the price received by producers to fall and the price paid by consumers to rise. Hence, even though the levies are initially collected from producers and increase farm production costs, ultimately, through the market mechanism, the levy burden is shared throughout the chain from producers to final consumers. Moreover, from the viewpoint of the government funding bodies, taxpayers' benefits also need to be considered. The Commonwealth Government has paid 50% of the total R&D expenditure in recent years (MRC 1996/97; MLA 1998/99). Relevant questions are: What share of the benefits do various parties receive? Is the share the same from alternative investments in different sectors? How do shares of the benefits compare to shares of the levy burden?

The major justification for government involvement in agricultural research is the assumption of "market failure" when relying on private investments in R&D. That is, the market fails to provide private individuals with the incentive to fund research at a level that would be socially optimal. Individuals are reluctant to pay for research when they do not receive all the benefits and others can "free ride" on the investment. This is particularly relevant to the so-called 'basic research' investments. Thus, it becomes the governments' role to intervene and one way of doing so is through legislation for compulsory industry levies; another way is through direct public funding for research. Alston, Norton and Pardey (1995, p12, p491) argue that when intervention is to correct a market failure, "the public sector ought to focus its support more heavily on types of research that have a high social pay-off but which the private sector has relatively little incentive to support". They suggested that, for research areas where the returns mainly accrue to the private sector, forms of intervention other than funding research are more appropriate. They also argued that from the whole society's point of view, a single objective of economic efficiency (ie. what will bring the greatest total benefits) for public research may be appropriate, and that research is actually a less efficient instrument for meeting social objectives such as income distribution compared with other forms of intervention such as taxes and subsidies. However, as pointed out by Alston, Norton and Pardey (1995, p16), it seems to be a "fact of life" that public-sector research funding is often driven by its impact on particular groups.

Putting aside the debate on what the objectives should be in allocating public research funding, at least one of the roles for economists is to provide the decision makers with relevant information to aid their decision. In the context of the Australian beef industry, this can be done by providing an economic framework so that the total returns, as well as their distribution among industry groups, can be simulated for various broad areas of investment in research and promotion. An integrated modelling framework is required so that various types of research and promotion can be assessed consistently. On the other hand, given the complexity of the industry, a disaggregated framework is necessary in order to represent the industry characteristics of multiple products (grass-fed and grain-fed cattle, export quality and domestic quality beef), multiple stages (cattle breeding, grass and grain finishing, processing and marketing) and multiple markets (domestic and various export markets).

1.2 Objectives of the Study

The broad objective of the study is to develop an economic framework for the Australian cattle and beef industry to characterise the relationship among the different sectors of the industry, so as to be able to consistently assess the economic impacts of research-induced new technologies, promotion campaigns and other external changes. The principal aims are:

- to estimate and compare the total returns from broad types of research in different sectors and generic promotion in different markets (for example, on-farm research versus off-farm research, research versus promotion and domestic promotion versus export promotion); and

- to estimate the distribution of the total returns among different industry participants such as producers, feedlotters, processors, exporters, retailers and domestic and overseas consumers.

The secondary aims are:

- to provide a consistent and disaggregated economic framework for the beef industry so that other types of changes, such as an export quota or a tax policy, can be analysed; and
- to examine some methodological and empirical issues encountered in developing and applying such a modelling framework.

In particular, the study provides estimated returns from 1% shifts in various supply or demand curves, resulting from research-induced cost reductions in individual sectors and increases in consumers' willingness-to-pay due to promotion in different markets. The question of the costs incurred to achieve the 1% changes is not addressed in this study. It is a question which must ultimately be examined in a complete cost-benefit analysis.

In addition, although the intention is to develop a model that can also be used to evaluate the impact of a particular technology or a promotion project, the focus of this study is on evaluation and comparison of broad categories of research and promotion to address general policy issues. Thus the results of this study are more relevant to policy questions regarding choices between broad investment areas such as promotion versus research, or production research versus processing research.

1.3 Overview of the Methods

The method used in this study involves economic surplus measures and a partial equilibrium displacement framework, which is sometimes referred to as Equilibrium Displacement Modelling (EDM) (Piggott 1992). EDM has grown in popularity in research and promotion evaluations in recent years. With this approach, the equilibrium of the industry is represented with a system of demand and supply relationships. Impacts of exogenous changes, such as new technologies or promotion campaigns, are modelled as shifts in demand or supply curves in the relevant markets. When the equilibrium is displaced due to these exogenous shifts, changes in prices and quantities in all markets are solved, and the consequent changes in producer and consumer surpluses are then estimated as welfare changes to various industry groups.

EDM is considered the most suitable framework for the purpose of this study. The basic single market EDM is extended vertically to accommodate the multi-stages of beef production and marketing. Horizontally, the model is disaggregated into grain and grass finishing streams and domestic and export markets. Additionally, a stochastic approach to sensitivity analysis in EDM is proposed and demonstrated.

1.4 Significance of the Study

Existing EDM applications have generally been at a highly aggregated market level (see Chapter 2). In this study, a multi-sector and multi-product EDM of the Australian beef industry is developed that realistically characterises the interaction among individual industry sectors. The study demonstrates how such a disaggregated yet integrated modelling framework can be used to consistently evaluate and compare a variety of research-induced technologies and generic promotions in the Australian beef industry.

The results derived from the study should be valuable at the strategic level of the industry for allocating R&D and promotion funds. The information on the returns from alternative investment scenarios will be informative to producer bodies for balancing expenditure between areas such as research versus promotion or production research versus marketing research. Additionally, the study is also relevant to public policy issues since the Commonwealth Government contributes half of the R&D funds of the beef industry and the coercive powers of the government are used to underpin the level system.

The study also provides a framework for evaluating the industry wide effects of individual R&D or promotion projects. For example, there are plans to use the model developed in this study to evaluate industry wide returns for some of the new technologies developed by the Cooperative Research Centre for the Cattle and Beef Industry (Beef CRC) (CRC-Beef 1999). Examples include some nutritional programs aimed at cattle performance during backgrounding or feedlot-finishing, and some meat science projects targeting beef processing technologies. In fact, one such application has been completed using an earlier version of this model (Griffith and Zhao 1998). Furthermore, the model is also useful for answering questions such as whether putting the majority of the Beef CRC resources into grain-finishing related research is a wise strategy from the industry point of view.

There are also some methodological contributions to the EDM literature. Some theoretical issues regarding the assumptions underlying the use of EDM are discussed. In particular, issues regarding the nature of the exogenous shifts, the functional forms of demand and supply curves and the sizes of the errors in empirical applications are examined (Chapter 3 and Zhao, Mullen and Griffith 1997). The results are important for identifying conditions for the EDM approach to be exact and for understanding whether significant errors are possible when a particular type of exogenous shift is assumed in applications.

Uncertainty about parameter values used in the EDM approach has been a major drawback in applications and it has been frustrating to undertake discrete sensitivity analysis when a large number of parameters are involved. A stochastic approach to sensitivity analysis in EDM is proposed and demonstrated (see Chapter 8; Zhao, Griffiths, Griffith and Mullen 1999; Griffiths and Zhao 2000). Some useful statistical measures are also defined to capture the relative sensitivity of results to individual parameters. The proposed approach permits policy-related conclusions to be presented to decision makers in terms of probabilities and probability intervals. Thus, conveyance of policy-relevant results to non-economists when risk and uncertainty are recognised is easier. The method being proposed should also be useful for sensitivity analysis in other economic models.

Finally, the issue of economic welfare measures in multi-market models is discussed in Chapter 6 in the context of the current model. In particular, the measure of economic surplus change in the case of two sources of equilibrium feedback (Thurman 1991a) is examined. It is pointed out that significant errors are possible, as in some past studies, if care is not taken in measuring the economic surplus changes in multi-markets. The derivation also indicates that, even when integrability conditions are not met in multi-market models, the first-order term in the change of economic surplus area (the trapezoid area) may still be path independent and equal to the first-order term of the compensating or equivalent variation measures. Thus, as long as the considered shift (λ) is small in a multi-market EDM, failure to satisfy integrability conditions may not result in significant errors in using economic surplus change ($\mathbf{O}(\lambda)$ in magnitude) as welfare measures. However, integrability is vital if the triangular 'deadweight loss' (($\mathbf{O}(\lambda^2)$ in magnitude) is of interest in a study (LaFrance 1991).

1.5 Outline of the Thesis

A literature review on methods of research and promotion evaluation, particularly those based on EDM, is given in Chapter 2. Some theoretical and empirical issues in the use of EDM are reviewed and some of these issues are further discussed in later chapters.

In Chapter 3, the assumptions about functional forms of demand and supply curves and types of research- or promotion-induced shifts necessary for the EDM results to be exactly correct are derived. Errors in both the estimated price and quantity changes and the welfare measures, when these assumptions are not met, are examined by deriving the error expressions for a single market model. The results suggest that, in empirical applications, functional form is not an issue when a parallel shift is assumed, but significant errors are possible for surplus measures when a proportional shift is assumed.

The market segments and product specifications of the beef industry are reviewed and an equilibrium displacement model is specified in Chapter 4. The model involves 58 endogenous variables and 12 exogenous shifters (representing 12 alternative research or promotion investment scenarios). The issue of integrability is also discussed in Chapter 4.

Details about specification of information required in the model are given in Chapter 5. Considerable effort is devoted in Chapter 5 to compile a consistent set of prices and quantities representing an average equilibrium situation of 1992-1997. Market elasticities are also specified based on review of existing empirical estimates, economic theory and subjective judgement. Integrability constraints are imposed on the specified market parameters.

Measures of economic surplus changes for all industry groups and all research and promotion scenarios are discussed in Chapter 6, by examining the profit and expenditure functions and the associated integrals of supply and demand functions. In particular, the situation where two sources of equilibrium feedback exist is studied. It is pointed out that care needs to be taken in these situations in order to measure the economic surplus changes correctly. As mentioned earlier, some insights are also given in using economic surplus changes as welfare measures when integrability conditions are not met in multi-market models.

The results on total economic surplus change and its distribution among industry groups from the 12 research and promotion investment scenarios are presented in Chapter 7. These results are interpreted and discussed in light of policy relevance. In particular, comparison of benefit distributions between some broad funding areas, such as research versus promotion and on-farm research versus off-farm research, are examined.

Sensitivity of the results to the market-related parameters used in the model is examined in Chapter 8 using Monte Carlo simulation. Subjective probability distributions for all parameters are specified representing uncertainty about the values of these parameters. Probability distributions of the estimated welfare measures are simulated. Levels of confidence in the policy-related conclusions in Chapter 7 are represented in terms of probabilities and probability intervals. Response surfaces that represent the relationship between the welfare measures and all parameters are estimated. Some statistical measures are also defined and calculated, based on the response surfaces, to represent the relative sensitivity of welfare measures to individual parameters. This information is useful for locating the most influential parameters.

The research is reviewed in Chapter 9, and limitations and further areas for research are also discussed in chapter 9.

Chapter 2. A Literature Review

2.1 Introduction

In this chapter, literature on evaluation of returns from research-induced technology and generic promotion is reviewed. In 2.2, alternative empirical approaches for research and promotion are reviewed briefly and the choice of an equilibrium displacement modelling (EDM) approach for this study is justified. A single-market EDM is presented in 2.3 to illustrate the approach. Extensions to the single-market model, both horizontally to include multiple markets for a product or multiple products and vertically to include multiple stages of production, are reviewed in 2.4. These extensions are relevant to this study because, as detailed in Chapter 4, the Australian beef industry is characterised by multiple production and marketing stages and multiple products. Some assumptions and methodological issues in the use of the EDM and economic surplus approach are discussed in 2.5. Some of the issues raised are closely examined in later chapters of the thesis. A summary in 2.6 concludes the chapter.

2.2 Alternative Approaches in Research and Promotion Evaluation

There are a number of tools that economists have used for evaluating impacts of research-induced technologies, ranging from a simple scoring approaches to more complicated frameworks, depending on the nature of the problem, resources available and the objectives of the evaluation (Alston, Norton and Pardey 1995). All use a cost-benefit framework either explicitly or implicitly. Whenever one investment project is preferred to another, an implicit cost-benefit ranking has been applied. There is now greater interest in using explicit forms of cost-benefit analysis to make the process repeatable and transparent, but there remains a wide range in the level of sophistication in applications.

Perhaps the most well known are the spreadsheet BCA models used by the R&D corporations. The majority of the R&D corporations that provide funds to Australian rural industries request cost-benefit information for project applications (Wilson 1996). Most funding bodies also have their standard spreadsheet package for cost-benefit analysis. However, these models often unrealistically assume elastic demand and inelastic supply. Also, while they provide estimates of total returns from total investments, they are not suitable for identifying distributions of benefits to individual groups such as producers.

There are a number of tools that could be used to account for the impact of new technology more realistically. One approach is to develop and estimate an econometric model of the industry. However, to answer the questions raised in this study, a very disaggregated econometric model would be required. To estimate such a model, sample data for variables at different stages and markets of the industry would be needed over a long period of time. Much of the required data are not available, especially given that some sectors of the industry are only new. The demand for sample data may be one of the reasons for the limited use of econometric models in the research evaluation literature.

Mathematical programming models are also used frequently in agricultural economic research. However, "mathematical-programming models have seldom been applied to assist with agricultural research priority setting at the strategic level" (Alston, Norton and Pardey 1995, p462). They are more suitable for actual resource allocation within a program portfolio and a research budget, after the measure of benefit from each program is estimated.

As pointed out by Piggott (1998), early studies on promotion have mostly focused on the effectiveness of promotion, relating promotion expenditures to sales using econometric models. Estimating this type of relationship would provide the average partial impact of promotion on quantity demanded or sales revenue in the particular market, but would not reflect the impacts to other sectors of the industry after the new equilibrium is reached. Also they were not focused on the measure of producer and consumer welfare. A recent study on promotion and consumer and producer welfare (Alston, Chalfant and Piggott 1999) has used a comprehensive econometric model, which involves explicitly specifying expenditure function and estimating an extended AIDS model. This approach measures consumer welfare using the more desirable compensating variation rather than consumer surplus. However, data availability for the multi-sectoral and multi-market industry structure in this study restricts the use of such econometric approach.

The approach that has grown in popularity in both research and promotion evaluations is what has been referred to as equilibrium displacement modelling (EDM). Early work on using economic surplus concepts to measure research benefits can be traced back to authors such as Griliches (1958) and Peterson (1967). The use of comparative static analysis to analyse impacts of policies is exemplified in Muth (1964) and Gardner (1975). There have since been many applications of EDM and the economic surplus approach to estimate the impacts of research-induced technologies, promotion campaigns and government interventions. Alston, Norton and Pardey (1995) provide a comprehensive review of this literature. They concluded that, for most purposes, EDM and economic surplus approach is the best available method for evaluating research returns (p40). Using EDM, demand and supply relationships among variables of an industry are described by a structural model under equilibrium. Effects of new technology, promotion or market distortion policies are modelled as initial shifts in supply or demand curves in a market. Comparative static analysis is applied to the equilibrium model to approximate the changes (displacements) in prices and quantities in all markets. Then, using the estimated price and quantity changes, the economic surplus changes are calculated as measures of benefits to individual industry groups and to the society as a whole. Literature on EDM is reviewed in more detail in later sections of this Chapter.

The EDM approach is considered the most suitable framework for the purpose of this study. The basic single market EDM is extended vertically to accommodate the multi-stages of beef production and marketing. Horizontally, the model is disaggregated into grain and grass finishing streams and domestic and export markets. Compared to other modelling approaches, EDM is convenient for examining various broad types of research and promotion in a consistent manner. It is not demanding on data. Actually, rather than needing historical time series data, it only requires one set of base price and quantity data at all markets representing the current level of industry equilibrium and some market-related parameters describing the responsiveness between quantities and prices. The usual approach is to assume, rather than estimate, values for key parameters such as Marshallian demand and supply elasticities. Sensitivity analysis can be carried out with such a framework to account for uncertainty in parameter values. The displacement model is a linear system, so even a very disaggregated EDM model can still be very easy to manipulate. It also provides a convenient framework to analyse many other types of external shocks to the beef industry.

In fact, as argued by Alston, Norton and Pardey (1995), other modelling methods can be used as complementary tools to EDM to form a complete research evaluation procedure. Econometric or mathematical programming models can be used to estimate the direct impact in productivity or willingness to pay to determine the amounts of initial shifts of demand or supply curves resulting from research or promotion. After the economic welfare changes are estimated, spreadsheet cost-benefit analysis can be used to distribute and discount costs and benefits into a time frame and to summarise the net benefits in terms of NPV (Net Present Value) and BCR (Benefit-Cost Ratio). Programming models can also be used to optimise portfolio funding allocation using the estimated economic welfare gains. From another perspective, Alston, Norton and Pardey (1995, p54-55) argued that both spreadsheet cost-benefit analysis and single equation econometric measures of benefits can actually be considered as implicitly using economic surplus analysis under polar demand or supply elasticity restrictions.

2.3 A Single-Market Model

In this section, a single-market model is presented to illustrate the EDM approach. Consider a simple model of a single product in a single market. Assume that the initial supply curve under the original technology is S_1 and the initial demand curve is D_1 (Figure 2.1). The intersection of the above curves, $E_1(Q_1, P_1)$, is the initial equilibrium point, with P_1 and Q_1 as the initial price and quantity. Consider the impacts from a research-induced technology. Assume that adoption of a new technology reduces the per unit cost of production and thus shifts down the supply curve to S_2, resulting in a new equilibrium point E_2, with price and quantity P_2 and Q_2. For the time being, the research-induced supply shift is assumed to be parallel along the price direction.

The displacement from E_1 to E_2 results in changes in economic surplus areas. Under the initial equilibrium, the initial producer surplus is area $A_1E_1P_1$, which is total revenue $OQ_1E_1P_1$ less production costs $OQ_1E_1A_1$, and the initial consumer surplus is area P_1E_1D, which is the difference between what the consumer is willing to pay for the consumption of Q_1 quantity (area OQ_1E_1D) and the actual expenditure of the consumption (area $OQ_1E_1P_1$). After the research-induced supply shift, the new producer surplus is area $A_2E_2P_2$ and the new consumer surplus is area P_2E_2D. When a parallel shift is assumed as illustrated in Figure 2.1, the change in producer surplus (ΔPS) equals area BCE_2P_2 and the change in consumer surplus (ΔCS) is area $P_2E_2E_1P_1$. The sum of the two changes, area $BCE_2E_1P_1$, is the change in total economic welfare (ΔTS), ie.

(2.1) $\Delta PS = \text{Area } (BCE_2P_2),$

(2.2) $\Delta CS = \text{Area } (P_2E_2E_1P_1),$ and

(2.3) $\Delta TS = \text{Area } (BCE_2E_1P_1).$

These areas are used as measures of the benefits accruing to producers and consumers of the product and, if there are no externalities associated with the technology, to society as a whole.

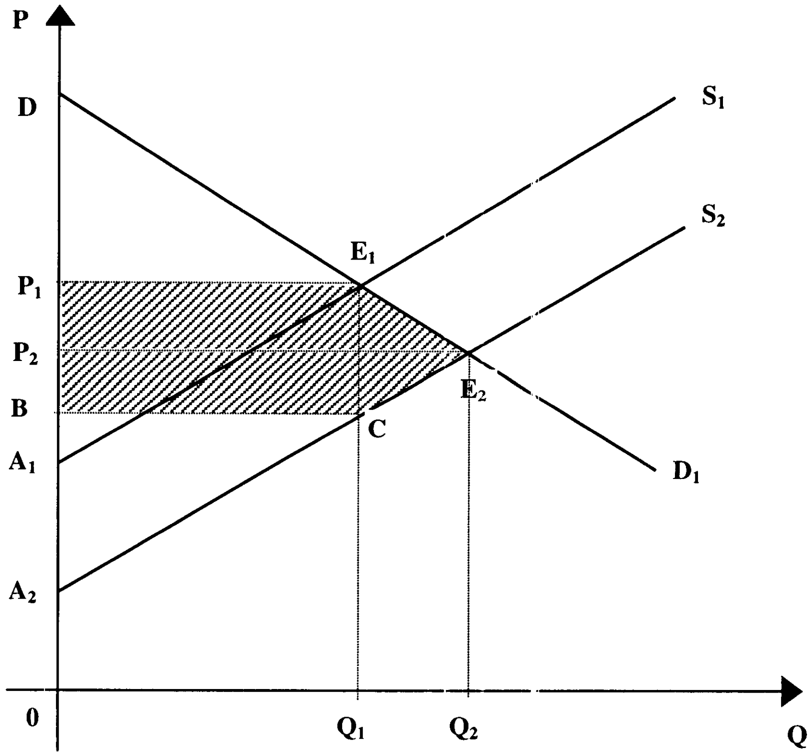

Figure 2.1 A Simple Model

Algebraically, assume that the initial supply and demand curves for the product can be represented in general form as

(2.4) S_1: $Q = S(P)$ *initial supply curve*

(2.5) D_1: $Q = D(P)$ *initial demand curve.*

The intersection of the above curves, $E_1(Q_1, P_1)$, is the initial equilibrium point in Figure 2.1. Assume that the new supply curve after a research-induced parallel shift is:

(2.6) S_2: $Q = S(P\text{-}K)$ *new supply curve*

where $K \equiv$constant is the amount of a supply shift along the price direction and $K<0$ represents a downward shift. In empirical applications, the per unit cost change at Q_1 is often expressed as a percentage of P_1 such that $K = \lambda P_1$. The new equilibrium point is the intersection of D_1 and S_2, i.e. $E_2(Q_2, P_2)$ in Figure 2.1.

Price and quantity changes resulting from the displacement from E_1 to E_2 are estimated by totally differentiating the logarithms of equations (2.5) and (2.6) to give:

(2.7) $\quad dQ/Q = \eta(dP/P)$

(2.8) $\quad dQ/Q = \varepsilon(dP/P - \lambda)$,

where η and ε are the demand and supply elasticities Solving (2.7) and (2.8) jointly gives the relative changes in price and quantity

(2.9) $\quad EP = dP/P = \lambda\varepsilon/(\varepsilon-\eta)$ and

(2.10) $\quad EQ = dQ/Q = \lambda\varepsilon\eta/(\varepsilon-\eta)$.

Assuming that the supply and demand curves are linear and the initial supply shift is parallel, the resulting changes in producer, consumer and total surplus as illustrated in Figure 2.1 are given by

(2.11) $\quad \Delta PS = \text{Area } (BCE_2P_2) = P_1Q_1(EP-\lambda)(1+0.5EQ)$

(2.12) $\quad \Delta CS = \text{Area } (P_2E_2E_1P_1) = -P_1Q_1EP(1+0.5EQ)$ and

(2.13) $\quad \Delta TS = \text{Area } (BCE_2E_1P_1) = -\lambda P_1Q_1(1+0.5EQ)$.

Derivation of (2.9)-(2.13) is straightforward and thus not presented (See Alston, Norton and Pardey 1995).

Note that the only data required in this simple model are the initial price and quantity P_1 and Q_1, the demand and supply elasticities η and ε, and the extent of the exogenous percentage shift λ at the initial equilibrium point.

2.4 Extensions to the Basic Model

The basic model can be disaggregated into various multi-market situations. The disaggregations, in essence, enable the allocation of total producer and consumer surpluses measured in the basic model to individual groups of factor suppliers and to all consumers directly or indirectly consuming the product. Horizontal disaggregation into different producers and consumers of a homogenous product and into multiple products is discussed in 2.4.1. Vertical disaggregation into multiple stages of production is given in 2.4.2. Applications of EDM in areas other than research and promotion evaluations are reviewed in 2.4.3.

2.4.1 Horizontal Disaggregation

In the basic model, it is assumed that there is only one homogeneous product being sold in a single closed market. In reality, trade among different countries or regions often exists. A product in an open economy is usually traded in multiple markets. Additionally, in many cases, it is also necessary to consider the more general equilibrium feedback effects to a product from interaction with other products. A multiple product framework is required in these situations.

Multiple Markets for a Single Product

Typical case for a multiple market model is international trade. Many agricultural commodities are either exported or imported. For an importing country there are multiple supplingcountries of the product, while for an exporter, multiple consuming countries are involved. In evaluations of innovation and promotion, it is often important to separate the domestic benefits from the benefits to overseas customers. Typically, in EDM studies involving trade, a Rest Of World (ROW) sector is identified. Innovation at home, for example, is modelled as shift in the home supply curve, which eventually has an effect on the world price of the product and hence on the economic welfare of market participants both home and overseas. It is often convenient to assume that the home country is a small exporter facing a highly elastic demand curve on the export market, and hence new technology at home has little impact on the world price. In this situation the benefits of new technology are largely captured by home producers (Akino and Hayami 1975; Nguyen 1977; Flores-Moya, Evenson and Hayami 1978; Norton, Ganoza and Pomareda 1987).

If however the home country has a large share of world trade in a commodity, such as is the case for Australian wool, then export demand will not be perfectly elastic and overseas buyers will capture some of the benefits of new Australian technology. Early studies involving trade with large countries include those by Martin and Havlicek (1977), Edwards and Freebairn (1984), and Mullen, Alston and Wohlgenant (1989). In addition, in some cases it is necessary to further separate the ROW into individual countries (Davis, Oram and Ryan 1987), depending on the objectives of the studies.

Another consideration is "technology spillover", where the ROW partly adopts the research results from the innovating country. Mostly, this has been modelled as supply shifts in both the home country and the ROW. Studies involving technology spillovers include Edwards and Freebairn (1984), Davis, Oram and Ryan (1987), and Mullen, Alston and Wohlgenant (1989).

Trade among different regions within a country can also be studied in a similar manner (for example, Brennan, Godyn and Johnson 1989). Also, in addition to trade, the horizontal disaggregation can be based on other criteria. For example, it maybe necessary to consider the welfare impacts on large farms versus small farms (Hayami and Herdt 1977), adopters versus non-adopters of new technology (Scobie and Posada 1978; Edwards and Freebairn 1982), or producers directly affected by a chemical residue versus those not directly affected (Hill, Griffith and Piggott 1997). For consumer surplus, in the political economy context, it maybe important to separate consumers according to socio- economic groups or income levels (Scobie and Posada 1978).

The EDM approach for all cases of horizontal disaggregation described above can be summarised with a general one-product-*n*-country model as follows. Consider the world market for a product with *n* countries:

(2.14) $$Q_i^d = D_i(P, N_i) \qquad (i = 1, \ldots, n) \qquad \textit{demand}$$

(2.15) $$Q_i^s = S_i(P, T_i) \qquad (i = 1, \ldots, n) \qquad \textit{supply}$$

(2.16) $$\sum_{i=1}^{n} Q_i^d = \sum_{i=1}^{n} Q_i^s \qquad \textit{market clearing}$$

where, for the ith country ($i=1, ..., n$), Q_i^s is the quantity supplied, Q_i^d is the quantity demanded, T_i is the supply shift variable representing impact of innovation, for example, and N_i is the demand shift variable representing impact of promotion, for example. $D_i(.)$ and $S_i(.)$ are demand and supply functions for the ith country ($i = 1, ..., n$) respectively, and Equation (2.16) is the market clearing condition. Zero transport costs are assumed among different markets for simplicity.

Totally differentiating the logarithms of all equations gives the following model expressed in percentage changes of the variables:

$$(2.17) \qquad E(Q_i^d) = \eta_i\,[\,E(P) - \tau_i] \qquad (i = 1, ..., n)$$

$$(2.18) \qquad E\,(Q_i^s) = \varepsilon_i\,[\,E(P) - \lambda_i] \qquad (i = 1, ..., n)$$

$$(2.19) \qquad \sum_{i=1}^{n} s_i^d\ E(Q_i^d) \ = \ \sum_{i=1}^{n} s_i^s\ E(Q_i^s)$$

where, for the ith country, $E(.)$=dln(.)=d(.)/(.) represents the relative change of variable (.), η_i and ε_i are demand and supply elasticities respectively, s_i^d and s_i^s are the shares of total production demanded and supplied respectively, and τ_i and λ_i are the upward vertical demand and supply shifts, respectively, expressed as percentages of initial prices (i = 1, ..., n). For example, τ_1=0.01 represents a 1% upward shift in the demand curve of *country-1*, and λ_2=-0.01 represents a 1% downward shift in the supply curve of *country-2*, both at the initial equilibrium point. The λ_i's (i = 1, ..., n) may be made dependent in the case of technology spill-over.

Relative price and quantity changes for all countries can be estimated by solving the $2n$+1 linear equation system in (2.17)-(2.19):

$$(2.20) \qquad E(P) = \sum_{i=1}^{n}\ (\,-s_i^d\,\tau_i\,\eta_i + s_i^s\,\lambda_i\,\varepsilon_i\,) \,\Big/ \sum_{i=1}^{n}\ (\,-s_i^d\eta_i + s_i^s\varepsilon_i\,)$$

$$(2.21) \qquad E(Q_i^d) = \eta_i\,[\,E(P) - \tau_i] \qquad (i = 1, ..., n)$$

$$(2.22) \qquad E(Q_i^s) = \varepsilon_i\,[\,E(P) - \lambda_i] \qquad (i = 1, ..., n).$$

If assumptions of linear demand and supply functions and parallel exogenous shifts are made, the economic welfare changes to the producers and consumers in each country and to the whole world can be calculated as

$$(2.23) \qquad \Delta CS_i = -PQ_i^d\,[E(P) - \tau_i]\,[\,1 + 0.5\,E(Q_i^d)\,] \qquad (i = 1, \ldots, n)$$

$$(2.24) \qquad \Delta PS_i = PQ_i^s\,[E(P) - \lambda_i]\,[\,1 + 0.5\,E(Q_i^s)\,] \qquad (i = 1, \ldots, n)$$

$$(2.25) \qquad \Delta TS_i = \Delta CS_i + \Delta PS_i \qquad (i = 1, \ldots, n)$$

$$(2.26) \qquad \Delta TS = \sum_{i=1}^{n} \Delta TS_i \qquad (i = 1, \ldots, n)$$

Simple models with two countries or regions can be illustrated or even solved graphically (for example, Edwards and Freebairn 1982; Brennan, Godyn and Johnston 1989). However, when more than two horizontal markets are involved or when the model also involves multiple stages of production, graphical illustration and solution becomes difficult.

Multiple Products

Technical changes in one industry will affect other industries that produce other products which are related to the innovating industry either through supply or demand. For example, the beef industry is related to the lamb industry in supply and related to lamb, chicken and pig industries in demand. That is, beef and lamb are often jointly produced and most meat consumers regard beef, chicken, lamb and pork as close substitutes. An innovation in the beef industry results in a fall in beef price in the first instance. The supply of lamb and demand for lamb, chicken and pork will all be shifted as a second round effect because they are conditional on the beef price. These changes in other industries may also feedback to induce further changes in demand and supply conditions in the beef industry. These types of interaction are often called general equilibrium effects.

In some cases, partial equilibrium analyses that concentrate on the industry of interest and ignore the general equilibrium feedback from other industries are appropriate, while in other cases it is necessary to consider the industry within the context of interaction with other industries. A general equilibrium multi-product framework is required in the latter case.

Another multi-product situation is to consider the horizontal relationship of two or more products within an industry. There may be two or more products that are produced as joint products from a joint production function. For example, Mullen, Wohlgenant and Farris (1988) considered a two product (beef and by-product) beef processing model. Other examples include cases of Australian sheep industry producing wool and lamb and the dairy processing industry that produces various milk products (Alston, Norton and Pardey 1995, p231). In other studies, it is necessary to separate a heterogeneous product into different quality types to evaluate the impacts of quality-enhancing research or of introducing new product varieties (see for example Brennan, Godyn and Johnston 1989; and Voon 1991). Note that there is a debate as to whether quality enhancing research should be modelled as causing a demand shift or a supply shift.

Price, quantity and revenue changes resulting from new technologies or promotion can be estimated from multi-product EDMs. However, complications arise regarding the measures of economic surplus changes when there is more than one source of equilibrium feedback in a multi-product model (Thurman 1991a, 1991b; Just, Hueth and Schmitz 1982, p192; Alston, Norton and Pardey 1995, p231-234). This occurs, for example, when two products are related in both demand and supply, and, as a result, both demand and supply curves in a market are shifted endogenously due to a single exogenous shock. The issue is particularly relevant to this study as there are multiple products involved in the proposed model. Issues regarding multi-market economic surplus measures are reviewed in 2.5.3 and 2.5.4 and further examined in Chapter 6 in the context of the model in this thesis. The concept of integrability in multi-market models as discussed in Chapter 4 is also relevant to this subject.

2.4.2 Vertical Disaggregation

Production of a final agricultural product involves a vertical chain that transforms the product through various intermediate value-adding stages. If the basic model in 2.1 is considered as relating to a particular stage of the chain, the producer surplus measured from the basic model will include benefits to all factor suppliers of the product at and prior to the stage being modelled. Similarly, the consumer surplus will measure benefits to all industry participants at the current and later stages of the chain. For example, if the basic model represents the market of a retail product, the consumer surplus measured at this market includes benefits to final consumers of the retail product, while the producer surplus includes benefits to retailers, distributors, processors and farmers. On the other hand, if the basic one-stage model represents the market of a farm product, the producer surplus only measures benefit to factor suppliers in farming, i.e. the farmers, while the consumer surplus includes benefits accruing to all sectors and their input suppliers beyond the farm gate, that is, processors, distributors and retailers, as well as to the final consumers.

Thus, disaggregation into multiple stages of production enables the identification of research benefits to different sectors in the chain. It also enables evaluations of investments at different sectors and thus a comparison of on- and off-farm research and promotion from the viewpoints of farmers, processors and consumers.

Muth (1964) presented an elegant two-factor one-output equilibrium displacement model of the housing market which has since been adopted and extended in many later studies. Using a similar framework, Gardner (1975) compared the impacts on the farm-retail price ratio of shifts in the supply of the farm and processing inputs and in retail demand. Miedema (1976) further investigated the framework by Muth (1964) and Gardner (1975) and pointed out the link between the two. All three studies used general functional forms for demand and supply relationships. The focus was on deriving the analytical solutions of the endogenous variables and the qualitative effects of the exogenous shifts.

Freebairn, Davis and Edwards (1982) addressed specifically the question of how the benefits from on- and off-farm research were distributed in a multistage production process. They used explicit linear demand and supply functions and small finite shifts of supply curves. Their major result was that the benefit distribution among industry groups was the same regardless of where the innovation occurs in the chain. However, this finding was dependant on the assumption that farm and non-farm inputs were used in fixed proportions. In a comment to Freebairn, Davis and Edwards (1982), Alston and Scobie (1983) pointed out that once the assumption of zero input substitution between farm and non-farm inputs is relaxed, not only do farmers share a greater proportion of benefits from farm research than from non-farm research, they could even lose from non-farm research. They emphasized the crucial role of input substitution elasticity in the distribution of benefits. They also derived the analytical conditions under which farmers will lose welfare from processing/marketing research if farm-non-farm input substitution elasticity is larger than the absolute value of the retail demand elasticity. Mullen, Farris and Wohlgenant (1988), in a study of innovation in the US beef industry, estimated that the elasticity of substitution between cattle and processing inputs was 0.1 and demonstrated that even this amount of substitution caused a significant change in the distribution of benefits. This topic was further discussed by Holloway (1989) and Wohlgenant (1993). Holloway (1989) separated the marketing sector into two sequential stages (i.e. processing and distribution) and pointed out that the farmers' benefits depend crucially on the stage in marketing system where the research occurs. Wohlgenant (1993) looked at the issue of farm and processing research versus promotion. He also discussed the issue of input substitution with respect to both theoretical insights and empirical evidence.

While Gardner (1975), Miedema (1976), Alston and Scobie (1983) and Holloway (1989) based their models on a production function following Muth (1964), Wohlgenant (1982) proposed a general single-output n-input model for the food marketing industry using a dual approach. This cost function specification has been followed by many later studies to examine the effects of exogenous shifts in input supply and retail demand, because it more easily accommodates multiple inputs and outputs. These include Mullen, Wohlgenant and Farris (1988), Lemieux and Wohlgenant (1989), Mullen, Alston and Wohlgenant (1989) and Wohlgenant (1993).

Since the proposed model in this thesis follows Wohlgenant's (1982) specification, though more disaggregated both vertically and horizontally and involving multiple products, a simplified dual model based on Wohlgenant (1982) is presented below.

Wohlgenant (1982) specified a general n-factor, single-output model from the dual side. The two-factor case of his specification is given by

(2.27) $Q = D(P, N)$ *output demand*

(2.28) $P = c(W_1, W_2)$ *long-run equilibrium condition*

(2.29) $X_1 = c_1(W_1, W_2)Q$ *output constrained factor demand*

(2.30) $X_2 = c_2(W_1, W_2)Q$ *output constrained factor demand*

(2.31) $X_1 = S_1(W_1, T_1)$ *factor supply*

(2.32) $X_2 = S_2(W_2, T_2)$ *factor supply*

where P and Q are price and quantity of retail product, W_i and X_i (i=1,2) are prices and quantities of the two factors, N and T_i (i=1, 2) represent exogenous shifts in output demand and input supplies. Equations (2.27) and (2.31)-(2.32) are retail demand and factor supply schedules. Equation (2.28) is retail supply imposing the long-run equilibrium condition that product price equals average per unit cost $c(.)$. This is equivalent to assuming constant returns to scale for the production function. The total cost function can thus be written as $C = Qc(W_1, W_2)$. The output constrained input demands in Equations (2.29) and (2.30) can then be derived through application of Shepherd's Lemma to the total cost function, where $c_i(.)$ (i=1,2) are partial derivatives of $c(.)$ with respect to input prices.

Totally differentiating the logarithm of Equations (2.27)-(2.32) gives the following model in relative change form:

(2.33) $EQ = \eta(EP - EN)$

(2.34) $EP = s_1 EW_1 + s_2 EW_2$

(2.35) $EX_1 = \tilde{\eta}_{11} EW_1 + \tilde{\eta}_{12} EW_2 + EQ$

(2.36) $EX_2 = \tilde{\eta}_{21} EW_1 + \tilde{\eta}_{22} EW_2 + EQ$

(2.37) $EX_1 = \varepsilon_1 (EW_1 - ET_1)$

(2.38) $EX_2 = \varepsilon_2 (EW_2 - ET_2)$

where $E(.)$ represents the relative change of (.), EN and ET_i (i=1, 2) are demand and supply shifts as percentages of the initial prices in the relevant markets, η and ε_i (i=1, 2) are retail demand and factor supply elasticities, s_i (i=1, 2) are the cost shares, and $\tilde{\eta}_{ij}$ represents the output-constrained input demand elasticity of factor i with respect to price of factor j (i, j = 1, 2).

Equations (2.35) and (2.36) can be expressed in terms of the input substitution elasticity σ and cost shares s_i (i=1, 2), by using Allen's definition of partial elasticity of input substitution, $\tilde{\eta}_{ij}=s_i\sigma_{ij}$ ($i\neq j$), and assumptions of symmetry, $\sigma_{ij}=\sigma_{ji}$. and homogeneity, $\sum_j \tilde{\eta}_{ij}=0$, for the cost function:

(2.35)' $$EX_1 = -s_2\sigma EW_1 + s_2\sigma EW_2 + EQ$$

(2.36)' $$EX_2 = s_1\sigma EW_1 - s_1\sigma EW_2 + EQ$$

Relative changes in prices and quantities of inputs and output can be solved from Equations (2.33), (2.34), (2.35)', (2.36)', (2.37) and (2.38). Under the assumptions of local linear demand and supply curves and parallel exogenous shifts in factor and output markets[1], the economic surplus changes to retail consumers (ΔCS) and factor suppliers (ΔPS_i, i=1,2) can be calculated as changes in economic surplus areas off the retail demand and input supply curves:

(2.39) $$\Delta CS = -P_1Q_1(EP - EN)(1+0.5EQ)$$

(2.40) $$\Delta PS_i = -W_iX_i(EW_i - ET_i)(1+0.5EX_i) \quad (i=1,2)$$

(2.41) $$\Delta TS = \Delta CS + \Delta PS_i$$

where ΔTS is the total welfare change.

2.4.3 Applications of EDM

Applications of EDM have ranged across many areas. In addition to the many studies on research-induced supply shifts (as reviewed in Alston, Noton and Pardey 1995), supply shifts resulting from other exogenous changes have been similarly examined. For example, Brennan, Godyn and Johnston (1989), Voon (1991, 1992), and Mangabat and Edwards (1996) separated a product into heterogenous quality levels and modelled the research-induced new varieties or quality changes as supply shifts across different markets. Hill, Piggott and Griffith (1997) modelled the chemical residue incident in the Australian beef industry partly as a shift in supply

[1] Assumptions required for the EDM results to be exact and the errors when these assumptions are not met are discussed in the next section of this Chapter and in Chapter 3.

across market segments and a further supply shift due to increased cost from extra testing procedures.

The approach has also been used to study the impacts of various exogenous demand shifts, resulting from promotional campaigns, product quality improvement or any other demand-enhancing factors such as population and income changes. Applications of EDM in modelling returns from product promotion include Wohlgenant (1993); Alston, Chalfant and Piggott (1995); Piggott, Piggott and Wright (1995); Hill, Piggott and Griffith (1996); Kinnucan and Christian (1997); and Kinnucan (1998). In addition to being modelled as supply shifts across discrete quality markets, the impacts of research-induced product quality changes have been mostly modelled as *ad hoc* demand shifts[2], under the notion that consumers demand more of the product at a given price if it contains more favourable quality characteristics. These include studies by Unnevehr (1986, 1990); Lemieux and Wohlgenant (1989); Voon and Edwards (1991a, 1992); and Mullen and Alston (1994). Demand shifts caused by population and income changes over time were considered by Norton, Ganoza and Pomareda (1987).

The EDM and economic surplus approach is also a useful tool for analysing agricultural policies. Gardner (1987) presented a systematic assessment of a range of agricultural policies using demand and supply analysis and welfare economics. Many recent studies also examined the impacts of various government policies on the benefits from research and promotion. Alston, Edwards and Freebairn (1988) studied the effects of a range of price policies on the size and distribution of research benefits for a range of market conditions. They found that there are no general rules about whether the total research benefits or benefits to a particular group would be increased, decreased or unchanged by market distortions, and therefore each case must be studied individually. Freebairn (1992) examined the influences of various Australian dairy industry policies on the returns from different types of research. He concluded that, compared to the free market situation, the current dairy policies do not change the total research gains dramatically, but do impact on the distribution of the benefits. Other studies on this subject include Norton, Ganoza and Pomareda(1987), Oehmke (1988; 1991); Voon and Edwards (1991b); Zachariah, Fox and Brinkman (1989); Murphy, Furtan and Schmitz (1993); and Voon (1993; 1994). Alston, Norton and Pardey (1993, p266) presented detailed methods for analysing research benefits in the presence of various distortion policies (price support, price ceilings, subsidies, taxes, tariffs, quotas, etc.) under different market conditions (closed

[2] Restrictive assumptions underlying the use of this approach can be found in Alston, Norton and Pardey (1995, p244).

economy, small or large country, importer or exporter, etc.). Boutonnat, Forker, Jones, Kinnucan and MacDonald (1991) examined qualitative implications of impacts of dairy policies on returns to dairy promotion. In addition, from a political economy perspective, there have been arguments on whether price distortion policies and public-sector research investments should be modelled as jointly determined by a single decision maker (ie. a single objective function). See Alston, Norton and Pardey (1995, p268) and references cited therein for discussions on this.

2.5 Some Assumptions and Methodological Issues in EDM Applications

2.5.1 Nature of Exogenous Shifts

The impact of new technology or promotion is modelled as an exogenous shift in supply or demand. The size of the exogenous shift at the initial equilibrium point can be estimated or specified from information on the reduction of production cost associated with the new technology or the change in willingness to pay from promotion[3]. However, as Duncan and Tisdell (1971) pointed out, the size of welfare changes and their distributions also depends on the effect of the technology or promotion at production levels other than the initial equilibrium. The amounts of shifts at other points on the supply or demand curve is an assumption that has to be made in order to calculate the welfare changes. In EDM applications, pivotal, parallel or proportional shifts (i.e. the third being a combination of the first two) have been assumed. For example, both Ayer and Schuh (1972) and Akino and Hayami (1975) assumed a pivotal supply shift, both Griliches (1958) and Peterson (1967) assumed a proportional supply shift, while the majority of EDM studies assumed parallel demand or supply shifts. Many authors have since pointed out the importance of the assumed types of shifts to the measures of welfare changes. Duncan and Tisdell (1971) examined the impact on producer surplus of different types of supply shifts assuming polar elasticities of demand. Lindner and Jarrett (1978, 1980) further pointed out that the assumption made about the nature of the supply shift has a significant impact on the total research benefits. Chung and Kaiser (1999) showed that the relative returns of research versus promotion is different from that in Wohlgenant (1993) if a pivotal shift rather than a parallel shift is assumed.

[3] Detailed discussions on how to estimate this amount for a supply shift based on technical information from research can be found in Alston, Norton and Pardey (1995, 5.3).

Rose (1980) argued that, for most innovations, the information available is not enough to determine the amount of supply shift beyond a single point. Wohlgenant (1997) has also shown that when not all firms are marginal and identical in how research affects their costs, the nature of an industry supply shift may be different from those of individual firms. Rose suggested that "The only realistic strategy is to assume that the supply shift is parallel." This argument has been accepted in many later EDM studies and a research-induced parallel supply shift has been assumed by most (for example, Alston, Norton and Pardey 1995, p64). Similarly, changes in demand or willingness to pay at other price and quantity levels of a demand curve are also difficult to know. Most studies on promotion have also used a parallel demand shift (for example, Piggott, Piggott and Wright 1995). It seems to be an unfortunate fact that little is known about the nature of exogenous shifts and assumption about it is unavoidable. However, it is important to be aware of the possible consequences from alternative assumptions.

The results derived in Zhao, Mullen and Griffith (1997) and Chapter 3 is also relevant to the use of a parallel shift. It is proven in Chapter 3 that, while the functional form of the demand and supply curves is another assumption to be made in applications, it will not affect the welfare measures significantly for a small research-induced shift *if a parallel shift is assumed.* However, in the case of a proportional shift, significant error is possible when the actual functional forms of demand and supply are unknown.

Parallel shifts resulting from various types of research and promotion are assumed in the model in this thesis.

2.5.2 Functional Form of Demand and Supply Curves

Another issue in the EDM literature is the functional form of demand and supply curves. It is often difficult to either theoretically determine or econometrically estimate the shape of supply or demand curves. In early studies, explicit linear (e.g. Freebairn, Davis and Edwards 1982) or constant elasticity (e.g. Ayer and Schuh 1972; Scobie and Posada 1978) functions have been assumed. One problem with a global linear supply curve is that an inelastic supply at the equilibrium point implies a negative price intercept, which does not make economic sense. For this reason, many have criticised the use of linear supply functions (Kim, Schaible, Hamilton and Barney 1987; Godyn, Brennan and Johnston 1987; and Voon and Edwards 1991c). A kink in the supply curve was suggested (Rose 1980; and Herford and Schmitz 1977) to overcome the problem. The restriction that a constant elasticity supply has to pass the origin, which makes a parallel shift impossible, also led to a modified of constant elasticity function with positive intercept (Lynam and Jones (1984); and Pachico, Lynam and Jones 1987).

Rather than explicitly specifying the functional form, many later studies have followed Muth (1964) in assuming a general functional form and converting the model to linear-in-relative-change form by differentiating the original model. This specification has been followed by most recent studies (for example, Alston and Scobie (1983); Holloway (1989)). It has been understood by most that linear approximation is implicitly required in such mathematical manipulation.

Alston and Wohlgenant (1990) showed empirically that when a parallel shift is assumed, the linear function provides a good approximation if the true functional form is constant elasticity. They claimed from this evidence that a linear function is a good approximation for any true functional form of demand and supply, and therefore specific assumptions on the functional forms is unnecessary in the use of EDM.

Despite the effort by Alston and Wohlgenant (1990), the implicit assumptions and the sizes of errors involved in using the Muth (1964) general function approach have not been fully appreciated. Some had to use of an elastic supply due to the apparent contradiction in using supply elasticity of less than one and the negative intercept implied by a global linear supply curve (Kim, et al. 1987; Godyn, Brennan and Johnston 1987; Voon and Edwards 1991c; Piggott 1992; Hill, Piggott and Griffith 1996). In addition there is concern about the size and determinants of errors when the true demand and supply curves are not linear or when the exogenous supply shift is not parallel. These questions were examined by Zhao, Mullen and Griffith (1997) and are discussed in Chapter 3.

In summary, it is shown in Chapter 3 that

(a) When there is a *parallel* exogenous shift, the EDM estimates are exactly correct if demand and supply curves are *locally* linear and if a relative change is defined as $E(.)=\Delta(.)/(.)$; and when these conditions are not met in empirical applications, the errors are small for a small parallel initial shift.

(b) When there is a *proportional* exogenous shift, the EDM estimates are exactly correct if demand and supply curves are *locally* log-linear (constant elasticity) and if relative change is defined as $E(.)=\Delta\ln(.)$; and when the true functional forms are not log-linear, the EDM estimates of price and quantity changes are still accurate for a small exogenous shift, but the welfare measures can involve significant errors.

The exact expressions and upper bounds of the EDM approximation errors for these two cases are also derived in Chapter 3 to identify the determinants and directions of the errors.

Since only local rather than global linearity is required for the case of a parallel shift, the assumption of global linearity and the restriction that supply has to be elastic in order to have a positive intercept becomes unnecessary.

2.5.3 Conceptual and Measurement Issues for Economic Surplus

Consumer surplus is the triangle-like area below the demand curve and above the price line, and producer surplus is the triangle-like area above the supply curve and below the price line. They have been used as measures of producer and consumer welfare, and changes in these areas represent changes in welfare. The concept of economic surplus dates back to the 19th and early 20th centuries (Ricardo 1829, Dupuit 1844 and Marshall 1930). It is "the most controversial of widely used economic concepts" (Hausman 1981) and "probably no single concept in the annals of economic theory has aroused so many emphatic expressions of opinion" (Pfouts 1953). While Hicks (1940-41) claimed that 'It is the foundation of an important branch of Economics", Little (1957, p.180) described it as a "theoretical toy" and Samuelson (1947, p.194) called it a "worse than useless" concept (because it confuses). There has been a vast literature about the exact measure of welfare and the empirical approximation of it. As McKenzie and Pearce (1982) put it, "the debate, ..., currently generates some ten to fifteen learned papers each year to add to a stock of literature already much too big for any single individual to read and understand in full". Thus, no attempt is made here to try to cover this literature extensively. Only the major conclusions emerging from the debate that are most relevant to this application are presented.

While the early debate centred mostly on the theoretical refinement of the concept (see, for example, a review by Currie, Murphy and Schmitz (1971) and the references cited therein), substantial agreement has been reached on the definition of the correct quantity to be measured; that is, the amounts correspond to Hicks' (1946) money metric of compensating variation (CV) and equivalent variation (EV). CV is defined as the amount that a consumer would be willing to pay or would need to be paid to be just as well off (i.e. to keep the pre-change utility level) after the price change as she was before the change, and EV is the similar 'willingness to pay' measure but bases the comparison on the post-price-change utility level.

Some recent debate has focused more on the empirical measurement of this quantity and, in particular, the relationship between the observable consumer surplus area, measured off the Marshallian demand curve, and the unobservable CV and EV measures corresponding to the area off the Hicksian demand curve. Marshall (1961, 9th ed.) showed that a sufficient condition for the Marshallian economic surplus area to be equal to the Hicksian compensating variation is to have constant marginal utility of income. In a well-known paper, Willig (1976) derived bounds for the percentage errors between the Marshallian measure and the correct Hicksian measures. He showed that these bounds, which depend on the income elasticity of demand and the proportion of the consumer's income spent on the good, will be very small, and certainly will be smaller than the errors involved in estimating the demand curve. Therefore he suggested that the apologetic caveat frequently employed by applied economists about the use of consumer surplus was unnecessary.

On the other hand, Hausman (1981) showed how "easily" the exact Hicksian welfare measures could be derived given a Marshallian demand curve, and argued that there was no reason not to calculate the 'exact' Hicksian measures. He also pointed out that in cases when the proportion of total income is large and when the interest is on the excess of compensating variation over tax revenue (i.e. the triangular area of 'deadweight loss' rather than the complete trapezoid area), the errors in using Marshallian measures could be significant. However, Alston and Larson (1993), drawing on some recent literature in environmental economics (e.g. Kling 1988, 1991, 1992), pointed out that, when correcting for the income effect as suggested by Hausman (1981), another source of error is added through the uncertainty in the income elasticity of demand. They suggested that the trade-off of precision for unbiasedness may not be worthwhile. This, together with Willig's (1976) results, suggest that since there are so many other sources of errors in empirical measures of the consumer surplus, ignoring the income effect may be unimportant.

McKenzie and Pearce (1982) argued that the exact quantity of the Hicksian measure *is* observable in the sense that it can be represented exactly, as in their Equation (6) (p675), through a Taylor expansion as a "linear fixed weight combination of products of prices, the fixed weights being constructed from first- and higher-order elasticities of demand and individual income changes, with elasticities evaluated at a base point" (p669). Thus the Hicksian welfare can be measured as precisely as we like by truncating the Taylor expression, given the information on the observable demand function. However, as stated in Alston, Norton and Pardey (1995), from an empirical point of view, econometrics can at most provide a local approximation of the demand function at a point, and it is difficult to know the slopes or elasticities at all points of a demand curve, let alone the exact functional form or its higher order derivatives. So in practice we can only use a linear (first-order approximation) demand curve, for example, and the errors involved in the approximation of the demand curve may well overshadow the error in ignoring the income effect, or assuming a constant marginal utility of income.

The measure of consumer surplus becomes more complicated in multi-product situations. As pointed out by Slesnick (1998), the measure of consumer surplus may become path dependent, or some restrictive assumptions have to be made. LaFrance (1991) extended Hausman's (1981) work on single demand equation to a demand system involving several products. He pointed out that using the common *ad hoc* demand models (e.g. linear models) that do not satisfy the integrability restrictions may result in significant errors. However, consistent with the case of single demand equation (Willig 1976), his empirical results showed that, when using the *ad hoc* linear models, the errors are significant in the estimates of the triangle deadweight loss, but not significant in the estimation of the trapezoid area of economic surplus change (Hausman 1981).

The issue of economic surplus measures in multi-market models is examined in Chapter 6 in the context of the current study. As argued in Chapter 6, most economic surplus measures in the present model only involve a single price change in a utility function. In these cases, measures of economic surplus changes are straightforward and they are good measures for welfare changes (Willig 1976 and Hausman 1981) . The only case that involves more than one price change in a utility function is the case of the domestic market, where prices of two beef products are both changed in the consumers' utility function. However, as the interest in this study is the trapezoid area of consumer surplus change rather than the triangular deadweight loss, and as the shift from the equilibrium is small, based on LaFrance's (1991) results and the derivation in Chapter 6, it is argued in Chapter 6 that changes in economic surplus are expected to be a close approximation to the exact CV or EV measures.

Symmetric to consumer surplus is the concept of producer surplus, also first introduced by Marshall (1930). Much of the above debate is also relevant to producer surplus. For example, exact measures of producer surplus are defined in the sense of CV and EV (Mishan 1959), and when ordinary supply curves are used to measure the producer surplus, it must be viewed as an approximation of the exact measures of CV or EV (Just, Hueth and Schmitz 1982). The debate on producer surplus has been mostly focused on what exactly the area above the ordinary supply curve measures and the relationship of producer surplus to welfare measures such as economic rents and profits. For example, Mishan (1959) pointed out that while ignoring the income effect may not add significant errors on the demand side (Willig 1976), the income effect on the supply side may be too big to ignore. Martin and Alston (1997) provided empirical results on the comparison between the conventional producer surplus change measured from the ordinary supply curve and changes in producer profits calculated from an explicitly specified profit function. They showed that, for common types of technical changes, conventional producer surplus may underestimate changes in profits, and the difference in many cases is equal to avoidable fixed costs. See more discussion on producer surplus in Mishan (1968, 1969); Shepherd (1970); Wessel (1969); Currie, Murphy and Schmitz (1971); Rose (1980) and Lindner and Jarrett (1980).

Regardless of all the controversy, the use of economic surplus in research evaluations and policy analyses has flourished among applied economists, especially agricultural economists, in recent years. Just, Hueth and Schmitz (1985) presented a thorough review of economic welfare theory and illustrated how this theory can be used to obtain policy information in various areas. Their work enhanced the application of economic surplus measures. As pointed out by Alston, Norton and Pardey (1995) and others (for example, Currie, Murphy and Schmitz 1971), it is still the best available tool for analysing technical changes and market distortions. In this thesis, Willig's (1976) and Alston and Larson's (1993) arguments are accepted and economic surplus areas measured off Marshallian curves are used as measures of research and promotion benefits.

A more theoretically consistent approach of measuring welfare effects in multi-product situations can be achieved through an exact approach as used by Martin and Alston (1994) and Alston, Chalfant and Piggott (1999). It involves the explicit specification of profit and expenditure functions and the inclusion of research and promotion variables in these functions. The changes in the profit and expenditure functions due to technical changes and promotion give the desirable compensating or equivalent variation measures. However, the possibility of using this approach to study the sectoral interaction within the beef industry, among both vertically and horizontally disaggregated sectors as in this model, and for estimating the welfare distributions among these individual groups, is questionable. Also, data availability also restricts the use of the approach in this study.

2.5.4 General Equilibrium Effect and Multi-market Economic Surplus Measures

The economic surplus approach is traditionally termed partial equilibrium analysis because, in a basic single-market model, prices in all other markets are assumed unaffected. This is unrealistic because, for example, when a new technology is adopted in cattle feedlots, not only other sectors within the beef industry, but also other meat industries will be affected. In fact, the whole economy may be affected as a result. In contrast to the extreme partial approach of a single-market model, a general equilibrium model of the whole economy can be considered where all other prices in the economy are allowed to change. Often, in empirical applications, a one-market model may be too unrealistic that important relationships are ignored, while a general equilibrium model of the whole economy maybe too expensive in terms of available time and resources. A model somewhere in between the two extreme cases, that includes a subset of markets from the whole economy and is reasonably realistic yet tractable, is often used. The vertical and horizontal extensions to the one-market model reviewed in 2.4 are efforts towards accounting for tractable general equilibrium effects.

One purpose of disaggregating the model vertically or horizontally is to obtain the total welfare effect and its distribution to individual industry groups. As shown by Just, Hueth and Schmitz (1982, p469), there are two ways to calculate the general equilibrium welfare effects. One way is to estimate the *general* equilibrium demand and supply in the market where the exogenous change occurs. The total welfare changes measured off these general equilibrium curves in that market alone capture the total welfare effect to the whole economy. However the distribution of the total welfare changes can not be obtained from this approach. An alternative approach that can provide the distributional effect of welfare changes is to measure the partial welfare effects off the partial equilibrium (or conditional) curves in all markets and add them up. However, the partial demand and supply curves in all markets involved have to be estimated in such a way that the sum of the implied partial effects is indeed the implied general equilibrium effects; that is, the sum of the partial welfare measures off the ordinary curves over all markets is the same as the general equilibrium welfare measure off the general equilibrium curves in any single market. This means that all market elasticities should be estimated consistently from a demand and supply system that relates to relevant decision making problems and satisfies certain theoretical relationships. This requirement is often termed the integrability conditions (Varian

1992; LaFrance 1991; Alston, Norton and Pardey 1995, p232). For example, if all relationships are estimated independently, the welfare measures may not be unique but depend on which market the total welfare is measured from and whether it is added up from the partial welfare effects of individual markets.

In this study, integrability among sectors within the beef industry is imposed at the initial equilibrium points (Section 4.7, Chapter 4). As only small shifts from the initial equilibrium points are considered, and based on the empirical results of LaFrance (1991), the errors resulting from not satisfying integrability conditions *globally* are expected to be small.

2.5.5 Comparative Statics and Dynamics of Displacement

Equilibrium displacement modelling in essence is a comparative static analysis in which two snapshot situations are compared – before and after the adoption of technology for example. Typically, gross annual benefits are estimated assuming that the technology has been 100% adopted, all potential cost reduction has been realised, and demand and supply have fully adjusted to reach a new equilibrium. In reality, there are usually lags between investing in a research project and generating new technology, and between the release of technology and its adoption. For example, Davis, Oram and Ryan (1987) surveyed some studies of the lag between the start of a research project and the availability of new technology and used a research and development lag of 8 years for their study on crops. It is often believed that this lag may be even longer in livestock industries (Scobie and Eveleens 1987; Scobie, Mullen and Alston 1991). In addition, adoption is a process over a long period before the technology becomes obsolete and abandoned. Research benefits therefore are a stream of benefit flows over a long period. Pardey and Craig (1989) estimated that it takes at least 30 years for the effects of research on aggregate U.S. agricultural productivity to disappear. This of course may vary according to the type of research. On the other hand, research costs are also incurred over a period. Other than the research investment at the initial period, maintenance research is often needed to compensate for the depreciation of technology. Evidence in the U.S. showed that maintenance research represents about one-third of production-related agricultural research (Alston, Norton and Pardey 1995, p32).

A complete evaluation of a particular research project should therefore take account of the dynamics of benefits and costs. In practice, a time frame can be decided for the research and development lag and for the adoption process. A logistic curve (following Griliches 1957), among other functional forms (Alston, Norton and Pardey 1995, p30), has often been used to represent the change in adoption rate over time. Alston, Norton and Pardey (1995, Figure 2.2-3, p30) illustrated a hypothetical adoption curve and the corresponding benefit and cost annual flows. These benefit and cost flows can also be summarised by net present value (NPV) or internal rate of return (IRR) for comparison among research projects.

A shortcut treatment is to run the model once with the maximum potential cost reduction to get the maximum gross annual benefits, and then, using an assumed time frame of research lag, adoption process and technology depreciation, to discount the annual benefits for each year. Together with the assumed cost flows over the whole period, NPV and IRR can be calculated. Examples of this approach are those of Scobie, Mullen and Alston (1991), and Scobie and Jacobsen (1992). Because the research benefits are quadratic functions of the amount of shift, the errors involved by using the shortcut will not be significant for small shifts typically used in research evaluations. However, if parameters other than the supply shift are also allowed to vary for different periods, the flows of benefits could be very different from those obtained by a simple discount of the same maximum annual benefits by the adoption and depreciation rates.

Another aspect that further complicates the dynamics of the problem is the time taken for the producers to completely adjust their supply to the new technology. Usually, it takes more than a year for the industry to fully respond to an exogenous change before reaching a new equilibrium. Just, Hueth and Schmitz (1982) analysed the welfare implications for the years after the new technology is adopted and before the new equilibrium is reached. They showed that "the correct measure of the total producer welfare impact over the two time periods is not the sum of all the short-run producer surplus ... but, rather, the sum of producer surpluses of variable lengths of run (as viewed from the initial point in time) over the affected production runs" (p65), and thus "In general, the change in producer welfare is determined by calculating the change in producer surplus corresponding to the one-period supply curve for the first period, the two-period supply curve for the second period, the three-period supply curve for the third period, and so on" (p66). This is a complicated area that has not been dealt with satisfactorily in empirical studies. Mullen, Wohlgenant and Farris (1988), Lemieux and Wohlgenant (1989), and Mullen, Alston and Wohlgenant (1989) have made attempts in this direction by assuming market elasticity values of various time runs to show the relative effects on welfare measures. Finer treatments of the displacement process that have followed Just, Hueth and Schmitz (1982) have not been done in research evaluation exercises.

Based on the length-of-run analysis by Just, Hueth and Schmitz (1982, p65-66), if the length of time needed for the industry adjustment to new technology can be decided, and the elasticity values corresponding to the same length of run are used in a conventional non-dynamic EDM, the estimated benefit will represent *the annual return for the last time period of the equilibrium adjustment and onwards over the whole period of benefit flow.* Presumably, the annual benefits would be smaller than the estimate for years during the equilibrium adjustment period. Thus, when resources are limited in empirical studies, non-dynamic estimates can still give a useful indication of benefits if care is taken in choosing the appropriate elasticities and interpreting the results.

In this study, the dynamic approach is not pursued. Market parameters corresponding to a medium run time frame are used, assuming that all considered research and promotion investments reach full equilibrium adjustment during a medium run period. Thus, the estimated benefits correspond to annual returns after the first few years of initial adjustment.

2.5.6 Sensitivity Analysis

In empirical applications of EDM and surplus estimation, almost all data required involve uncertainty to some extent. To calculate the changes in economic surplus resulting from a new technology or promotion, initial price and quantity levels before the exogenous change, the amount of exogenous supply or demand shift, and a set of market-related parameters such as demand and supply elasticities are required. The estimated research or promotion returns and distributions could be significantly different using different values of these parameters.

Uncertainty is involved in the base price and quantity levels that are supposed to represent the "without"-technology or "without"-promotion scenario (Alston, Norton and Pardey 1995, p316). Risks are also involved in the success of research and in the industry's response to the new technology. Errors are thus possible in eliciting the research-related parameters that give the amount of supply shifts and level of adoption over the whole time period. A similar situation exists for assessing a promotional campaign.

However, most of the concerns in the EDM applications have been related to the robustness of the estimated surplus changes to uncertainty in the market elasticities. In most studies, a value is chosen for each of these parameters base on published econometric estimates, economic theory and the modeller's subjective judgement, and a point estimate of the surplus change is calculated. A common approach to uncertainty about parameter values has been to undertake traditional sensitivity analysis (Piggott 1992; Alston, Norton and Pardey 1995, p369). However, when a model involves more than a few uncertain parameters, an extensive nonstochastic sensitivity analysis can become frustrating or impossible. Facing a table of some possible parameter values and the corresponding welfare changes, it is difficult to draw a conclusion about the most likely values for the benefits. Additionally, choosing a few discrete values for each parameter and arbitrarily choosing the combination of values among different parameters could misrepresent the complete picture of the relationship between the surplus measures and the parameters and thus could be misleading.

An alternative but more feasible and rigorous method for sensitivity analysis in this context is to treat the welfare changes as stochastic measures or random variables, reflecting the uncertainty in the market parameters. As proposed in Zhao, Griffiths, Griffith and Mullen (1999), uncertainty about the parameters can be represented through subjective probability distributions for the parameters. Any restrictions or theoretically required correlations among parameters can also be imposed through the distributions. The implied probability distributions for the welfare changes can be obtained via simulation. More importantly, from these distributions, various probabilities can be calculated that represent the levels of confidence about the estimated benefits and the resulting policy recommendations. In particular, the probability of a policy variable exceeding a break-even point, which would result in a different policy recommendation, can be calculated.

Studies concerning the stochastic approach are Tulpule, *et al.* (1992); Scobie and Jacobsen (1992); Davis and Espinoza (1998); Zhao *et al.* (1999) and Griffiths and Zhao (2000). Scobie and Jacobsen (1992) used a portfolio approach to examine the research priorities for the Australian Wool Research Council. They used triangular distributions to represent the uncertainty in various research programs in the context of risk analysis following Sprow (1967). Tulpule, *et al.* (1992) also used triangular distributions to represent the uncertainty in market elasticities in their model of textile industry. Davis and Espinoza (1998) promoted the stochastic approach to sensitivity analysis in EDM by looking at the sensitivity of changes in the farm-retail price ratio in the Gardner (1976) model to uncertainty in market parameters. They used more complicated probability distributions and suggested the use of "confidence interval" and "hypothesis testing" as ways of summarising the simulation results. Griffiths and Zhao (2000) commented on some conceptual issues in Davis and Espinoza paper (1998), and they also pointed out that the use of the Chebychev inequality led to unnecessary imprecision. They illustrated a precise way of calculating probabilities and probability intervals, using the simulation data. Using a model by Mullen, Alston and Wohlgenant (1989), Zhao *et al.* (1999) presented a formalised approach for stochastic sensitivity analysis in EDMs. The work by Zhao *et al.* (1999) stemmed from this thesis and was an application of the approach with a model of smaller scale than the one in this thesis. In addition to placing the approach of stochastic sensitivity analysis into a more formal framework, other contributions in Zhao *et al.* (1999) include the use of hierarchical distributions to accommodate diverse views on possible values of a parameter and definition of a mean sensitivity elasticity to represent the sensitivity of model results to individual parameters. These sensitivity elasticities are useful in identifying the parameters to which the results are most sensitive so that more effort can be focused in the estimation of these important parameters.

In Chapter 8, the proposed approach in Zhao *et al.* (1999) is applied to the more disaggregated model in this study. Some statistical measures are also defined in Chapter 8 in an effort to characterise the relative sensitivity of results to individual parameters.

2.6 Summary

In this chapter, alternative modelling approaches for evaluating returns from research-induced technology and promotion are reviewed, and the choice of an equilibrium displacement modelling (EDM) framework for this study is justified. The chapter reviews the literature on EDM within this context. A basic single-market model is presented to illustrate the approach both graphically and algebraically. Extensions in model structure and areas of applications are then reviewed. Horizontally, the EDM can be used to model multiple market locations of a homogenous product or multiple products. Vertically, the model can be disaggregated into multiple stages of production and marketing to identify returns to individual industry sectors. Finally, some assumptions and methodological issues in the EDM applications are discussed. Controversy around these issues in the literature is examined, and the assumptions made or approaches taken in this study in relation to these issues are justified. Some of these issues will be further examined in later chapters. For example the results proven in Chapter 3 will help understanding the relationship between assumptions about the nature of exogenous shifts and functional forms for demand and supply curves and their implications for the EDM results. Welfare measures in multi-market models are examined in Chapter 6 in the context of this study. A stochastic approach to sensitivity analysis in EDM models is proposed in Chapter 8.