

# **An Equilibrium Displacement Model of the Australian Beef Industry**

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## Acronyms and Abbreviations Used in the Report

ABARE	Australian Bureau of Agricultural and Resource Economics
AFFA	Agriculture, Fisheries and Forestry Australia
AMLC	Australian Meat and Live-Stock Corporation
APMAA	Aggregate Programming Model of Australian Agriculture
CALM	Computer Aided Livestock Marketing
CS	Consumer surplus
EDM	Equilibrium displacement model
EMABA	Econometric Model of Australian Broadacre Agriculture
GE	General equilibrium
MLA	Meat and Livestock Australia
MRC	Meat Research Corporation
NLRS	National Livestock Reporting Service
ORANI	A computable general equilibrium model of the Australian economy
OTH	Over-the-hooks
PE	Partial equilibrium
PS	Producer surplus
R&D	Research and development
SHAZAM	An econometrics software program
TS	Total economic surplus
US	United States

# **An Equilibrium Displacement Model of the Australian Beef Industry**

## **Executive Summary**

Around \$100 million has been spent annually on R&D and promotion in the Australian red meat industries in recent years. The R&D investments are made throughout the production, processing and marketing chain in both the grass and grain finished sectors. Promotion investments are made in both export and domestic markets. Despite this large investment of industry and government funds there is great uncertainty about the returns from these investments. Not only is it unclear what the total industry returns are but it is even less clear how producers and the community benefit from the many alternative investment options. Hence, it is unclear how funds should be allocated between these alternatives.

Zhao (1999) addressed these issues in research for her PhD degree from the University of New England. An important component of this research was the development of an equilibrium displacement model of the Australian beef industry. The objective of this Report is to thoroughly document the model and the procedures followed in defining the price, quantity and market parameters (supply, demand and substitution elasticities) used in the model. The results of the base run are also reported.

Twelve investment scenarios were considered relating to 1% shifts in the relevant supply or demand curves due to new technologies in individual sectors and promotion in export or domestic markets. For each scenario, total returns in terms of economic surplus gains and the distribution of total returns among individual groups, namely, among cattle producers, feedlotters, processors, exporters, retailers and domestic and overseas consumers, were estimated. Producers and domestic consumers were shown to be the main beneficiaries in all scenarios. The results indicated that, in general, producers receive larger benefit shares from on-farm research than from off-farm research. They also receive significantly larger shares from export marketing research and promotion than from domestic marketing research and promotion. In general, while they should prefer research investments over domestic promotion, they gain as large or even larger shares from export promotion than from various research scenarios.

# 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 pigmeat 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 (US) 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 be used in the most efficient way to enhance industry competitiveness.

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, or less inputs are 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 improving efficiency in feedlots, abattoirs, or in the domestic or export marketing sectors.

Promotion includes activities to enhance the image of a product in the minds of potential buyers. It can take different forms, ranging from advertising to activities such as trade displays, conveyance of technical information and in-store displays. There has been controversy regarding how to represent the effects of promotion in the 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 or, equivalently, an increase in the quantity demanded at a given level of price. Promotion of Australian beef is carried out both domestically and in various overseas markets.

Research or promotion investment may be directed to particular sectors 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 will benefit, but there will also be impacts on cattle producers, feedlots and domestic and overseas consumers.

As the industry faces tougher market situations and governments tighten budgets, both producers and governments are concerned to see that R&D and promotion funds are allocated efficiently to ensure the highest returns. 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 -- which enables better decisions to be made about who should fund these investments.

Some relevant questions are: How should funds be allocated 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 feedlotting, processing and marketing? Who will benefit? Who should pay?

Primary producers contributed about 60% of the total MLA funds in 1998/99 (MLA 1998). From the cattle producers' point of view, since they are the ones who pay the bulk of the levies, there is an issue of accountability. Relevant questions are: What share of the benefits do they receive? Is the share the same from alternative investments at different sectors? How does the share of the benefits compare to their contribution to the levies? On the other hand, from the viewpoint of the government funding bodies, taxpayers' benefits need to be considered.

## 1.2 Objectives of the Study

The broad objective of the study is to develop an economic framework of the Australian cattle and beef industry that characterises 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 of the industry and generic promotion programs in different markets (for example, research versus promotion and on-farm research versus off-farm research); and
- to estimate the distribution of the total return from an R&D or promotion investment among different industry participants such as farmers, feedlotters, processors, exporters, retailers and domestic and overseas consumers;

A secondary aim is to provide a consistent and disaggregated economic framework for the beef industry so that other types of changes, such as a tax or a price policy, an export quota, or a particular new technology, can be analysed.

In particular, the specific objective of the study is to compare the impacts of 1% reductions of per unit costs resulting from research-induced technologies in various sectors and 1% increases in consumers' *willingness-to-pay* resulting from generic promotion in different markets. The question of the costs of achieving the 1% changes is not addressed in this study, but it is a question which must ultimately be answered in order to ensure an effective allocation of funds. However, as pointed out later in the study, comparisons among alternative investment scenarios of the percentage *shares* of the total benefits to individual groups are always meaningful even without the information on investment efficiency.

In addition, although the model 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.

Evaluation of a particular R&D or advertising project involves a comprehensive process including eliciting the resulting amount of the supply or demand shift in a particular market.

### **1.3 Method of the Study**

The method used in this study involves the use of a partial equilibrium framework, which is sometimes referred to as Equilibrium Displacement Modelling (EDM) (Piggott 1992). EDM has been widely used in research and promotion evaluations in recent years. With this approach, 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 from an initial equilibrium. Changes in prices and quantities in all markets that arise when the system equilibrium is displaced due to these exogenous shifts are estimated as are the consequent changes in producer and consumer surplus reflecting 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.

#### ***1.3.1 Outline of the Report***

The next section begins with a description of the key sectors of the Australian beef industry that are to be captured in this model. Most of this section is devoted to describing the EDM model of the Australian beef industry. The model involves 58 endogenous variables and 12 exogenous shifters, representing 12 research or promotion investment scenarios. The issue of integrability is also discussed in Section 2.

Detailed information about price and quantity at equilibrium for all markets is presented in Section 3 along with a review of the market parameters that drive the model. Integrability constraints are imposed on the specified market parameters.

Economic surplus measures for all industry groups and all research and promotion scenarios are explained in Section 4. The issue of measuring economic surplus changes in markets where multiple sources of equilibrium feedback exist is examined. It is pointed out that care needs to be taken in these situations in order to measure the economic surplus changes correctly.

The results on total economic surplus change and its distribution among industry groups from the twelve research and promotion investment scenarios are presented in Section 5. 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. These are important items of information for decision makers who have to allocate investments between these funding areas.

Conclusions, limitations and further areas for research are discussed in Section 6.

This Report is largely drawn from Zhao (1999). The focus has been on documenting the model, making it accessible to others with an interest in R&D and promotion in the beef industry and reporting some of the key findings.

In the course of her research, Zhao addressed a number of common assumptions made when applying the EDM framework. First, she assessed the conditions under which alternative assumptions about functional forms of demand and supply curves and types of research or promotion induced shifts give EDM results that are exactly correct. Errors in both the estimated price and quantity changes and welfare measures, when these assumptions are not met, were examined by deriving the error expressions for a single market model. The results suggested 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. This research is reported in Zhao (1999) and Zhao, Mullen and Griffith (1997).

A second assumption evaluated was that of a competitive market structure. The method developed by Holloway (1991) was used to examine the hypothesis that the Australian beef industry could be assumed to be not significantly different from a perfectly competitive industry. The results showed that the domestic market could be regarded as being competitive but the same could not be said of the export market. However the noncompetitive attributes of the export market were believed to be due to the United States beef import quota and the Japanese beef import quota which were in place over much of the historical period from which the test data were derived. Since both quotas are no longer imposed, it was assumed that the current export market for Australian beef could also be regarded as being competitive. This work was reported in Zhao, Griffith and Mullen (1998).

A third key issue addressed by Zhao was the sensitivity of the results to the market-related parameters used in the model. 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 new stochastic approach to sensitivity analysis in EDM was developed. Subjective probability distributions for all parameters were specified representing the uncertainty in the values of these parameters. Probability distributions of the estimated welfare measures were simulated using Monte Carlo techniques. Response surfaces that represent the relationship between the estimated benefits and all parameters were estimated. A sensitivity elasticity was also defined and calculated, based on the response surface, to represent the responsiveness of each welfare measure to each individual parameter. This information is very informative for locating the important parameters that most affect how different sectors of the industry benefit from research and promotion. Confidence in some policy-related conclusions was expressed with probabilities. This work is reported in Zhao (1999), Zhao, Griffiths, Griffith and Mullen (2000) and Griffiths and Zhao (2000).

## 2 An EDM Model of the Australian Beef Industry

### 2.1 Introduction

In this Section, the structure of the Australian beef industry is reviewed and an EDM for the industry is specified.

The horizontal and vertical structure of the beef industry is examined next. The industry is defined as producing grain-finished or grass-finished beef for the export or domestic markets. Vertically, beef production and marketing is disaggregated into breeding, backgrounding, grass/grain finishing, processing, marketing and final consumption sectors.

In 2.3, production, revenue, cost and market clearing functions are specified for all industry sectors in general functional form. From these, the demand and supply relationships for all sectors are derived in 2.4. These are the functions that are the basis of the EDM. Integrability conditions underlying the model specification are examined in 2.5. Constraints among market parameters implied by these integrability conditions are derived. The final model, with integrability conditions imposed at the initial equilibrium, is presented in 2.6.

### 2.2 Industry Review and Model Structure

#### 2.2.1 *Horizontal Market Segments and Product Specifications*

Based on information from various sources (ABARE 1998, MRC 1995, AFFA 1998), the size of the various market segments of the Australian beef industry and the associated product specifications for 1992-1997 are summarised in Table 2.1. The method of calculating these market shares is detailed in Section 3. As stated there, the model simulates the average equilibrium situation over the period of 1992-1997 to abstract from any climatic impacts (such as drought in 1994) or abnormal events (such as 'mad cow' disease in 1996 and the Asian crisis in 1998) that occurred in an individual year.

#### **Export Market**

As shown in Table 2.1, during 1992-97, 62% of Australian-produced beef was sold overseas. On average, 14% of exported beef was grain finished and 86% was grass finished. The dominant destination of Australian grainfed beef was Japan, which accounted for over 90% of export grain-finished beef. The second significant market was South Korea, accounting for the majority of the rest of the export grainfed segment. The Japanese grainfed market primarily consisted of four product categories (B3, B2, B1 and Grainfed Yearling). Each has a different specification in terms of days on feed, age and slaughtering weight. The percentage break-downs among the four components was based on information from the Japanese middle market, into which about 70% of Australian exports to Japan was sent (MRC 1995). There are two major product specifications for the South Korean market.

The two biggest markets for Australian grassfed beef are the US and Japan. Australian beef to the US is predominately lower quality manufacturing beef, while grassfed beef to Japan is mostly yearling grassfed and high quality grassfed (MRC 1995, p47).

### **Domestic Market**

Competition from chicken and pork and an increasing requirement for consistency in meat quality by the major supermarket chains have resulted in an increase in the amount of grainfed beef in the domestic market. In Table 2.1, the domestic grainfed segment is disaggregated into two categories: cattle that are fed in major commercial feedlots and cattle that are grain-supplemented on pasture or in small opportunistic feedlots (with capacity of less than 500 head). As data on grain-supplemented cattle and opportunistic feedlots are unavailable, cattle grain-supplemented outside the major feedlots are modelled as part of the grass-finishing sector. This treatment accommodates the study of grain-finishing technologies that are specific for cattle backgrounding and feedlots. According to information from an AMLC/ALFA feedlot survey (Toyne, ABARE, per. comm. 1998), the cattle turn-off from the surveyed major feedlots has almost doubled during 1992-1997.

Australian consumers have a preference for yearling beef. As can be seen from Table 2.1, there are two differences between the domestic grainfed yearling and the Japanese grainfed yearling. Firstly, heifers are acceptable in Australia. Secondly, the Australian slaughtering weight is slightly lower than that for the Japanese market for this category. Domestic grassfed are mostly yearlings, which are lighter and younger in comparison to export cattle.

#### ***2.2.2 Vertical Structure of Beef Production and Marketing***

Production of beef for consumers involves various stages that separate the industry into different sectors. A typical grassfed beef production system can be stylised as follows. The calves are bred and produced in the cattle breeding sector. They are weaned from cows at around 9 months to become weaners. Weaners are sold for restocking to the grass-finishing sector. They stay on pasture, and sometimes are supplemented with grain (especially during drought years), until they reach a certain age and weight. They are then sold as finished live cattle in the saleyard to go to abattoirs. They are slaughtered and processed in the abattoirs and then sold as beef carcasses to domestic retailers (major supermarket chains and butchers) and exporters. Domestic retailers cut and trim the carcasses into saleable retail beef cuts, and pack them as ready-to-sell packs on the shelf for final consumers. Similarly, exporters, although in reality they are often not separated physically from abattoirs, convert beef carcasses into the export cuts as required by overseas destinations.

A similar process applies to grainfed beef production in terms of the breeding, processing and marketing phases. In addition, grain finishing of cattle also involves backgrounding and feedlot-finishing. The backgrounding phase is critical to the achievement of age and weight requirements for feedlot entry, especially for certain Japanese grainfed categories. It is often done on pasture by cattle producers, sometimes contracted by large feedlots. The cattle are introduced to grain and additives in this phase. The backgrounded cattle then enter the feedlot for a strictly controlled nutritional program for fixed numbers of days, in order to reach the specifications of particular markets. In Table 2.2, the age and weight requirements for each stage of weaning, backgrounding, grain finishing and processing for the various grainfed

Table 2.1 Australian Beef Industry Disaggregation and Product Specifications

Market Segments			Product Specifications			
<b>Export (62%)</b>	<b>Grainfed (14%)</b>		Carcass Weight(kg)	Age (mths)	Sex	Days on Feed (days)
		JP B3 (18%)	380-420	24-28	steers	230-300
		JP B2 (37%)	340-380	24-28	steers	150
		Japan: JP B1 (34%) JP Grainfed Yearling (11%) (92%)	330-360	26-30	steers	100
		240-260	16-18	steers	100	
	K1	220-320	30-36	steers & heifers	100	
	Korea: Fullset (7%)	280-350	24-36	mainly steers	100	
	Others: Taiwan, EU, (1%) US, Canada, etc.					
	<b>Grassfed (86%)</b>	US (37%) Japan (28%) Korea (9%) Canada (7%) Taiwan (5%) Others (14%)	Mainly lower quality manufacturing beef for the US market and high quality fullset and yearlings for the Japanese market. Quality to other countries are mixed.			
<b>Domestic (38%)</b>	<b>Grainfed (18%)</b>	Commercial feedlot finished	Carcass weight(kg)	Age (mths)	Sex	Days on Feed (days)
		(18%)	200-260	16-20	steers & heifers	70
	<b>Grassfed (82%)</b>	Grain supplemented on pasture or fed in opportunistic feedlots	Mostly yearling beef.			

Sources: ABARE (1998), MRC (1995) and AFFA (1998)

Table 2.2 Grainfed Cattle Requirements at Different Phases

	<b>JP B3</b>	<b>JP B2</b>	<b>JP B1</b>	<b>JP Grainfed Yearling</b>	<b>Korean K1</b>	<b>Korean Fullsets</b>	<b>Domestic Grainfed</b>
<b>Abattoir</b> <b>Output:</b> Weight: Age: Saleable yield:	380-420 kg 24-28 mths 67-69%	360 kg 24-28 mths 69-70%	330-360 kg 26-30 mths 70% plus	240-260 kg 16-20 mths 70%	220-320 kg 24-36 mths 70% plus	280-350 kg 24-36 mths 70%	240-260 kg 16-20 mths 70% plus
<b>Feedlot</b> <b>Output:</b> Weight: Age: Days on feed:	680-720 kg 24-28 mths 230-300days	680 kg 24-28 mths 150 days	600-660 kg 26-30 mths 100 days	420-470 kg 18-20 mths 100 days	400-580 kg max 36 mths 100 days	500-650 kg 24-36 mths 100 days	420-450 kg 20 mths 70 days
<b>Back- Ground</b> <b>Output:</b> Weight: Age: Days on feed:	380-420 kg 16-18 mths 6-12 mths	400-500 kg 20-22 mths 10-12 mths	400-500 kg 22-26 mths 10-12 mths	290-350 kg 15-17 mths 10-12 mths	250-430 kg 24-32 mths 14-22 mths	330-470 kg 22-32 mths 12-22 mths	330-350 kg 16-18 mths 6-8 mths
<b>Cow- Calf Operator</b> <b>Output:</b> Weight: Age:	250-280 kg 9-10 mths	180-240 kg 7-10 mths	180-240 kg 7-10 mths	170-220 kg 7-10 mths	150-170 kg 7-10 mths	160-190 kg 7-10 mths	170-220 kg 7-10 mths

Source: MRC (1995)

Note: Liveweight through to feedlotting, carcase weight at the abattoir.

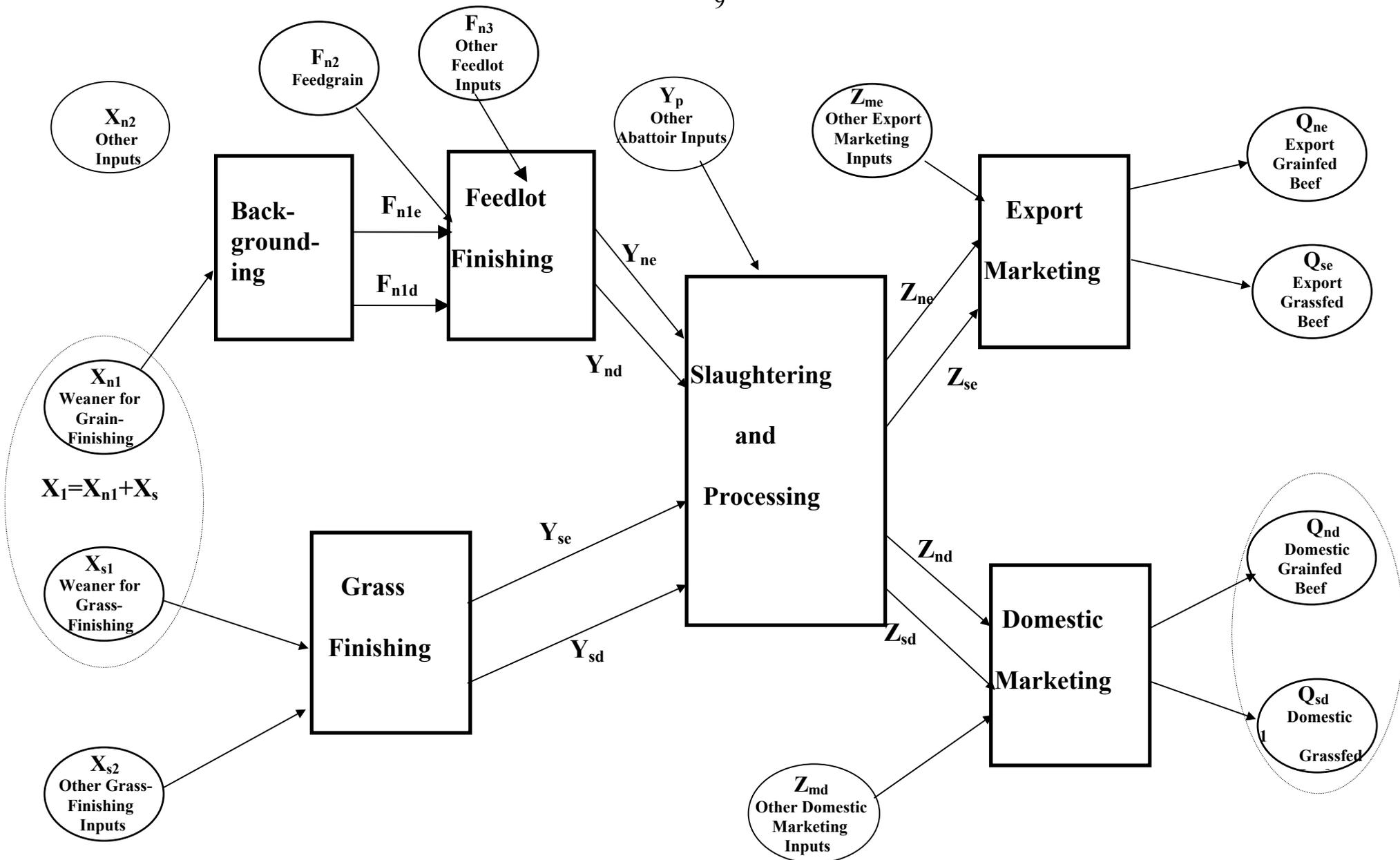


Figure 2.1 Model Structure

market segments, as reviewed by a MRC research report (MRC 1995), are reproduced. It provides an indication of the timing and requirements of various phases of grainfed cattle production.

### ***2.2.3 Structure of the Model***

As pointed out in Section 1, a model disaggregated along both vertical and horizontal directions is required in order to study the returns from new technologies and promotion campaigns that occur in various industry sectors and markets, as well as the distribution of benefits among different industry groups. Based on the above review of the industry structure, the structure of the model is specified in Figure 2.1, where each rectangle represents a production function, each arrowed straight line represents the market for a product, with the non-arrowed end being the supply of the product and the arrowed end being the demand for the product, and each oval represents a supply or demand schedule where an exogenous shift may occur.

Horizontally, the industry is modelled as producing four products along most parts of the vertical chain, based on whether it is grain- or grass-finished and whether it is for the domestic or export market. Inputs other than the cattle input and feedgrain (in feedlot sector) are combined as ‘other inputs’ in all sectors. As shown in Table 2.1, beef is not a homogenous product, and different market segments have different product specifications. The product specifications are controlled along most stages of the production chain and differentiated in prices. Note that the supply of weaners ( $X_7$ ) for all four product categories is assumed homogenous in quality. There are some differences in breeds making them more suitable for grain- or grass-finishing, however, there are no observable price differences at this level. Weaner prices fluctuate more with changes of weather or season than with destinations (Gaden, NSW Agriculture, per. comm. 1999).

Vertically, the industry is disaggregated into breeding, backgrounding-feedlot-finishing/grass finishing, processing, marketing and consumption. This enables separate analyses of various technologies in traditional farm production, feedlot nutrition, meat processing and meat marketing, as well as beef promotion.

## **2.3 Specification of Production Functions and Decision-Making Problems**

### ***2.3.1 Cost and Revenue Functions and Derived Demand and Supply Schedules for the Six Industry Sectors***

As can be seen from Figure 2.1, there are six industry sectors (in the six rectangles) whose production functions and decision-making problems can be specified completely within the model. All are characterised by multi-output technologies.

Assume that (1) all sectors in the model are profit maximizers; (2) all multi-output production functions are separable in inputs and outputs; and (3) all production functions are characterised by constant returns to scale.

Consider first the specification of a general multi-output technology represented by a twice-continuously differentiable product transformation function

$$(2.3.1) \quad F(x, y)=0$$

that uses  $k$  inputs  $x=(x_1, x_2, \dots, x_k)'$  to produce  $n$  outputs  $y=(y_1, y_2, \dots, y_n)'$ . The output separability assumption ensures that there exists a scalar output index  $g=g(y)$  such that Equation (2.3.1) can be written as<sup>1</sup> (Chambers 1988, p286)

$$(2.3.2) \quad g(y) = f(x).$$

The assumption of profit maximization implies that the industry's allocation problem can be considered in two parts. The first is cost minimization for a given level of the output vector. The cost function can be specified as

$$(2.3.3) \quad C(w, y) = \min \{w'x: y\}$$

where  $w=(w_1, w_2, \dots, w_k)'$  are input prices for  $x$ . When the technology is assumed to be output separable, the multi-output cost function can be simplified to a single-output cost function as (Chambers 1988)

$$(2.3.4) \quad C(w, y) = \min_x \{w'x: y\} = \min_x \{w'x: g=g(y)\} = \hat{C}(w, g)$$

where  $\hat{C}(w, g)$  is the cost function for single-output technology  $g=f(x)$ .

When constant returns to scale is also assumed, which implies in the case of output and input separable technology that  $f(\lambda x) = \lambda g$  and  $g(\lambda y) = \lambda f$  for any  $\lambda > 0$ , the cost function can be written as

$$(2.3.5) \quad \begin{aligned} \hat{C}(w, g) &= \min_x \{w'x: f(x)=g\} \\ &= \min_x \{w'x: f(x/g)=1\} \quad (\text{use } \lambda=1/g) \\ &= g \min_x \{w'(x/g): f(x/g)=1\} = g \hat{C}(w, 1) = g \hat{c}(w) \end{aligned}$$

where  $\hat{c}(w)$  is the unit cost function associated with the minimum cost for producing one unit of  $g$ .

Assume  $\hat{c}(w)$  is differentiable in  $w$ . Applying Shephard's lemma (Chambers, 1988, p262) to the above cost function gives the output-constrained input demand functions

$$(2.3.6) \quad x_i = \frac{\partial}{\partial w_i} \hat{C}(w, g) = g \hat{c}'_i(w) \quad (i = 1, 2, \dots, k)$$

where  $\hat{c}'_i(w)$  ( $i=1, 2, \dots, k$ ) are partial derivatives of the unit cost function  $\hat{c}(w)$ .

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<sup>1</sup> In this instance, the assumption of input separability, that ensures the existence of an input index  $f(x)$  such that  $f(x)=g(y)$ , is equivalent to the assumption of output separability.

The second part of the profit maximization is to maximize revenue for a given input mix; that is, the revenue function can be written as

$$(2.3.7) \quad R(p, x) = \max_y \{p'y: x\}$$

where  $p=(p_1, p_2, \dots, p_n)'$  are output prices. Similarly, the input separability and constant returns to scale assumptions imply that

$$(2.3.8) \quad \begin{aligned} R(p, x) &= \max_y \{p'y: x\} = \max_y \{p'y: f=f(x)\} \\ &= \hat{R}(p, f) = \max_y \{p'y: g(y)=f\} = f \max_y \{p'(y/f): g(y/f)=1\} \\ &= f \hat{R}(p, 1) = f \hat{r}(p) \end{aligned}$$

where  $\hat{R}(p, f)$  is the revenue function for single-input technology  $g(y)=f$  and  $\hat{r}(p)$  is the unit revenue function associated with maximum revenue from one unit of input index  $f$ . If  $\hat{r}(p)$  is differentiable in  $p$ , the input-constrained output supply functions can be derived using Samuelson-McFadden Lemma (Chambers, 1988, p264)

$$(2.3.9) \quad y_j = \frac{\partial R(p, x)}{\partial p_j} = f \hat{r}'_j(p) \quad (j = 1, 2, \dots, n)$$

where  $\hat{r}'_j(p)$  ( $j = 1, 2, \dots, n$ ) are partial derivatives of the unit revenue function  $\hat{r}(p)$ .

Based on these general results for any multi-output technology, and under the three assumptions made at the beginning of this section, the product transformation functions for the six industry sectors in the model can be written as

$$(2.3.10) \quad F_{n1}(F_{n1e}, F_{n1d}) = X_n(X_{n1}, X_{n2}) \quad \textit{backgrounding}$$

$$(2.3.11) \quad Y_n(Y_{ne}, Y_{nd}) = F_n(F_{n1e}, F_{n1d}, F_{n2}, F_{n3}) \quad \textit{feedlot finishing}$$

$$(2.3.12) \quad Y_s(Y_{se}, Y_{sd}) = X_s(X_{s1}, X_{s2}) \quad \textit{grass-finishing}$$

$$(2.3.13) \quad Z(Z_{se}, Z_{sd}, Z_{ne}, Z_{nd}) = Y(Y_{se}, Y_{sd}, Y_{ne}, Y_{nd}, Y_p) \quad \textit{processing}$$

$$(2.3.14) \quad Q_d(Q_{nd}, Q_{sd}) = Z_d(Z_{nd}, Z_{sd}, Z_{md}) \quad \textit{domestic marketing}$$

$$(2.3.15) \quad Q_e(Q_{ne}, Q_{se}) = Z_e(Z_{ne}, Z_{se}, Z_{me}) \quad \textit{export marketing}$$

All symbols are defined in Table 2.3. The variables on the left sides of the equations are outputs for the relevant sectors; those on the right sides are inputs. Given the vertical structure of the sectors, outputs from an earlier sector become inputs for later sectors. In general, variables subscripted with “n” and “s” are related to grainfed and grassfed respectively, and those related to domestic and export markets carry a “d” and “e” respectively.

**Table 2.3 Definition of Variables and Parameters in the Model**

<b><u>Endogenous Variables:</u></b>	
$X_{n1}, X_{n2}$ :	Quantities of weaner cattle for lot-finishing and other inputs to the backgrounding sector, respectively.
$X_n$ :	Aggregated input index for the feedlot finishing sector.
$w_{n2}$ :	Price of other inputs to the backgrounding sector.
$F_{n1e}, F_{n1d}, F_{n2}, F_{n3}$ :	Quantities of backgrounded cattle for export and domestic markets, feedgrain and other feedlot inputs, respectively.
$F_{n1}$ :	Aggregated output index of the backgrounding sector.
$F_n$ :	Aggregated input index of the feedlot sector.
$S_{n1e}, S_{n1d}, S_{n2}, S_{n3}$ :	Prices of $F_{n1e}, F_{n1d}, F_{n2}, F_{n3}$ .
$Y_{ne}, Y_{nd}$ :	Quantities of feedlot-finished live cattle for export and domestic markets, respectively.
$Y_n$ :	Aggregated output index of feedlot sector.
$v_{ne}, v_{nd}$ :	Prices of grain-finished live cattle for export and domestic markets, respectively.
$X_{s1}, X_{s2}$ :	Quantities of weaner cattle and other inputs to the grass finishing sector, respectively.
$X_s$ :	Aggregated input index for the grass finishing sector.
$X_1$ :	Quantity of total weaners, $X_1 = X_{n1} + X_{s1}$
$w_1$ :	Price of weaners.
$w_{s2}$ :	Price of other inputs to the grass finishing sector.
$Y_{se}, Y_{sd}$ :	Quantities of grass-finished live cattle for export and domestic markets, respectively.
$Y_s$ :	Aggregated output index for the grass finishing sector;
$v_{se}, v_{sd}$ :	Prices of grass-finished live cattle for export and domestic markets, respectively.
$Y_p$ :	Quantity of other inputs used in the processing sector.
$v_p$ :	Price of other inputs used in the processing sector.
$Y$ :	Aggregated input index for the processing sector.
$Z$ :	Aggregated output index for the processing sector.
$Z_{ne}, Z_{nd}$ :	Quantities of processed grain-fed beef carcass for export and domestic markets, respectively.
$u_{ne}, u_{nd}$ :	Prices of processed grain-fed beef carcass for export and domestic markets, respectively.
$Z_{se}, Z_{sd}$ :	Quantities of processed grass-fed beef carcass for export and domestic markets, respectively.
$u_{ne}, u_{nd}$ :	Prices of processed grass-fed beef carcass for export and domestic markets, respectively.
$Z_{me}, Z_{md}$ :	Quantities of other marketing inputs to export marketing and domestic marketing sectors, respectively.
$u_{me}, u_{md}$ :	Prices of other marketing inputs to export marketing and domestic marketing sectors, respectively.
$Z_e, Z_d$ :	Aggregated input indices to export marketing and domestic marketing sectors, respectively.
$Q_e, Q_d$ :	Aggregated output indices for export marketing and domestic marketing sectors, respectively.
$Q_{ne}, Q_{se}$ :	Quantities of export grain-fed and grass-fed beef, respectively.
$p_{ne}, p_{se}$ :	Prices of export grain-fed and grass-fed beef, respectively.
$Q_{nd}, Q_{sd}$ :	Quantities of domestic grain-fed and grass-fed retail beef cuts, respectively.
$p_{nd}, p_{sd}$ :	Prices of domestic grain-fed and grass-fed retail beef cuts, respectively.

**Table 2.3 Definition of Variables and Parameters in the Model (cont.)**

<b><u>Exogenous Variables:</u></b>	
$T_x$ :	Supply shifter shifting down supply curve of x vertically due to cost reduction in production of x ( $x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{md}, Z_{me}$ ).
$t_x$ :	Amount of shift $T_x$ as a percentage of price of x ( $x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{md}, Z_{me}$ ).
$N_x$ :	Demand shifter shifting up demand curve of x vertically due to promotion or taste changes that increase the demand in x ( $x = Q_{se}, Q_{ne}, Q_{sd}, Q_{nd}$ ).
$n_x$ :	Amount of shift $N_x$ as a percentage of price of x ( $x = Q_{sd}, Q_{se}, Q_{nd}, Q_{ne}$ ).
<b><u>Parameters:</u></b>	
$\eta_{(x,y)}$ :	Demand elasticity of variable x with respect to change in price y.
$\varepsilon_{(x,y)}$ :	Supply elasticity of variable x with respect to change in price y.
$\tilde{\eta}_{(x,y)}$ :	Constant-output input demand elasticity of input x with respect to change in input price y.
$\tilde{\varepsilon}_{(x,y)}$ :	Constant-input output supply elasticity of output x with respect to change in output price y.
$\sigma_{(x,y)}$ :	Allen's elasticity of input substitution between input x and input y.
$\tau_{(x,y)}$ :	Allen's elasticity of product transformation between output x and output y.
$\kappa_x$ :	Cost share of input x ( $x = X_{n1}, X_{n2}, X_{s1}, X_{s2}, F_{n1e}, F_{n1d}, F_{n2}, F_{n3}, Y_{ne}, Y_{nd}, Y_{se}, Y_{sd}, Y_p, Z_{nd}, Z_{sd}, Z_{md}, Z_{ne}, Z_{se}$ and $Z_{me}$ ), where $\sum_{i=1}^2 \kappa_{X_{ni}} = 1$ , $\sum_{i=1}^2 \kappa_{X_{si}} = 1$ , $\sum_{i=1e,1d,2,3} \kappa_{F_{ni}} = 1$ , $\sum_{i=ne,nd,se,sd,p} \kappa_{Y_i} = 1$ , $\sum_{i=n,s,m} \kappa_{Z_{id}} = 1$ , $\sum_{i=n,s,m} \kappa_{Z_{ie}} = 1$ .
$\gamma_y$ :	Revenue share of output y ( $y = F_{n1e}, F_{n1d}, Y_{ne}, Y_{nd}, Y_{se}, Y_{sd}, Z_{ne}, Z_{nd}, Z_{se}, Z_{sd}, Q_{ne}, Q_{se}, Q_{nd}$ and $Q_{sd}$ ), where $\sum_{i=e,d} \gamma_{F_{ni}} = 1$ , $\sum_{i=e,d} \gamma_{Y_{ni}} = 1$ , $\sum_{i=e,d} \gamma_{Y_{si}} = 1$ , $\sum_{i=ne,nd,se,sd} \gamma_{Z_i} = 1$ , $\sum_{i=n,s} \gamma_{Q_{ie}} = 1$ , $\sum_{i=n,s} \gamma_{Q_{id}} = 1$ .
$\rho_{X_{n1}}, \rho_{X_{s1}}$ :	Quantity shares of $X_{n1}$ and $X_{s1}$ , ie. $\rho_{X_{n1}} = X_{n1}/(X_{n1} + X_{s1})$ , $\rho_{X_{s1}} = X_{s1}/(X_{n1} + X_{s1})$ .

As shown in Equation (2.3.5), the total cost functions related to these production functions are also separable for given output levels and can be written as

$$(2.3.16) \quad C_{F_{n1}} = F_{n1} * c_{F_{n1}}(w_1, w_{n2}) \quad \textit{backgrounding}$$

$$(2.3.17) \quad C_{Y_n} = Y_n * c_{Y_n}(s_{n1e}, s_{n1d}, s_{n2}, s_{n3}) \quad \textit{feedlot-finishing}$$

$$(2.3.18) \quad C_{Y_s} = Y_s * c_{Y_s}(w_1, w_{s2}) \quad \textit{grass-finishing}$$

$$(2.3.19) \quad C_Z = Z * c_Z(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \textit{processing}$$

$$(2.3.20) \quad C_{Q_d} = Q_d * c_{Q_d}(u_{nd}, u_{sd}, u_{md}) \quad \textit{domestic marketing}$$

$$(2.3.21) \quad C_{Q_e} = Q_e * c_{Q_e}(u_{ne}, u_{se}, u_{me}) \quad \textit{export marketing}$$

where  $C_y$  represents the total cost of producing output index level  $y$  and  $c_y(\cdot)$  represents the unit cost function ( $y = F_{n1}, Y_n, Y_s, Z, Q_d$  and  $Q_e$ ). Quantities are represented by capital letters and prices by lower-case variables.

Following Equation (2.3.8), the revenue functions subject to given input levels for the six multi-output sectors can be represented as

$$(2.3.22) \quad R_{X_n} = X_n * r_{X_n}(s_{n1e}, s_{n1d}) \quad \textit{backgrounding}$$

$$(2.3.23) \quad R_{F_n} = F_n * r_{F_n}(v_{ne}, v_{nd}) \quad \textit{feedlot-finishing}$$

$$(2.3.24) \quad R_{X_s} = X_s * r_{X_s}(v_{se}, v_{sd}) \quad \textit{grass-finishing}$$

$$(2.3.25) \quad R_Y = Y * r_Y(u_{nd}, u_{sd}, u_{ne}, u_{se}) \quad \textit{processing}$$

$$(2.3.26) \quad R_{Z_d} = Z_d * r_{Z_d}(p_{nd}, p_{sd}) \quad \textit{domestic marketing}$$

$$(2.3.27) \quad R_{Z_e} = Z_e * r_{Z_e}(p_{ne}, p_{se}) \quad \textit{export marketing}$$

where  $R_x$  represents total revenue produced from the fixed input index level  $x$  and  $r_x(\cdot)$  represents the unit revenue function associated with one unit of input index  $x$  ( $x = X_n, F_n, X_s, Y, Z_d$  and  $Z_e$ ).

Following Equations (2.3.6) and (2.3.9), the demand and supply functions for all endogenous input and output variables in the model can be derived accordingly.

### 2.3.2 Profit Functions and Exogenous Supplies of Factors

Supply schedules for factors  $X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$  and demand schedules for beef products  $Q_i$  ( $i = ne, se, nd$  and  $sd$ ) (refer to definitions of variables in Table 2.3) are exogenous to the model. Decision making problems from which the supplies of these factors and the demands of these products are derived can not be completely specified within the

context of the model, because only some of the decision variables for these decision makers are included in the model.

Consider first the specification of the exogenous factor supply. Let  $x$  be any exogenous input to the model, i.e.  $x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  or  $Z_{md}$ . Suppose the production function for the producer of  $x$  is

$$F(x, O) = 0$$

where  $O$  is the vector of all inputs and other outputs of the production function. The profit function can be specified as

$$(2.3.28) \quad \pi = \max_{x,O} \{ w_x x + W'O : F(x, O) = 0 \} = \pi(w_x, W)$$

where  $w_x$  is the price for  $x$  and  $W$  is the price vector for  $O$ . Following Varian (1992, p25), each element in  $O$  is set negative if it is an input and positive if it is an output. The supply of  $x$  can be derived using Hotelling's Lemma as

$$(2.3.29) \quad x = \frac{\partial}{\partial w_x} \pi(w_x, W) = \pi_{wx}'(w_x, W) = x(w_x, W)$$

where  $\pi_{wx}'(\cdot)$  is the partial derivative of  $\pi(w_x, W)$  with respect to  $w_x$ . Supply of  $X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  or  $Z_{md}$  can be derived accordingly.

Note that, as shown in Figure 2.1, as it has been assumed that the weaners supplied to both grain-finishing and grass-finishing sectors are homogenous,  $X_{n1}$  and  $X_{s1}$  have a joint supply schedule (the supply of  $X_1 = X_{n1} + X_{s1}$ ) and receive the same price. They do have separate demands, the sum of which being the demand for  $X_1$ .

### 2.3.3 Utility Functions and Exogenous Demand for Beef Products

Demands for the final beef products are exogenous to the model. Consider first the export demand. As reviewed in 2.2, export grainfed and grassfed beef ( $Q_{ne}$  and  $Q_{se}$ ) are of very different quality and are mostly exported to markets in different countries. For example, during 1992-97 around 92% of total Australian export grainfed beef went to Japan, while only 28% of export grass-fed beef were sold in Japan (Table 2.1). The majority of export grass-fed beef is sold in North America and other Asian countries, where almost no Australian grain-fed beef was sold. For this reason, the demand for  $Q_{ne}$  and  $Q_{se}$  are assumed to be independent and to relate to different consumers.

Suppose that the indirect utility function for a given income level  $m$  for the consumer of  $Q_{ie}$  ( $i = n, s$ ) can be specified as (Varian 1992, p99)

$$(2.3.30) \quad v(p_{ie}, P, m) = \max_{Q_{ie}, Q} \{ u(Q_{ie}, Q) : p_{ie} Q_{ie} + P'Q = m \}$$

where  $p_{ie}$  is the price of  $Q_{ie}$  ( $i = n, s$ ),  $Q$  is the vector of all other commodities that the consumer of  $Q_{ie}$  also consumes,  $P$  is the price vector of  $Q$ , and  $u(\cdot)$  is the consumer's utility function. The Marshallian demand equations can be derived using Roy's identity (Varian 1992, p106) as:

$$(2.3.31) \quad Q_{ie}(p_{ie}, P, m) = - \frac{\frac{\partial v(p_{ie}, P, m)}{\partial p_{ie}}}{\frac{\partial v(p_{ie}, P, m)}{\partial m}} \quad (i = n, s)$$

That is, the demand for each of  $Q_{ne}$  and  $Q_{se}$  is only related to own price and is independent of the rest of the model. In particular, the demand for  $Q_{ne}$  is not affected by the price of  $Q_{se}$ , and *vice versa*.

However, for the domestic retail market, grainfed and grassfed beef ( $Q_{nd}$  and  $Q_{sd}$ ) are substitutes for consumers. Grainfed beef often appears on the shelf as high quality gourmet brands, while the cheaper brands (like 'Savings' or 'Farmland' in the major supermarkets) are often grassfed. The consumers' demands for the two beef products respond to the relative prices of the two products as well as prices of other competing meat products such as lamb, pork and chicken. In this case, there are two variables ( $Q_{nd}$  and  $Q_{sd}$ ) in the domestic consumers' decision making problem that are from within the model. Assume that the indirect utility function for given income  $m$  for domestic consumers is (Varian 1992, p99):

$$(2.3.32) \quad v(p_{nd}, p_{sd}, P, m) = \max_{Q_{nd}, Q_{sd}, Q} \{u(Q_{nd}, Q_{sd}, Q) : p_{nd}Q_{nd} + p_{sd}Q_{sd} + P'Q = m\}$$

where  $p_{nd}$  and  $p_{sd}$  are prices for  $Q_{nd}$  and  $Q_{sd}$ , and  $P$  and  $Q$  are price and quantity vectors of all other commodities. The Marshallian demand equations can be derived using Roy's identity as:

$$(2.3.33) \quad Q_{nd}(p_{nd}, p_{sd}, P, m) = - \frac{\frac{\partial v(p_{nd}, p_{sd}, P, m)}{\partial p_{nd}}}{\frac{\partial v(p_{nd}, p_{sd}, P, m)}{\partial m}}$$

$$(2.3.34) \quad Q_{sd}(p_{nd}, p_{sd}, P, m) = - \frac{\frac{\partial v(p_{nd}, p_{sd}, P, m)}{\partial p_{sd}}}{\frac{\partial v(p_{nd}, p_{sd}, P, m)}{\partial m}}$$

## 2.4 The Equilibrium Model and its Displacement Form

### 2.4.1 Structural Model

As shown above, the structural model describing the demand and supply relationships among all variables in the model can be derived as partial derivatives from the decision-making problems specified in Equations (2.3.16)-(2.3.27), (2.3.28), (2.3.30) and (2.3.32).

Comparative statics can then be applied to the structural model to derive the relationships

among the *changes* in all variables, that is, the EDM. The changes in all prices and quantities due to a new technology or promotion can then be estimated in order to measure the welfare implications.

At this stage, general functional forms for all decision-making functions as well as for all demand and supply functions are assumed. Also assume that exogenous changes result in parallel shifts in the relevant demand or supply curves. Incorporating the exogenous shifters that represent impacts of various new technologies and promotions in the demand or supply functions, the structural model system that describes the equilibrium of the Australian beef industry is given as follows. Variables outside the partial system are assumed unaffected by the displacements and thus kept constant. As a result, without losing generality, they are not included explicitly in the model. Again, definitions of all endogenous and exogenous variables in the general form model below are given in Table 2.3.

*Input Supply to Backgrounding and Grass-Finishing Sectors:*

- (2.4.1)  $X_1 = X_1(w_1, T_{X1})$  *weaner supply*
- (2.4.2)  $X_1 = X_{n1} + X_{s1}$  *weaner supply equality*
- (2.4.3)  $X_{n2} = X_{n2}(w_{n2}, T_{Xn2})$  *supply of other backgrounding inputs*
- (2.4.4)  $X_{s2} = X_{s2}(w_{s2}, T_{Xs2})$  *supply of other grass-finishing inputs*

Following Equation (2.3.29), Equations (2.4.1) and (2.4.3)-(2.4.4) are supply functions of weaners and other inputs to the backgrounding and grass-finishing sectors, derived from their individual profit functions in (2.3.28). Other prices in  $W$  in Equation (2.3.29) are assumed exogenously constant and thus are not included in the equations. The supply for  $X_{n1}$  and  $X_{s1}$  are restricted by the same supply schedule for  $X_i$  in (2.4.1) through the identity in (2.4.2).

$T_{X_i}$  is the supply shifter shifting down the supply curve of  $X_i$  due to technologies that reduce the production cost of  $X_i$  ( $i = 1, n2$  and  $s2$ ). In particular,  $T_{X1}$  represents exogenous changes such as breeding and farm technologies in weaner production,  $T_{Xn2}$  represents backgrounding technologies in areas such as nutrition and management, and  $T_{Xs2}$  represents, for example, farm technologies and improved farm management in cattle grass-finishing.

*Output-Constrained Input Demand of Backgrounding and Grass-Finishing Sectors:*

- (2.4.5)  $X_{n1} = F_{n1} c'_{F_{n1},1}(w_1, w_{n2})$  *demand for weaners for backgrounding*
- (2.4.6)  $X_{n2} = F_{n1} c'_{F_{n1},n2}(w_1, w_{n2})$  *demand for other backgrounding inputs*
- (2.4.7)  $X_{s1} = Y_s c'_{Y_s,1}(w_1, w_{s2})$  *demand for weaners for grass-finishing*
- (2.4.8)  $X_{s2} = Y_s c'_{Y_s,s2}(w_1, w_{s2})$  *demand for other grass-finishing inputs*

Following (2.3.6), Equations (2.4.5)-(2.4.8) are derived as partial derivatives of the cost functions in Equations (2.3.16) and (2.3.18) using Shephard's Lemma.  $c'_{F_{n1},j}(w_1, w_{n2})$

( $j = 1$  and  $n2$ ) and  $c'_{Ys,j}(w_1, w_{s2})$  ( $j = 1$  and  $s2$ ) are partial derivatives of the unit cost functions  $c_{Yn}(w_1, w_{n2})$  and  $c_{Ys}(w_1, w_{s2})$  respectively.

Backgrounding and Grass-Finishing Sectors Equilibrium:

$$(2.4.9) \quad X_n(X_{n1}, X_{n2}) = F_{n1}(F_{n1e}, F_{n1d}) \quad \textit{backgrounding quantity equilibrium}$$

$$(2.4.10) \quad c_{F_{n1}}(w_1, w_{n2}) = r_{X_n}(S_{n1e}, S_{n1d}) \quad \textit{backgrounding value equilibrium}$$

$$(2.4.11) \quad X_s(X_{s1}, X_{s2}) = Y_s(Y_{se}, Y_{sd}) \quad \textit{grass-finishing quantity equilibrium}$$

$$(2.4.12) \quad c_{Y_s}(w_1, w_{s2}) = r_{X_s}(V_{se}, V_{sd}) \quad \textit{grass-finishing value equilibrium}$$

Equations (2.4.9) and (2.4.11) are the multi-output product transformation functions of the two sectors, imposing aggregated inputs equal to aggregated outputs in quantity. Equations (2.4.10) and (2.4.12) set the unit costs ( $c_{F_{n1}}$  and  $c_{Y_s}$ ) incurred per unit of aggregated outputs ( $F_{n1}$  and  $Y_s$ ) equal to the unit revenue ( $r_{X_n}$  and  $r_{X_s}$ ) earned per unit of aggregated input ( $X_n$  and  $X_s$ ). They are derived from the industry equilibrium condition that total cost equals total revenue and equalities in (2.4.9) and (2.4.11).

Input-Constrained Output Supply of Backgrounding and Grass-Finishing Sectors:

$$(2.4.13) \quad F_{n1e} = X_n r'_{X_n, n1e}(S_{n1e}, S_{n1d}) \quad \textit{export-backgrounded-feeder supply}$$

$$(2.4.14) \quad F_{n1d} = X_n r'_{X_n, n1d}(S_{n1e}, S_{n1d}) \quad \textit{domestic-backgrounded-feeder supply}$$

$$(2.4.15) \quad Y_{se} = X_s r'_{X_s, se}(V_{se}, V_{sd}) \quad \textit{export-grass-finished cattle supply}$$

$$(2.4.16) \quad Y_{sd} = X_s r'_{X_s, sd}(V_{se}, V_{sd}) \quad \textit{domestic-grass-finished cattle supply}$$

Following Equation (2.3.9), Equations (2.4.13)-(2.4.16) are derived as partial derivatives of the revenue functions in Equations (2.3.22) and (2.3.24) using the Samuelson-McFadden Lemma (Chambers, 1988, p264).  $r'_{X_n, j}(S_{n1e}, S_{n1d})$  ( $j = n1e$  and  $n1d$ ) and  $r'_{X_s, j}(V_{se}, V_{sd})$  ( $j = se$  and  $sd$ ) are partial derivatives of  $r_{X_n}(S_{n1e}, S_{n1d})$  and  $r_{X_s}(V_{se}, V_{sd})$ , respectively.

Other Input Supply to Feedlot Sector

$$(2.4.17) \quad F_{n2} = F_{n2}(S_{n2}, T_{F_{n2}}) \quad \textit{feedgrain supply}$$

$$(2.4.18) \quad F_{n3} = F_{n3}(S_{n3}, T_{F_{n3}}) \quad \textit{supply of other feedlot inputs}$$

Equations (2.4.17) and (2.4.18) are the supplies of feedgrain and other inputs to the feedlot sector, following (2.3.29).  $T_{F_{n2}}$  represents feedgrain industry technologies that shift down the feedgrain supply curve.  $T_{F_{n3}}$  represents feedlot technologies due to, for example, feed nutrition research and improved feedlot management.

Output-Constrained Input Demand of Feedlot Sector:

$$(2.4.19) \quad F_{n1e} = Y_n c'_{Y_n, n1e}(S_{n1e}, S_{n1d}, S_{n2}, S_{n3}) \quad \text{export-feeder demand}$$

$$(2.4.20) \quad F_{n1d} = Y_n c'_{Y_n, n1d}(S_{n1e}, S_{n1d}, S_{n2}, S_{n3}) \quad \text{domestic-feeder demand}$$

$$(2.4.21) \quad F_{n2} = Y_n c'_{Y_n, n2}(S_{n1e}, S_{n1d}, S_{n2}, S_{n3}) \quad \text{feedgrain demand}$$

$$(2.4.22) \quad F_{n3} = Y_n c'_{Y_n, n3}(S_{n1e}, S_{n1d}, S_{n2}, S_{n3}) \quad \text{other feedlot input demand}$$

Following (2.3.6), Equations (2.4.19)-(2.4.22) are derived from the cost function in Equation (2.3.17) using Shephard's Lemma.  $c'_{Y_n, j}(\cdot)$  ( $j = n1e, n1d, n2$  and  $n3$ ) are partial derivatives of the unit cost functions  $c_{Y_n}(\cdot)$ .

Feedlot Sector Equilibrium:

$$(2.4.23) \quad F_n(F_{n1e}, F_{n1d}, F_{n2}, F_{n3}) = Y_n(Y_{ne}, Y_{nd}) \quad \text{quantity equilibrium}$$

$$(2.4.24) \quad c_{Y_n}(S_{n1e}, S_{n1d}, S_{n2}, S_{n3}) = r_{F_n}(v_{ne}, v_{nd}) \quad \text{value equilibrium}$$

As explained for the backgrounding and grass-finishing equilibrium in (2.4.9)-(2.4.12), Equations (2.4.23) and (2.4.24) are the quantity and value equilibrium for the feedlot sector.

Input-Constrained Output Supply of Feedlot Sector:

$$(2.4.25) \quad Y_{ne} = F_n r'_{F_n, ne}(v_{ne}, v_{nd}) \quad \text{export-grain-finished cattle supply}$$

$$(2.4.26) \quad Y_{nd} = F_n r'_{F_n, nd}(v_{ne}, v_{nd}) \quad \text{domestic-grain-finished cattle supply}$$

Following Equation (2.3.9), Equations (2.4.25)-(2.4.26) are derived from the revenue function in (2.3.23) using Samuelson-McFadden Lemma.  $r'_{F_n, j}(\cdot)$  ( $j = ne$  and  $nd$ ) are the partial derivatives of  $r_{F_n}(\cdot)$ .

Other Input Supply to Processing Sector:

$$(2.4.27) \quad Y_p = Y_p(v_p, T_{Y_p}) \quad \text{supply of other processing inputs}$$

Equation (2.4.27) is the supply of other inputs to the processing sector, derived as in Equation (2.3.29).  $T_{Y_p}$  is the exogenous supply shifter representing processing technologies in abattoirs due to research and improved management.

Output-Constrained Input Demand of Processing Sector:

$$(2.4.28) \quad Y_{se} = Z c'_{Z, se}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \text{export-grass-fed cattle demand}$$

$$(2.4.29) \quad Y_{sd} = Z c'_{Z, sd}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \text{domestic-grass-fed cattle demand}$$

$$(2.4.30) \quad Y_{ne} = Z c'_{Z, ne}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \text{export-grain-fed cattle demand}$$

$$(2.4.31) \quad Y_{nd} = Z c'_{Z,nd}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \text{domestic-grain-fed cattle demand}$$

$$(2.4.32) \quad Y_p = Z c'_{Z,p}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) \quad \text{other processing input demand}$$

Following Equation (2.3.6), the above five equations are derived from the cost function of the processing sector in Equation (2.3.19) using Shephard's Lemma, where  $c'_{Z,j}(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p)$  ( $j = se, sd, ne, nd, p$ ) are partial derivatives of the unit cost function  $c_Z(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p)$ .

Processing Sector Equilibrium:

$$(2.4.33) \quad Y(Y_{se}, Y_{sd}, Y_{ne}, Y_{nd}, Y_p) = Z(Z_{se}, Z_{sd}, Z_{ne}, Z_{nd}) \quad \text{quantity equilibrium}$$

$$(2.4.34) \quad c_Z(v_{se}, v_{sd}, v_{ne}, v_{nd}, v_p) = r_Y(u_{se}, u_{sd}, u_{ne}, u_{nd}) \quad \text{value equilibrium}$$

Equation (2.4.33) is the product transformation function for the processing sector in (2.3.13) that equalizes the aggregated input index  $Y$  with the aggregated output index  $Z$ . Equation (2.4.34) sets the unit cost  $c_Z$  of producing a unit of aggregated output  $Z$  equal to the unit revenue  $r_Y$  earned per unit of aggregated input  $Y$ .

Input-Constrained Output Supply of Processing Sector:

$$(2.4.35) \quad Z_{se} = Y r'_{Y,se}(u_{se}, u_{sd}, u_{ne}, u_{nd}) \quad \text{export-grassfed beef carcass supply}$$

$$(2.4.36) \quad Z_{sd} = Y r'_{Y,sd}(u_{se}, u_{sd}, u_{ne}, u_{nd}) \quad \text{domestic-grassfed beef carcass supply}$$

$$(2.4.37) \quad Z_{ne} = Y r'_{Y,ne}(u_{se}, u_{sd}, u_{ne}, u_{nd}) \quad \text{export-grainfed beef carcass supply}$$

$$(2.4.38) \quad Z_{nd} = Y r'_{Y,nd}(u_{se}, u_{sd}, u_{ne}, u_{nd}) \quad \text{domestic-grainfed beef carcass supply}$$

Following Equation (2.3.9), Equations (2.4.35)-(2.4.38) are derived as partial derivatives of the processing revenue function in Equation (2.3.25) using the Samuelson-McFadden Lemma.  $r'_{Y,j}(u_{se}, u_{sd}, u_{ne}, u_{nd})$  ( $j = se, sd, ne$  and  $nd$ ) are partial derivatives of the unit revenue function  $r_Y(u_{se}, u_{sd}, u_{ne}, u_{nd})$ .

Other Input Supply to Marketing Sectors:

$$(2.4.39) \quad Z_{md} = Z_{md}(u_{md}, T_{Zmd}) \quad \text{supply of other domestic marketing inputs}$$

$$(2.4.40) \quad Z_{me} = Z_{me}(u_{me}, T_{Zme}) \quad \text{supply of other export marketing inputs}$$

Equations (2.4.39) and (2.4.40) are the supplies of other inputs to the domestic and export marketing sectors respectively, following equation (2.3.29).  $T_{Zmd}$  represents technologies (in boning, packing, distributing, etc.) and more efficient management in domestic marketing sector (such as major supermarket chains).  $T_{Zme}$  represents technologies in boning, packing, etc. and improved management in export marketing sector.

Output-Constrained Input Demand of Marketing Sectors:

$$(2.4.41) \quad Z_{sd} = Q_d c'_{Qd,sd}(u_{sd}, u_{nd}, u_{md}) \text{ domestic-grass-fed beef carcass demand}$$

$$(2.4.42) \quad Z_{nd} = Q_d c'_{Qd,nd}(u_{sd}, u_{nd}, u_{md}) \text{ domestic-grain-fed beef carcass demand}$$

$$(2.4.43) \quad Z_{md} = Q_d c'_{Qd,md}(u_{sd}, u_{nd}, u_{md}) \text{ other domestic marketing input demand}$$

$$(2.4.44) \quad Z_{se} = Q_e c'_{Qe,se}(u_{se}, u_{ne}, u_{me}) \text{ export-grass-fed beef carcass demand}$$

$$(2.4.45) \quad Z_{ne} = Q_e c'_{Qe,ne}(u_{se}, u_{ne}, u_{me}) \text{ export-grain-fed beef carcass demand}$$

$$(2.4.46) \quad Z_{me} = Q_e c'_{Qe,me}(u_{se}, u_{ne}, u_{me}) \text{ other export marketing input demand}$$

Again following Equation (2.3.6), Equations (2.4.41)-(2.4.46) are derived from the cost functions of the marketing sectors in Equations (2.3.20) and (2.3.21) using Shephard's Lemma.  $c'_{Qd,j}(u_{sd}, u_{nd}, u_{md})$  ( $j = sd, nd, md$ ) and  $c'_{Qe,j}(u_{se}, u_{ne}, u_{me})$  ( $j = se, ne, me$ ) are partial derivatives of the unit cost functions  $c_{Qd}(u_{sd}, u_{nd}, u_{md})$  and  $c_{Qe}(u_{se}, u_{ne}, u_{me})$ , respectively.

Domestic Marketing Sector Equilibrium:

$$(2.4.47) \quad Z_d(Z_{sd}, Z_{nd}, Z_{md}) = Q_d(Q_{sd}, Q_{nd}) \quad \text{quantity equilibrium}$$

$$(2.4.48) \quad c_{Qd}(u_{sd}, u_{nd}, u_{md}) = r_{Zd}(p_{sd}, p_{nd}) \quad \text{value equilibrium}$$

Export Marketing Sector Equilibrium:

$$(2.4.49) \quad Z_e(Z_{se}, Z_{ne}, Z_{me}) = Q_e(Q_{se}, Q_{ne}) \quad \text{quantity equilibrium}$$

$$(2.4.50) \quad c_{Qe}(u_{se}, u_{ne}, u_{me}) = r_{Ze}(p_{se}, p_{ne}) \quad \text{value equilibrium}$$

Equations (2.4.47) and (2.4.49) are the product transformation functions for the domestic and export marketing sectors respectively, and equations (2.4.48) and (2.4.50) impose value equilibrium between unit costs and unit revenues in the two marketing sectors.

Input-Constrained Output Supply of Marketing Sectors:

$$(2.4.51) \quad Q_{sd} = Z_d r'_{Zd,sd}(p_{sd}, p_{nd}) \quad \text{domestic-retail-grass-fed beef supply}$$

$$(2.4.52) \quad Q_{nd} = Z_d r'_{Zd,nd}(p_{sd}, p_{nd}) \quad \text{domestic-retail-grain-fed beef supply}$$

$$(2.4.53) \quad Q_{se} = Z_e r'_{Ze,se}(p_{se}, p_{ne}) \quad \text{export-grass-fed beef supply}$$

$$(2.4.54) \quad Q_{ne} = Z_e r'_{Ze,ne}(p_{se}, p_{ne}) \quad \text{export-grain-fed beef supply}$$

Following Equation (2.3.9), Equations (2.4.51)-(2.4.54) are derived as partial derivatives of the revenue functions in Equations (2.3.26) and (2.3.27) using the Samuelson-McFadden

Lemma.  $r_{Zd,j}(p_{sd}, p_{nd})$  ( $j = sd, nd$ ) and  $r_{Ze,j}(p_{se}, p_{ne})$  ( $j = se, ne$ ) are partial derivatives of the unit revenue functions  $r_{Zd}(p_{sd}, p_{nd})$  and  $r_{Ze}(p_{se}, p_{ne})$ , respectively.

Domestic Retail Beef Demand:

$$(2.4.55) \quad Q_{sd} = Q_{sd}(p_{sd}, p_{nd}, N_{Qsd}, N_{Qnd}) \quad \text{domestic grassfed beef demand}$$

$$(2.4.56) \quad Q_{nd} = Q_{nd}(p_{sd}, p_{nd}, N_{Qsd}, N_{Qnd}) \quad \text{domestic grainfed beef demand}$$

Following Equations (2.3.33) and (2.3.34), Equations (2.4.55) and (2.4.56) are the demand equations for domestic grassfed and grainfed beef. Income is assumed constant during the modelled small displacements and thus omitted in the demand equations.  $N_{Qsd}$  and  $N_{Qnd}$  are domestic demand shifters representing changes in demand for grass-fed and grain-fed beef, respectively, due to promotion or taste changes in the domestic market.

Export Demand for Australian Beef:

$$(2.4.57) \quad Q_{se} = Q_{se}(p_{se}, N_{Qse}) \quad \text{export grassfed beef demand}$$

$$(2.4.58) \quad Q_{ne} = Q_{ne}(p_{ne}, N_{Qne}) \quad \text{export grainfed beef demand}$$

Following the derivation of Equation (2.3.31), Equations (2.4.57) and (2.4.58) are export demand functions for Australian grassfed and grainfed beef. As discussed in Section 2.3.3, Australian grassfed and grainfed beef are assumed non-substitutable due to their very different quality, end uses and countries of consumption. Also, income is assumed constant during the small shift and impacts from other competing meat prices in overseas markets are also not included explicitly.  $N_{Qse}$  is a demand shifter representing changes in demand for grain-fed Australian beef in Japanese or Korean markets due to promotion or taste changes.  $N_{Qne}$  represents promotion or demand changes for grass-fed Australian beef in overseas markets.

Equations (2.4.1)-(2.4.58) represent the structural equilibrium model of the Australian beef industry in general functional form. As can be seen from Figure 2.1, there are 23 factor or product markets that involve 46 price and quantity variables. There are also 12 aggregated input and output index variables for the six multi-output sectors. This amounts to 58 endogenous variables for the 58 equations in the system. The exogenous variables are the 12 shifters (ie.  $T_{Xi}$  ( $i = 1, n2, s2$ ),  $T_{Fni}$  ( $i = 2, 3$ ),  $T_{Yp}$ ,  $T_{Zi}$  ( $i = md, me$ ), and  $N_{Qi}$  ( $i = se, ne, sd, nd$ )) representing impacts of new technologies in individual sectors and promotion in domestic and overseas markets. The ultimate objective is to estimate the resulting changes in all prices and quantities in order to estimate the welfare implications of these exogenous shifts.

## 2.4.2 The Model in Equilibrium Displacement Form

The system given by equations (2.4.1)-(2.4.58) defines an equilibrium status in all markets involved. When a new technology or promotion disturbs the system through an exogenous shifter, a displacement from the base equilibrium results. The relationships among changes in all the endogenous price and quantity variables and the exogenous shifters can be derived by totally differentiating the system of equations at the initial equilibrium points. The model in equilibrium displacement form is given by Equations (2.4.1)'-(2.4.58)' as follows.

$E(.)=\Delta(.)/(.)$  represents a small finite relative change of variable (.). All market parameters refer to elasticity values at the initial equilibrium points. Local linear approximation is implied while totally differentiating the model and approximating the finite changes, and the approximation errors in the resulting relative changes of all variables are small as long as the initial exogenous shifts are small. Definitions of all parameters are also given in Table 2.3.

Input Supply to Backgrounding and Grass-Finishing Sectors:

$$(2.4.1)' \quad EX_1 = \varepsilon_{(X1, w1)}(EW_1 - t_{X1})$$

$$(2.4.2)' \quad EX_1 = \rho_{Xn1}EX_{n1} + \rho_{Xs1}EX_{s1}$$

$$(2.4.3)' \quad EX_{n2} = \varepsilon_{(Xn2, wn2)}(EW_{n2} - t_{Xn2})$$

$$(2.4.4)' \quad EX_{s2} = \varepsilon_{(Xs2, ws2)}(EW_{s2} - t_{Xs2})$$

Output-Constrained Input Demand of Backgrounding and Grass-Finishing Sectors:

$$(2.4.5)' \quad EX_{n1} = \tilde{\eta}_{(Xn1, w1)}EW_{n1} + \tilde{\eta}_{(Xn1, wn2)}EW_{n2} + EF_{n1}$$

$$(2.4.6)' \quad EX_{n2} = \tilde{\eta}_{(Xn2, w1)}EW_{n1} + \tilde{\eta}_{(Xn2, wn2)}EW_{n2} + EF_{n1}$$

$$(2.4.7)' \quad EX_{s1} = \tilde{\eta}_{(Xs1, w1)}EW_{s1} + \tilde{\eta}_{(Xs1, ws2)}EW_{s2} + EY_s$$

$$(2.4.8)' \quad EX_{s2} = \tilde{\eta}_{(Xs2, w1)}EW_{s1} + \tilde{\eta}_{(Xs2, ws2)}EW_{s2} + EY_s$$

Backgrounding and Grass-Finishing Sectors Equilibrium:

$$(2.4.9)' \quad \kappa_{Xn1}EX_{n1} + \kappa_{Xn2}EX_{n2} = \gamma_{Fn1e}EF_{n1e} + \gamma_{Fn1d}EF_{n1d}$$

$$(2.4.10)' \quad \kappa_{Xn1}EW_1 + \kappa_{Xn2}EW_{n2} = \gamma_{Fn1e}ES_{n1e} + \gamma_{Fn1d}ES_{n1d}$$

$$(2.4.11)' \quad \kappa_{Xs1}EX_{s1} + \kappa_{Xs2}EX_{s2} = \gamma_{Yse}EY_{se} + \gamma_{Ysd}EY_{sd}$$

$$(2.4.12)' \quad \kappa_{Xs1}EW_1 + \kappa_{Xs2}EW_{s2} = \gamma_{Yse}EV_{se} + \gamma_{Ysd}EV_{sd}$$

Input-Constrained Output Supply of Backgrounding and Grass-Finishing Sectors:

$$(2.4.13)' \quad EF_{n1e} = \tilde{\varepsilon}_{(Fn1e, sn1e)}ES_{n1e} + \tilde{\varepsilon}_{(Fn1e, sn1d)}ES_{n1d} + EX_n$$

$$(2.4.14)' \quad EF_{n1d} = \tilde{\varepsilon}_{(Fn1d, sn1e)}ES_{n1e} + \tilde{\varepsilon}_{(Fn1d, sn1d)}ES_{n1d} + EX_n$$

$$(2.4.15)' \quad EY_{se} = \tilde{\varepsilon}_{(Yse, vse)}EV_{se} + \tilde{\varepsilon}_{(Yse, vsd)}EV_{sd} + EX_s$$

$$(2.4.16)' \quad EY_{sd} = \tilde{\varepsilon}_{(Ysd, vse)}EV_{se} + \tilde{\varepsilon}_{(Ysd, vsd)}EV_{sd} + EX_s$$

Other Input Supply to Feedlot Sector

$$(2.4.17)' \quad EF_{n2} = \varepsilon_{(Fn2, sn2)}(ES_{n2} - t_{Fn2})$$

$$(2.4.18)' \quad EF_{n3} = \varepsilon_{(Fn3, sn3)}(ES_{n3} - t_{Fn3})$$

Output-Constrained Input Demand of Feedlot Sector:

$$(2.4.19)' \quad EF_{n1e} = \tilde{\eta}_{(Fn1e, sn1e)}ES_{n1e} + \tilde{\eta}_{(Fn1e, sn1d)}ES_{n1d} + \tilde{\eta}_{(Fn1e, sn2)}ES_{n2} + \tilde{\eta}_{(Fn1e, sn3)}ES_{n3} + EY_n$$

$$(2.4.20)' \quad EF_{n1d} = \tilde{\eta}_{(Fn1d, sn1e)}ES_{n1e} + \tilde{\eta}_{(Fn1d, sn1d)}ES_{n1d} + \tilde{\eta}_{(Fn1d, sn2)}ES_{n2} + \tilde{\eta}_{(Fn1d, sn3)}ES_{n3} + EY_n$$

$$(2.4.21)' \quad EF_{n2} = \tilde{\eta}_{(Fn2, sn1e)}ES_{n1e} + \tilde{\eta}_{(Fn2, sn1d)}ES_{n1d} + \tilde{\eta}_{(Fn2, sn2)}ES_{n2} + \tilde{\eta}_{(Fn2, sn3)}ES_{n3} + EY_n$$

$$(2.4.22)' \quad EF_{n3} = \tilde{\eta}_{(Fn3, sn1e)}ES_{n1e} + \tilde{\eta}_{(Fn3, sn1d)}ES_{n1d} + \tilde{\eta}_{(Fn3, sn2)}ES_{n2} + \tilde{\eta}_{(Fn3, sn3)}ES_{n3} + EY_n$$

Feedlot Sector Equilibrium:

$$(2.4.23)' \quad \kappa_{Fn1e}EF_{n1e} + \kappa_{Fn1d}EF_{n1d} + \kappa_{Fn2}EF_{n2} + \kappa_{Fn3}EF_{n3} = \gamma_{Yne}EY_{ne} + \gamma_{Ynd}EY_{nd}$$

$$(2.4.24)' \quad \kappa_{Fn1e}ES_{n1e} + \kappa_{Fn1d}ES_{n1d} + \kappa_{Fn2}ES_{n2} + \kappa_{Fn3}ES_{n3} = \gamma_{Yne}EV_{ne} + \gamma_{Ynd}EV_{nd}$$

Input-Constrained Output Supply of Feedlot Sector:

$$(2.4.25)' \quad EY_{ne} = \tilde{\varepsilon}_{(Yne, vne)}EV_{ne} + \tilde{\varepsilon}_{(Yne, vnd)}EV_{nd} + EF_n$$

$$(2.4.26)' \quad EY_{nd} = \tilde{\varepsilon}_{(Ynd, vne)}EV_{ne} + \tilde{\varepsilon}_{(Ynd, vnd)}EV_{nd} + EF_n$$

Other Input Supply to Processing Sector

$$(2.4.27)' \quad EY_p = \varepsilon_{(Yp, vp)}(EV_p - t_{Yp})$$

Output-Constrained Input Demand of Processing Sector:

$$(2.4.28)' \quad EY_{se} = \tilde{\eta}_{(Yse, vse)}EV_{se} + \tilde{\eta}_{(Yse, vsd)}EV_{sd} + \tilde{\eta}_{(Yse, vne)}EV_{ne} \\ + \tilde{\eta}_{(Yse, vnd)}EV_{nd} + \tilde{\eta}_{(Yse, vp)}EV_p + EZ$$

$$(2.4.29)' \quad EY_{sd} = \tilde{\eta}_{(Ysd, vse)}EV_{se} + \tilde{\eta}_{(Ysd, vsd)}EV_{sd} + \tilde{\eta}_{(Ysd, vne)}EV_{ne} \\ + \tilde{\eta}_{(Ysd, vnd)}EV_{nd} + \tilde{\eta}_{(Ysd, vp)}EV_p + EZ$$

$$(2.4.30)' \quad EY_{ne} = \tilde{\eta}_{(Yne, vse)}EV_{se} + \tilde{\eta}_{(Yne, vsd)}EV_{sd} + \tilde{\eta}_{(Yne, vne)}EV_{ne} \\ + \tilde{\eta}_{(Yne, vnd)}EV_{nd} + \tilde{\eta}_{(Yne, vp)}EV_p + EZ$$

$$(2.4.31)' \quad EY_{nd} = \tilde{\eta}_{(Ynd, vse)}EV_{se} + \tilde{\eta}_{(Ynd, vsd)}EV_{sd} + \tilde{\eta}_{(Ynd, vne)}EV_{ne} \\ + \tilde{\eta}_{(Ynd, vnd)}EV_{nd} + \tilde{\eta}_{(Ynd, vp)}EV_p + EZ$$

$$(2.4.32)' \quad EY_p = \tilde{\eta}_{(Yp, vse)}EV_{se} + \tilde{\eta}_{(Yp, vsd)}EV_{sd} + \tilde{\eta}_{(Yp, vne)}EV_{ne} \\ + \tilde{\eta}_{(Yp, vnd)}EV_{nd} + \tilde{\eta}_{(Yp, vp)}EV_p + EZ$$

Processing Sector Equilibrium:

$$(2.4.33)' \quad \begin{aligned} & \kappa_{Y_{se}}EY_{se} + \kappa_{Y_{sd}}EY_{sd} + \kappa_{Y_{ne}}EY_{ne} + \kappa_{Y_{nd}}EY_{nd} + \kappa_{Y_p}EY_p \\ & = \gamma_{Z_{se}}EZ_{se} + \gamma_{Z_{sd}}EZ_{sd} + \gamma_{Z_{ne}}EZ_{ne} + \gamma_{Z_{nd}}EZ_{nd} \end{aligned}$$

$$(2.4.34)' \quad \begin{aligned} & \kappa_{Y_{se}}EV_{se} + \kappa_{Y_{sd}}EV_{sd} + \kappa_{Y_{ne}}EV_{ne} + \kappa_{Y_{nd}}EV_{nd} + \kappa_{Y_p}EV_p \\ & = \gamma_{Z_{se}}Eu_{se} + \gamma_{Z_{sd}}Eu_{sd} + \gamma_{Z_{ne}}Eu_{ne} + \gamma_{Z_{nd}}Eu_{nd} \end{aligned}$$

Input-Constrained Output Supply of Processing Sector:

$$(2.4.35)' \quad EZ_{se} = \tilde{\varepsilon}_{(Z_{se}, use)}Eu_{se} + \tilde{\varepsilon}_{(Z_{se}, usd)}Eu_{sd} + \tilde{\varepsilon}_{(Z_{se}, une)}Eu_{ne} + \tilde{\varepsilon}_{(Z_{se}, und)}Eu_{nd} + EY$$

$$(2.4.36)' \quad EZ_{sd} = \tilde{\varepsilon}_{(Z_{sd}, use)}Eu_{se} + \tilde{\varepsilon}_{(Z_{sd}, usd)}Eu_{sd} + \tilde{\varepsilon}_{(Z_{sd}, une)}Eu_{ne} + \tilde{\varepsilon}_{(Z_{sd}, und)}Eu_{nd} + EY$$

$$(2.4.37)' \quad EZ_{ne} = \tilde{\varepsilon}_{(Z_{ne}, use)}Eu_{se} + \tilde{\varepsilon}_{(Z_{ne}, usd)}Eu_{sd} + \tilde{\varepsilon}_{(Z_{ne}, une)}Eu_{ne} + \tilde{\varepsilon}_{(Z_{ne}, und)}Eu_{nd} + EY$$

$$(2.4.38)' \quad EZ_{nd} = \tilde{\varepsilon}_{(Z_{nd}, use)}Eu_{se} + \tilde{\varepsilon}_{(Z_{nd}, usd)}Eu_{sd} + \tilde{\varepsilon}_{(Z_{nd}, une)}Eu_{ne} + \tilde{\varepsilon}_{(Z_{nd}, und)}Eu_{nd} + EY$$

Other Input Supply to Marketing Sectors:

$$(2.4.39)' \quad EZ_{md} = \varepsilon_{(Z_{md}, umd)}(Eu_{md} - t_{Z_{md}})$$

$$(2.4.40)' \quad EZ_{me} = \varepsilon_{(Z_{me}, ume)}(Eu_{me} - t_{Z_{me}})$$

Output-Constrained Input Demand of Marketing Sectors:

$$(2.4.41)' \quad EZ_{sd} = \tilde{\eta}_{(Z_{sd}, usd)}Eu_{sd} + \tilde{\eta}_{(Z_{sd}, und)}Eu_{nd} + \tilde{\eta}_{(Z_{sd}, umd)}Eu_{md} + EQ_d$$

$$(2.4.42)' \quad EZ_{nd} = \tilde{\eta}_{(Z_{nd}, usd)}Eu_{sd} + \tilde{\eta}_{(Z_{nd}, und)}Eu_{nd} + \tilde{\eta}_{(Z_{nd}, umd)}Eu_{md} + EQ_d$$

$$(2.4.43)' \quad EZ_{md} = \tilde{\eta}_{(Z_{md}, usd)}Eu_{sd} + \tilde{\eta}_{(Z_{md}, und)}Eu_{nd} + \tilde{\eta}_{(Z_{md}, umd)}Eu_{md} + EQ_d$$

$$(2.4.44)' \quad EZ_{se} = \tilde{\eta}_{(Z_{se}, use)}Eu_{se} + \tilde{\eta}_{(Z_{se}, une)}Eu_{ne} + \tilde{\eta}_{(Z_{se}, ume)}Eu_{me} + EQ_e$$

$$(2.4.45)' \quad EZ_{ne} = \tilde{\eta}_{(Z_{ne}, use)}Eu_{se} + \tilde{\eta}_{(Z_{ne}, une)}Eu_{ne} + \tilde{\eta}_{(Z_{ne}, ume)}Eu_{me} + EQ_e$$

$$(2.4.46)' \quad EZ_{me} = \tilde{\eta}_{(Z_{me}, use)}Eu_{se} + \tilde{\eta}_{(Z_{me}, une)}Eu_{ne} + \tilde{\eta}_{(Z_{me}, ume)}Eu_{me} + EQ_e$$

Domestic Marketing Sector Equilibrium:

$$(2.4.47)' \quad \kappa_{Z_{sd}}EZ_{sd} + \kappa_{Z_{nd}}EZ_{nd} + \kappa_{Z_{md}}EZ_{md} = \gamma_{Q_{sd}}EQ_{sd} + \gamma_{Q_{nd}}EQ_{nd}$$

$$(2.4.48)' \quad \kappa_{Z_{sd}}Eu_{sd} + \kappa_{Z_{nd}}Eu_{nd} + \kappa_{Z_{md}}Eu_{md} = \gamma_{Q_{sd}}Ep_{sd} + \gamma_{Q_{nd}}Ep_{nd}$$

Export Marketing Sector Equilibrium:

$$(2.4.49)' \quad \kappa_{Zse}EZ_{se} + \kappa_{Zne}EZ_{ne} + \kappa_{Zme}EZ_{me} = \gamma_{Qse}EQ_{se} + \gamma_{Qne}EQ_{ne}$$

$$(2.4.50)' \quad \kappa_{Zse}Eu_{se} + \kappa_{Zne}Eu_{ne} + \kappa_{Zme}Eu_{me} = \gamma_{Qse}Ep_{se} + \gamma_{Qne}Ep_{ne}$$

Input-Constrained Output Supply of Marketing Sectors:

$$(2.4.51)' \quad EQ_{sd} = \tilde{\varepsilon}_{(Qsd, psd)}Ep_{sd} + \tilde{\varepsilon}_{(Qsd, pnd)}Ep_{nd} + EZ_d$$

$$(2.4.52)' \quad EQ_{nd} = \tilde{\varepsilon}_{(Qnd, psd)}Ep_{sd} + \tilde{\varepsilon}_{(Qnd, pnd)}Ep_{nd} + EZ_d$$

$$(2.4.53)' \quad EQ_{se} = \tilde{\varepsilon}_{(Qse, pse)}Ep_{se} + \tilde{\varepsilon}_{(Qse, pne)}Ep_{ne} + EZ_e$$

$$(2.4.54)' \quad EQ_{ne} = \tilde{\varepsilon}_{(Qne, pse)}Ep_{se} + \tilde{\varepsilon}_{(Qne, pne)}Ep_{ne} + EZ_e$$

Domestic Retail Beef Demand:

$$(2.4.55)' \quad EQ_{sd} = \eta_{(Qsd, psd)}(Ep_{sd} - n_{Qsd}) + \eta_{(Qsd, pnd)}(Ep_{nd} - n_{Qnd})$$

$$(2.4.56)' \quad EQ_{nd} = \eta_{(Qnd, psd)}(Ep_{sd} - n_{Qsd}) + \eta_{(Qnd, pnd)}(Ep_{nd} - n_{Qnd})$$

Export Demand for Australian Beef:

$$(2.4.57)' \quad EQ_{se} = \eta_{(Qse, pse)}(Ep_{se} - n_{Qse})$$

$$(2.4.58)' \quad EQ_{ne} = \eta_{(Qne, pne)}(Ep_{ne} - n_{Qne})$$

Derivation of Equations (2.4.1)'-(2.4.58)' from the general form model in Equations (2.4.1)-(2.4.58) is tedious, but straightforward. Details are not presented.

## 2.5 Integrability Conditions

### 2.5.1 The Integrability Problem

So far, the demand and supply equations for all inputs and outputs in the model have been derived conceptually from the underlying decision-making specifications in equations (2.3.16)-(2.3.27), (2.3.28), (2.3.30) and (2.3.32) without specific functional forms. Using local linear approximation of all demand and supply functions, linear relationships for small finite relative changes of all variables have been derived. If all the market-related parameters are known in the displacement model in Equations (2.4.1)'-(2.4.58)', the changes in all 58 price and quantity variables resulting from any one of the 12 exogenous shifts can be solved. However, there is a crucial question for a multi-market model like this one which is not always addressed in EDM applications: how can it be guaranteed that all the parameters and specifications of demand and supply equations are consistent in the sense that (a) there exists a set of underlying decision-making preference functions in Equations (2.3.16)-(2.3.27), (2.3.28), (2.3.30) and (2.3.32) that can be recovered from the demand and supply functions in

Equations (2.4.1)-(2.4.58)' (*mathematical integrability*); and (b) the preference functions satisfy the regularity conditions to be *bona fide* cost, revenue, profit and utility functions (*economic integrability*)? In short, the demand and supply specification needs to satisfy the integrability conditions.

The integrability problem is especially relevant when the purpose of the model is to measure economic welfare and its distribution. Just, Hueth and Schmitz (1982) have shown that the distribution of the total benefits from an exogenous shift in a market can be measured as economic surplus change areas off the partial (*ceteris paribus*) supply and demand curves in various markets, and that they add up to the total benefits, which can also be measured as surplus area changes off the general equilibrium (*mutatis mutandis*) supply and demand curves *in any single market*. However, empirically, the above results will not be exactly true if all the demand and supply functions are specified in an *ad hoc* fashion and the parameter values in different equations are estimated or chosen independently. That is, if the integrability conditions do not hold, total welfare change can be different from different ways of measuring it (Just, Hueth and Schmitz 1982, Appendices A.5, B.13 and D.4). Thus, integrability is a necessary and sufficient condition for the existence of exact welfare measures (LaFrance 1991, p1496).

In the context of this model, for the six sectors whose input and output decisions are completely determined within the model, all input demand and output supply functions need to be integrable with the relevant underlying cost and revenue functions. Also, as the two types of beef in the domestic market ( $Q_{nd}$  and  $Q_{sd}$ ) are assumed substitutes for the same consumer group, the demand for  $Q_{nd}$  and  $Q_{sd}$  needs to be consistent with the consumers' utility function.

### 2.5.2 Integrability Conditions in Terms of Market Parameters

In Appendix 1, the required properties of cost, revenue, profit and utility functions are examined to derive the required properties for the demand and supply functions. The implied constraints in terms of market-related parameters are summarised below.

#### Output-Constrained Input Demand

Integrability relating the output-constrained input demand in Equation (2.3.6) to the cost function in (2.3.4) will be satisfied if the following homogeneity, symmetry and concavity conditions hold. The notation is the same as that in Section 2.3 except that the output index  $g$  is represented by  $y$  here for convenience.

Homogeneity is given by

$$(2.5.1) \quad \sum_{j=1}^k \tilde{\eta}_{ij}(w, y) = 0 \quad (i=1, \dots, k) \quad (\text{homogeneity}),$$

where  $\tilde{\eta}_{ij}(w, y)$  is the constant-output input demand elasticity of  $x_i$  with respect to a change in input price  $w_j$  ( $i, j = 1, \dots, k$ ).

The symmetry condition requires that

$$(2.5.2) \quad s_i(w, y)\tilde{\eta}_{ij}(w, y) = s_j(w, y)\tilde{\eta}_{ji}(w, y) \quad (i, j = 1, \dots, k) \quad (\text{symmetry}),$$

where  $s_i(\cdot) = (w_i x_i / C)$  is the cost share of the  $i$ th input in total cost ( $i = 1, \dots, k$ ).

Concavity requires that  $H_\eta = (\tilde{\eta}_{ij}(w, y))_{k \times k}$  is negative semidefinite, or specifically

$$(2.5.3) \quad (-1)^m H_{\eta m} = (-1)^m \begin{vmatrix} \tilde{\eta}_{11} & \tilde{\eta}_{12} & \cdots & \tilde{\eta}_{1m} \\ \tilde{\eta}_{21} & \tilde{\eta}_{22} & \cdots & \tilde{\eta}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{\eta}_{m1} & \tilde{\eta}_{m2} & \cdots & \tilde{\eta}_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, k) \quad (\text{concavity}),$$

where  $H_{\eta m} = |(\tilde{\eta}_{ij})_{m \times m}| = |(\tilde{\eta}_{ij}(w, y))_{m \times m}|$  ( $m = 1, \dots, k$ ) is the  $m$ th principal minor of  $H_\eta$ .

That is, the principal minors of the input demand elasticity matrix  $H_\eta$  alternate in sign between nonpositive (when  $k$  is odd) and nonnegative (when  $k$  is even). In fact, it can be shown that under the homogeneity condition in (2.5.1),  $H_\eta$  is singular and thus  $H_{\eta k} = 0$ .

Using the Allen-Uzawa definition of the elasticity of input substitution (McFadden 1978, p79-80)

$$(2.5.4) \quad \tilde{\eta}_{ij}(w, y) = s_j(w, y)\sigma_{ij}(w, y) \quad (i, j = 1, \dots, k),$$

where  $\sigma_{ij}(w, y)$  is the Allen-Uzawa elasticity of substitution between the  $i$ th and  $j$ th inputs ( $i, j = 1, \dots, k$ ), the homogeneity condition can also be written as

$$(2.5.1)' \quad \sum_{j=1}^k s_j(w, y)\sigma_{ij}(w, y) = 0 \quad (i = 1, \dots, k) \quad (\text{homogeneity}).$$

The symmetry condition becomes

$$(2.5.2)' \quad \sigma_{ij}(w, y) = \sigma_{ji}(w, y) \quad (i, j = 1, \dots, k) \quad (\text{symmetry}).$$

In other words, in terms of input substitution, the symmetry condition simply means that the Allen-Uzawa substitution elasticities are symmetric.

The concavity condition in terms of the input substitution parameter implies

$H_\sigma = (\sigma_{ij}(w, y))_{k \times k}$  is negative semidefinite, or,

$$(2.5.3)' \quad (-1)^m H_{\sigma m} = (-1)^m \begin{vmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1m} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2m} \\ \vdots & \vdots & & \vdots \\ \sigma_{m1} & \sigma_{m2} & \cdots & \sigma_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, k) \quad (\text{concavity}).$$

where  $H_{\sigma m} = \left| (\sigma_{ij})_{m \times m} \right| = \left| (\sigma_{ij}(w, y))_{m \times m} \right|$  ( $m=1, \dots, k$ ) is the  $m$ th principal minor of  $H_{\sigma}$ . That is, the principal minors of the input substitution elasticity matrix  $H_{\sigma}$  alternate signs. In addition, it can be shown that under the homogeneity condition in (2.5.1),  $H_{\sigma}$  is singular and thus  $H_{\sigma k} \equiv 0$ . In other words, the condition in Equation (2.5.3)' only needs to be checked for  $m = 1, \dots, k-1$ .

In summary, the output-constrained input demand functions in Equations (2.4.5)-(2.4.8), (2.4.19)-(2.4.22), (2.4.28)-(2.4.32) and (2.4.41)-(2.4.46) in the model need to satisfy conditions in Equations (2.5.1)-(2.5.3), or equivalently (2.5.1)'-(2.5.3)', in order to be integrable.

### Input-Constrained Output Supply

The input-constrained output supply functions in the model are derived following general results in Equations (2.3.8) and (2.3.9). In order to be integrable relative to the revenue function in (2.3.8), the output supply in (2.3.9) needs to satisfy the following homogeneity, symmetry and convexity conditions. The derivation is in Appendix 1.

Using the Allen-Uzawa definition of the elasticity of product transformation (McFadden 1978, p79-80), i.e.

$$(2.5.5) \quad \tilde{\varepsilon}_{ij}(p, x) = \gamma_j(p, x) \tau_{ij}(p, x),$$

the homogeneity condition is given by

$$(2.5.6) \quad \sum_{j=1}^n \tilde{\varepsilon}_{ij}(p, x) = 0 \quad (i = 1, \dots, n) \quad (\text{homogeneity}), \text{ or}$$

$$(2.5.6)' \quad \sum_{j=1}^n \gamma_j(p, x) \tau_{ij}(p, x) = 0 \quad (i = 1, \dots, n) \quad (\text{homogeneity}),$$

where  $\tilde{\varepsilon}_{ij}(p, x)$  is the input-constrained output supply elasticity of  $y_i$  with respect to a change in output price  $p_j$ ,  $\gamma_j(\cdot) = (p_j y_j / R)$  is the share of the  $j$ th output in total revenue, and  $\tau_{ij}(p, x)$  is the Allen-Uzawa elasticity of product transformation between the  $i$ th and  $j$ th outputs ( $i, j = 1, \dots, n$ ).

The symmetry condition is given by

$$(2.5.7) \quad \gamma_i(p, x) \tilde{\varepsilon}_{ij}(p, x) = \gamma_j(p, x) \tilde{\varepsilon}_{ji}(p, x) \quad (i, j = 1, \dots, n) \quad (\text{symmetry}), \text{ or}$$

$$(2.5.7)' \quad \tau_{ij}(w, y) = \tau_{ji}(w, y) \quad (i, j = 1, \dots, n) \quad (\text{symmetry}).$$

In other words, the symmetry condition simply implies symmetry of the Allen-Uzawa product transformation elasticities.

The convexity condition requires that  $H_\varepsilon = (\tilde{\varepsilon}_{ij}(p, x))_{n \times n}$  or  $H_\tau = (\tau_{ij}(p, x))_{n \times n}$  is positive semidefinite. Thus, in terms of principal minors of these matrices, the convexity condition is equivalent to

$$(2.5.8) \quad H_{\varepsilon m} = \begin{vmatrix} \tilde{\varepsilon}_{11} & \tilde{\varepsilon}_{12} & \cdots & \tilde{\varepsilon}_{1m} \\ \tilde{\varepsilon}_{21} & \tilde{\varepsilon}_{22} & \cdots & \tilde{\varepsilon}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{\varepsilon}_{m1} & \tilde{\varepsilon}_{m2} & \cdots & \tilde{\varepsilon}_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, n) \quad (\text{convexity}), \text{ or}$$

$$(2.5.8)' \quad H_{\tau m} = \begin{vmatrix} \tau_{11} & \tau_{12} & \cdots & \tau_{1m} \\ \tau_{21} & \tau_{22} & \cdots & \tau_{2m} \\ \vdots & \vdots & & \vdots \\ \tau_{m1} & \tau_{m2} & \cdots & \tau_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, n) \quad (\text{convexity}).$$

That is, all principal minors of  $H_\varepsilon$  and  $H_\tau$  are non-negative. Again, both matrices are singular under the homogeneity condition, so the condition in (2.5.8) and (2.5.8)' is always true for  $m=n$ .

In summary, the integrability conditions for the output supplies in Equations (2.4.13)-(2.4.16), (2.4.25)-(2.4.26), (2.4.35)-(2.4.38) and (2.4.51)-(2.4.54) are given by the homogeneity, symmetry and convexity conditions in Equations (2.5.6)-(2.5.8), or their equivalent forms in (2.5.6)'-(2.5.8)'. These conditions will ensure the recovery of the "proper" underlying revenue functions (Equations (2.3.22)-(2.3.27)).

### Exogenous Input Supply

For the exogenous supply of inputs  $X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$  in Equations (2.4.1), (2.4.3)-(2.4.4), (2.4.17)-(2.4.18), (2.4.27), and (2.4.39)-(2.4.40), the decision-making problem is given in (2.3.28)-(2.3.29). As each of these eight inputs is the only decision variable from the model that appears in each relevant profit function, the three conditions as derived in Appendix 1 become very simple for this case. In fact, ensuring that the own-price supply elasticity is non-negative, ie.

$$(2.5.9) \quad \varepsilon_x \geq 0 \quad (x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me} \text{ and } Z_{md}),$$

is the only requirement for the model for the recovery of the 'proper' profit functions, where  $\varepsilon_x$  is the own-price supply elasticity of input  $x$  ( $x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$ ).

### Exogenous Output Demand

The integrability conditions for the group of demand equations in the model are discussed in Appendix 1. For the exogenous demand for  $Q_{ne}$  and  $Q_{se}$  in the export market, because the two types of beef are assumed to be consumed by different consumers and thus non-substitutable, the demand for each of  $Q_{ne}$  and  $Q_{se}$  needs to be integrable with the demand for other commodities that are not in the model. As a result, the only requirement within the model

system necessary for the recovery of a ‘proper’ utility function in Equation (2.3.30) is that the own-price demand elasticities in Equations (2.4.57) and (2.4.58) are non-positive, ie.

$$(2.5.10) \quad \eta_{(Q_{ie}, p_{ie})} \leq 0 \quad (i = n, s).$$

For the domestic demand for  $Q_{nd}$  and  $Q_{se}$ , the two types of beef are modelled as substitutes and relate to the utility maximization by the same domestic consumer in Equation (2.3.32). As a result, the demand for  $Q_{nd}$  and  $Q_{se}$  need to relate integrably with each other, as well as with demands for other commodities in the domestic consumer’s budget. The Marshallian economic surplus areas will be used as measures of welfare, which implies that the marginal utility of income is constant and the income effect will be ignored. Under this restrictive assumption, the integrability conditions of a symmetric and negative semidefinite Slutsky matrix means a symmetric and negative semidefinite Marshallian substitution matrix (Appendix 1). In particular, symmetry implies

$$(2.5.11) \quad \eta_{ij} = (\lambda_j/\lambda_i)\eta_{ji} \quad (i, j = nd, sd)$$

where  $\lambda_j/\lambda_i$  is the relative budget shares of the two commodities. As shown in Appendix 1, homogeneity and concavity conditions will not be violated when

$$(2.5.12) \quad \eta_{ii} \leq 0, \quad \eta_{ij} \geq 0 \quad \text{and} \quad |\eta_{ii}| > |\eta_{ij}| \quad (i, j = nd, sd),$$

which will always be satisfied by choosing sensible values of demand elasticities.

### 2.5.3 Integrability Considerations for EDM

Under the EDM approach, linear-in-price functions for all the demand and supply functions described in Equations (2.4.1)-(2.4.58) are in effect assumed around the local areas of the initial equilibrium points in all markets involved. This implies that the underlying preference functions in Equations (2.3.16)-(2.3.27), (2.3.28), (2.3.30) and (2.3.32) are of quadratic-in-price form locally. As discussed in Appendix 1, the homogeneity condition requires the constrained demand and supply functions to be homogeneous of degree zero (HD(0)) in prices. An immediate problem for satisfying the integrability conditions is that local linear demand and supply functions are locally HD(1) in prices by default rather HD(0). That is to say, the homogeneity condition can not be imposed on a linear function beyond a single point. In other words, to be globally integrable, the demand and supply functions can not be of an ordinary linear form.

However, the linear functions implicitly assumed in the derivation of the displacement model in Equations (2.4.1)-(2.4.58) are only local linear approximations of the true demand and supply functions in Equations (2.4.1)-(2.4.58), which are not necessarily of a linear functional form and which *can* satisfy the integrability conditions locally or even globally. For example, a normalised quadratic cost function (that is, a quadratic function with all prices divided by one input price) is globally HD(1) and the derived normalised linear input demands are globally HD(0). Thus, a symmetric and semidefinite parameter matrix for this functional form will give a global integrable specification. In other words, imposing the integrability conditions at a single point for this functional form implies satisfaction of integrability globally.

In the empirical specification of the model below, integrability conditions are imposed at the *initial equilibrium point*. These conditions are assumed to also hold locally for the true demand and supply functions in Equations (2.4.1)-(2.4.58) (for example if the true functional form is normalised linear). The displacement equations in (2.4.1)'-(2.4.58)' are viewed as a local linear approximation to the integrable model in Equations (2.4.1)-(2.4.58). Equivalently, the preference functions underlying Equations (2.4.1)'-(2.4.58)' are local second-order approximations to the true integrable preference functions underlying Equations (2.4.1)-(2.4.58) around the initial equilibrium point. As only small displacements from the initial equilibrium point (resulting from 1% exogenous shifts) are considered in the study and the model is integrable at the initial equilibrium point, the errors in the welfare measures will be small when parallel exogenous shifts are assumed.

The argument of second-order-approximation was suggested by Burt and Brewer (1971, p816) and explained by LaFrance (1991) in the case of the integrability of an incomplete demand system. LaFrance (1991) pointed out that, when the integrability conditions are imposed at a single point, a quadratic preference function based on the integrable values of first and second order derivatives at the base point "allows us to approximate the exact compensating variation of a price change from the base point to second order" (p1496).

Another justification for the small-error argument in this model is based on the empirical results by LaFrance (1991), who examined the integrability problem and its effects on consumer welfare measures in the context of an incomplete demand system. He compared four ways of imposing integrability conditions in the econometric estimation of a demand system. The first three approaches involve linear demand functions: the first one imposing symmetry of cross-price derivatives to ensure a unique welfare measure; the second one imposing Slutsky symmetry at a single point (sample mean); and the third one restricting the cross-price effect matrix to be symmetric, negative semidefinite. The fourth approach involved nonlinear demand functions satisfying so-called "weak integrability" (LaFrance and Hanemann 1989) for the incomplete demand system, which is claimed to enable the estimation of "exact welfare measures" (LaFrance and Hanemann 1989, p263). In his empirical example of a price policy, the estimates for the trapezoid welfare changes from all four approaches were very similar. However, when the triangular "deadweight loss" is the measure of interest, the first two approaches exhibited significant errors while the third approach was still a reasonably good approximation (15% error). While the model described here deals with a different empirical problem, some insights can still be drawn from LaFrance's (1991) results. In the current study, it is the whole trapezoid welfare change rather than the triangular 'deadweight loss' that is of interest. Thus, the errors in using a linear demand and supply system satisfying integrability conditions at the base equilibrium are expected to be small for the small displacements considered.

## 2.6 Displacement Model with Point Integrability Conditions

Using the definitions of the elasticities of input substitution and product transformation in Equations (2.5.4) and (2.5.5) and imposing equality restrictions of homogeneity and symmetry in Equations (2.5.1)'-(2.5.2)', (2.5.6)'-(2.5.7)' and (2.5.11), the displacement model in Equations (2.4.1)'-(2.4.58)' is transformed to Equations (2.6.1)-(2.6.58) below. Inequality constraints required by concavity and convexity in Equations (2.5.3)', (2.5.8)', (2.5.9), (2.5.10) and (2.5.12) will be ensured when setting the parameter values in Section 3.

Input Supply to Backgrounding and Grass-Finishing Sectors:

$$(2.6.1) \quad EX_1 = \varepsilon_{(X1, w1)}(EW_1 - t_{X1})$$

$$(2.6.2) \quad EX_1 = \rho_{Xn1}EX_{n1} + \rho_{Xs1}EX_{s1}$$

$$(2.6.3) \quad EX_{n2} = \varepsilon_{(Xn2, wn2)}(EW_{n2} - t_{Xn2})$$

$$(2.6.4) \quad EX_{s2} = \varepsilon_{(Xs2, ws2)}(EW_{s2} - t_{Xs2})$$

Output-Constrained Input Demand of Backgrounding and Grass-Finishing Sectors:

$$(2.6.5) \quad EX_{n1} = -\kappa_{Xn2}\sigma_{(Xn1, Xn2)}EW_1 + \kappa_{Xn2}\sigma_{(Xn1, Xn2)}EW_{n2} + EF_{n1}$$

$$(2.6.6) \quad EX_{n2} = \kappa_{Xn1}\sigma_{(Xn1, Xn2)}EW_1 - \kappa_{Xn1}\sigma_{(Xn1, Xn2)}EW_{n2} + EF_{n1}$$

$$(2.6.7) \quad EX_{s1} = -\kappa_{Xs2}\sigma_{(Xs1, Xs2)}EW_1 + \kappa_{Xs2}\sigma_{(Xs1, Xs2)}EW_{s2} + EY_s$$

$$(2.6.8) \quad EX_{s2} = \kappa_{Xs1}\sigma_{(Xs1, Xs2)}EW_1 - \kappa_{Xs1}\sigma_{(Xs1, Xs2)}EW_{s2} + EY_s$$

Backgrounding and Grass-Finishing Sectors Equilibrium:

$$(2.6.9) \quad \kappa_{Xn1}EX_{n1} + \kappa_{Xn2}EX_{n2} = \gamma_{Fn1e}EF_{n1e} + \gamma_{Fn1d}EF_{n1d}$$

$$(2.6.10) \quad \kappa_{Xn1}EW_1 + \kappa_{Xn2}EW_{n2} = \gamma_{Fn1e}ES_{n1e} + \gamma_{Fn1d}ES_{n1d}$$

$$(2.6.11) \quad \kappa_{Xs1}EX_{s1} + \kappa_{Xs2}EX_{s2} = \gamma_{Yse}EY_{se} + \gamma_{Ysd}EY_{sd}$$

$$(2.6.12) \quad \kappa_{Xs1}EW_1 + \kappa_{Xs2}EW_{s2} = \gamma_{Yse}EV_{se} + \gamma_{Ysd}EV_{sd}$$

Input-Constrained Output Supply of Backgrounding and Grass-Finishing Sectors:

$$(2.6.13) \quad EF_{n1e} = -\gamma_{Fn1d}\tau_{(Fn1e, Fn1d)}ES_{n1e} + \gamma_{Fn1d}\tau_{(Fn1e, Fn1d)}ES_{n1d} + EX_n$$

$$(2.6.14) \quad EF_{n1d} = \gamma_{Fn1e}\tau_{(Fn1e, Fn1d)}ES_{n1e} - \gamma_{Fn1e}\tau_{(Fn1e, Fn1d)}ES_{n1d} + EX_n$$

$$(2.6.15) \quad EY_{se} = -\gamma_{Ysd}\tau_{(Yse, Ysd)}EV_{se} + \gamma_{Ysd}\tau_{(Yse, Ysd)}EV_{sd} + EX_s$$

$$(2.6.16) \quad EY_{sd} = \gamma_{Yse}\tau_{(Yse, Ysd)}EV_{se} - \gamma_{Yse}\tau_{(Yse, Ysd)}EV_{sd} + EX_s$$

Other Input Supply to Feedlot Sector

$$(2.6.17) \quad EF_{n2} = \varepsilon_{(Fn2, sn2)}(ES_{n2} - t_{Fn2})$$

$$(2.6.18) \quad EF_{n3} = \varepsilon_{(Fn3, sn3)}(ES_{n3} - t_{Fn3})$$

Output-Constrained Input Demand of Feedlot Sector:

$$(2.6.19) \quad EF_{n1e} = -(\kappa_{Fn1d}\sigma_{(Fn1e, Fn1d)} + \kappa_{Fn2}\sigma_{(Fn1e, Fn2)} + \kappa_{Fn3}\sigma_{(Fn1e, Fn3)})ES_{n1e} \\ + \kappa_{Fn1d}\sigma_{(Fn1e, Fn1d)}ES_{n1d} + \kappa_{Fn2}\sigma_{(Fn1e, Fn2)}ES_{n2} + \kappa_{Fn3}\sigma_{(Fn1e, Fn3)}ES_{n3} + EY_n$$

$$(2.6.20) \quad EF_{n1d} = \kappa_{Fn1e}\sigma_{(Fn1e, Fn1d)}ES_{n1e} + \kappa_{Fn2}\sigma_{(Fn1d, Fn2)}ES_{n2} + \kappa_{Fn3}\sigma_{(Fn1d, Fn3)}ES_{n3} \\ - (\kappa_{Fn1e}\sigma_{(Fn1e, Fn1d)} + \kappa_{Fn2}\sigma_{(Fn1d, Fn2)} + \kappa_{Fn3}\sigma_{(Fn1d, Fn3)})ES_{n1d} + EY_n$$

$$(2.6.21) \quad EF_{n2} = \kappa_{Fn1e}\sigma_{(Fn1e, Fn2)}ES_{n1e} + \kappa_{Fn1d}\sigma_{(Fn1d, Fn2)}ES_{n1d} + \kappa_{Fn3}\sigma_{(Fn2, Fn3)}ES_{n3} \\ - (\kappa_{Fn1e}\sigma_{(Fn1e, Fn2)} + \kappa_{Fn1d}\sigma_{(Fn1d, Fn2)} + \kappa_{Fn3}\sigma_{(Fn2, Fn3)})ES_{n2} + EY_n$$

$$(2.6.22) \quad EF_{n3} = \kappa_{Fn1e}\sigma_{(Fn1e, Fn3)}ES_{n1e} + \kappa_{Fn1d}\sigma_{(Fn1d, Fn3)}ES_{n1d} + \kappa_{Fn2}\sigma_{(Fn2, Fn3)}ES_{n2} \\ - (\kappa_{Fn1e}\sigma_{(Fn1e, Fn3)} + \kappa_{Fn1d}\sigma_{(Fn1d, Fn3)} + \kappa_{Fn2}\sigma_{(Fn2, Fn3)})ES_{n3} + EY_n$$

Feedlot Sector Equilibrium:

$$(2.6.23) \quad \kappa_{Fn1e}EF_{n1e} + \kappa_{Fn1d}EF_{n1d} + \kappa_{Fn2}EF_{n2} + \kappa_{Fn3}EF_{n3} = \gamma_{Yne}EY_{ne} + \gamma_{Ynd}EY_{nd}$$

$$(2.6.24) \quad \kappa_{Fn1e}ES_{n1e} + \kappa_{Fn1d}ES_{n1d} + \kappa_{Fn2}ES_{n2} + \kappa_{Fn3}ES_{n3} = \gamma_{Yne}EV_{ne} + \gamma_{Ynd}EV_{nd}$$

Input-Constrained Output Supply of Feedlot Sector:

$$(2.6.25) \quad EY_{ne} = -\gamma_{Ynd}\tau_{(Yne, Ynd)}EV_{ne} + \gamma_{Ynd}\tau_{(Yne, Ynd)}EV_{nd} + EF_n$$

$$(2.6.26) \quad EY_{nd} = \gamma_{Yne}\tau_{(Yne, Ynd)}EV_{ne} - \gamma_{Yne}\tau_{(Yne, Ynd)}EV_{nd} + EF_n$$

Other Input Supply to Processing Sector

$$(2.6.27) \quad EY_p = \varepsilon_{(Yp, vp)}(EV_p - t_{yp})$$

Output-Constrained Input Demand of Processing Sector:

$$(2.6.28) \quad EY_{se} = -(\kappa_{Ysd}\sigma_{(Yse, Ysd)} + \kappa_{Yne}\sigma_{(Yse, Yne)} + \kappa_{Ynd}\sigma_{(Yse, Ynd)} + \kappa_{Yp}\sigma_{(Yse, Yp)})EV_{se} \\ + \kappa_{Ysd}\sigma_{(Yse, Ysd)}EV_{sd} + \kappa_{Yne}\sigma_{(Yse, Yne)}EV_{ne} + \kappa_{Ynd}\sigma_{(Yse, Ynd)}EV_{nd} + \kappa_{Yp}\sigma_{(Yse, Yp)}EV_p + EZ$$

$$(2.6.29) \quad EY_{sd} = \kappa_{Yse}\sigma_{(Yse, Ysd)}EV_{se} - (\kappa_{Yse}\sigma_{(Yse, Ysd)} + \kappa_{Yne}\sigma_{(Ysd, Yne)} + \kappa_{Ynd}\sigma_{(Ysd, Ynd)} \\ + \kappa_{Yp}\sigma_{(Ysd, Yp)})EV_{sd} + \kappa_{Yne}\sigma_{(Ysd, Yne)}EV_{ne} + \kappa_{Ynd}\sigma_{(Ysd, Ynd)}EV_{nd} \\ + \kappa_{Yp}\sigma_{(Ysd, Yp)}EV_p + EZ$$

$$(2.6.30) \quad EY_{ne} = \kappa_{Yse}\sigma_{(Yse, Yne)}EV_{se} + \kappa_{Ysd}\sigma_{(Ysd, Yne)}EV_{sd} - (\kappa_{Yse}\sigma_{(Yse, Yne)} + \kappa_{Ysd}\sigma_{(Ysd, Yne)} \\ + \kappa_{Ynd}\sigma_{(Yne, Ynd)} + \kappa_{Yp}\sigma_{(Yne, Yp)})EV_{ne} + \kappa_{Ynd}\sigma_{(Yne, Ynd)}EV_{nd} + \kappa_{Yp}\sigma_{(Yne, Yp)}EV_p + EZ$$

$$(2.6.31) \quad EY_{nd} = \kappa_{Yse}\sigma_{(Yse, Ynd)}EV_{se} + \kappa_{Ysd}\sigma_{(Ysd, Ynd)}EV_{sd} + \kappa_{Yne}\sigma_{(Yne, Ynd)}EV_{ne} \\ - (\kappa_{Yse}\sigma_{(Yse, Ynd)} + \kappa_{Ysd}\sigma_{(Ysd, Ynd)} + \kappa_{Yne}\sigma_{(Yne, Ynd)} + \kappa_{Yp}\sigma_{(Ynd, Yp)})EV_{nd} + \kappa_{Yp}\sigma_{(Ynd, Yp)}EV_p + EZ$$

$$(2.6.32) \quad EY_p = \kappa_{Yse}\sigma_{(Yse, Yp)}EV_{se} + \kappa_{Ysd}\sigma_{(Ysd, Yp)}EV_{sd} + \kappa_{Yne}\sigma_{(Yne, Yp)}EV_{ne} \\ + \kappa_{Ynd}\sigma_{(Ynd, Yp)}EV_{nd} - \\ (\kappa_{Yse}\sigma_{(Yse, Yp)} + \kappa_{Ysd}\sigma_{(Ysd, Yp)} + \kappa_{Yne}\sigma_{(Yne, Yp)} + \kappa_{Ynd}\sigma_{(Ynd, Yp)})EV_p + EZ$$

Processing Sector Equilibrium:

$$(2.6.33) \quad \kappa_{Yse}EY_{se} + \kappa_{Ysd}EY_{sd} + \kappa_{Yne}EY_{ne} + \kappa_{Ynd}EY_{nd} + \kappa_{Yp}EY_p \\ = \gamma_{Zse}EZ_{se} + \gamma_{Zsd}EZ_{sd} + \gamma_{Zne}EZ_{ne} + \gamma_{Znd}EZ_{nd}$$

$$(2.6.34) \quad \kappa_{Yse}EV_{se} + \kappa_{Ysd}EV_{sd} + \kappa_{Yne}EV_{ne} + \kappa_{Ynd}EV_{nd} + \kappa_{Yp}EV_p \\ = \gamma_{Zse}Eu_{se} + \gamma_{Zsd}Eu_{sd} + \gamma_{Zne}Eu_{ne} + \gamma_{Znd}Eu_{nd}$$

Input-Constrained output supply of Processing Sector:

$$(2.6.35) \quad EZ_{se} = -(\gamma_{Zsd}\tau_{(Zse, Zsd)} + \gamma_{Zne}\tau_{(Zse, Zne)} + \gamma_{Znd}\tau_{(Zse, Znd)})Eu_{se} \\ + \gamma_{Zsd}\tau_{(Zse, Zsd)}Eu_{sd} + \gamma_{Zne}\tau_{(Zse, Zne)}Eu_{ne} + \gamma_{Znd}\tau_{(Zse, Znd)}Eu_{nd} + EY$$

$$(2.6.36) \quad EZ_{sd} = \gamma_{Zse}\tau_{(Zse, Zsd)}Eu_{se} + \gamma_{Zne}\tau_{(Zsd, Zne)}Eu_{ne} + \gamma_{Znd}\tau_{(Zsd, Znd)}Eu_{nd} \\ - (\gamma_{Zse}\tau_{(Zse, Zsd)} + \gamma_{Zne}\tau_{(Zsd, Zne)} + \gamma_{Znd}\tau_{(Zsd, Znd)})Eu_{sd} + EY$$

$$(2.6.37) \quad EZ_{ne} = \gamma_{Zse}\tau_{(Zse, Zne)}Eu_{se} + \gamma_{Zsd}\tau_{(Zsd, Zne)}Eu_{sd} + \gamma_{Znd}\tau_{(Zne, Znd)}Eu_{nd} \\ - (\gamma_{Zse}\tau_{(Zse, Zne)} + \gamma_{Zsd}\tau_{(Zsd, Zne)} + \gamma_{Znd}\tau_{(Zne, Znd)})Eu_{ne} + EY$$

$$(2.6.38) \quad EZ_{nd} = \gamma_{Zse}\tau_{(Zse, Znd)}Eu_{se} + \gamma_{Zsd}\tau_{(Zsd, Znd)}Eu_{sd} + \gamma_{Zne}\tau_{(Zne, Znd)}Eu_{ne} \\ - (\gamma_{Zse}\tau_{(Zse, Znd)} + \gamma_{Zsd}\tau_{(Zsd, Znd)} + \gamma_{Zne}\tau_{(Zne, Znd)})Eu_{nd} + EY$$

Other Input Supply to Marketing Sectors:

$$(2.6.39) \quad EZ_{md} = \varepsilon_{(Zmd, umd)}(Eu_{md} - t_{Zmd})$$

$$(2.6.40) \quad EZ_{me} = \varepsilon_{(Zme, ume)}(Eu_{me} - t_{Zme})$$

Output-Constrained Input Demand of Marketing Sectors:

$$(2.6.41) \quad EZ_{sd} = -(\kappa_{Znd}\sigma_{(Zsd, Znd)} + \kappa_{Zmd}\sigma_{(Zsd, Zmd)})Eu_{sd} \\ + \kappa_{Znd}\sigma_{(Zsd, Znd)}Eu_{nd} + \kappa_{Zmd}\sigma_{(Zsd, Zmd)}Eu_{md} + EQ_d$$

$$(2.6.42) \quad EZ_{nd} = \kappa_{Zsd}\sigma_{(Zsd, Znd)}Eu_{sd} + \kappa_{Zmd}\sigma_{(Znd, Zmd)}Eu_{md} \\ - (\kappa_{Zsd}\sigma_{(Zsd, Znd)} + \kappa_{Zmd}\sigma_{(Znd, Zmd)})Eu_{nd} + EQ_d$$

$$(2.6.43) \quad EZ_{md} = \kappa_{Zsd}\sigma_{(Zsd, Zmd)}Eu_{sd} + \kappa_{Znd}\sigma_{(Znd, Zmd)}Eu_{nd} \\ - (\kappa_{Zsd}\sigma_{(Zsd, Zmd)} + \kappa_{Znd}\sigma_{(Znd, Zmd)})Eu_{md} + EQ_d$$

$$(2.6.44) \quad EZ_{se} = -(\kappa_{Zne}\sigma_{(Zse, Zne)} + \kappa_{Zme}\sigma_{(Zse, Zme)})Eu_{se} \\ + \kappa_{Zne}\sigma_{(Zse, Zne)}Eu_{ne} + \kappa_{Zme}\sigma_{(Zse, Zme)}Eu_{me} + EQ_e$$

$$(2.6.45) \quad EZ_{ne} = \kappa_{Zse}\sigma_{(Zse, Zne)}Eu_{se} + \kappa_{Zme}\sigma_{(Zne, Zme)}Eu_{me} \\ - (\kappa_{Zse}\sigma_{(Zse, Zne)} + \kappa_{Zme}\sigma_{(Zne, Zme)})Eu_{ne} + EQ_e$$

$$(2.6.46) \quad EZ_{me} = \kappa_{Zse}\sigma_{(Zse, Zme)}Eu_{se} + \kappa_{Zne}\sigma_{(Zne, Zme)}Eu_{ne} \\ - (\kappa_{Zse}\sigma_{(Zse, Zme)} + \kappa_{Zne}\sigma_{(Zne, Zme)})Eu_{me} + EQ_e$$

Domestic Marketing Sector Equilibrium:

$$(2.6.47) \quad \kappa_{Zsd}EZ_{sd} + \kappa_{Znd}EZ_{nd} + \kappa_{Zmd}EZ_{md} = \gamma_{Qsd}EQ_{sd} + \gamma_{Qnd}EQ_{nd}$$

$$(2.6.48) \quad \kappa_{Zsd}Eu_{sd} + \kappa_{Znd}Eu_{nd} + \kappa_{Zmd}Eu_{md} = \gamma_{Qsd}Ep_{sd} + \gamma_{Qnd}Ep_{nd}$$

Export Marketing Sector Equilibrium:

$$(2.6.49) \quad \kappa_{Zse}EZ_{se} + \kappa_{Zne}EZ_{ne} + \kappa_{Zme}EZ_{me} = \gamma_{Qse}EQ_{se} + \gamma_{Qne}EQ_{ne}$$

$$(2.6.50) \quad \kappa_{Zse}Eu_{se} + \kappa_{Zne}Eu_{ne} + \kappa_{Zme}Eu_{me} = \gamma_{Qse}Ep_{se} + \gamma_{Qne}Ep_{ne}$$

Input-Constrained Output Supply of Marketing Sectors:

$$(2.6.51) \quad EQ_{sd} = -\gamma_{Qnd}\tau_{(Qsd, Qnd)}Ep_{sd} + \gamma_{Qnd}\tau_{(Qsd, Qnd)}Ep_{nd} + EZ_d$$

$$(2.6.52) \quad EQ_{nd} = \gamma_{Qsd}\tau_{(Qsd, Qnd)}Ep_{sd} - \gamma_{Qsd}\tau_{(Qsd, Qnd)}Ep_{nd} + EZ_d$$

$$(2.6.53) \quad EQ_{se} = -\gamma_{Qne}\tau_{(Qse, Qne)}Ep_{se} + \gamma_{Qne}\tau_{(Qse, Qne)}Ep_{ne} + EZ_e$$

$$(2.6.54) \quad EQ_{ne} = \gamma_{Qse}\tau_{(Qse, Qne)}Ep_{se} - \gamma_{Qse}\tau_{(Qse, Qne)}Ep_{ne} + EZ_e$$

Domestic Retail Beef Demand:

$$(2.6.55) \quad EQ_{sd} = \eta_{(Qsd, psd)}(Ep_{sd} - n_{Qsd}) + \eta_{(Qsd, pnd)}(Ep_{nd} - n_{Qnd})$$

$$(2.6.56) \quad EQ_{nd} = \eta_{(Qnd, psd)}(Ep_{sd} - n_{Qsd}) + \eta_{(Qnd, pnd)}(Ep_{nd} - n_{Qnd})$$

where  $\eta_{(Qnd, psd)} = \eta_{(Qsd, pnd)} \left( \frac{p_{sd}^{(1)} Q_{sd}^{(1)}}{p_{nd}^{(1)} Q_{nd}^{(1)}} \right)$ , and  $p_i^{(1)}$  and  $Q_i^{(1)}$  ( $i=sd$  and  $nd$ ) are the initial price and quantity, respectively, for the two domestic beef products.

Export Demand for Australian Beef:

$$(2.6.57) \quad EQ_{se} = \eta_{(Qse, pse)}(Ep_{se} - n_{Qse})$$

$$(2.6.58) \quad EQ_{ne} = \eta_{(Qne, pne)}(Ep_{ne} - n_{Qne})$$

### 3 Specifications of Base Equilibrium Values, Market Parameters and Exogenous Shifts

#### 3.1 Introduction

The information required for operating the equilibrium displacement model in Equations (2.6.1)-(2.6.58) is in three parts: (1) base price and quantity values for all inputs and outputs, which define the base equilibrium status of the system; (2) market parameters required in the model, which describe the market responsiveness of quantity variables to price changes; and (3) the values of all exogenous shift variables for all simulated scenarios, which quantify the effects of new technologies and promotions. In this Section, the specification of these data is described.

Under the three assumptions given in the model specification in Section 2.3, the total cost is equal to the total revenue for each industry sector, that is

$$(3.1) \quad \sum_{i=n,s,m} u_{ie} Z_{ie} = \sum_{i=n,s} p_{ie} Q_{ie} \quad \text{export marketing equilibrium,}$$

$$(3.2) \quad \sum_{i=n,s,m} u_{id} Z_{id} = \sum_{i=n,s} p_{id} Q_{id} \quad \text{domestic marketing equilibrium,}$$

$$(3.3) \quad \sum_{i=ne,nd,se,sd,p} v_i Y_i = \sum_{i=ne,nd,se,sd} u_i Z_i \quad \text{processing sector equilibrium,}$$

$$(3.4) \quad \sum_{i=1e,1d,2,3} s_{ni} F_{ni} = \sum_{i=e,d} v_{ni} Y_{ni} \quad \text{feedlot sector equilibrium,}$$

$$(3.5) \quad w_1 X_{n1} + w_{n2} X_{n2} = \sum_{i=1e,1d} s_{ni} F_{ni} \quad \text{backgrounding sector equilibrium,}$$

$$(3.6) \quad w_1 X_{s1} + w_{s2} X_{s2} = \sum_{i=e,d} v_{si} Y_{si} \quad \text{grass-finishing sector equilibrium.}$$

To keep the model and data requirements manageable, it is assumed in the above equalities that all by-products such as hide, offal, fat and trim in each sector are of zero value. In reality, these values are non-zero but less than a few percent of total sectoral revenues<sup>2</sup>.

The input cost shares and output revenue shares for all sectors, which are required for solving the model, can be calculated after specification of the equilibrium prices and quantities. The cost share for ‘other inputs’ in each sector is calculated as the residual using the equilibrium identities in Equations (3.1)-(3.6).

<sup>2</sup> For example, using a price of \$0.1/kg for all by-products (Griffith, Green and Duff 1991), the ignored revenue shares of by-products are around 3.5% for the processing sector, 1% for the domestic marketing sector and 2% for the export marketing sector.

In 3.2 and Appendix 2, the specification of a set of base equilibrium prices and quantities for all inputs and outputs is described. The base equilibrium values are specified as the average prices and quantities for 1992 to 1997. In other words, the study is based on an average situation during 1992-1997. Input cost shares and output revenue shares are derived accordingly. More details of the sources, the assumptions made and the derivation of prices and quantities of all sectors for each year of 1992 to 1997 are documented in Zhao and Griffith (2000).

Market parameters required in the model are specified in 3.3, based on information from existing empirical studies, economic theory and subjective judgement. These parameters include input substitution elasticities, product transformation elasticities, and various beef demand and factor supply elasticities. The elasticity values are chosen to reflect a medium run time frame, the time required for the industry to reach a new equilibrium after an exogenous shock. Integrability constraints among the elasticities at the base equilibrium points as outlined in Section 2.5, including the curvature conditions, are ensured in the parameter specification.

In 3.4, the values of all exogenous shifter variables in the model are specified as 1% of the base price level in the relevant markets. In other words, results for all scenarios relate to equal 1% vertical shifts in the relevant demand or supply curves in the markets where the exogenous changes occur.

## **3.2 Base Equilibrium Price and Quantity Values**

### ***3.2.1 Prices and Quantities***

The annual quantities and prices of the four types of cattle or beef products at all production and marketing stages are required for the period of 1992 to 1997. These include quantities of weaners, backgrounded cattle, grass/grain finished cattle, processed beef carcass, and final products as f.o.b. (free on board) export boxes and domestic retail cuts. The annual feedgrain consumption by the beef industry and the associated prices are also needed for the period.

Significant effort has been invested in this study to compile a set of consistent equilibrium prices and quantities for all sectors and product types. There are no published data that are disaggregated to the level required in the model. Published data are taken from various government and industry agencies and other available sources, assumptions are made regarding the relationship of cattle prices and quantities at different levels, and the rest of the required prices and quantities are derived based on these assumptions (Zhao and Griffith 2000).

The specification of prices and quantities for all inputs and outputs for all sectors are detailed in Appendix 2. The resulting average prices and quantities for 1992-1997 are listed in Table 3.1. Refer to Table 2.3 or Figure 2.1 for variable definitions.

**Table 3.1 Base Equilibrium Prices, Quantities and Cost and Revenue Shares  
(average of 1992-1997)**

	<b>Quantity and Price</b>	<b>Cost and Revenue Shares</b>
<b>Final Beef Products</b>	<p><b>Export</b> (in <i>kt</i> and <i>\$/kg</i>, shipped weight):</p> $Q_{ne} = 110, p_{ne} = 5.66,$ $Q_{se} = 665, p_{se} = 3.06. TV_{Qe} = 2658$	<p><b>Export Marketing Revenue Shares:</b></p> $\gamma_{Qne} = 0.23, \gamma_{Qse} = 0.77$
	<p><b>Domestic</b> (in <i>kt</i> and <i>\$/kg</i>, retail cuts):</p> $Q_{nd} = 92, p_{nd} = 10.31$ $Q_{sd} = 404, p_{sd} = 7.81. TV_{Qd} = 4104$	<p><b>Domestic Marketing Revenue shares:</b></p> $\gamma_{Qnd} = 0.23, \gamma_{Qsd} = 0.77$
	$TV_Q = 6762$	
<b>Wholesale Carcass</b>	<p>(in <i>kt</i> and <i>\$/kg</i>, carcass weight)</p> $Z_{ne} = 161, u_{ne} = 2.45,$ $Z_{se} = 974, u_{se} = 2.13. TV_{Zc} = 2469$	<p><b>Export Marketing Cost Shares:</b></p> $\kappa_{Zne} = 0.15, \kappa_{Zse} = 0.78$ $\kappa_{Zme} = 0.07$
	$Z_{nd} = 128, u_{nd} = 2.70,$ $Z_{sd} = 561, u_{sd} = 2.45. TV_{Zd} = 1720$	<p><b>Domestic Marketing Cost Shares:</b></p> $\kappa_{Znd} = 0.08, \kappa_{Zsd} = 0.34$ $\kappa_{Zmd} = 0.58$
	$TV_Z = 4189$	<p><b>Processing Sector Revenue Shares:</b></p> $\gamma_{Zne} = 0.09, \gamma_{Zse} = 0.50,$ $\gamma_{Znd} = 0.08, \gamma_{Zsd} = 0.33.$
<b>Finished Live Cattle</b>	<p>(in <i>kt</i> and <i>\$/kg</i>, live weight)</p> $Y_{ne} = 293, v_{ne} = 1.20,$ $Y_{nd} = 232, v_{nd} = 1.34. TV_{Yn} = 662$	<p><b>Processing Sector Cost Shares:</b></p> $\kappa_{Yne} = 0.08, \kappa_{Yse} = 0.43,$ $\kappa_{Ynd} = 0.07, \kappa_{Ysd} = 0.29,$ $\kappa_{Yp} = 0.12.$
	$Y_{se} = 1772, v_{se} = 1.03,$ $Y_{sd} = 1019, v_{sd} = 1.21. TV_{Ys} = 3058$	<p><b>Feedlot Sector Revenue Shares:</b></p> $\gamma_{Yne} = 0.53, \gamma_{Ynd} = 0.47$
	$TV_Y = 3720$	<p><b>Grass Finishing Sector Revenue Shares:</b></p> $\gamma_{Yse} = 0.60, \gamma_{Ysd} = 0.40$
<b>Feeder Cattle and Feedgrain</b>	<p><b>Feeders</b> (in <i>kt</i> and <i>\$/kg</i>, live weight):</p> $F_{n1e} = 205, s_{n1e} = 1.12,$ $F_{n1d} = 172, s_{n1d} = 1.02. TV_{F1} = 405$	<p><b>Feedlot Sector Cost Shares:</b></p> $\kappa_{Fn1e} = 0.35, \kappa_{Fn1d} = 0.26,$ $\kappa_{Fn2} = 0.22, \kappa_{Fn3} = 0.17.$
	<p><b>Feedgrain</b> (in <i>kt</i> and <i>\$/kg</i>):</p> $F_{n2} = 819, s_{n2} = 0.176$	<p><b>Backgrounding Sector Revenue Shares:</b></p> $\gamma_{Fn1e} = 0.57, \gamma_{Fn1d} = 0.43.$
<b>Weaner Cattle</b>	<p>(in <i>kt</i> and <i>\$/kg</i>, live weight)</p> $X_{n1} = 206, X_{s1} = 1542,$ $X_1 = 1748, w_1 = 1.12. TV_{X1} = 1958$	<p><b>Backgrounding Sector Cost Shares:</b></p> $\kappa_{Xn1} = 0.57, \kappa_{Xn2} = 0.43.$
		<p><b>Grass Finishing Sector Cost Shares:</b></p> $\kappa_{Xs1} = 0.56, \kappa_{Xs2} = 0.44.$

Table 3.2 Published Estimates of Domestic Retail Beef Demand Elasticities for Australia

Source	Beef Demand Elasticities					Income	Data Period (Annual or Quarterly Data)	Area
	Beef	Lamb	Mutton	Pork	Chicken			
Taylor (1961)	-0.96	*	*	*	*	*	1950/51-1959/60 (A)	Aust.
Van der Meulen (1961)	-0.71	0.49	*	*	*	0.40	1948/49-1959/60 (A)	Sydney
Taylor (1963)	-0.87, -1.03	*	*	*	*	*	1950/51-1959/60 (A)	Aust.
Marceau (1967)	-1.33	0.02	*	*	*	-0.24	1951-1963 (Q)	N.S.W.
Gruen,et.al.(1967,a &b)	-0.79, -0.96	*	*	*	*	*	1949/50-1964/65 (A)	Aust.
Van der Meulen (68)	-1.3	*	*	*	*	-0.24	1949/50-1961/62(A)	Aust.
Papadopoulos (71)	-2.06	-0.23	-0.13	1.43	*	0.98	1962(I)- 1970(II) (Q)	N.S.W.
Throsby (72)	-1.90	*	*	*	*	0.59	1962-1972 (Q)	Aust.
Throsby (74)	-0.76, -0.7~-1.0	0.04, 0~0.2	*	*	*	0.22, 0.2~0.4	1962-1972 (Q)	Aust.
Greenfield (74)	-1.71	*	*	*	*	1.23	1955-1972 (A)	Aust.
Main et.al. (76)	-1.38~-1.46	0.03~0.09	0.32~0.34	*	*	0.37~0.47	1962(I)- 1975(II) (Q)	Aust
Freebairn&Gruen (1977)							1962(I)- 1975(IV) (A)	Aust.
high prices	-1.85	*	*	*	*	*		
low prices	-0.90	*	*	*	*	*		
Johnson (1978)	-1.21~-1.56	*	*	*	*	0.38~0.46	1962(I)-1975(IV) (A)	Aust.
Fisher (1979)	-1.19	0.14	*	0.14	*	0.54	1962-1977(A)	Aust.
Murray (1984)							1949/50-1978/79 (A)	Aust.
AIDS	-1.95	0.32	0.18	0.19	0.09	1.18		
Translog	-1.42	0.15	0.20	0.13	0.01	0.93		
Addilog	-1.62	0.12	0.09	0.08	-0.03	1.36		
Dewbre et.al. (1985)	-0.98	*	*	*	*	*	*	Aust.
Martin&Porter (1985)	-1.13	0.06	0.20	0.63	0.19	0.68	1962(I)-1983(I) (Q)	Aust.
Chalfant&Alston (1986)	-1.38, -1.46	*	*	*	*	1.49, 1.46	1962-1983 (Q)	Aust.
Cashin (1991)	-1.24	-0.02	*	-0.20	-0.19	1.65	1967(I)-1990(II) (Q)	Aust.
	-0.82	-0.11	*	*	-0.36	1.38	1982(I)-1990(II) (Q)	Aust.
Harris&Shaw (1992)	-0.92	*	*	*	*	0.26	1960-1980 (A)	Aust.
Piggott <i>et.al.</i> (1996)	-0.42	0.43	*	0.13	-0.14	1.82	1978(3)-1988(4)	Aust.

Source: Griffith, *et al.* (2000a)

### 3.2.2 Cost and Revenue Shares

Based on the price and quantity values specified in Appendix 2, the cost and revenue shares required in the model are derived for all sectors. The input cost shares for the ‘other inputs’ variables in all sectors are calculated as residuals using the equilibrium conditions in Equations (3.1)-(3.6).

The average total sector values ( $TV_{(.)}$ 's) and the cost and revenue shares ( $\kappa_{(.)}$ 's and  $\gamma_{(.)}$ 's) for all sectors for the period of 1992-1997 are summarised in Table 3.1. These cost and revenue shares are required for solving the equilibrium displacement model in Equations (2.6.1) and (2.6.58).

### 3.3 Market Parameters

Values of market elasticities are based on economic theory, existing econometric estimations and subjective judgement. As discussed below, very limited empirical estimates are available for many of these elasticities. As a result, considerable uncertainty is involved when specifying the market elasticities (or parameters). A systematic approach to sensitivity analysis was developed by Zhao, Griffiths, Griffith and Mullen (1999) to quantify the uncertainty in the model results with regard to the uncertainty in the choice of parameter values. In the context of the probability distributions developed in that paper, the single value specified for each parameter below can be viewed as the ‘most likely’ value for the parameter. The integrability restrictions discussed in Section 2.5 are also guaranteed in the parameter specification.

#### 3.3.1 Exogenous Beef Demand Elasticities

##### Domestic

The own-price and cross-price demand elasticities for domestic grainfed and grassfed beef at retail level (i.e.  $\eta_{(Qnd, pnd)}$ ,  $\eta_{(Qnd, psd)}$ ,  $\eta_{(Qsd, pnd)}$  and  $\eta_{(Qsd, psd)}$ ) are required for solving the model. As discussed earlier, Australia does not have a domestic grading system that could provide the data on separate grainfed and grassfed beef. Consequently, the published estimates on beef demand elasticities are all with regard to aggregated beef as a homogenous product.

There is a large amount of literature dealing with domestic beef demand. Although data periods, model specifications and estimation methods are different in these studies, the range of the estimated demand elasticities is relatively stable. Both Richardson (1976) and Main, Reynolds and White (1976) reviewed some earlier estimates of domestic beef demand elasticities, and Griffith *et al.* (2000a) surveyed more recent studies. The published estimates are summarised in Table 3.2. As can be seen from the Table, the estimated domestic beef demand elasticities range from -0.71 to -2.06. The majority of the nearly 30 estimates reviewed are between -0.70 and -1.50, with -1.1 as the mid-point of the range. This compares to some earlier estimates of -0.9 to -1.0 for the United States and around -1.0 for the United Kingdom (see Throsby 1974 and references therein).

The majority of the Australian domestic consumed beef is grassfed, and this was certainly the case when the earlier studies of meat demand were conducted. Thus the elasticities in Table 3.2 are considered to be a good indication of the domestic grassfed beef demand elasticity. Grainfed beef has a higher price and better quality in comparison to grassfed beef, and thus it is expected to be more price elastic than grassfed beef. In the base model, -1.1 and -1.6 are used respectively as the grassfed and grainfed beef elasticities for domestic demand. That is,  $\eta_{(Q_{sd}, p_{sd})} = -1.1$  and  $\eta_{(Q_{nd}, p_{nd})} = -1.6$ .

The cross-price elasticities need to satisfy the symmetry condition in Equation (2.5.11) of Section 2, ie.  $\eta_{(Q_{nd}, p_{sd})} = (\lambda_{sd}/\lambda_{nd})\eta_{(Q_{nd}, p_{nd})}$ , where  $(\lambda_{sd}/\lambda_{nd})$  is the ratio of the expenditure shares of the two types of beef. For the base equilibrium defined in Table 3.1,  $\lambda_{sd}/\lambda_{nd} = (p_{sd}Q_{sd})/(p_{nd}Q_{nd}) = 3.3$ .

Again, taking the cross-price elasticities for beef in Table 3.2 as an indication of the grassfed beef cross-price elasticities, the consumption of grassfed beef should be more responsive to price changes of another type of beef than of other meat products. Because many of the early studies concentrated on the estimation of the beef own-price elasticity using single equation methods, only limited cross-price estimates are available. The cross-price elasticities in Table 3.2 vary markedly, even with conflicting signs, but the majority of the beef cross-price elasticities are between 0 and 0.2. In the base run of the model, the cross-price elasticity for grassfed beef with respect to changes in price of grainfed beef is taken as 0.3. This gives  $\eta_{(Q_{sd}, p_{nd})} = 0.3$  and  $\eta_{(Q_{nd}, p_{nd})} = (3.3)(0.3) = 0.99$  by the symmetry condition.

## Export

There are fewer studies of the export demand elasticity for Australian beef. It is generally believed that changes in the quantity of Australian beef exported have only a minor influence on export prices ('small country' argument), and thus the export demand for Australian beef is relatively price elastic (Papadopoulos 1973, Parton 1978, and Scobie and Johnson 1979). As commented by Scobie and Johnson (1979), some earlier estimates for the export demand elasticity are often too small due to inadequacies in statistical techniques. In the EMABA econometric model (Dewbre *et.al.* 1985 and Harris and Shaw 1992), the export demand elasticity for Australian beef was estimated as -0.64 for the short run, -0.88 for the medium run and -1.25 for the long run. In some studies where an export demand elasticity for beef was required, researchers often choose values in an *ad hoc* manner. For example, Parton (1978) used an elasticity range of -1.0 to -2.0 for a high price regime and -0.25 to -1.0 for a low price regime.

Another popular approach to estimating the elasticity of export demand is to use a formula that relates the export demand elasticity of a country to the price responsiveness of other consumers and suppliers of the commodity in the world market and the quantity of the country's export in comparison with the quantities of other buyers and sellers. The simplest version of this formula, as used by Papadopoulos (1973) and Butler and Saad (1974), is  $\eta_a = \eta/s_a$ , where  $\eta_a$  is the export demand elasticity facing country  $a$ ,  $\eta$  is the demand elasticity in the rest of the world and  $s_a$  is the share of the world market by country  $a$ . This simple formula is only true for the special case when there is no supply response from competing producers, no product differentiation among different countries in the world market and no government intervention in exporting or importing countries. It often produces very high

export demand elasticities for commodities where Australia's world market share is small. Taplin (1971), Scobie and Johnson (1979) and Cronin (1979) generalise the simple formula to relax some or all of the restrictions. Cronin's formula involves own-price elasticities, price transformation elasticities and the quantity shares for all importing and exporting countries. Scobie and Johnson (1979) estimated a value of -10.3 for export demand elasticity for Australian beef. Cronin (1979) estimated a value of -64 when beef from all countries is assumed to be homogenous or perfectly substitutable and a value of -4 for a more realistic situation. Wittwer and Connolly (1993) also used Cronin's formula with the elasticity values in Tyers and Anderson (1992). Their calculated elasticity for beef is -4.5 for the short run and -14 for the long run.

In the current model, export grainfed and grassfed beef is assumed nonsubstitutable in demand due to the fact that almost all grainfed beef is sold in Japan while the majority of grassfed beef goes to countries other than Japan. As a result, the cross-price elasticities are assumed zero. Again, as grassfed beef constitutes the majority of Australian beef exports and is sold to various countries, the reviewed export beef demand studies are more relevant to grassfed beef. In the base model, the export demand elasticity for grassfed beef is specified as -5 based on the above review<sup>3</sup>, that is,  $\eta_{(Q_{se,pse})} = -5$ .

About 95% of the Australian grainfed beef goes to Japan, and Australia is the major country that supplies the high quality Japanese grainfed market. Australian high marbling grainfed beef is a highly specified product that has little substitutability with other countries' products (which implies a very small price transformation elasticity of supply). As a result, the demand elasticity for the Australian grainfed feed beef is expected to be less elastic than the grassfed beef. A value of -2.5 is used for the base model, ie.  $\eta_{(Q_{ne,pne})} = -2.5$ .

### 3.3.2 Exogenous Factor Supply Elasticities

#### Weaner Supply

There have been many studies of the supply response of Australian agricultural products, where the supply elasticity of beef to changes in its own price is estimated. Econometric models or mathematical programming models of Australian broadacre agriculture have often been used in these studies. Unlike demand response, it often takes several years for cattle producers to respond fully to an initial price change. As a result, the magnitude of the supply elasticity relates to the time frame considered. In Table 3.3, the published estimates of Australian beef supply elasticity for various time runs are summarised based on a review by Griffith, *et al.* (2000b). As only the own-price elasticity of weaner supply is required in the model, the cross-price elasticities in these studies are not reviewed. It can be observed from Table 3.3 that the estimates for the cattle supply elasticity range from 0.05 to 1.01 for short-run, 0.10 to 1.34 for medium run and 2.0 to 2.99 for long run. In a study on American beef processing industry, where 0.15, 0.30 and 3.0 are used respectively for the short, medium and long run elasticities of cattle supply, Mullen, Wohlgenant and Farris (1988) referenced estimates of 1.0 and 1.06 for this parameter for the United Kingdom and West Germany respectively. Based on these estimates, a value of 1 for the cattle supply elasticity is considered reasonable for the medium run time frame considered in the model.

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<sup>3</sup> Zhao *et al.* (1999) found that results become insensitive to this parameter when the value is large. For example, there is little difference in the results when the demand elasticity is changed from -10 to -20.

**Table 3.3 Published Estimates of Beef Cattle Supply Elasticity for Australia**

Source	Own-Price Elasticity	Time-Run	Area
Gruen <i>et al.</i> (1967b)	0.16	S	Aust.
Freebairn (1973)	0.11	4-yr	NSW
Wicks & Dillon (1978)	0.69	S	Aust.
	0.90	M	Aust.
Longmire <i>et al.</i> (1979)	0.69	S	Aust.
Vincent, Dixon & Powell (1980)	1.01	S	pastoral zone
	0.48	S	wheat/sheep zone
	0.34	S	high rainfall zone
Fisher & Munro (1983)	0.70	S	NSW wheat/sheep
	0.40	S	NSW pastoral
Easter & Paris (1983)	0.51	S	Aust. table beef
	0.62	S	Aust. Manufacturing beef
Dewbre <i>et al.</i> (1985)	0.30	M	Aust.
	2.00	L	Aust.
Hall & Menz (1985)	1.34	M	Aust.
Adams (1987)	0.60	S	Aust.
Hall, Fraser & Purtil (1988)	0.50	M	Aust.
	2.40	L	Aust.
Johnson, Powell & Dixon (1990)	0.68	S	pastoral zone
	0.37	S	wheat/sheep zone
	0.27	S	high rainfall zone
Harris & Shaw (1992)	-0.04	S	Aust.
	0.10	M	Aust.
	0.88	10-yr	Aust.
	2.99	L	Aust.
Kokic <i>et al.</i> (1993)	0.05	S	pastoral zone
	0.15	S	wheat/sheep zone
	0.07	S	high rainfall zone
Coelli (1996)	0.27	L	WA wheat-sheep zone

Source: Griffith, *et al.* (2000b).

While the reviewed elasticity estimates are for the finished cattle, it is the supply elasticity at the weaner level that is required in the present model. The relationship between the supply elasticity at the weaner level and the supply elasticity at the finished cattle level depends on how the prices and quantities spread between the two levels. Assume that the price and quantity for finished cattle are  $v$  and  $Y$ , and for weaners  $w_1$  and  $X_1$ . Also assume that the quantities at the two levels are proportional, i.e.  $Y = \alpha X_1$  where  $\alpha$  is a constant-percentage conversion factor. This is a reasonable assumption as the average weaner weight and the cattle slaughtering weight should not be too different across different ‘normal’ years. Now the relationship between the two prices is critical. It can be shown that if we assume a proportional price difference between the two points, the supply elasticities will be the same, i.e.  $\varepsilon_Y = \varepsilon_{X_1}$ . However, if we assume there is a constant price mark up or the combination of the two, i.e.  $v = w_1 + \Delta$  or  $v = \lambda w_1 + \Delta$ , it can be shown that the elasticity changes according to the ratio of the two prices, i.e.  $\varepsilon_Y = (v/w_1)\varepsilon_{X_1}$ . Using this relationship,  $\varepsilon_{X_1} = (w_1/v)\varepsilon_Y = (1.12/0.55/2.24)\varepsilon_Y = 0.91\varepsilon_Y$ . A value of 1 for  $\varepsilon_Y$  implies a value of 0.91 for  $\varepsilon_{X_1}$ . In the base model, 0.9 is used for the weaner supply elasticity, i.e.  $\varepsilon_{X_1} = 0.9$ .

### **Feedgrain and “Other Inputs” Supplies**

In addition to the cattle inputs, all sectors in the model involve other inputs, the supply elasticities of which are required. A supply elasticity of 0.8 for feedgrain is assumed based on a study of feedgrain supply in NSW (Campbell 1994).

There are few empirical estimates for the supply elasticity of ‘other inputs’ in the processing sector, or any other sectors in the model. Conventionally, it is believed that, since most of the other inputs such as labour and capital are not specialised, the supply of these inputs is highly elastic. In the base run, the supply elasticities for ‘other inputs’ in all sectors are assigned a value of 5.

#### **3.3.3 Input Substitution Elasticities**

The Allen-Uzawa elasticity of input substitution<sup>4</sup>, as defined in Equation (2.5.4), is required for all pairs of inputs for all sectors. For the six industry sectors in the model, there are mainly two types of input substitution: (1) substitution between cattle/beef inputs and ‘other inputs’, and (2) substitution between different types of cattle/beef inputs. In addition, substitution elasticities of feedgrain with cattle inputs and with ‘other inputs’ are also required.

There is very little empirical information on the substitutability between cattle inputs and other inputs. A conventional approach is to assume zero substitution elasticity implying fixed proportions between farm input and other marketing inputs. However, allowing a small amount of input substitution could significantly change the estimated distribution of research benefits (Alston and Scobie 1983). As pointed out by Mullen, Wohlgenant and Farris (1988), one source of input substitution in beef processing has been technologies such as boxed beef that reduce shrinkage and spoilage. Also, greater input substitution is expected at the industry level than that at the firm level (Diewert 1981) as firms switch between technologies that use inputs in different proportions.

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<sup>4</sup> For a discussion of this concept, see Blackorby and Russell (1989).

One set of estimates of the substitution elasticities between farm and marketing inputs was given by Wohlgenant (1989) for American farm products. His results showed a very high substitution elasticity value of 0.72 for the beef industry and values of 0.35, 0.11 and 0.25 for the pork, poultry and egg industries respectively. Another relevant study is by Ball and Chambers (1982) for the aggregated US meat products industry. It showed different signs for substitution between material input and other individual inputs such as capital, labour and energy (-0.64 to 0.33, Table 4).

Under some restrictive assumptions, Mullen, Wohlgenant and Farris (1988) estimated an output-constrained demand function for cattle, which gives estimates of the Allen input substitution elasticity between cattle and marketing inputs of 0.12 and 0.093, using different estimation methods. In many EDM studies of agricultural industries, the substitution elasticity between farm inputs and other inputs has been assumed to take a small value of around 0.1 (for example, Mullen, Wohlgenant and Farris 1988; Mullen, Alston and Wohlgenant 1989). An exception is the work by Wohlgenant (1993) which used the Wohlgenant (1989) estimates of 0.72 and 0.35 for the beef and pork industries respectively.

In the base scenario of the model, the same value of 0.1 is assigned to all input substitution elasticities between cattle/beef inputs and 'other inputs' for all sectors. Extensive sensitivity analysis is carried out by Zhao *et al.* (2000) to study the impact when this parameter takes higher values. No empirical estimate is available for the substitutability between feedgrain and cattle, and between feedgrain and 'other inputs' for the cattle feedlot sector. A small value of 0.1 is also assigned to both parameters in the base run.

There is no information available on the input substitution elasticities between grainfed and grassfed cattle, or between cattle for export and cattle for domestic consumption. Existing studies have not disaggregated the industry to the required degree. For single output models, substitution between imported and domestic farm inputs has been assumed highly possible. Mullen, Alston and Wohlgenant (1989) surveyed some Australian and US empirical estimates of substitution elasticities between wool from different countries. They show rather low values ranging from 0.6 to 1.68. They used a value of 5 in their model, and they reported an estimate of 6.5 for this parameter in a preliminary study. In the ORANI computable equilibrium displacement (CGE) model of the Australian economy (Dixon, Parmenter, Sutton and Vincent 1997), a value of 2 is used for the domestic-imported substitution elasticities for commodities such as meat cattle, sheep, milk cattle and poultry.

However, while there is a high possibility of substitution between farm inputs from different sources (such as imported and domestic) in producing a single homogeneous retail product, the substitution possibility among different types of cattle inputs for the multi-output technologies in the current model is expected to be much smaller. In each of the feedlot, processing and marketing sectors, there is almost a one-to-one relationship between a specific input and a specific output. For example, in the processing sector, the four types of live cattle are combined with processing inputs to produce four types of beef carcass. As discussed in Section 2, the four cattle/beef types have distinct product specifications. Thus, it is very unlikely for example, that a heavy Japanese grainfed steer will be sold as grassfed hamburger meat in the U.S. Although there may be substitution among the lower quality cuts such as mince or trimmed meat, given the multi-input and multi-output specification in this model,

the possibility of such substitution is expected to be very small. In the base model, a small value of 0.05 is used for all 9 input substitution elasticities between different types of cattle/beef inputs in the feedlot, processing and marketing sectors.

### 3.3.4 Product Transformation Elasticities

There are even fewer empirical estimates available on product transformation elasticities, and no studies on the transformation possibilities between heterogenous beef products. Product transformation elasticities between various Australian agricultural products for the three agricultural zones, using common labour and capital inputs, are estimated by Vincent, Dixon and Powell (1980, Tables 2, 4 and 6) with a CRESH/CRETH production system. The estimated transformation elasticities of cattle with wool, sheep and grain in this study are mostly in the range of  $-0.04$  to  $-2.13$ . In the ORANI/Monash model, product transformation elasticities among agricultural products are all assumed the same value of 2 (Dixon, Parmenter, Sutton and Vincent 1997).

For the backgrounding and grass-finishing sectors in the current model specification, because the same weaner can be used to produce cattle for either export or domestic market, there is considerable flexibility for changing what product to produce according to relative prices. A value of 2 is used for both  $\tau_{(Fn1e, Fn1d)}$  and  $\tau_{(Yse, Ysd)}$ .

However, for the feedlot, processing and marketing sectors that use differentiated inputs to produce differentiated outputs, the product transformation elasticities are expected to be much smaller, just as input substitution between cattle/beef inputs was small. The product transformation elasticity measures the possibility of changing the product mix *for given inputs*. For example, in the case of the beef processing sector, once the amounts of the finished cattle for the four cattle input types are fixed, there are very limited possibilities for increasing a particular beef product because its price has risen. A small value of  $-0.05$  is used for all 9  $\tau$ 's for the feedlot, processing and marketing sectors.

All elasticity values specified for the base run are summarised in Table 3.4.

### 3.3.5 Concavity/Convexity Conditions

As discussed in Section 2.5, the elasticity values need to satisfy homogeneity, symmetry and concavity/convexity conditions to be integrable at the base equilibrium point. Most of the equality restrictions required by the homogeneity and symmetry conditions have been imposed explicitly in the displacement model in Equations (2.6.1)-(2.6.58). The symmetry condition for the two domestic demand elasticities and the second order inequality conditions of concavity/convexity are checked below for the specified elasticities.

It can be verified easily that the domestic and export beef demand elasticities ( $\eta_{(Qi, pj)}$ ,  $i, j = nd, sd$ , and  $\eta_{(Qne, pne)}$  and  $\eta_{(Qse, pse)}$ ) in Table 3.4 satisfy conditions in Equations (2.5.10)-(2.5.12), which are necessary conditions for integrability at the base equilibrium point. Also, all exogenous factor supply elasticities (for weaners, feedgrain and 'other inputs') are positive, which is the only necessary condition (Equation (2.5.9)).

Table 3.4 Market Elasticity Values for the Base Run

<p><b><u>Domestic Beef Demand Elasticities</u></b>  <math>\eta_{(Qnd, pnd)} = -1.6</math>, <math>\eta_{(Qnd, psd)} = 1.0</math>,  <math>\eta_{(Qsd, pnd)} = 0.3</math>, <math>\eta_{(Qsd, psd)} = -1.1</math></p> <p><b><u>Export Beef Demand Elasticities</u></b>  <math>\eta_{(Qne, pne)} = -2.5</math>, <math>\eta_{(Qse, pse)} = -5</math>,</p> <p><b><u>Input Substitution Elasticities</u></b></p> <p><b><i>Backgrounding Sector</i></b>  <math>\sigma_{(Xn1, Xn2)} = 0.1</math>,</p> <p><b><i>Feedlot Sector</i></b>  <math>\sigma_{(Fn1e, Fn1d)} = 0.05</math>, <math>\sigma_{(Fn1e, Fn2)} = 0.1</math>,  <math>\sigma_{(Fn1e, Fn3)} = 0.1</math>, <math>\sigma_{(Fn1d, Fn2)} = 0.1</math>,  <math>\sigma_{(Fn1d, Fn3)} = 0.1</math>, <math>\sigma_{(Fn2, Fn3)} = 0.1</math>,</p> <p><b><i>Grass-Finishing Sector</i></b>  <math>\sigma_{(Xs1, Xs2)} = 0.1</math>,</p> <p><b><i>Processing Sector</i></b>  <math>\sigma_{(Yne, Ynd)} = 0.05</math>, <math>\sigma_{(Yne, Yse)} = 0.05</math>,  <math>\sigma_{(Yne, Ysd)} = 0.05</math>, <math>\sigma_{(Ynd, Yse)} = 0.05</math>,  <math>\sigma_{(Ynd, Ysd)} = 0.05</math>, <math>\sigma_{(Yse, Ysd)} = 0.05</math>,  <math>\sigma_{(Yne, Yp)} = 0.1</math>, <math>\sigma_{(Ynd, Yp)} = 0.1</math>,  <math>\sigma_{(Yse, Yp)} = 0.1</math>, <math>\sigma_{(Ysd, Yp)} = 0.1</math>.</p> <p><b><i>Export Marketing Sector</i></b>  <math>\sigma_{(Zne, Zse)} = 0.05</math>, <math>\sigma_{(Zne, Zme)} = 0.1</math>  <math>\sigma_{(Zse, Zme)} = 0.1</math></p> <p><b><i>Domestic Marketing Sector</i></b>  <math>\sigma_{(Znd, Zsd)} = 0.05</math>, <math>\sigma_{(Znd, Zmd)} = 0.1</math>,  <math>\sigma_{(Zsd, Zmd)} = 0.1</math>,</p>	<p><b><u>Weaner Supply Elasticity</u></b>  <math>\varepsilon_{(X1, w1)} = 0.9</math>,</p> <p><b><u>Feedgrain Supply Elasticity</u></b>  <math>\varepsilon_{(Fn2, sn2)} = 0.8</math>,</p> <p><b><u>Other Factor Supply Elasticities</u></b>  <math>\varepsilon_{(Xn2, wn2)} = 5</math>, <math>\varepsilon_{(Xs2, ws2)} = 5</math>,  <math>\varepsilon_{(Fn3, sn3)} = 5</math>, <math>\varepsilon_{(Yp, vp)} = 5</math>,  <math>\varepsilon_{(Zme, ume)} = 5</math>, <math>\varepsilon_{(Zmd, umd)} = 5</math>.</p> <p><b><u>Product Transformation Elasticities</u></b></p> <p><b><i>Backgrounding Sector</i></b>  <math>\tau_{(Fn1e, Fn1d)} = -2</math>,</p> <p><b><i>Feedlot Sector</i></b>  <math>\tau_{(Yne, Ynd)} = -0.05</math>,</p> <p><b><i>Grass-Finishing Sector</i></b>  <math>\tau_{(Yse, Ysd)} = -2</math></p> <p><b><i>Processing Sector</i></b>  <math>\tau_{(Zne, Zse)} = -0.05</math>, <math>\tau_{(Zne, Znd)} = -0.05</math>,  <math>\tau_{(Zne, Zsd)} = -0.05</math>, <math>\tau_{(Zse, Znd)} = -0.05</math>,  <math>\tau_{(Zse, Zsd)} = -0.05</math>, <math>\tau_{(Znd, Zsd)} = -0.05</math>.</p> <p><b><i>Export Marketing Sector</i></b>  <math>\tau_{(Qne, Qse)} = -0.05</math>,</p> <p><b><i>Domestic Marketing Sector</i></b>  <math>\tau_{(Qnd, Qsd)} = -0.05</math>.</p>
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All input substitution elasticities need to satisfy the concavity condition in Equation (2.5.3)'. The inequality condition requires that the principal minors of the input substitution elasticity matrix  $H_\sigma$  have alternate signs; that is, the first principal minor is nonpositive, the second principal minor is nonnegative, and so on. It can be shown that, when only two or three inputs are involved in a production technology and when the homogeneity and symmetry conditions in (2.5.1)' and (2.5.2)' are satisfied, nonnegative substitution elasticities ( $\sigma_{ij} \geq 0$ ,  $i, j = 1, 2, 3$ ;  $i < j$ ) will guarantee the satisfaction of the concavity condition in Equation (2.5.3). All input substitution elasticities in Table 3.4 are nonnegative. As a result, the concavity condition is satisfied for backgrounding, grass-finishing, export marketing and domestic marketing sectors, which have less than four inputs.

Four inputs are involved in the feedlot sector. Using the subscripts 1 to 4 for simplification, the four cost shares are  $\kappa_1=0.35$ ,  $\kappa_2=0.26$ ,  $\kappa_3=0.28$ ,  $\kappa_4=0.11$ , and, from Table 3.4,  $\sigma_{12}=0.05$  and all the rest  $\sigma_{ij}=0.1$  ( $i < j$ ,  $(i,j) \neq (1,2)$ ). Using the homogeneity condition in Equation (2.5.1)', the first three diagonal elements of the substitution elasticity matrix are

$$\begin{aligned}\sigma_{11} &= -(\kappa_2\sigma_{12} + \kappa_3\sigma_{13} + \kappa_4\sigma_{14})/\kappa_1 = -0.15, \\ \sigma_{22} &= -(\kappa_1\sigma_{12} + \kappa_3\sigma_{23} + \kappa_4\sigma_{24})/\kappa_2 = -0.22, \\ \sigma_{33} &= -(\kappa_1\sigma_{13} + \kappa_2\sigma_{23} + \kappa_4\sigma_{34})/\kappa_3 = -0.26.\end{aligned}$$

The substitution elasticity matrix becomes

$$H_\sigma = \begin{pmatrix} -0.15 & 0.05 & 0.1 & 0.1 \\ 0.05 & -0.22 & 0.1 & 0.1 \\ 0.1 & 0.1 & -0.26 & 0.1 \\ 0.1 & 0.1 & 0.1 & \sigma_{44} \end{pmatrix}$$

The three principal minors of  $H_\sigma$  are

$H_{\sigma_1} = -0.15 \leq 0$ ,  $H_{\sigma_2} = 0.03 \geq 0$ , and  $H_{\sigma_3} = -0.003 \leq 0$ , while, from the discussion of Equation (2.5.3)' in Section 2.5.2,  $H_{\sigma_4} = 0$ . Thus the concavity condition is satisfied for the input substitution elasticities for the feedlot sector.

Similarly, for the processing sector that involves 5 inputs, it is checked that the concavity condition in Equation (2.5.3)' is satisfied for the substitution elasticity values in Table 3.4 and the cost shares in Table 3.1. Details of the verification are similar to that of the feedlot sector.

Similarly, all product transformation elasticities for all sectors need to satisfy the convexity condition in Equation (2.5.8)', ie. all principal minors of the matrix of transformation elasticities  $H_\tau$  are non-negative. Again, for the transformation elasticities in Table 3.4 and the base revenue shares in Table 3.1, Equation (2.5.8)' is satisfied for all six industry sectors. Details of the verification are omitted to save space.

### **3.4 Exogenous Shifter Variables**

There are 12 exogenous demand and supply shifters in the model. These represent alternative scenarios resulting from research and promotion investments into different industry sectors and markets. The 12 scenarios and the values of exogenous variables for these scenarios are specified in Table 3.5.

As stated in Section 1, the focus of this study is on evaluation and comparison of broad categories of research-induced technologies and promotions to address policy issues. Consequently, the study concentrates on equal 1% vertical shifts of the relevant supply or demand curves that result from alternative investment scenarios. In other words, the comparison is among the impacts of the same 1% reductions in per unit costs in various production sectors and the same 1% increases in consumer's 'willingness to pay' in various markets. The costs involved in the R&D or promotion programs that bring about these 1% shifts are not studied.

**Table 3.5 Exogenous Shift Variables for Various Investment Scenarios****Scenario 1: Weaner Production Research:**

$t_{X1} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Cost reduction in weaner production resulting from any breeding or farm technologies that reduce the cost of producing weaners.

**Scenario 2: Grass-Finishing Research**

$t_{Xs2} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in the grass-finishing sector resulting from any farm technologies or new management strategies that increase the productivity of 'other inputs'. This also includes nutritional technologies in grain supplementing cattle, because cattle topped up on pasture are modelled as part of the grass-finishing sector.

**Scenario 3: Backgrounding Research**

$t_{Xn2} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in the backgrounding sector resulting from new backgrounding technologies.

**Scenario 4: Feedgrain Industry Research**

$t_{Fn2} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Cost reductions in the feedgrain production resulting from research and technical changes in the grain industry.

**Scenario 5: Feedlot Research**

$t_{Fn3} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in the feedlot sector due to research into areas such as feedlot nutrition and management.

**Scenario 6: Processing Research**

$t_{Yp} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in the beef processing due to new technologies or management strategies in the processing sector.

**Scenario 7: Domestic Marketing Research**

$t_{Zmd} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in the domestic marketing and retailing sector resulting from research-induced technologies and improved management.

**Scenario 8: Export Marketing Research**

$t_{Zme} = -0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Other cost reductions in export marketing due to research for varstments that increase export marketing efficiency.

**Scenario 9: Export-Grainfed Beef Promotion**

$n_{Qne} = 0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Increase in the 'willingness to pay' by the export-grainfed beef consumers due to beef promotion or changes in taste in the overseas market.

**Scenario 10: Export-Grassfed Beef Promotion**

$n_{Qse} = 0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Increase in the 'willingness to pay' by export-grassfed beef consumers due to beef promotion or changes in taste in the overseas market.

**Scenario 11: Domestic-Grainfed Beef Promotion**

$n_{Qnd} = 0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Increase in the 'willingness to pay' by domestic-grainfed beef consumers due to beef promotion or changes in taste in the domestic market.

**Scenario 12: Domestic-Grassfed Beef Promotion**

$n_{Qsd} = 0.01$ , rest  $t_{()} = 0$  and  $n_{()} = 0$ .

Increase in the 'willingness to pay' by domestic-grassfed beef consumers due to beef promotion or changes in taste in the domestic market.

## 4 Measuring Economic Surplus Changes

### 4.1 Introduction

So far, the displacement model involving 58 price and quantity variables has been specified in Section 2, and the integrability restrictions have been imposed among parameters at the base equilibrium point. Data required for the base equilibrium prices and quantities, market elasticities and exogenous variables for the 12 scenarios have been specified in Section 3. Using these data, the displacement model in Equations (2.6.1)-(2.6.58) can be solved to obtain the changes in all prices and quantities for each policy scenario. The ultimate aim of the study is to use these price and quantity changes to estimate the economic welfare implications for the various industry groups.

The arguments of Willig (1976) and Alston and Larson (1993) are accepted in this study, and changes in the economic surplus areas measured off Marshallian demand and supply curves are used as measures of welfare changes. In line with the empirical results of Hausman (1981) for single market models and LaFrance (1991) for a multi-market case, and as also implied by the derivation below, since only small shifts are considered in the study and since it is the *trapezoid* area of welfare change rather than the *triangular* ‘deadweight loss’ that is of interest, the errors from using economic surplus changes to approximate changes in Hicksian welfare measures are expected to be small.

The economic surplus changes to the various industry groups for the 12 policy scenarios are examined in this Section. For each scenario where an exogenous demand or supply shift occurs in a market, demand and supply curves in other markets in the model may be shifted endogenously. As a result, all prices and quantities in the model are changed. Thurman (1991a) pointed out that complications may arise in the measurement of welfare when there are more than two sources of general equilibrium feedback, or when both demand and supply curves are shifted endogenously. The welfare measures are relatively straightforward when there is no induced shift in the supply and demand curves in a market.

Also the relationship between the analytical welfare integrals and the conventional “off-the-curve” economic surplus areas is examined. This is done through examining the profit and expenditure functions for these industry groups in the context of the current model.

Eleven industry groups comprising exogenous factor suppliers and final beef consumers are identified in the model. Only a single price change is involved in each of the profit or expenditure functions of ten of the industry groups. As shown in Equation (2.3.28), for each of the eight exogenous factor supplier groups, the profit function does not contain any variables endogenous to the model other than own price. Thus, the supply functions for these factors are determined completely exogenously and do not shift as a result of any other exogenous shocks considered in the model. Similarly, the demand curves for the two export beef products are also assumed unrelated to any other variables in the model other than own prices. There is only a single source of equilibrium feedback in these markets. Hence for these ten producer and consumer groups, the conventional economic surplus areas measured off the ordinary supply or demand curves are used as welfare measures for the relevant groups.

According to the results in Willig (1976) and Hausman (1981) for a single market situation, the trapezoid areas of economic surplus changes are good approximations of the Hicksian welfare changes. The welfare implications for these ten industry groups in the 12 investment scenarios are discussed in details in 4.2 and 4.3 respectively.

However, the two domestic beef products are related in both demand and supply, and both demand and supply curves shift endogenously as a result. This is the case that Thurman (1991a) identified as having two sources of equilibrium feedback, and called for extra caution when measuring welfare effects. The measures of economic surplus changes for the domestic consumers are discussed in 4.4. Two alternative approaches are investigated: measuring the total welfare change off the general equilibrium curves in a single market or measuring directly off the partial equilibrium curves in individual markets. In this case, the domestic consumers' expenditure function involves two price changes. However, based on the empirical results in LaFrance (1991), as long as the shifts considered are small, the trapezoid shaped areas of economic surplus changes are still good approximations to the exact compensating or equivalent variation measures.

## 4.2 Producer Surplus Changes for Exogenous Factor Suppliers

In the displacement model specified in Section 2, factor supplies of  $X_1$ ,  $X_{n2}$ ,  $X_{s2}$ ,  $F_{n2}$ ,  $F_{n3}$ ,  $Y_p$ ,  $Z_{me}$  and  $Z_{md}$  (defined in Table 2.3) are not related to any other variables within the model other than own prices. For each of the 12 scenarios described in Table 3.5, when an exogenous shock occurs in one of the markets in the model, the demand curves in these factor markets are shifted endogenously through its demand interaction with other markets in the model, which induces changes in the prices and quantities of these factors. However, the supply curves of these factors do not shift endogenously. As a result, the producer surplus areas measured off these supply curves represent the benefit to the producers of the relevant factors.

Take the welfare change to the weaner ( $X_1$ ) producers as an example. Following the specification in Section 2.3.2, assume that the profit function for the weaner producer is  $\pi(w_1, W)$ , where  $w_1$  is the price of  $X_1$  and  $W$  is the vector of other prices affecting the profit function which are exogenous to the model. Consequently,  $W$  is assumed constant during the displacement. Now consider separately the scenario when the supply of weaners is exogenously shifted (Scenario 1) and the scenarios when the initial shifts occur in other markets (Scenarios 2 to 12).

In scenario 1, suppose that the per unit cost of producing weaners is reduced by  $|K|$  for all output levels ( $K < 0$  is a constant, i.e. parallel shift). Consequently, the profit function is shifted from  $\pi(w_1, W)$  to  $\pi(w_1 - K, W)$  and the supply curve from  $S(w_1, W)$  to  $S(w_1 - K, W)$ . As the variable  $W$  is assumed unaffected by the shift, it is omitted in the supply functions below without losing generality. In the first instance, the initial downward shift in weaner supply reduces the equilibrium price of weaners. The decrease in the weaner price then induces shifts in other markets and changes other prices and quantities in the model. As a feedback effect of these other price and quantity changes, the demand curve of weaners is also shifted up endogenously. A new set of equilibrium prices and quantities are reached eventually in all markets. Suppose the initial price and the new price for weaners are  $w_1^{(1)}$  and  $w_1^{(2)}$  respectively. The change in weaner producers' welfare is the change in their profit before and after the displacement:

$$\begin{aligned}
(4.1) \quad \Delta\pi &= \pi(w_1 - K)\Big|_{w_1=w_1^{(2)}} - \pi(w_1)\Big|_{w_1=w_1^{(1)}} = \pi(w_1^{(2)} - K) - \pi(w_1^{(1)}) \\
&= \int_{w_1^{(1)}}^{w_1^{(2)}-K} \frac{\partial\pi(w_1)}{\partial w_1} dw_1 = \int_{w_1^{(1)}}^{w_1^{(2)}-K} S(w_1) dw_1 = \int_{w_1^{(1)}+K}^{w_1^{(2)}} S(w_1 - K) dw_1.
\end{aligned}$$

The last expression relates to the producer surplus area measured off the new supply curve  $S(w_1-K)$ . This is illustrated in Figure 4.1. The dotted trapezoid area  $ABCE^{(2)}$  is the producer surplus change given by the last integral above.

If the amount of shift  $K$  is represented as a percentage of initial price  $w_1^{(1)}$ , i.e.  $t_{x1} = K/w_1^{(1)}$ , and the proportional changes in price and quantity are represented as  $Ew_1 = (w_1^{(2)} - w_1^{(1)})/w_1^{(1)}$  and  $EX_1 = (X_1^{(2)} - X_1^{(1)})/X_1^{(1)}$ , respectively, it can be shown easily that the producer welfare change to the weaner producers, i.e. the last integral in Equation (4.1) given by area  $ABCE^{(2)}$ , can be calculated as

$$(4.2) \quad \Delta PS_{X1} = w_1^{(1)} X_1^{(1)} (Ew_1 - t_{x1}) (1 + 0.5 EX_1) \quad \text{weaner producers}$$

Similarly, for any one of the other eleven scenarios (Scenario 2 to 12), the initial shift in another market in the model induces a shift in the demand curve for weaners and thus changes the equilibrium price and quantity of weaners. The supply curve is not affected. In other words, the weaner producer's profit function  $\pi(w_1)$  and the derived supply function  $S(w_1)$  remain the same before and after the shift. The producers' welfare change is given by the change in their profit

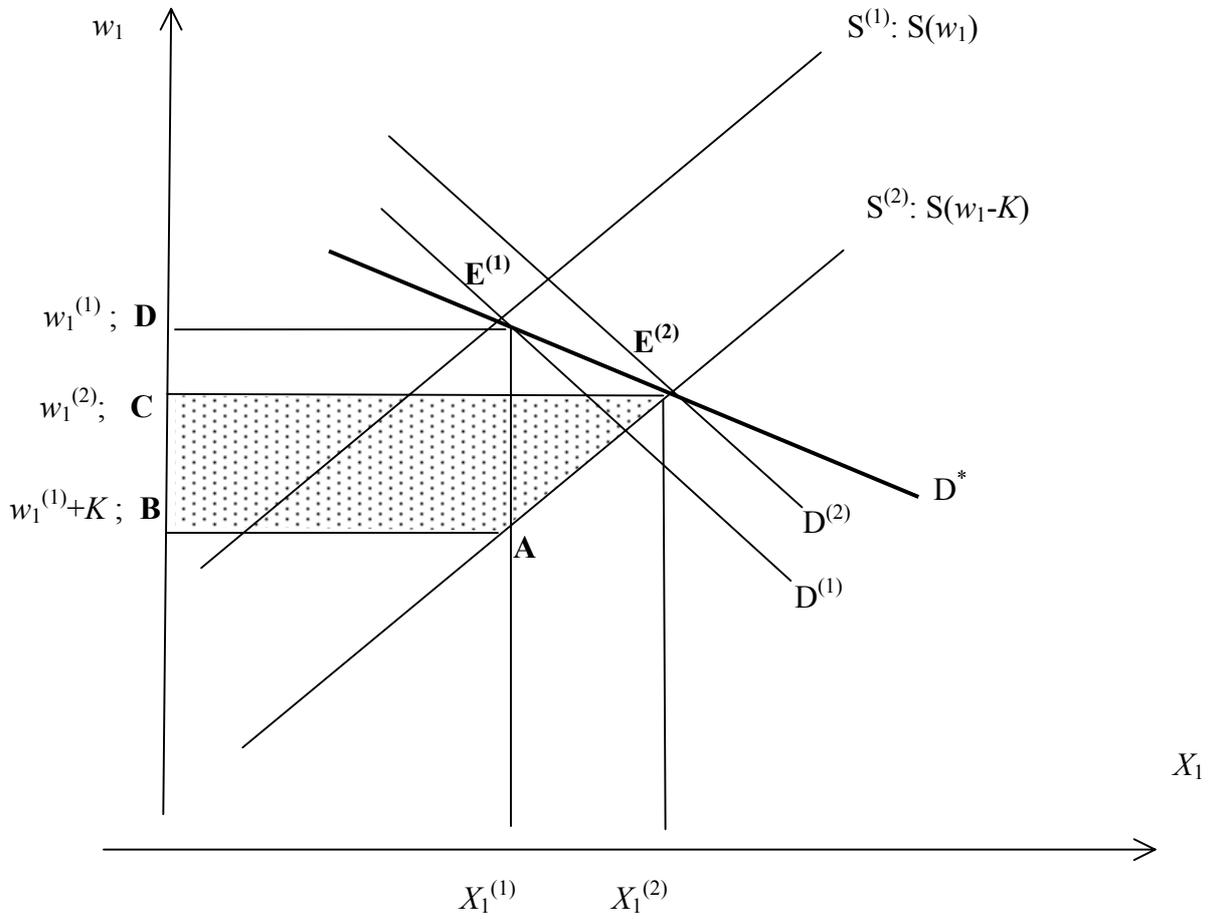
$$\Delta\pi = \pi(w_1^{(2)}) - \pi(w_1^{(1)}) = \int_{w_1^{(1)}}^{w_1^{(2)}} \frac{\partial\pi(w_1)}{\partial w_1} dw_1 = \int_{w_1^{(1)}}^{w_1^{(2)}} S(w_1) dw_1,$$

which is the integral measured off the fixed supply curve. This is shown in Figure 4.2. The welfare change to the weaner producers is given by the trapezoid area  $ABE^{(2)}E^{(1)}$ . This area can be calculated using the percentage price and quantity changes as

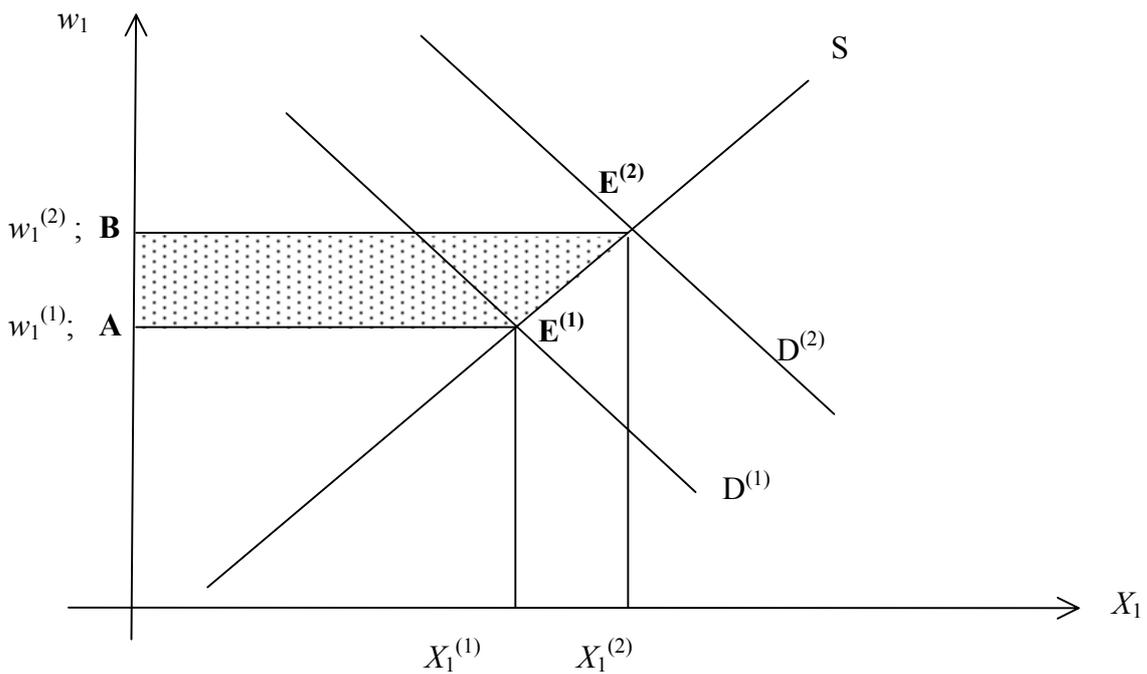
$$\Delta PS_{X1} = w_1^{(1)} X_1^{(1)} Ew_1 (1 + 0.5 EX_1).$$

In summary, for all the twelve scenarios, the changes in weaner producer's welfare is given by Equation (4.2). For scenario 1,  $t_{x1} = -0.01$ , and for other scenarios,  $t_{x1} = 0$ .

The producer welfare changes for all other exogenous factor suppliers (i.e. the backgrounders, grass-finishers, grain producers, feedlotters, processors, exporters and domestic retailers) can be derived similarly. The formulas for all producer surplus changes for all twelve scenarios are summarised in Table 4.1.



**Figure 4.1 Weaner Producers' and Total Surplus Changes for Scenario 1 ( $t_{X1}=-1\%$ )**



**Figure 4.2 Weaner Producers' Surplus Change for Scenarios 2 to 12**

**Table 4.1 Formulas of Factor Producer Surplus Changes and Export Consumer Surplus Changes for All 12 Scenarios**

Weaner Producers	$\Delta PS_{X_1} = w_1^{(1)} X_1^{(1)} (E w_1 - t_{X_1}) (1 + 0.5 E X_1)$
Backgrounders	$\Delta PS_{X_{n2}} = w_{n2}^{(1)} X_{n2}^{(1)} (E w_{n2} - t_{X_{n2}}) (1 + 0.5 E X_{n2})$
Grass-finishers	$\Delta PS_{X_{s2}} = w_{s2}^{(1)} X_{s2}^{(1)} (E w_{s2} - t_{X_{s2}}) (1 + 0.5 E X_{s2})$
Grain Producers	$\Delta PS_{F_{n2}} = s_{n2}^{(1)} F_{n2}^{(1)} (E s_{n2} - t_{F_{n2}}) (1 + 0.5 E F_{n2})$
Feedlotters	$\Delta PS_{F_{n3}} = s_{n3}^{(1)} F_{n3}^{(1)} (E s_{n3} - t_{F_{n3}}) (1 + 0.5 E F_{n3})$
Processors	$\Delta PS_{Y_p} = v_p^{(1)} Y_p^{(1)} (E v_p - t_{Y_p}) (1 + 0.5 E Y_p)$
Exporters	$\Delta PS_{Z_{me}} = u_{me}^{(1)} Z_{me}^{(1)} (E u_{me} - t_{Z_{me}}) (1 + 0.5 E Z_{me})$
Domestic Retailers	$\Delta PS_{Z_{md}} = u_{md}^{(1)} Z_{md}^{(1)} (E u_{md} - t_{Z_{md}}) (1 + 0.5 E Z_{md})$
Export Grainfed Beef Consumers	$\Delta CS_{Q_{ne}} = p_{ne}^{(1)} Q_{ne}^{(1)} (n_{Q_{ne}} - E p_{ne}) (1 + 0.5 E Q_{ne})$
Export Grassfed Beef Consumers	$\Delta CS_{Q_{se}} = p_{se}^{(1)} Q_{se}^{(1)} (n_{Q_{se}} - E p_{se}) (1 + 0.5 E Q_{se})$
<b>Sum (of above ten groups)</b>	$\Delta ES_{rest(Qd)} = \sum_{i=X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}, Z_{md}} \Delta PS_i + \sum_{i=Q_{ne}, Q_{se}} \Delta CS_i,$

### 4.3 Consumer Surplus Changes for Export Consumers

In the model specification, the demand functions for the two export beef products ( $Q_{ne}$  and  $Q_{se}$ ), in Equations (2.6.57) and (2.6.58), are assumed unrelated to each other and to any other variables in the model other than own prices. Consequently, the demand curves for these two products are completely exogenous. As shown below, the economic surplus changes measured off the demand curves can be used as measures of welfare changes to the respective export consumers.

Consider the demand for export grainfed beef  $Q_{ne}$ . Assume that the minimum expenditure necessary to achieve the initial utility level  $u^{(1)}$  is given by the expenditure function  $e(p_{ne}, P, u^{(1)})$ , where  $P$  is the price vector for all other commodities the consumer also consumes.  $P$  is assumed exogenous and constant for all exogenous shift scenarios. Now consider the scenario when the demand for  $Q_{ne}$  is shifted up (Scenario 9 when  $n_{Q_{ne}}=1\%$ ). Assume that a promotional campaign has increased the consumer's willingness to pay per unit of export grainfed beef by  $K$  ( $K>0$ ). As a result, the expenditure function shifts from  $e(p_{ne}, P, u^{(1)})$  to  $e(p_{ne}-K, P, u^{(1)})$  and the derived Hicksian demand from  $D^h(p_{ne}, P, u^{(1)})$  to  $D^h(p_{ne}-K, P, u^{(1)})$ . The price change induced by this initial demand shift will result in shifts in other markets and changes in other prices and quantities. The supply of  $Q_{ne}$  will also be shifted endogenously as a feedback effect.

Let  $p_{ne}^{(1)}$  and  $p_{ne}^{(2)}$  be the initial and new prices and  $Q_{ne}^{(1)}$  and  $Q_{ne}^{(2)}$  be the initial and new quantities. Again,  $P$  and  $u^{(1)}$  are omitted from the expressions for simplicity. The *compensating variation* is the change in income that is necessary to compensate the consumer in order to maintain the original utility level  $u^{(1)}$  (if  $e(\cdot)$  is defined as relating to the *new* utility level after the change, it will be called *equivalent variation*). The welfare gain for the export grainfed beef consumers can be represented as the negative of the *compensating variation* as

$$\begin{aligned} -\Delta e &= - (e(p_{ne} - K)|_{p_{ne}=p_{ne}^{(2)}} - e(p_{ne})|_{p_{ne}=p_{ne}^{(1)}}) = e(p_{ne}^{(1)}) - e(p_{ne}^{(2)} - K) \\ &= \int_{p_{ne}^{(2)}-K}^{p_{ne}^{(1)}} \frac{\partial}{\partial p_{ne}} e(p_{ne}) dp_{ne} = \int_{p_{ne}^{(2)}-K}^{p_{ne}^{(1)}} D^h(p_{ne}) dp_{ne} = \int_{p_{ne}^{(2)}}^{p_{ne}^{(1)}+K} D^h(p_{ne} - K) dp_{ne} \end{aligned}$$

This last expression represent the welfare change measured off the shifted Hicksian demand curve. As discussed earlier, welfare measures off the Marshallian curves are used in this study to approximate the exact Hicksian measures. Based on the results in Willig (1976), Hausman (1981) and Alston and Larson (1993), the exact measure suggested by Hausman (1981) is not pursued and the errors in using the Marshallian measures are expected to be small. Using the observable Marshallian demand curve  $D(\cdot)$  in the above expression, the consumers' welfare gain to the export grainfed beef consumers is given by

$$(4.3) \quad \Delta CS_{Q_{ne}} = \int_{p_{ne}^{(2)}}^{p_{ne}^{(1)}+K} D(p_{ne} - K) dp_{ne}.$$

In Figure 4.3, the above integral relates to the trapezoid area ABCE<sup>(2)</sup>. Letting  $n_{Q_{ne}}=K/p_{ne}^{(1)}$  be the initial percentage shift in  $Q_{ne}$  demand and  $E(\cdot)$  be the percentage change of variable  $(\cdot)$  before and after the equilibrium displacement, it can be shown that this area can be calculated as

$$(4.4) \quad \Delta CS_{Q_{ne}} = p_{ne}^{(1)} Q_{ne}^{(1)} (n_{Q_{ne}} - E p_{ne}) (1 + 0.5 E Q_{ne}) \quad \text{export grainfed consumers}$$

It can be shown similarly that for all other 11 scenarios, when an initial shift occurs in another market in the model, the above equation is still correct with  $n_{Q_{ne}}=0$ . This is illustrated in Figure 4.4 with area of  $P_{ne}^{(2)} E^{(2)} E^{(1)} P_{ne}^{(1)}$ . Thus Equation (4.4) is a measure for economic surplus change for export grainfed consumers for all twelve scenarios.

Similarly, the welfare change for the export grassfed beef consumers for all scenarios can be derived as

$$(4.5) \quad \Delta CS_{Q_{se}} = p_{se}^{(1)} Q_{se}^{(1)} (n_{Q_{se}} - E p_{se}) (1 + 0.5 E Q_{se}) \quad \text{export grassfed consumers}$$

They are also summarised in Table 4.1.

#### 4.4 Domestic Consumers' Welfare Changes

As shown above, because all factor supplies and export beef demands are determined completely exogenously, the welfare changes to the factor suppliers and export consumers can be measured straightforwardly. However, as the two domestic beef products are related in

both demand and supply, the welfare measure for the domestic consumers is not as straightforward. This is the case Thurman (1991a) referred to as having more than two sources of feedback. In this situation, both demand and supply curves in the two markets are shifted endogenously.

For most domestic consumers, grassfed and grainfed beef are close substitutes. Hence it makes sense to think of welfare changes of a consumer who consumes both products rather than to attempt to identify separate welfare effects from the consumption of grainfed and grassfed beef. This can be done by estimating the welfare change to domestic consumers, ( $\Delta CS_{Qd}$ ), from a single expenditure function where the prices of both beef products are arguments.

In the following, the welfare implication to the domestic consumers ( $\Delta CS_{Qd}$ ) is discussed separately for the scenarios when the initial shocks occur in the domestic beef markets themselves (Scenarios 11 and 12) and in other markets (Scenarios 1 to 10).

#### **4.4.1 Scenarios 1 to 10 – Two Alternative Approaches**

When integrability conditions are met, there are two ways of calculating the general equilibrium (GE) welfare effects (Just, Hueth and Schmitz 1982, p469; Alston, Norton and Pardey 1995, p232): measuring the total welfare change off the *general* equilibrium curves in the single market where the initial shift occurs, or measuring the individual welfare effects off the *partial* equilibrium curves in individual markets and adding up. As argued in Section 2.5, because the integrability restrictions have been imposed at the base equilibrium point, the two ways of measuring should give the same results.

##### **A. Measuring through $\Delta TS$ from GE Curves in a Single Market**

For Scenarios 1 to 10 as specified in Table 3.5, the initial shift occurs in a demand or supply curve that is completely exogenous to the model system. In these cases, the GE demand curves in all factor markets and the GE supply curves in the two export beef markets are easily identified. The total welfare changes ( $\Delta TS$ ) can be measured through the GE curve in the single market that involves the exogenous shift. The benefits to the domestic consumers can be obtained as the difference between  $\Delta TS$  and the sum of benefits to the other ten industry groups ( $\Delta ES_{rest(Qd)}$ ) calculated from formulas in Table 4.1.

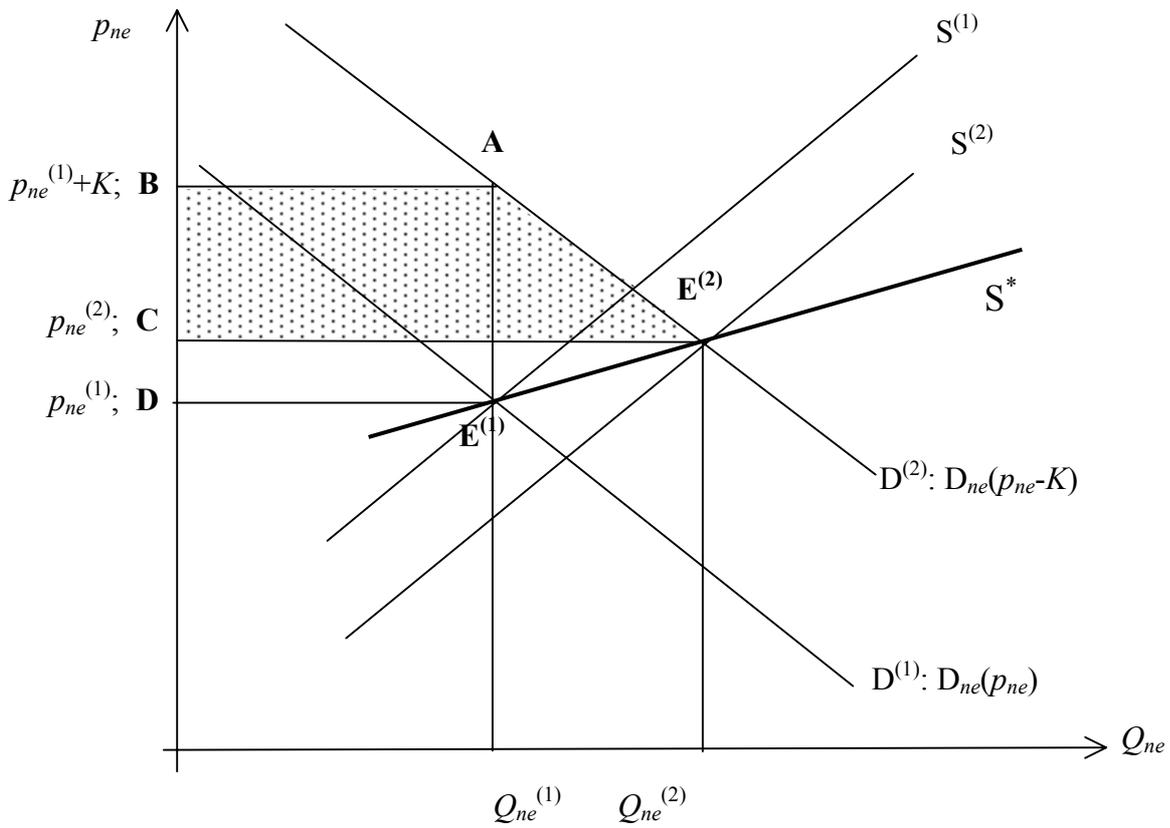


Figure 4.3 Export Grainfed Beef Consumers' and Total Surplus Changes for Scenario 9 ( $n_{Q_{ne}}=1\%$ )

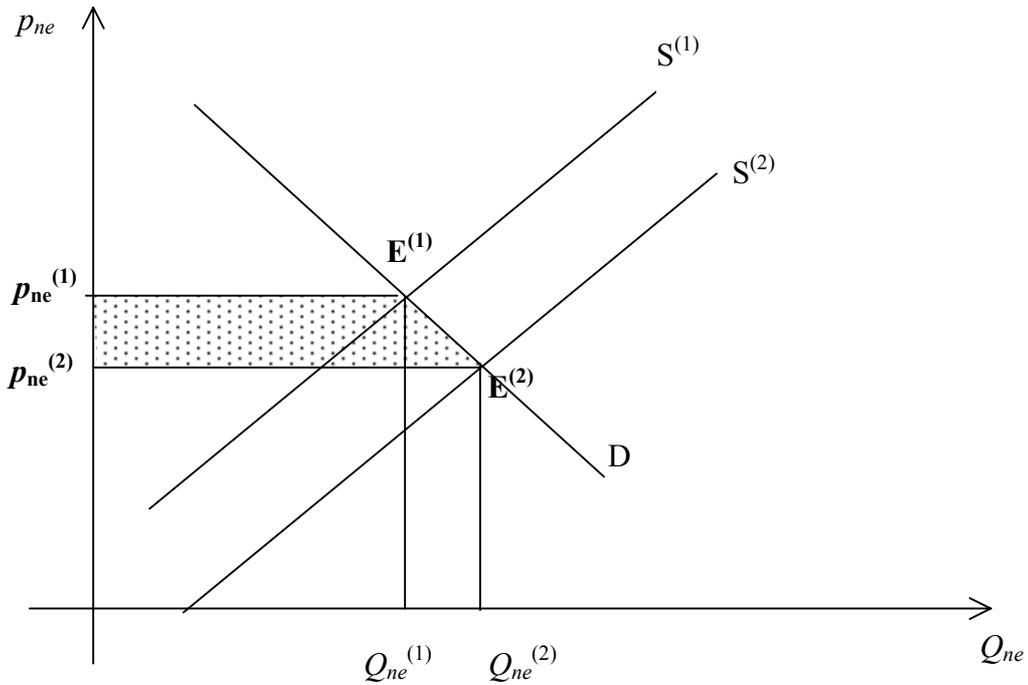


Figure 4.4 Export grainfed Beef Consumers' Surplus Change for Scenarios 2 to 12

Take weaner production research (Scenario 1) for example, where the weaner supply curve is exogenously shifted down by 1% ( $t_{X1}=-0.01$ ). Based on Just, Hueth and Schmitz (1982) and Thurman<sup>5</sup> (1991b), the total welfare gain to the ‘whole society’ ( $\Delta TS$ ) can be measured in the  $X_1$  market alone. In particular,  $\Delta TS$  is the sum of the producer surplus change measured off the exogenously determined supply curve of  $X_1$  and the consumer surplus change measured off the *general equilibrium* demand curve of  $X_1$ .

Figure 4.1 illustrates the  $X_1$  market for Scenario 1. As discussed in Section 4.2.1, the producer surplus change to weaner producers is given by area  $ABCE^{(2)}$  and Equation (4.2). The partial equilibrium (or *conditional*) demand curve for  $X_1$  has been shifted up endogenously from  $D^{(1)}$ :  $D(w_1|P^{(1)})$  to  $D^{(2)}$ :  $D(w_1|P^{(2)})$ , where  $P^{(1)}$  and  $P^{(2)}$  are the levels of all other prices in the model before and after the equilibrium displacement.  $E^{(1)}$  and  $E^{(2)}$  are the old and new equilibrium points. The line connecting  $E^{(1)}$  and  $E^{(2)}$ , denoted  $D^*$ , is the general equilibrium demand curve for  $X_1$  that traces the demand-price relationship for different levels of  $t_{X1}$  and  $P$ . The change in consumer surplus area measured off  $D^*$  is given by

$$(4.6) \quad \begin{aligned} \Delta CS_{X1}^* &= \int_{w_1^{(1)}}^{w_1^{(2)}} D^*(w_1) dw_1 = Area(CDE^{(1)}E^{(2)}) \\ &= -w_1^{(1)} X_1^{(1)} E w_1 (1 + 0.5EX_1). \end{aligned}$$

In this case,  $\Delta CS_{X1}^*$  measures the benefits to all other factor suppliers and all downstream industry sectors that directly or indirectly consume weaners. Using the expression for  $\Delta PS_{X1}$  in Equation (4.1), the total welfare change for Scenario 1 is given by

$$(4.7) \quad \begin{aligned} \Delta TS &= \Delta PS_{X1} + \Delta CS_{X1}^* = Area(ABDE^{(1)}E^{(2)}) \\ &= \int_{w_1^{(1)+K}}^{w_1^{(2)}} S(w_1 - K) dw_1 + \int_{w_1^{(1)}}^{w_1^{(2)}} D^*(w_1) dw_1 \\ &= w_1^{(1)} X_1^{(1)} (E w_1 - t_{X1})(1 + 0.5EX_1) - w_1^{(1)} X_1^{(1)} E w_1 (1 + 0.5EX_1) \\ &= -w_1^{(1)} X_1^{(1)} t_{X1} (1 + 0.5EX_1). \end{aligned}$$

Thus, the benefit to domestic consumers can be obtained as the residual as

$$(4.8) \quad \Delta CS_{Qd} = \Delta TS - \Delta ES_{rest(Qd)}, \quad \text{where}$$

$$(4.9) \quad \Delta ES_{rest(Qd)} = \sum_{\substack{i=X_1, X_{n2}, X_{s2}, \\ F_{n2}, F_{n3}, Y_p, Z_{me}, Z_{md}}} \Delta PS_i + \sum_{i=Q_{ne}, Q_{se}} \Delta CS_i,$$

where  $\Delta PS_i$  ( $i = X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$ ) and  $\Delta CS_i$  ( $i = Q_{ne}$  and  $Q_{se}$ ) are the surplus changes to the other ten industry groups, given by formulas in Table 4.1.

<sup>5</sup> The derivation of this result via integrals is given in Thurman (1991a, p2-7), for the case when the two products are related in demand but not in supply, and is not repeated here.

**Table 4.2 Economic Surplus Changes for Domestic Consumers for all 12 Scenarios – Two Alternative Approaches**

<b>A. Via GE Curves in the Exogenously Shifted Market</b>	<b>B. Directly from the PE Curves in the Domestic Beef Markets</b>
<p><math>\dot{\Delta}CS_{Qd} = \Delta TS - \Delta ES_{rest(Qd)}</math></p> <p>where <math>\Delta ES_{rest(Qd)}</math> is given in Table 4.1 and <math>\Delta TS</math> is given below.</p> <p><b>Scenario 1 ( <math>t_{X1}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{X1} + \Delta CS_{X1}^* = -w_1^{(1)} X_1^{(1)} t_{X1} (1 + 0.5EX_1)</math></p> <p><b>Scenario 2 ( <math>t_{Xn2}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Xn2} + \Delta CS_{Xn2}^* = -w_{n2}^{(1)} X_{n2}^{(1)} t_{Xn2} (1 + 0.5EX_{n2})</math></p> <p><b>Scenario 3 ( <math>t_{Xs2}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Xs2} + \Delta CS_{Xs2}^* = -w_{s2}^{(1)} X_{s2}^{(1)} t_{Xs2} (1 + 0.5EX_{s2})</math></p> <p><b>Scenario 4 ( <math>t_{Fn2}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Fn2} + \Delta CS_{Fn2}^* = -s_{n2}^{(1)} F_{n2}^{(1)} t_{Fn2} (1 + 0.5EF_{n2})</math></p> <p><b>Scenario 5 ( <math>t_{Fn3}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Fn3} + \Delta CS_{Fn3}^* = -s_{n3}^{(1)} F_{n3}^{(1)} t_{Fn3} (1 + 0.5EF_{n3})</math></p> <p><b>Scenario 6 ( <math>t_{Yp}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Yp} + \Delta CS_{Yp}^* = -v_p^{(1)} Y_p^{(1)} t_{Yp} (1 + 0.5EY_p)</math></p> <p><b>Scenario 7 ( <math>t_{Zme}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Zme} + \Delta CS_{Zme}^* = -u_{me}^{(1)} Z_{me}^{(1)} t_{Zme} (1 + 0.5EZ_{me})</math></p> <p><b>Scenario 8 ( <math>t_{Zmd}=-0.01</math>):</b>  <math>\Delta TS = \Delta PS_{Zmd} + \Delta CS_{Zmd}^* = -u_{md}^{(1)} Z_{md}^{(1)} t_{Zmd} (1 + 0.5EZ_{md})</math></p> <p><b>Scenario 9 ( <math>n_{Qne}=0.01</math>):</b>  <math>\Delta TS = \Delta CS_{Qne} + \Delta PS_{Qne}^* = p_{ne}^{(1)} Q_{ne}^{(1)} n_{Qne} (1 + 0.5EQ_{ne})</math></p> <p><b>Scenario 10( <math>n_{Qse}=0.01</math>):</b>  <math>\Delta TS = \Delta CS_{Qse} + \Delta PS_{Qse}^* = p_{se}^{(1)} Q_{se}^{(1)} n_{Qse} (1 + 0.5EQ_{se})</math></p> <p><b>Scenario 11 ( <math>n_{Qnd}=0.01</math>):</b>  <math>\Delta TS = p_{nd}^{(1)} Q_{nd}^{(1)} n_{Qnd} (1 + 0.5EQ_{nd})</math></p> <p><b>Scenario 12( <math>n_{Qsd}=0.01</math>):</b>  <math>\Delta TS = p_{sd}^{(1)} Q_{sd}^{(1)} n_{Qsd} (1 + 0.5EQ_{sd})</math></p>	$\Delta CS_{Qd} = p_{nd}^{(1)} Q_{nd}^{(1)} (n_{Qnd} - Ep_{nd}) (1 + 0.5EQ_{nd}) + p_{sd}^{(1)} Q_{sd}^{(1)} (n_{Qsd} - Ep_{sd}) (1 + 0.5EQ_{sd})$

The welfare changes for domestic consumers for Scenarios 2 to 10 can be obtained similarly. The formulas for calculating  $\Delta CS_{Qd}$  through the total welfare changes ( $\Delta TS$ ) off the GE curves in the exogenously shifted markets for Scenarios 1 to 10 are summarised in the left column of Table 4.2. The sum of the surplus changes for the other ten groups,  $\Delta ES_{rest(Qd)}$ , is given in Table 4.1.

## B. Measuring Directly from PE Curves in Individual Markets

Alternatively, the welfare change to domestic consumers can be measured directly as the consumer surplus areas off the partial equilibrium demand curves in the two domestic beef markets. Two price changes are involved in the domestic consumers' expenditure function in this case. As more than one source of equilibrium feedback exists, care needs to be taken to measure the area in a sequential manner.

Consider the two domestic beef markets in Figure 4.5 for Scenario 1, where the cost of producing weaners is reduced by 1% ( $t_{X1}=-1\%$ ). The expenditure function for domestic consumers and its derived demand functions are not changed by the exogenous shift in the weaner market. They are denoted as  $e(p_{nd}, p_{sd}, P)$  and  $D_{nd}(p_{nd}, p_{sd}, P)$  and  $D_{sd}(p_{nd}, p_{sd}, P)$ , for both before and after the displacement, where  $P$  is the vector of other prices outside the model and is omitted below without losing generality. The profit function and the derived supply functions for the domestic beef producers *are* changed as a direct result of the initial shift in weaner supply. In particular, in the first instance, both supply curves for  $Q_{nd}$  and  $Q_{sd}$  are shifted down. If we assume all profit and utility functions in the model are quadratic and all demand and supply functions are linear around the local areas of the initial equilibrium, a parallel initial shift in the supply of weaners ( $X_1$ ) implies that all induced shifts in other markets are also parallel around the local areas.<sup>6</sup> Because the two products are assumed substitutes in both demand and supply, as second round effects, both the conditional demand and supply curves are shifted further as the result of price changes of the substitute beef product. The situation is illustrated in Figure 4.5.

Following the approach in Thurman (1991a, p3), as the expenditure function is unchanged, the changes in the domestic beef consumers' welfare can be measured as

$$\begin{aligned}
 (4.10) \quad -\Delta e &= -(e(p_{nd}^{(2)}, p_{sd}^{(2)}) - e(p_{nd}^{(1)}, p_{sd}^{(1)})) \\
 &= -(e(p_{nd}^{(2)}, p_{sd}^{(1)}) - e(p_{nd}^{(1)}, p_{sd}^{(1)}) + e(p_{nd}^{(2)}, p_{sd}^{(2)}) - e(p_{nd}^{(2)}, p_{sd}^{(1)})) \\
 &= -\left( \int_{p_{nd}^{(1)}}^{p_{nd}^{(2)}} \frac{\partial e(p_{nd}, p_{sd}^{(1)})}{\partial p_{nd}} dp_{nd} + \int_{p_{sd}^{(1)}}^{p_{sd}^{(2)}} \frac{\partial e(p_{nd}^{(2)}, p_{sd})}{\partial p_{sd}} dp_{sd} \right) \\
 &= \int_{p_{nd}^{(2)}}^{p_{nd}^{(1)}} D_{nd}^h(p_{nd} | p_{sd}^{(1)}) dp_{nd} + \int_{p_{sd}^{(2)}}^{p_{sd}^{(1)}} D_{sd}^h(p_{sd} | p_{nd}^{(2)}) dp_{sd}
 \end{aligned}$$

<sup>6</sup> In this example, the initial shift K in the weaner market changes the profit function of domestic beef producers from  $\pi(p_{nd}, p_{sd}, w_1, W)$  to  $\pi(p_{nd}, p_{sd}, w_1-K, W)$ , where  $w_1$  is the price of weaners and  $W$  is the price for all other prices in the model. The conditional demand curves before and after the shift for  $Q_{nd}$  are  $S_{nd}(p_{nd} | p_{sd}^{(1)}, w_1^{(1)}, W^{(1)})$  and  $S_{nd}(p_{nd} | p_{sd}^{(2)}, w_1^{(2)}-K, W^{(2)})$ . If  $\pi(\cdot)$  is quadratic, changing the values of other prices or subtracting another price variable with a constant only changes the intercept of the conditional supply curve, which implies a parallel shift of the linear supply curve.

If the Marshallian demand curves are used in place of the Hicksian demand curves in the above integrals, the welfare change can be approximated by conventional economic surplus areas as

$$(4.11) \quad \Delta CS_{Qd} = \int_{p_{nd}^{(2)}}^{p_{nd}^{(1)}} D_{nd}(p_{nd} | p_{sd}^{(1)}) dp_{nd} + \int_{p_{sd}^{(2)}}^{p_{sd}^{(1)}} D_{sd}(p_{sd} | p_{nd}^{(2)}) dp_{sd}$$

That is, the change in the economic surplus of domestic consumers is given by the sum of areas integrated sequentially off the partial demand curves in both markets. Note that, in Figure 4.5, the first integral is area  $Ap_{nd}^{(2)}p_{nd}^{(1)}E^{(1)}$  integrated off the *initial* demand curve in the  $Q_{nd}$  market, and the second integral relates to area  $BE^{(2)}p_{sd}^{(2)}p_{sd}^{(1)}$  integrated off the *new* demand curve in the  $Q_{sd}$  market.

Note, however, these areas are not the same as the changes between the old and new consumer surplus areas one might intuitively expect. The consumer surplus in the  $Q_{nd}$  market off the initial and new PE demand curves are areas  $p_{nd}^{(1)}E^{(1)}C^{(1)}$  and  $p_{nd}^{(2)}E^{(2)}C^{(2)}$ , giving a difference of area  $GHE^{(2)}p_{nd}^{(2)}$ . Similarly, the change in consumer surplus areas off the new and old conditional demand curves in  $Q_{sd}$  market is area  $IJE^{(2)}p_{sd}^{(2)}$ . It is tempting to use the areas  $GHE^{(2)}p_{nd}^{(2)}$  and  $IJE^{(2)}p_{sd}^{(2)}$  as the domestic consumers' welfare measure  $\Delta CS_{Qd}$ <sup>7</sup>. As shown in Figure 4.5, this could seriously underestimate the economic surplus change for domestic consumers for this particular case. An example of the error is given in Part C below.

It can be shown that, for local linear demand functions,  $\Delta CS_{Qd}$  in Equation (4.11) can be calculated as

$$(4.12) \quad \begin{aligned} \Delta CS_{Qd} &= \text{Area}(Ap_{nd}^{(2)}p_{nd}^{(1)}E^{(1)}) + \text{Area}(BE^{(2)}p_{sd}^{(2)}p_{sd}^{(1)}) \\ &= -p_{nd}^{(1)}Q_{nd}^{(1)}Ep_{nd}(1+0.5\eta_{(Q_{nd}, p_{nd})}Ep_{nd}) \\ &\quad -p_{sd}^{(1)}Q_{sd}^{(1)}Ep_{sd}(1+EQ_{sd}-0.5\eta_{(Q_{sd}, p_{sd})}Ep_{sd}). \end{aligned}$$

Two things are worth mentioning at this point. First, the derivation in Equation (4.10) followed a particular equilibrium path from  $E^{(1)}$  to  $E^{(2)}$ ; that is,  $(p_{nd}^{(1)}, p_{sd}^{(1)})$  to  $(p_{nd}^{(2)}, p_{sd}^{(1)})$  first and then  $(p_{nd}^{(2)}, p_{sd}^{(1)})$  to  $(p_{nd}^{(2)}, p_{sd}^{(2)})$ . There is an infinite number of paths for the same displacement from  $E^{(1)}$  to  $E^{(2)}$ . For example, considering a path via  $(p_{nd}^{(1)}, p_{sd}^{(2)})$  instead of  $(p_{nd}^{(2)}, p_{sd}^{(1)})$  in Equation (4.10), we would have

$$(4.13) \quad \begin{aligned} \Delta CS_{Qd} &= \int_{p_{nd}^{(2)}}^{p_{nd}^{(1)}} D_{nd}(p_{nd} | p_{sd}^{(2)}) dp_{nd} + \int_{p_{sd}^{(2)}}^{p_{sd}^{(1)}} D_{sd}(p_{sd} | p_{nd}^{(1)}) dp_{sd} \\ &= -p_{nd}^{(1)}Q_{nd}^{(1)}Ep_{nd}(1+EQ_{nd}-0.5\eta_{(Q_{nd}, p_{nd})}Ep_{nd}) \\ &\quad -p_{sd}^{(1)}Q_{sd}^{(1)}Ep_{sd}(1+0.5\eta_{(Q_{sd}, p_{sd})}Ep_{sd}) \end{aligned}$$

<sup>7</sup> For example, these were the areas used in Piggott, Piggott and Wright (1995) and Hill, Piggott and Griffith (1996) for producer surplus changes in multi-feedback models.

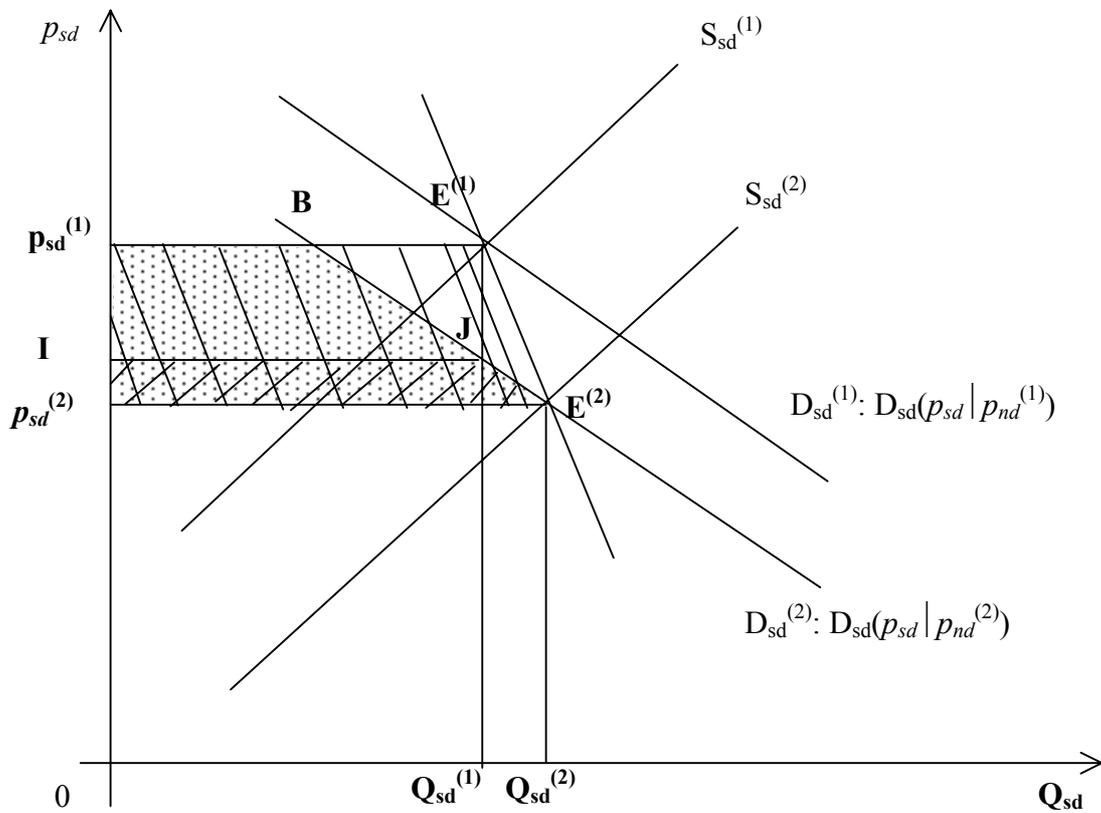
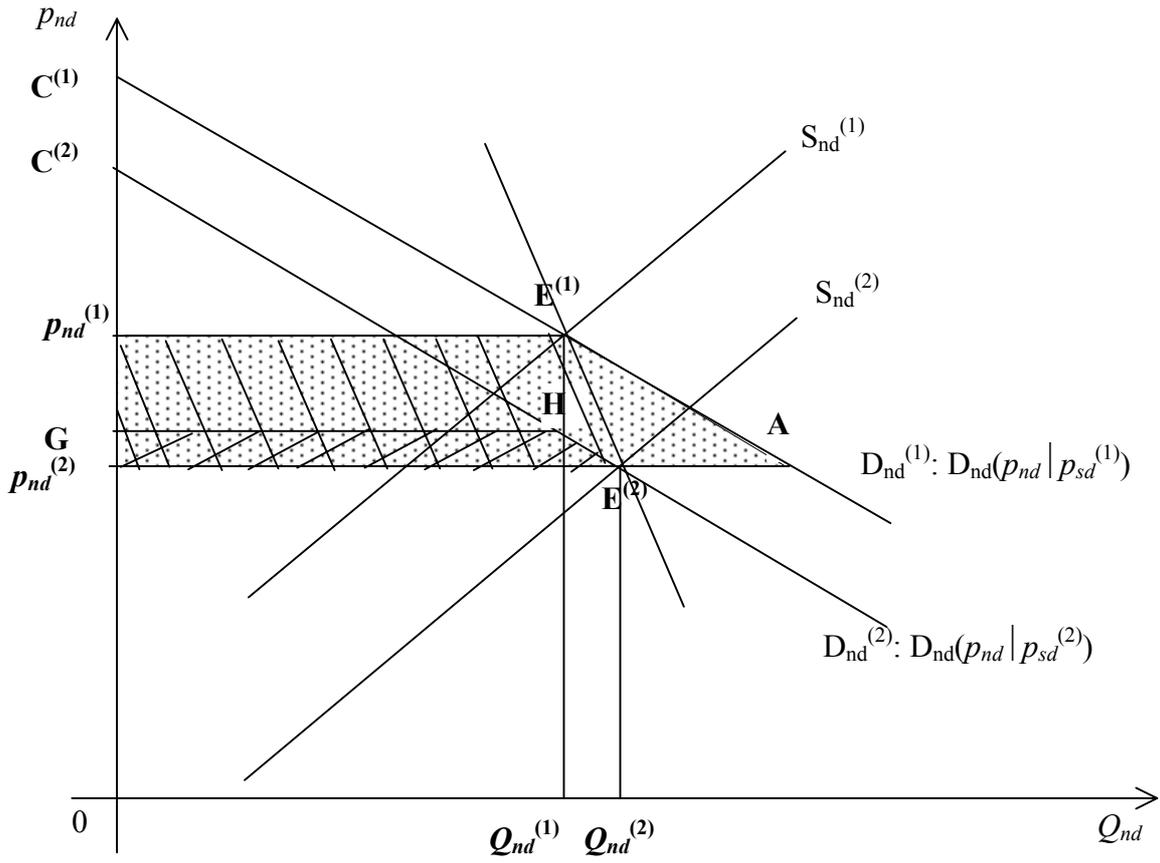


Figure 4.5 Domestic Consumer Welfare Changes for Scenario 1-10

It can be shown that, under the symmetry condition for the Marshallian cross-price elasticities at the equilibrium point in Equation (2.5.11), that is,

$$(4.14) \quad p_{nd}^{(1)} Q_{nd}^{(1)} \eta_{(Q_{nd}, p_{sd})} = p_{sd}^{(1)} Q_{sd}^{(1)} \eta_{(Q_{sd}, p_{nd})},$$

and given Equations (2.6.55) and (2.6.56), Equations (4.12) and (4.13) are exactly the same. In other words, the symmetry condition imposed on the Marshallian elasticities in Equation (4.14) guarantees path independence, or the uniqueness of the domestic consumers' surplus change.

Second, it can be shown that, under the symmetry condition in Equation (4.14), both the expressions in Equations (4.12) and (4.13) can be written as

$$(4.15) \quad \Delta CS_{Qd} = p_{nd}^{(1)} Q_{nd}^{(1)} (n_{Q_{nd}} - E p_{nd}) (1 + 0.5 E Q_{nd}) \\ + p_{sd}^{(1)} Q_{sd}^{(1)} (n_{Q_{sd}} - E p_{sd}) (1 + 0.5 E Q_{sd}),$$

where  $n_{Q_{nd}} = n_{Q_{sd}} = 0$  for Scenario 1.

In Figure 4.5, the expression in Equation (4.15) relates to conventional areas for economics surplus changes measured off the curve connecting  $E^{(1)}$  and  $E^{(2)}$  in both markets, that is, area  $p_{nd}^{(1)} E^{(1)} E^{(2)} p_{nd}^{(2)}$  in the  $Q_{nd}$  market and area  $p_{sd}^{(1)} E^{(1)} E^{(2)} p_{sd}^{(2)}$  in the  $Q_{sd}$  market. Note that any one of these two areas does not have significant economic meaning, but the sum of the two areas measures the consumer surplus change to domestic consumers.

It is obvious from the above derivation that, without the guarantee of integrability conditions, the measure for economic surplus change in the case of multiple price changes is not unique but path dependent. However, an important insight from this exercise is that integrability conditions may only affect the welfare measures at the second order terms. The first-order term, i.e.  $p_{nd}^{(1)} Q_{nd}^{(1)} (n_{Q_{nd}} - E p_{nd}) + p_{sd}^{(1)} Q_{sd}^{(1)} (n_{Q_{sd}} - E p_{sd})$  in this example, seems to be the same for alternative paths and does not seem to be affected by the integrability conditions. This may be the reason behind Hausman's (1981) and LaFrance's (1991) empirical results that, as long as the shifts considered are small, the errors from using Marshallian measures or ignoring integrability conditions are insignificant for the trapezoid areas of economic welfare changes, though they could be significant in the measures of triangular areas of 'deadweight loss'. The triangular area is a second order measure ( $O(\lambda^2)$ ), where  $\lambda$  relates to the amount of the initial shift), but the trapezoid area is of first-order in magnitude ( $O(\lambda)$ ).

Finally, it is obvious that the above derivation is also correct for the other scenarios when the initial shifts occur in other markets of the model (Scenarios 2 to 10). Thus, the formula in Equation (4.15) also applies to Scenarios 2 to 10. The formula for economic surplus changes for domestic consumers in Scenario 1 to 10 is summarised in the second column of Table 4.2.

### Comparison of the Two Approaches

The concern in Thurman (1991a) for the situation of multiple equilibrium feedback relates to whether the total welfare change can be measured in a 'single' market, and whether the economic surplus areas measured off the GE curves in a single market relate to identifiable groups. However, from the derivation in part B above, given that we have a disaggregated multi-market model and given that we have specified the information on all the partial

equilibrium curves in individual markets, the welfare changes for individual groups can be measured as areas off the partial equilibrium curves in individual markets.

As discussed in Section 2.5, the necessary condition for the equivalence of the two approaches in parts A and B is that of integrability. As the integrability conditions have been imposed at the initial equilibrium, the two approaches should give consistent answers. In Table 4.3, using the data specified in Section 3, the results of the domestic consumer welfare changes and the total welfare changes calculated from the two approaches for Scenario 1 are presented. They are almost the same.

**Table 4.3 Comparison of Results from Three Alternative Approaches for Scenario 1 ( $t_{X1} = -0.01$ ) (in \$m)**

<b>Factor Providers:</b>		
$\Delta PS_{X1} = 8.1308,$	$\Delta PS_{Xn2} = 0.0482,$	$\Delta PS_{Xs2} = 0.4730,$
$\Delta PS_{Fn3} = 0.0313,$	$\Delta PS_{Yp} = 0.6309,$	$\Delta PS_{Zme} = 0.1589,$
		$\Delta PS_{Zmd} = 0.4869.$
<b>Overseas Consumers:</b>		
$\Delta CS_{Qne} = 1.0263,$	$\Delta CS_{Qse} = 1.8300.$	
<b>Sub-Total:</b>		
$\Delta ES_{rest(Qd)} = 13.0421$		
<b>Approach A</b> (via GE curve):	<b>Approach B</b> (via same PE curves):	<b>Approach C</b> (via different PE curves in both markets):
$\Delta TS = \Delta PS_{X1} + \Delta CS_{X1}^*$ $= 8.1308 + 11.4833$ $= 19.6141$	$\Delta CS_{Qd} = \text{Area}(Ap_{nd}^{(2)}p_{nd}^{(1)}E^{(1)})$ $+ \text{Area}(BE^{(2)}p_{sd}^{(2)}p_{sd}^{(1)})$ $= 1.6126 + 4.9531$ $= 6.5657$	$\Delta CS_{Qnd} + \Delta CS_{Qsd}$ $= \text{Area}(GHE^{(2)}p_{nd}^{(2)})$ $+ \text{Area}(IJE^{(2)}p_{sd}^{(2)})$ $= 4.1320$
$\Delta CS_{Qd} = \Delta TS - \Delta ES_{rest(Qd)}$ $= 6.5720$	$\Delta TS = 19.6079$	$\Delta TS = 17.1741$

The areas relating to the differences of two economic surplus areas off the old and new PE demand curves, which have been used in some published studies, are also calculated for Scenario 1 in Table 4.3. The consumer surplus, \$4.1m is underestimated with 37% error.

In the base run of the model in Section 5, Approach B using the PE areas sequentially as in the second column of Table 4.2 is used.

#### 4.4.2 Scenario 11 and 12 – Two Alternative Approaches

Now consider the welfare changes for domestic consumers for Scenarios 11 and 12, where the initial shocks are the demand shifts in the domestic beef markets. In these cases, in addition to the initial demand shifts, both demand and supply curves are further shifted endogenously. Again, there are two alternatives to measuring the domestic consumers' welfare gains.

##### A. Measuring through $\Delta TS$ off GE Curves in a Single Market

Consider the markets for the two domestic beef products in Figure 4.6 for Scenario 11, where an initial upward shift occurs in the demand curve for grainfed beef ( $Q_{nd}$ ). Initially, the demand curve for  $Q_{nd}$  is shifted from  $D_{nd}^{(1)}: D_{nd}(p_{nd}|p_{sd}^{(1)})$  to  $D_{nd}^{(1)}: D_{nd}(p_{nd}-K, p_{sd}^{(1)})$ . Because the two products are related to each other in both demand and supply, the demand and supply curves for both products are subsequently shifted endogenously before reaching a new equilibrium  $E^{(2)}$  in both markets.

Based on the derivation in Thurman (1991a) for the situation involving two channels of equilibrium feedback, the total welfare change can be measured as the sum of the surplus areas measured off the GE demand and supply curves  $D_{nd}^*$  and  $S_{nd}^*$ , although these two areas do not have welfare significance individually. In Figure 4.6, the GE supply curve  $S_{nd}^*$  is given by the curve connecting  $E^{(1)}$  and  $E^{(2)}$ . The GE demand curve  $D_{nd}^*$  is given by the connection of  $E^{(2)}$  and G, where G relates to the price the consumer is willing to pay for the initial quantity  $Q_{nd}^{(1)}$  after the promotion. Thus, the total economic surplus change is given by

$$\begin{aligned}
 \Delta TS &= Area(HGE^{(2)}E^{(1)}C) \\
 (4.16) \quad &= \int_{p_{nd}^{(2)}}^{p_{nd}^{(1)}} D_{nd}^*(p_{nd}) dp_{nd} + \int_{p_{nd}^{(1)}}^{p_{nd}^{(2)}} S_{nd}^*(p_{nd}) dp_{nd} \\
 &= p_{nd}^{(1)} Q_{nd}^{(1)} n_{Q_{nd}} (1 + 0.5EQ_{nd}).
 \end{aligned}$$

Similarly, the surplus change to the domestic consumer from Scenario 12 is given by

$$(4.17) \quad \Delta TS = p_{sd}^{(1)} Q_{sd}^{(1)} n_{Q_{sd}} (1 + EQ_{sd}).$$

The domestic consumers' surplus change is thus given by

$$(4.18) \quad \Delta CS_{Qd} = \Delta TS - \Delta ES_{rest(Qd)},$$

where  $\Delta ES_{rest(Qd)}$  is the sum of the welfare changes to the other ten industry groups given in Table 4.1.

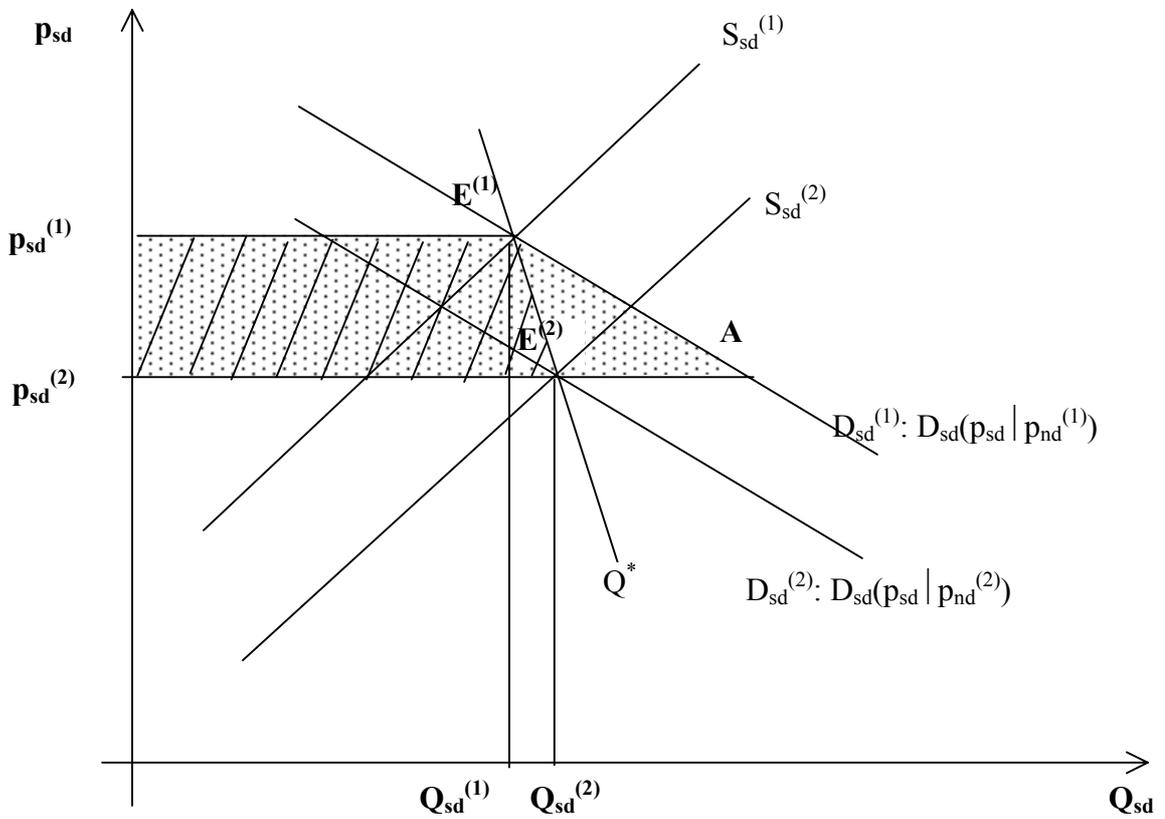
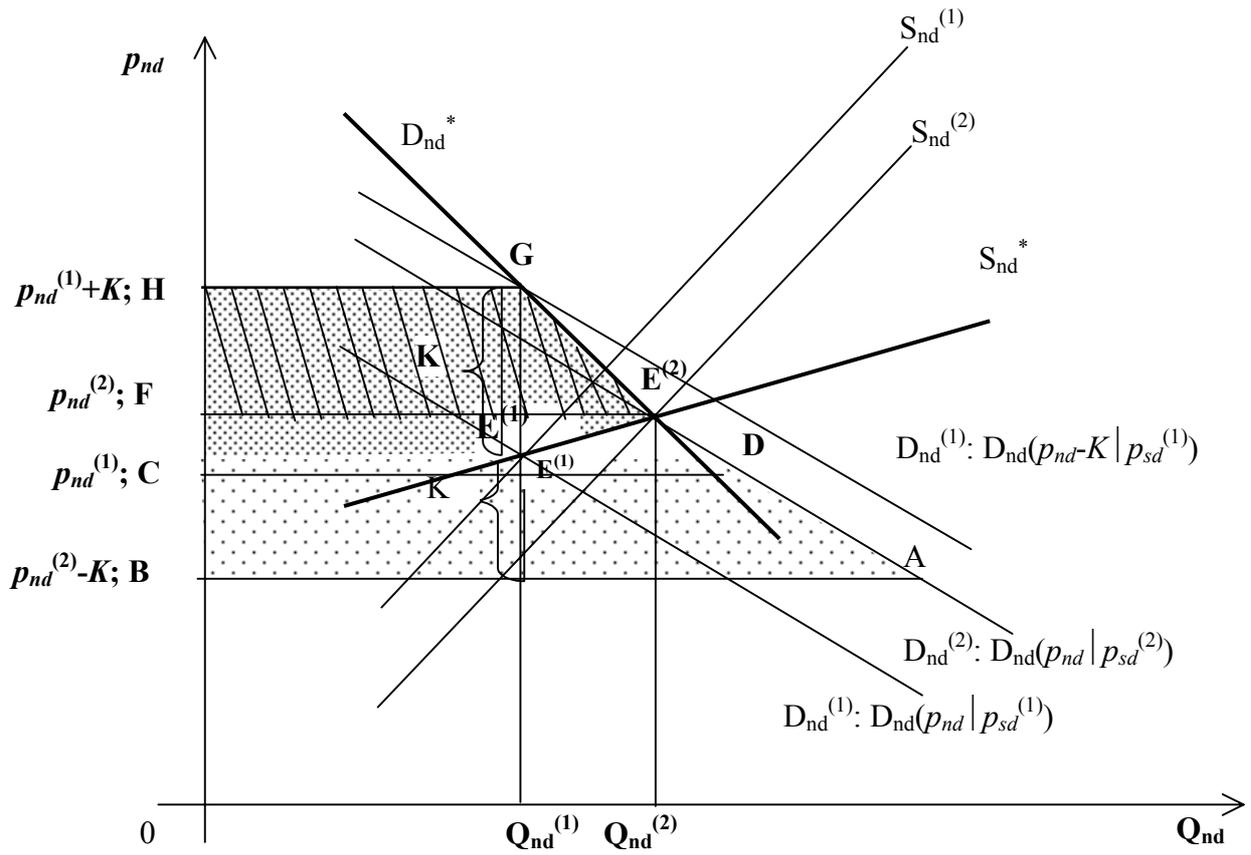


Figure 4.6 Domestic Consumer Welfare Change for Scenario 11 ( $n_{Qnd} = 0.01$ )

## B. Measuring Directly from PE Curves

The domestic consumers' benefits can also be measured directly through the partial equilibrium curves in the  $Q_{nd}$  and  $Q_{sd}$  markets.

Examine first the economic welfare change for the domestic consumers for scenario 11 when the initial shock to the system is from a 1% exogenous demand shift in the  $Q_{nd}$  market ( $n_{Q_{nd}}=0.01$ ). The expenditure functions before and after the exogenous shift are  $e(p_{nd}, p_{sd})$  and  $e(p_{nd}-K, p_{sd})$ , where  $K$  ( $K>0$ ) is the increase in the domestic consumers' willingness to pay per unit of grainfed beef. The compensating variation (CV) is given by

$$\begin{aligned}
 (4.19) \quad -\Delta e &= e(p_{nd}^{(2)} - K, p_{sd}^{(2)}) - e(p_{nd}^{(1)}, p_{sd}^{(1)}) \\
 &= -(e(p_{nd}^{(2)} - K, p_{sd}^{(2)}) - e(p_{nd}^{(1)}, p_{sd}^{(2)}) + e(p_{nd}^{(1)}, p_{sd}^{(2)}) - e(p_{nd}^{(1)}, p_{sd}^{(1)})) \\
 &= -\left( \int_{p_{nd}^{(1)}}^{p_{nd}^{(2)}-K} D_{nd}^h(p_{nd}, p_{sd}^{(2)}) dp_{nd} + \int_{p_{sd}^{(1)}}^{p_{sd}^{(2)}} D_{sd}^h(p_{nd}^{(1)}, p_{sd}) dp_{sd} \right)
 \end{aligned}$$

Using Marshallian demand curves, the consumer surplus change is given by

$$(4.20) \quad \Delta CS_{Qd} = - \int_{p_{nd}^{(1)}}^{p_{nd}^{(2)}-K} D_{nd}(p_{nd}, p_{sd}^{(2)}) dp_{nd} - \int_{p_{sd}^{(1)}}^{p_{sd}^{(2)}} D_{sd}(p_{nd}^{(1)}, p_{sd}) dp_{sd}$$

These two integrals relate to areas measured off the *new* demand curve  $D_{nd}^{(2)}$  in the  $Q_{nd}$  market and *initial* demand curve  $D_{sd}^{(1)}$  in the  $Q_{sd}$  market. In Figure 4.6, the first integral relates to area ABCD in the  $Q_{nd}$  market and the second integral relates to area  $Ap_{sd}^{(2)}p_{sd}^{(1)}E^{(1)}$  in the  $Q_{sd}$  market. It can be shown that they can be calculated as

$$\begin{aligned}
 (4.21) \quad \Delta CS_{Qd} &= Area(ABCD) + Area(Ap_{sd}^{(2)}p_{sd}^{(1)}E^{(1)}) \\
 &= p_{nd}^{(1)}Q_{nd}^{(1)}(n_{Q_{nd}} - Ep_{nd})(1 + EQ_{nd} - 0.5\eta_{(Q_{nd}, p_{nd})}(Ep_{nd} - n_{Q_{nd}})) \\
 &\quad - p_{sd}^{(1)}Q_{sd}^{(1)}Ep_{sd}(1 + 0.5\eta_{(Q_{sd}, p_{sd})}Ep_{sd}).
 \end{aligned}$$

Similar to the analysis in Part B of 4.4.1 (Equations (4.10)-(4.15)), it can be shown that under the symmetry condition of Marshallian elasticities in Equation (4.14),  $\Delta CS_{Qd}$  is uniquely defined and path independent. Using the condition in Equation (4.14), it can be shown that Equation (4.21) can be written as

$$\begin{aligned}
 (4.22) \quad \Delta CS_{Qd} &= Area(HGE^{(2)}F) + Area(p_{sd}^{(1)}E^{(1)}E^{(2)}p_{sd}^{(2)}) \\
 &= p_{nd}^{(1)}Q_{nd}^{(1)}(n_{Q_{nd}} - Ep_{nd})(1 + 0.5EQ_{nd}) \\
 &\quad + p_{sd}^{(1)}Q_{sd}^{(1)}(n_{Q_{sd}} - Ep_{sd})(1 + 0.5EQ_{sd}),
 \end{aligned}$$

These relate to area  $HGE^{(2)}F$  in  $Q_{nd}$  market and  $p_{sd}^{(1)}E^{(1)}E^{(2)}p_{sd}^{(2)}$  in  $Q_{sd}$  market in Figure 4.6.

Similarly, for Scenario 12 when the initial shift occurs in the  $Q_{sd}$  market, the domestic consumers' welfare change can be calculated as

$$(4.23) \quad \Delta CS_{Qd} = -\Delta e = -p_{nd}^{(1)} Q_{nd}^{(1)} E p_{nd} (1 + 0.5 \eta_{(Qnd, pnd)} E p_{nd}) \\ + p_{sd}^{(1)} Q_{sd}^{(1)} (n_{Qsd} - E p_{sd}) (1 + E Q_{sd} - 0.5 \eta_{(Qsd, psd)} (E p_{sd} - n_{Qsd})).$$

Also, Equation (4.23) becomes Equation (4.22) under symmetry condition (4.14) and Equations (2.6.55) and (2.6.56) in Section 2. In other words, the formula for  $\Delta CS_{Qd}$  is the same for all 12 scenarios under the Marshallian symmetry condition. These formulas are summarised in Table 4.2.

## 5 Results from the Base Model

### 5.1 Introduction

Using the data and parameters specified in Section 3, the equilibrium displacement model given in Equations (2.6.1)-(2.6.58) is solved to obtain the percentage changes in all price and quantity variables for each of the 12 policy scenarios specified in Table 3.7. Changes in economic surpluses for the various industry groups are then calculated using the formulas derived in Section 4 (summarised in Tables 4.1, 4.2 and 4.4). The model was solved using the econometric package SHAZAM and the code is given in Appendix 4 in Zhao (1999). The percentage changes in prices and quantities in all sectors for the 12 scenarios are given in Tables 5.1-I and 5.1-II. The resulting total economic surplus changes and their distributions among various industry groups are given in Tables 5.2-I and 5.2-II.

Although the results for all 12 exogenous shift scenarios are presented and compared for their policy implications, only the results of six scenarios are discussed in detail in Section 5.2. These are: new weaner production technology (Scenario 1), new grass-finishing technology (Scenario 2), new feedlot technology (Scenario 5), new processing technology (Scenario 6), new domestic marketing technology (Scenario 7) and new domestic grassfed beef promotion (Scenario 12).

Comparisons across the twelve investment scenarios and their policy implications are given in 5.3. In particular, some typical choices among broad funding areas that might be faced by decision makers are discussed in this section.

### 5.2 Results for Selected Investment Scenarios

#### 5.2.1 *New Technology for Weaner Production (Scenario 1)*

In Scenario 1, a 1% downward shift of the supply curve for total weaner cattle  $X_1$  is simulated; that is,  $t_{X_1} = -0.01$  and all other exogenous shift variables are set at zero in the displacement model. This scenario could be the result of any research-induced technical changes that reduce the cost of producing weaner cattle. Typically, genetic research that increases the calving percentage and other farm research that increases the efficiency of weaner production are examples of such exogenous changes.

The resulting percentage changes in all prices and quantities are calculated, and the results other than those for the aggregated input and output indices are reported in the first column of Table 5.1-I. Shifts in demand and supply curves and the resulting equilibrium displacements in all markets involved are illustrated in Figure 5.1. The weaner cattle may be inputs into the grass-finishing chain ( $X_{s1}$ ) or the grain-finishing chain ( $X_{s1}$ ); so, due to the reduced cost in weaner production, the supply curves of all cattle and beef products in the downstream sectors (i.e.  $F_{n1e}$ ,  $F_{n1d}$ ,  $Y_{ne}$ ,  $Y_{nd}$ ,  $Y_{se}$ ,  $Y_{sd}$ ,  $Z_{ne}$ ,  $Z_{nd}$ ,  $Z_{se}$ ,  $Z_{sd}$ ,  $Q_{ne}$ ,  $Q_{nd}$ ,  $Q_{se}$ ,  $Q_{sd}$ ) are shifted down, decreasing prices and increasing quantities of these products. On the other hand, the increased final beef consumption, resulting from the lower beef prices, also shifts the demand curves for all the cattle and intermediate beef products to the right. Additionally, the supply and demand curves for all cattle and beef products (other than the demand curves of  $Q_{ne}$  and  $Q_{se}$ ) are also shifted

due to the substitution relationships among different types of cattle and beef from both the demand and supply sides. As illustrated in Figure 5.1, as the end result of all these displacements, the downward supply shifts dominate and all cattle and beef prices decrease and quantities increase. The equilibrium price for weaners is estimated to decrease by 0.69% and the equilibrium quantity to increase by 0.28%. Other cattle and beef products at downstream levels are estimated to have 0.05% to 0.62% lower prices and 0.18% to 0.25% higher quantities.

The supply curves of other inputs in all sectors (i.e.  $X_{n2}$ ,  $X_{s2}$ ,  $F_{n2}$ ,  $F_{n3}$ ,  $Y_p$ ,  $Z_{me}$  and  $Z_{md}$ ) remain stationary in Scenario 1. However, the demand curves for these other inputs are shifted by two opposing forces. The increased beef consumption leads to increases in the demand for all other inputs, but the reduced cattle and beef input prices also decrease the demand for other inputs due to the input substitution effect. As only small substitution elasticities between cattle/beef inputs and other inputs have been assumed in the base run (all set equal to 0.1), the substitution effect is smaller than the scale effect due to the increased consumption and hence demand for these inputs increases although by less than the amount were fixed input proportions assumed. This can be seen from the example of the demand for other grass-finishing inputs ( $X_{s2}$ ) in Equation (2.6.8). The intercept of the demand curve is related to two terms: the negative  $\kappa_{Xs1}\sigma_{(Xs1,Xs2)}EW_l$  representing the 12 scut substitution effect due to the lower weaner price  $EW_l$  and the positive  $EY_s$  imposing an increase in input demand due to the increased aggregated output level  $EY_s$ . In this case, the two terms are -0.04 and 0.24 respectively, and the resulting demand curve for  $X_{s2}$  is shifted to the right. In fact, all demand curves for other inputs in the model eventually settle at the right of their original positions, which, together with their exogenously fixed supply curves, give rise to their higher quantities (0.15% to 0.21%) and higher prices (0.03% to 0.05%, but 0.24% for feedgrain) after the displacements.

Using these changes in prices and quantities, the changes in economic surpluses for the various industry groups are calculated based on the formulas given in Table 4.1 and 4.2. The results are reported in the first column of Table 5.2-I. The corresponding economic surplus areas are illustrated in Figure 5.1.

Based on a beef industry gross revenue of \$4,000 million per year at the farm gate (as specified in Table 5.3), the total economic surplus gain for this scenario is estimated as \$19.60 million per year. All industry groups involved enjoy increased economic surpluses. Farmers, including breeders, backgrounders and grass-finishers, share 33.7%, or \$6.61 million, of the total benefits. The assumption of non-zero input substitution elasticities between the weaner input and other inputs in the backgrounding and grass-finishing sectors has meant that it is possible to use more of the relatively cheaper weaner input to substitute for the use of some other inputs (a force that shifts out the demand curve for  $X_1$  further), and thus farmers receive a larger share of total benefits than they would under the assumption of fixed input proportions.

The other major beneficiaries are domestic consumers, gaining \$9.97 million or 50.8% of total benefits. This is because of the high value of the domestic retail beef sector ( $p_{nd}Q_{nd} + p_{sd}Q_{sd} = \$4,104$  million) and the much smaller domestic demand elasticities in comparison to export demand. Although having a higher volume ( $Z_{ne}+Z_{se}=1,135$ kt) at the carcass level than domestic beef ( $Z_{nd}+Z_{sd}=689$ kt), exported beef has a much lower price than domestic retail

beef and thus a much lower sector value ( $p_{ne}Q_{ne}+p_{se}Q_{se}=\$2,658$  million). This, and the assumption of a highly elastic overseas demand for Australian beef (own price elasticities of  $-5$  for grassfed and  $-2.5$  for grainfed), results in much smaller surplus gains to overseas consumers ( $\$1.62$  million or  $8.3\%$ ) than to domestic consumers. The feedlotter, grain producers, processors, exporters and domestic retailers (supermarkets and butchers) only benefit by small amounts, sharing  $7.2\%$  of the total benefits among them, due to the assumption of elastic supply of other inputs in these sectors<sup>8</sup>.

### 5.2.2 *New Grass-Finishing Technology (Scenario 2)*

In the second column of Table 5.1-I, the estimated percentage changes for the price and quantity variables resulting from a  $1\%$  downward shift in the other grass-finishing input supply ( $t_{X_{s2}}=-0.01$ ) are reported. Due to the new technologies in the grass-finishing sector that reduce the cost of other grass-finishing inputs and shift down the supply curve of  $X_{s2}$ , the supply curves for all downstream products, that is the two types of grass-finished cattle ( $Y_{se}$  and  $Y_{sd}$ ) and all types of processed beef ( $Z_{ne}$ ,  $Z_{se}$ ,  $Z_{nd}$  and  $Z_{sd}$ ) and final beef products for consumers ( $Q_{ne}$ ,  $Q_{se}$ ,  $Q_{nd}$  and  $Q_{sd}$ ), are shifted down. Prices fall and quantities increase. As a feedback effect due to increased consumption, the derived demand curves for these beef and cattle products (except for the final beef products) are shifted up, giving opposing forces on prices. The supply and demand curves are also shifted due to the minor substitution effects allowed in the model. The final results show the dominating effects of the downward supply shifts: the price of  $X_{s2}$  decreases by  $0.96\%$  and the prices for the above mentioned beef and cattle products that directly or indirectly use  $X_{s2}$  decrease by  $0.04\%$  to  $0.46\%$ . The quantities in these markets increase by  $0.13\%$  to  $0.24\%$ .

The supply curves for weaners ( $X_1$ ) and for all other inputs in all sectors ( $X_{n2}$ ,  $F_{n2}$ ,  $F_{n3}$ ,  $Y_p$ ,  $Z_{me}$  and  $Z_{md}$ ) remain stationary in this scenario, while the demand curves in these markets are shifted up due to the increased consumption. The results are increased prices ( $0.02\%$  to  $0.19\%$ ) and increased quantities ( $0.11\%$  to  $0.17\%$ ) in these markets.

In the grain-finishing stream producing feeder cattle ( $F_{n1e}$  and  $F_{n1d}$ ) and grain-finished cattle ( $Y_{ne}$  and  $Y_{nd}$ ), there are two opposing forces shifting their demand curves. For example, referring to Equations (2.6.30) and (2.6.31), the demands for  $Y_{ne}$  and  $Y_{nd}$  are shifted up due to the increased beef consumption downstream ( $EZ>0$ ), but shifted down at the same time due to the small substitution effect resulting from the lower prices of  $Y_{se}$  and  $Y_{sd}$  ( $E_{v_{se}}<0$  and  $E_{v_{sd}}<0$ ). There are also input substitution effects between the two grainfed cattle types ( $E_{v_{nd}}>0$  in Equation (2.6.30) and  $E_{v_{ne}}>0$  in Equation (2.6.31)) and between cattle inputs and processing inputs ( $E_{v_p}>0$  in both (2.6.30) and (2.6.31)), shifting up the demand curves for  $Y_{ne}$  and  $Y_{nd}$ . The upward shifts dominate and the results show an increase of  $0.16\%$  in quantities and an increase of  $0.11\%$  in prices for the two grain-finished cattle types. Similarly, the prices and quantities for the two types of feeder cattle,  $F_{n1e}$  and  $F_{n1d}$ , are also increased ( $0.10\%$  and  $0.16\%$  respectively).

The resulting welfare implications are given in the second column of Table 5.2-I. The total annual surplus change is estimated as  $\$13.32$  million. This figure is smaller than the total benefit of  $\$19.6$  million for Scenario 1 (new weaner production technology). As can be seen

<sup>8</sup> Implications when this assumption is altered are discussed in Zhao, Griffiths, Griffith and Mullen (2000).

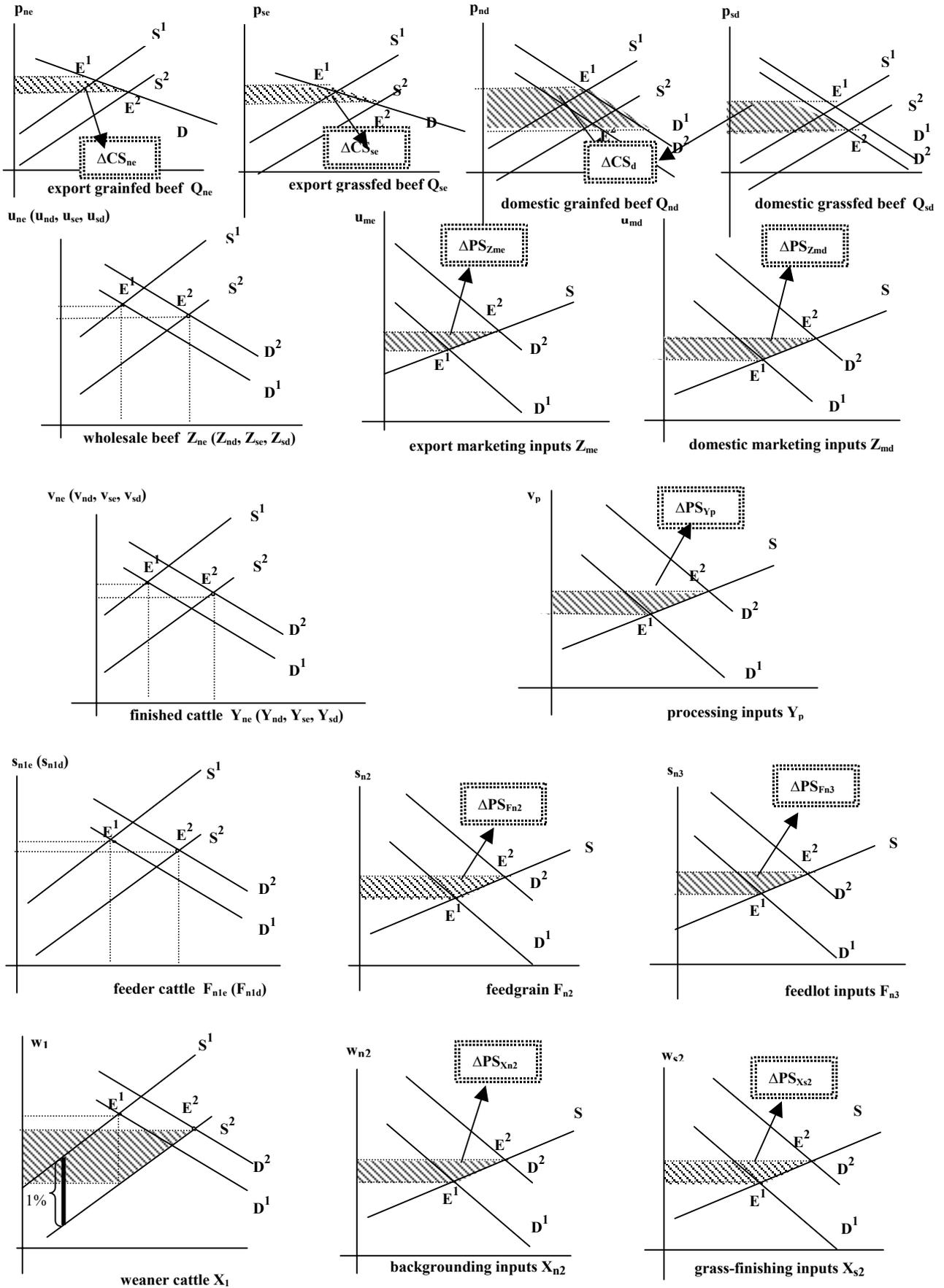


Figure 5.1 Market Displacement and Surplus Changes in Scenario 1 (t<sub>X1</sub>=-1%)

**Table 5.1-I Percentage Changes in Prices and Quantities for Alternative Investment Scenarios (%)**

	<b>Scenario 1 (<math>t_{X1}=-1\%</math>)</b>	<b>Scenario 2 (<math>t_{Xs2}=-1\%</math>)</b>	<b>Scenario 3 (<math>t_{Xn2}=-1\%</math>)</b>	<b>Scenario 4 (<math>t_{Fn2}=-1\%</math>)</b>	<b>Scenario 5 (<math>t_{Fn3}=-1\%</math>)</b>	<b>Scenario 6 (<math>t_{Vp}=-1\%</math>)</b>
<b>Quantities:</b>						
EX <sub>n1</sub>	0.28	0.15	0.01	0.01	0.01	0.05
EX <sub>s1</sub>	0.27	0.13	0.02	0.02	0.01	0.05
EX <sub>1</sub>	0.28	0.14	0.02	0.01	0.01	0.05
EX <sub>n2</sub>	0.21	0.17	0.11	0.01	0.01	0.05
EX <sub>s2</sub>	0.20	0.24	0.02	0.02	0.01	0.05
EF <sub>n1e</sub>	0.25	0.16	0.05	0.01	0.01	0.05
EF <sub>n1d</sub>	0.25	0.16	0.05	0.01	0.01	0.05
EF <sub>n2</sub>	0.19	0.15	0.01	0.10	0.01	0.05
EF <sub>n3</sub>	0.21	0.17	0.01	0.01	0.11	0.05
EY <sub>se</sub>	0.24	0.18	0.02	0.02	0.01	0.05
EY <sub>sd</sub>	0.24	0.18	0.02	0.02	0.01	0.05
EY <sub>ne</sub>	0.23	0.16	0.04	0.03	0.02	0.05
EY <sub>nd</sub>	0.23	0.16	0.04	0.03	0.02	0.05
EY <sub>p</sub>	0.20	0.15	0.02	0.01	0.01	0.15
EZ <sub>ne</sub>	0.25	0.18	0.02	0.02	0.02	0.06
EZ <sub>se</sub>	0.25	0.18	0.02	0.02	0.02	0.06
EZ <sub>me</sub>	0.24	0.17	0.02	0.02	0.01	0.06
EZ <sub>nd</sub>	0.22	0.16	0.02	0.02	0.01	0.06
EZ <sub>sd</sub>	0.22	0.16	0.02	0.02	0.01	0.06
EZ <sub>md</sub>	0.15	0.11	0.02	0.01	0.01	0.04
EQ <sub>ne</sub>	0.24	0.18	0.02	0.02	0.02	0.06
EQ <sub>se</sub>	0.25	0.18	0.02	0.02	0.02	0.06
EQ <sub>nd</sub>	0.18	0.13	0.02	0.01	0.01	0.05
EQ <sub>sd</sub>	0.18	0.14	0.02	0.01	0.01	0.05
<b>Prices:</b>						
EW <sub>1</sub>	-0.69	0.15	0.02	0.02	0.01	0.05
EW <sub>n2</sub>	0.04	0.03	-0.98	0.02	0.001	0.01
EW <sub>s2</sub>	0.04	-0.95	0.004	0.003	0.003	0.01
ES <sub>n1e</sub>	-0.38	0.10	-0.41	0.01	0.01	0.04
ES <sub>n1d</sub>	-0.38	0.10	-0.41	0.01	0.01	0.04
ES <sub>n2</sub>	0.24	0.19	0.01	-0.88	0.01	0.06
ES <sub>n3</sub>	0.04	0.03	0.002	0.002	-0.98	0.01
EV <sub>se</sub>	-0.37	-0.33	0.01	0.01	0.01	0.04
EV <sub>sd</sub>	-0.37	-0.33	0.01	0.01	0.01	0.04
EV <sub>ne</sub>	-0.17	0.11	-0.25	-0.19	-0.16	0.04
EV <sub>nd</sub>	-0.17	0.11	-0.25	-0.19	-0.16	0.04
EV <sub>p</sub>	0.04	0.03	0.004	0.003	0.003	-0.97
EU <sub>ne</sub>	-0.07	-0.05	-0.01	-0.005	-0.004	-0.02
EU <sub>se</sub>	-0.07	-0.05	-0.01	-0.005	-0.004	-0.02
EU <sub>me</sub>	0.05	0.03	0.005	0.003	0.003	0.01
EU <sub>nd</sub>	-0.62	-0.46	-0.06	-0.05	-0.04	-0.16
EU <sub>sd</sub>	-0.62	-0.46	-0.06	-0.05	-0.04	-0.16
EU <sub>md</sub>	0.03	0.02	0.003	0.002	0.002	0.01
EP <sub>ne</sub>	-0.10	-0.07	-0.01	-0.01	-0.01	-0.03
EP <sub>se</sub>	-0.05	-0.04	-0.005	-0.004	-0.003	-0.01
EP <sub>nd</sub>	-0.26	-0.19	-0.03	-0.02	-0.02	-0.07
EP <sub>sd</sub>	-0.24	-0.18	-0.02	-0.02	-0.01	-0.06

**Table 5.1-II Percentage Changes in Prices and Quantities for Alternative Investment Scenarios (%)**

	<b>Scenario 7</b> ( $t_{Zmd}=-1\%$ )	<b>Scenario 8</b> ( $t_{Zme}=-1\%$ )	<b>Scenario 9</b> ( $n_{Qnc}=1\%$ )	<b>Scenario 10</b> ( $n_{Qse}=1\%$ )	<b>Scenario 11</b> ( $n_{Qnd}=1\%$ )	<b>Scenario12</b> ( $n_{Qsd}=1\%$ )
<b>Quantities:</b>						
EX <sub>n1</sub>	0.19	0.02	0.08	0.26	0.09	0.29
EX <sub>s1</sub>	0.19	0.02	0.08	0.26	0.09	0.29
EX <sub>1</sub>	0.19	0.02	0.08	0.26	0.09	0.29
EX <sub>n2</sub>	0.20	0.02	0.08	0.28	0.10	0.32
EX <sub>s2</sub>	0.21	0.02	0.08	0.28	0.10	0.32
EF <sub>n1e</sub>	0.20	0.02	0.08	0.27	0.09	0.31
EF <sub>n1d</sub>	0.20	0.02	0.08	0.27	0.09	0.31
EF <sub>n2</sub>	0.19	0.02	0.08	0.25	0.09	0.29
EF <sub>n3</sub>	0.21	0.02	0.08	0.28	0.10	0.32
EY <sub>se</sub>	0.20	0.02	0.08	0.27	0.09	0.31
EY <sub>sd</sub>	0.20	0.02	0.08	0.27	0.09	0.31
EY <sub>ne</sub>	0.20	0.02	0.08	0.27	0.09	0.30
EY <sub>nd</sub>	0.20	0.02	0.08	0.27	0.09	0.30
EY <sub>p</sub>	0.21	0.02	0.08	0.28	0.10	0.32
EZ <sub>ne</sub>	0.19	0.03	0.09	0.30	0.09	0.29
EZ <sub>se</sub>	0.19	0.03	0.09	0.30	0.09	0.29
EZ <sub>me</sub>	0.18	0.13	0.11	0.36	0.08	0.28
EZ <sub>nd</sub>	0.21	0.02	0.07	0.23	0.10	0.33
EZ <sub>sd</sub>	0.21	0.02	0.07	0.23	0.10	0.33
EZ <sub>md</sub>	0.34	0.01	0.05	0.16	0.11	0.38
EQ <sub>ne</sub>	0.19	0.03	0.13	0.26	0.09	0.29
EQ <sub>se</sub>	0.19	0.03	0.08	0.31	0.09	0.29
EQ <sub>nd</sub>	0.28	0.02	0.06	0.19	0.14	0.32
EQ <sub>sd</sub>	0.29	0.02	0.06	0.19	0.10	0.37
<b>Prices:</b>						
EW <sub>1</sub>	0.21	0.03	0.09	0.29	0.10	0.33
EW <sub>n2</sub>	0.04	0.005	0.02	0.06	0.02	0.06
EW <sub>s2</sub>	0.04	0.005	0.02	0.06	0.02	0.06
ES <sub>n1e</sub>	0.14	0.02	0.06	0.19	0.06	0.21
ES <sub>n1d</sub>	0.14	0.02	0.06	0.19	0.06	0.21
ES <sub>n2</sub>	0.23	0.03	0.10	0.32	0.11	0.36
ES <sub>n3</sub>	0.04	0.005	0.02	0.06	0.02	0.06
EV <sub>se</sub>	0.14	0.02	0.06	0.19	0.06	0.21
EV <sub>sd</sub>	0.14	0.02	0.06	0.19	0.06	0.21
EV <sub>ne</sub>	0.14	0.02	0.06	0.19	0.07	0.22
EV <sub>nd</sub>	0.14	0.02	0.06	0.19	0.07	0.22
EV <sub>p</sub>	0.04	0.005	0.02	0.06	0.02	0.06
EU <sub>ne</sub>	-0.05	0.07	0.22	0.74	-0.02	-0.08
EU <sub>se</sub>	-0.05	0.07	0.22	0.74	-0.02	0.60
EU <sub>me</sub>	0.04	-0.97	0.02	0.07	0.02	0.06
EU <sub>nd</sub>	0.38	-0.06	-0.19	-0.64	0.18	0.60
EU <sub>sd</sub>	0.38	-0.06	-0.19	-0.64	0.18	0.60
EU <sub>md</sub>	-0.93	0.003	0.01	0.03	0.02	0.08
EP <sub>ne</sub>	-0.07	-0.01	0.95	-0.10	-0.03	-0.12
EP <sub>se</sub>	-0.04	-0.01	-0.02	0.94	-0.02	-0.06
EP <sub>nd</sub>	-0.41	-0.02	-0.08	-0.27	0.83	-0.49
EP <sub>sd</sub>	-0.37	-0.02	-0.07	-0.25	-0.13	0.53

**Table 5.2-I Absolute Economic Surplus Changes (in \$million) and Percentage Shares of Total Surplus Changes (in %) to Various Industry Groups from Alternative Investment Scenarios**

	Scenario 1 ( $t_{X1}=-1\%$ )		Scenario 2 ( $t_{Xs2}=-1\%$ )		Scenario 3 ( $t_{Xn2}=-1\%$ )		Scenario 4 ( $t_{Fn2}=-1\%$ )		Scenario 5 ( $t_{Fn3}=-1\%$ )		Scenario 6 ( $t_{Yp}=-1\%$ )	
	\$m	%	\$m	%	\$m	%	\$m	%	\$m	%	\$m	%
$\Delta PS_{X1}$ weaner producers	6.00	30.6	2.98	22.3	0.41	23.3	0.30	21.1	0.26	23.3	1.05	22.5
$\Delta PS_{Xs2}$ grass-finishers	0.54	2.7	0.65	4.9	0.06	3.3	0.04	3.0	0.04	3.3	0.14	3.0
$\Delta PS_{Xn2}$ backgrounders	0.07	0.4	0.06	0.4	0.04	2.2	0.003	0.2	0.002	0.2	0.02	0.4
$\Delta PS_{X1} +$ $\Delta PS_{Xs2} + \Delta PS_{Xn2}$ <b>farmers subtotal</b>	6.61	33.7	3.69	27.6	0.51	28.8	0.34	24.3	0.29	26.8	1.21	25.9
$\Delta PS_{Fn2}$ <b>feedgrain growers</b>	0.34	1.8	0.27	2.0	0.02	1.0	0.17	12.0	0.01	1.1	0.09	1.8
$\Delta PS_{Fn3}$ <b>feedlotters</b>	0.05	0.2	0.04	0.3	0.002	0.1	0.002	0.1	0.02	2.1	0.01	0.3
$\Delta PS_{Yp}$ <b>processors</b>	0.19	1.0	0.14	1.1	0.02	1.1	0.01	1.0	0.01	1.1	0.14	3.0
$\Delta PS_{Zme}$ <b>exporters</b>	0.09	0.5	0.07	0.5	0.01	0.5	0.006	0.4	0.006	0.5	0.02	0.5
$\Delta PS_{Zmd}$ <b>domestic retailers</b>	0.74	3.8	0.55	4.1	0.07	4.1	0.05	3.7	0.05	4.1	0.19	4.1
<b>Overseas Consumers:</b>												
$\Delta CS_{Qne}$ grainfed beef	0.61	3.1	0.45	3.4	0.06	3.4	0.04	3.0	0.04	3.6	0.16	3.4
$\Delta CS_{Qse}$ grassfed beef	1.01	5.2	0.75	5.6	0.10	5.6	0.07	5.2	0.06	5.4	0.26	5.6
$\Delta CS_{Qne} + \Delta CS_{Qse}$ <b>subtotal</b>	1.62	8.3	1.20	9.0	0.16	9.0	0.11	8.2	0.10	9.0	0.42	9.0
$\Delta CS_{Qne}$ <b>domestic consumers</b>	9.97	50.8	7.38	55.4	0.97	55.4	0.72	50.3	0.63	55.2	2.60	55.4
<b>Total Surplus</b>	19.60	100	13.32	100	1.74	100	1.44	100	1.13	100	4.69	100

**Table 5.2-II Absolute Economic Surplus Changes (in \$million) and Percentage Shares of Total Surplus Changes (in %) to Various Industry Groups from Alternative Investment Scenarios**

	Scenario 7 ( $t_{Zmd}=-1\%$ )		Scenario 8 ( $t_{Zme}=-1\%$ )		Scenario 9 ( $n_{Qne}=1\%$ )		Scenario 10 ( $n_{Qse}=1\%$ )		Scenario 11 ( $n_{Qnd}=1\%$ )		Scenario12 ( $n_{Qsd}=1\%$ )	
	\$m	%	\$m	%	\$m	%	\$m	%	\$m	%	\$m	%
$\Delta PS_{X1}$ weaner producers	4.10	17.2	0.49	26.2	1.69	27.2	5.60	27.4	1.91	20.1	6.40	20.3
$\Delta PS_{Xs2}$ grass-finishers	0.55	2.3	0.07	3.5	0.23	3.6	0.75	3.7	0.25	2.7	0.85	2.7
$\Delta PS_{Xn2}$ backgrounders	0.07	0.3	0.01	0.5	0.03	0.5	0.10	0.5	0.03	0.4	0.11	0.4
$\Delta PS_{X1}+$ $\Delta PS_{Xs2}+\Delta PS_{Xn2}$ <b>farmers subtotal</b>	4.72	19.8	0.57	30.2	1.95	31.3	6.45	31.6	2.19	23.2	7.36	23.4
$\Delta PS_{Fn2}$ <b>feedgrain growers</b>	0.34	1.4	0.04	2.1	0.14	2.2	0.46	2.3	0.16	1.7	0.52	1.7
$\Delta PS_{Fn3}$ <b>feedlotters</b>	0.05	0.2	0.006	0.3	0.02	0.3	0.06	0.3	0.02	0.2	0.07	0.2
$\Delta PS_{Yp}$ <b>processors</b>	0.19	0.8	0.02	1.2	0.08	1.3	0.26	1.3	0.09	0.9	0.30	1.0
$\Delta PS_{Zme}$ <b>exporters</b>	0.07	0.3	0.05	2.6	0.04	0.7	0.14	0.7	0.03	0.3	0.11	0.3
$\Delta PS_{Zmd}$ <b>domestic retailers</b>	1.63	6.8	0.07	3.6	0.23	3.7	0.76	3.7	0.54	5.7	1.81	5.7
<b>Overseas Consumers:</b>												
$\Delta CS_{Qne}$ grainfed beef	0.46	1.9	0.08	4.3	0.32	5.1	0.65	3.2	0.22	2.3	0.72	2.3
$\Delta CS_{Qse}$ grassfed beef	0.76	3.2	0.14	7.4	0.33	5.3	1.28	6.3	0.36	3.7	1.19	3.8
$\Delta CS_{Qne}+\Delta CS_{Qse}$ <b>subtotal</b>	1.22	5.1	0.22	11.7	0.65	10.4	1.93	9.5	0.58	6.0	1.91	6.1
$\Delta CS_{Qd}$ <b>domestic consumers</b>	15.66	65.6	0.91	48.3	3.12	50.1	10.32	50.6	5.87	61.9	19.45	61.7
<b>Total Surplus</b>	23.88	100	1.88	100	6.23	100	20.38	100	9.48	100	31.55	100

from the formulas in Tables 4.2, the total surplus change is predominantly determined by the size of the market where the initial exogenous shift occurs. Because the value for  $X_{s2}$  ( $w_{s2}X_{s2}=\$1,346$  million) is smaller than the value of weaner cattle  $X_1$  ( $w_1X_1=\$1,958$ ), the total benefit created by a 1% cost reduction in cattle grass-finishing is also smaller than that in weaner production.

The grass-finishers themselves only gain \$0.65 million or 4.9% of the total benefit due to the assumption of highly elastic supply of grass-finishing inputs (with elasticity of 5). Farmers and domestic consumers are the two major winners, gaining \$3.69 million (27.6%) and \$7.38 million (55.4%) respectively. The rest of the groups share the remaining \$2.25 million (17%) due to the assumption of highly elastic supply or demand in the relevant sectors.

### 5.2.3 *New Feedlot Technology (Scenario 5)*

New feedlot technology is modelled as a downward shift in the supply curve of other feedlot inputs, as feedlot operators are able to provide feedlot inputs with lower cost. In Scenario 5, a 1% downward shift in feedlot input supply ( $t_{F_{n3}}=-0.01$ ) is simulated (Column 5 of Table 5.1).

The resulting percentage changes in prices and quantities are shown in the fifth column of Table 5.1. The cost reduction in the other feedlot inputs ( $F_{n3}$ ) consequently reduces the costs of all downstream products that directly or indirectly use  $F_{n3}$ ; these are: grain-finished cattle ( $Y_{ne}$  and  $Y_{nd}$ ), all processed beef carcasses ( $Z_{ne}$ ,  $Z_{se}$ ,  $Z_{nd}$  and  $Z_{sd}$ ) and all final beef products ( $Q_{ne}$ ,  $Q_{se}$ ,  $Q_{nd}$  and  $Q_{sd}$ ). As a result, the supply curves of these products are shifted down, reducing their prices and increasing the quantities. On the other hand, while the demand curves for  $Q_{ne}$ ,  $Q_{se}$ ,  $Q_{nd}$  and  $Q_{sd}$  remain stationary in this scenario, the increased consumption of final beef products due to lower prices shifts the derived demand curves for  $Z_{ne}$ ,  $Z_{se}$ ,  $Z_{nd}$ ,  $Z_{sd}$ ,  $Y_{ne}$  and  $Y_{nd}$  upward. The supply shifts again dominate the demand shifts and any other minor shifts due to substitution effects: the prices for these beef products are estimated to decrease by 0.004% to 0.16% and the quantities increase by 0.01% to 0.02%.

All factor supply curves other than that for  $F_{n3}$  are fixed, and the derived input demand curves in these markets are shifted up due to the increased outputs in all sectors. There are also some demand shifts due to input substitution. The results show increases in both prices (by 0.001% to 0.01%) and quantities (by around 0.01%) in these markets.

Regarding the intermediate cattle products  $F_{n1e}$ ,  $F_{n1d}$ ,  $Y_{se}$  and  $Y_{sd}$ , both demand and supply curves in these markets are shifted endogenously from several sources. For example, the demands for  $F_{n1e}$  and  $F_{n1d}$  are increased due to the lower feedlot costs and the increased demands for  $Y_{ne}$  and  $Y_{nd}$ . The supply and demand curves of  $F_{n1e}$  and  $F_{n1d}$  are also shifted due to the substitution effects from both supply and demand. The results show a small 0.01% increase in all prices and quantities for  $F_{n1e}$ ,  $F_{n1d}$ ,  $Y_{se}$  and  $Y_{sd}$ .

As can be seen from the Column 5 of Table 5.2-I, the total benefit of the new feedlot technology is only \$1.13 million annually because the feedlot sector is only a small part of the total industry in gross revenue terms. Of this total return, farmers, domestic consumers and overseas consumers receive 26.8%, 55.2% and 9%, respectively. The other sectors share the remaining 9% of the total benefit.

#### **5.2.4 New Processing Technology (Scenario 6)**

The initial effect of a new processing technology is to shift down the supply curve for processing inputs ( $Y_p$ ) because the cost of these inputs is reduced. The results for a 1% shift in the supply curve of  $Y_p$  ( $t_{Y_p}=-0.01$ ) are presented in the sixth columns of Table 5.1-I and Table 5.2-I.

The reduction in processing cost induces downward shifts in the supply curves for the downstream processed beef ( $Z_{ne}$ ,  $Z_{se}$ ,  $Z_{nd}$  and  $Z_{sd}$ ) and final products ( $Q_{ne}$ ,  $Q_{se}$ ,  $Q_{nd}$  and  $Q_{sd}$ ). As the demand curves for final beef products are not exogenously shifted (except for some minor demand shifts for  $Q_{nd}$  and  $Q_{sd}$  due to the substitution effect between themselves), lower prices (0.01% to 0.07%) and higher quantities (0.05% to 0.06%) are observed for  $Q_{ne}$ ,  $Q_{se}$ ,  $Q_{nd}$  and  $Q_{sd}$ . Although the derived demand curves for the four beef carcass products are subsequently also shifted up, and there are also some further demand and supply shifts in these markets due to input substitution and product transformation possibilities, the supply shifts dominate and lower prices (0.02% to 0.16%) and higher quantities (0.06%) for  $Z_{ne}$ ,  $Z_{se}$ ,  $Z_{nd}$  and  $Z_{sd}$  are the end results.

As for the upstream cattle intermediate products and all exogenously supplied factors, the increased volume of the final beef products (due to lower prices) results in upward shifts in the derived input demands. These demand shifts dominate the outward output supply shifts and any other shifts due to substitution. Increases in both prices (0.01% to 0.06%) and quantities (around 0.05%) in these markets result.

Again, the gross annual gain from this scenario is rather small (\$4.69 million) because the value of processing inputs is small in comparison with the total industry value. The small price margins between live finished cattle and the slaughtered beef carcass imply that, under equilibrium with perfect competition, only small values are added to the products through processing.

The processors themselves only receive 3% (\$0.14 million) of the total benefit from the new processing technology due to the small value of processing inputs and the assumption of highly elastic supply for the processing inputs. Domestic consumers receive 55.4% or \$2.60 million due to the large size of the domestic market in revenue terms and the moderate domestic beef demand elasticities. The overseas consumers' share is \$0.42 million (9%), much less than the domestic consumers because of the lower gross revenue of export beef and the highly elastic demand in the overseas markets. As for the rest of the groups, as with the case of feedlot technology, farmers receive 25.9% of the total return with the remaining 9.7% shared by grain producers, feedlotters, exporters and retailers.

#### **5.2.5 New Domestic Marketing Technology (Scenario 7)**

In this scenario, a 1% reduction in domestic marketing costs is modelled (ie.  $t_{Z_{md}}=-0.01$ ). This could be the result of a new domestic marketing technology or management strategy that increases efficiency in domestic supermarkets and butcher shops.

The initial effect of lower domestic marketing costs is to shift down the supply curves of domestic retail beef ( $Q_{nd}$  and  $Q_{sd}$ ), reducing retail prices and increasing domestic

consumption. There are no exogenous changes from the demand side for  $Q_{nd}$  and  $Q_{sd}$ . However, the changes in their relative prices due to supply shifts subsequently shift both demand and supply curves in the two markets due to substitution effects. As a result, there are falls of 0.41% and 0.37% in prices and increases of 0.28% and 0.29% in quantities, respectively.

The increased domestic consumption in turn increases the demand for domestic marketing sector inputs ( $Z_{nd}$ ,  $Z_{sd}$  and  $Z_{md}$ ) and the demands for all inputs in the upstream sectors (all Y's, F's and X's). For domestic processed beef ( $Z_{nd}$  and  $Z_{sd}$ ), even though there may be minor shifts in their supply curves due to changes in the volume of cattle supplied upstream, and in both demand and supply due to substitution between them, their prices increase by 0.38% due to the dominating force of increased demand. Prices and quantities of all Y's, F's and X's also increase due to the dominating upward demand shifts: prices by 0.04% to 0.23% and quantities by 0.19% to 0.21%.

The impacts on the export sectors are increased quantities and decreased prices for export beef ( $Z_{ne}$ ,  $Z_{se}$ ,  $Q_{ne}$  and  $Q_{se}$ ). The shifts in the supply curves of  $Z_{ne}$  and  $Z_{se}$  are the results of opposing forces. The increased supply in both grass- and grain-finishing streams, due to higher domestic prices, shifts the supply curves of  $Z_{ne}$  and  $Z_{se}$  outward. However, higher prices in domestic wholesale beef also shift the supply curves of  $Z_{ne}$  and  $Z_{se}$  inward due to product transformation in the processing sector. The outward shifts dominate, due to the small product transformation elasticities of 0.05, and prices for  $Z_{ne}$ ,  $Z_{se}$ ,  $Q_{ne}$  and  $Q_{se}$  decrease by 0.04% to 0.07%. The quantities increase by around 0.19% in these markets.

The total surplus gains from the increased productivity in domestic marketing is \$23.88 million. According to the base equilibrium values specified in Table 3.1, the domestic marketing sector turns the \$1,720 million value of slaughtered beef carcasses into \$4,104 million value of retail cuts. In other words, significant value is added by the meat retailers, which implies that a change in the productivity in the retail sector would result in significant welfare gains. However, due to the assumption of highly elastic supply of marketing inputs, domestic marketer/retailers only receive \$1.63 or 6.8% of the total benefits. Domestic consumers receive 65.6% of the benefit and overseas consumers receive 5.1%. The farmers' share of 19.8% is smaller than their shares in the other scenarios already discussed so far, because the moderate retail demand elasticities have made the majority of benefits go to domestic consumers directly. However, the gain of \$4.72 million to farmers in absolute value is still relatively large. Feedgrain producers, feedlotters, processors and exporters receive only 2.7% of the total benefits due to the highly elastic supply of other inputs in these sectors.

### **5.2.6 New Domestic Grassfed Beef Promotion (Scenario 12)**

Another type of exogenous shock simulated in the model is a new effective promotional campaign. Following the conventional approach in EDM studies (for example Wohlgenant 1993; Piggott, Piggott and Wright 1995), the direct effect of successful advertising of a product is modelled as an upward shift in the demand curve for the product, as consumers are *willing to pay* more per unit of the product, or are willing to consume more for a given price after the advertising. In this scenario, a 1% vertical shift in the demand curve of domestic grassfed beef ( $Q_{sd}$ ) is examined ( $n_{Q_{sd}}=0.01$ ).

The upward shift in the demand of  $Q_{sd}$  increases both its own price and quantity. Referring to the demand function for domestic grainfed beef  $Q_{nd}$  in Equation (2.6.56), as the two types of domestic beef are assumed substitutes in demand, the immediate effect of this exogenous shift in  $Q_{sd}$  demand on the demand for  $Q_{nd}$  is twofold: an inward shift due to the initial shift  $n_{Q_{sd}}$  (the negative impact of promotion of  $Q_{sd}$ ) and a smaller outward shift due to the increase in the price of  $Q_{sd}$  (the substitution effect). This will lower the price of  $Q_{nd}$ , which in turn shifts down the demand curve for  $Q_{sd}$ . There will be further demand shifts in both markets due to the substitution effects before a new equilibrium is reached. On the supply side, there is a contraction in the supply of  $Q_{nd}$  and an expansion in the supply of  $Q_{sd}$  due to product transformation as it is now more profitable to produce  $Q_{sd}$ . Both supply curves may also be shifted up due to the increased level of input supply upstream (a result of higher cattle prices;  $EZ_d > 0$  in Equations (2.6.51) and (2.6.52)). The consequence is an increase of 0.53% in the price of  $Q_{sd}$  and a decrease of 0.49% in the price of  $Q_{nd}$ . Both quantities are increased:  $Q_{sd}$  by 0.37% and  $Q_{nd}$  by 0.32%.

Due to the increase in consumption in both domestic beef types, the derived input demand for processed beef for domestic markets ( $Z_{nd}$  and  $Z_{sd}$ ) and for all inputs in the pre-processing sectors (Y's, F's and X's) are shifted outwards (refer to their respective demand equations in Section 2). There are also supply shifts due to increased cattle supply upstream and small shifts in both their demand and supply curves due to substitution effects. Both prices and quantities are increased in these markets as outward demand shifts dominate.

Similar to the reasoning behind the impacts of domestic marketing technology on the export marketing sector, because of the increased quantities and prices for  $Z_{nd}$  and  $Z_{sd}$ , there are increased quantities and decreased prices for export beef ( $Z_{ne}$ ,  $Z_{se}$ ,  $Q_{ne}$  and  $Q_{se}$ ); all quantities increase by about 0.29% and prices decrease by 0.06% to 0.12%.

Because of the large gross revenue of the domestic grassfed beef market, the total return from this promotion scenario is significant at \$31.55 million. The welfare of domestic consumers increases by \$19.45 million (61.7% of the total returns); the difference between what they are 'willing to pay' and what they are actually paying is significantly increased because of the promotion. Farmers gain an increase in surplus of \$7.36 million (23.4%) due to higher cattle prices and larger throughput. Overseas consumers and domestic marketers receive \$1.91 million (6.1%) and \$1.81 million (5.7%) of the benefits respectively. Feedgrain producers, feedlotter and processors and exporters share the remaining 3.1%, although the benefits in dollar terms are still rather significant in comparison to some of the research scenarios discussed earlier.

The result that overseas consumers gain from domestic promotion seems to be counter-intuitive. The intuition often comes from the assumption that products for both domestic and export markets are homogenous, and thus the products are perfectly substitutable. However, when the products are assumed heterogenous for the two markets, the situation is more complicated. The impact on the supply of export beef involves a substitution effect as well as the effect from the increased supply upstream, due to the jointness in both grainfed and grassfed beef production for the two markets. In this case, the effect of the small product transformation possibility between domestic and export beef is dominated by the effect of an increase in supply of both grainfed and grassfed cattle (due to increased consumption in the domestic market). As a result, the supply curves for  $Z_{ne}$ ,  $Z_{se}$ ,  $Q_{ne}$  and  $Q_{se}$  shift outward,

resulting in lower prices, higher quantities and thus increased welfare for overseas consumers. This can be seen from, for example, the output supply function for  $Z_{ne}$  in Equation (2.6.37). The impact of an increased supply of cattle ( $EY > 0$ ) dominates the product transformation effect ( $E_{u_{nd}} > 0$  and  $E_{u_{sd}} > 0$ , both with negative coefficients) due to the small product transformation elasticities ( $\tau$ 's of 0.05).

### 5.3 Comparison of Alternative Scenarios

As pointed out in the Introduction to this Report, information on the sizes and distributions of benefits from alternative investment scenarios is important in allocating R&D and promotion funds and in answering questions regarding who should pay for the various investments. The results in Table 5.2 are a summary of the welfare gains and their distributions among industry groups for the 12 scenarios simulated in the model. Valuable insights can be gained by comparing the results of different scenarios.

#### 5.3.1 *Some Qualifications*

A few caveats should be noted before any comparison is undertaken. First, the results in Table 5.2 relate to equal 1% exogenous shifts in the relevant supply or demand curves. The question of how much money is required to bring about the 1% shift (i.e. a 1% cost reduction in a particular sector or a 1% increase in the consumers' "willingness to pay" in a particular market) is not discussed here. Issues regarding the efficiency of investments requires a knowledge of particular R&D and promotion projects. For example, Lemieux and Wohlgenant (1989) used experimental data from research into a particular biotechnology to quantify the shift in the supply curve. Alternatively, attempts have been made to estimate the increase in productivity due to R&D expenditure and the average increase in sales due to promotion investments using observed data. For example, Scobie, Mullen and Alston (1991) examined the shape of a research production function for the wool industry, which relates R&D expenditures to productivity growth and, consequently, the magnitudes of research-induced supply shifts. Mullen and Cox (1995) and Cox, Mullen and Hu (1997) also studied the relationship between research expenditure and productivity of Australian broadacre agriculture. For promotional effects, Piggott, Piggott and Wright (1995) simply assumed values of some advertising elasticities that link the promotion expenditures to the size of demand shifts. However, accurate estimation of the average relationships between R&D/promotional expenditures and supply/demand shifts requires considerable observed data and analysis which is beyond the scope of the present study.

Second, although the same amount of investments at different points of the industry may result in demand or supply shifts of different magnitudes, and although the actual returns in dollar terms are dependent on the magnitudes of initial shifts, the distribution of the total benefits among industry groups for a particular scenario is independent of the size of the initial shift<sup>9</sup>. For example, the farmers' percentage share of the total benefits of a processing

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<sup>9</sup> It can be proved mathematically that the share of the total benefits to a particular industry group is independent of the amount of the initial shift. Take Scenario 1 as an example. As the EDM is a linear system between the endogenous variables (the percentage changes of prices and quantities) and the exogenous variables (the exogenous shifts) without constant terms, the resulting percentage change for any price variable is proportional to  $t_{x1}$ , the initial percentage shift. As a result, the total surplus changes and the surplus changes to particular industry groups in the formulas in Tables 4.1, and 4.2 are all proportional to  $t_{x1}$ . Consequently, the ratios of these surplus changes (i.e. the shares to individual groups) are independent of  $t_{x1}$ .

technology (i.e. 25.9% in the sixth column of Table 5.2) is the same regardless of whether the technology reduces the processing cost by 1% or 10%. Therefore, comparison of benefit shares among alternative investment scenarios is always meaningful even without knowledge of the efficiency of research and promotion investments. This result follows from the assumed competitive structure of the beef industry and the assumed parallel supply and demand shifts.

Third, the welfare changes in Table 5.2 are based on a particular set of market parameters given in the base run. The results are likely to be sensitive to changes in the values of these parameters. In particular, small elasticities of input substitution and product transformation (0.05 to 0.1) and large elasticities of other input supply (with a value of 5) have been assumed for all sectors in the base run. There have been very limited empirical estimates of these parameters. The sensitivity of model results to values of all market parameters is examined extensively in Zhao (1999) and Zhao, Griffiths, Griffith and Mullen (2000). The conclusions based on the comparison of alternative investment strategies in this Section are conditional on the 'best bet' parameter values. Some of the conclusions could be altered when different sets of parameter values are assumed.

### ***5.3.2 General Results for All Investment Scenarios***

Consider first the total welfare gains from alternative scenarios. As pointed out earlier, for the same 1% exogenous shift, the size of the total welfare change is predominantly determined by the gross revenue in the market where the exogenous shift occurs. It can be seen from the last row of Table 5.2 that, for equal 1% shifts in the relevant markets, domestic grassfed beef promotion (Scenario 12) and domestic beef marketing technology (Scenario 7) result in the largest total returns: \$31.55 million and \$23.88 million, respectively. In terms of total benefit, these two scenarios are followed by export grassfed beef promotion (Scenario 10, \$20.38 million), weaner production research (Scenario 1, \$19.60 million), and grainfed beef promotion (\$9.48 million for the domestic market and \$6.23 million for the export market). The total benefits from research in the backgrounding, feedlot, processing and export marketing sectors are much smaller (less than \$4.69 million) due to the small value added to the cattle/beef products in these sectors.

For all 12 scenarios, the majority of total benefits accrue to domestic consumers and cattle farmers. Domestic consumers gain the largest share of total benefits (48.3% to 65.6%) in all 12 cases. This is because domestic retail beef comprises the bulk of total industry value at retail and because domestic beef demand is far from perfectly elastic. Farmers, including weaner producers, grass-finishers and backgrounders, receive between 19.8% to 33.7% of total benefits for the 12 scenarios.

Overseas consumers and domestic retailers are the other two groups who gain significant shares of total returns. Although more than half of Australian beef goes overseas, the total value of export beef (valued at f.o.b.) is much smaller than the value of domestic beef at retail. More importantly, overseas demand for Australian beef (both grainfed and grassfed) is substantially more elastic than domestic demand. As a result, overseas consumers gain much

less surplus than domestic consumers in all cases. The shares of the total surplus gains accruing to overseas consumers range from 5.1% to 11.7%.

Domestic retailers share 3.6% to 6.8% of total benefits in all scenarios. Beef value is more than doubled through the domestic marketing sector, which makes the value of the retail sector substantial. However, the assumption of a highly elastic supply of marketing inputs means that the welfare gain to the retail sector is still rather small.

The shares of benefits to feedgrain producers, feedlotters, processors and exporters are very small for all investment scenarios (mostly less than 3%). The values added to the cattle/beef products in the feedlots and abattoirs are small, and the supply curves of other inputs in these sectors are assumed to be highly elastic.

### ***5.3.3 On-Farm Research versus Off-Farm Research***

How should R&D funds be allocated between traditional farm research and R&D beyond the farm gate? Should farmers be indifferent towards paying for pasture research and for processing research? The results from the model can be used to shed light on these questions.

Typically, research into new technologies in weaner production (Scenario 1), cattle grass-finishing (Scenario 2) and cattle backgrounding (Scenario 3) are treated as 'traditional' on-farm research. Examples include genetic research increasing calving percentage, pasture research increasing grazing efficiency and education initiatives improving producers' farm management. Off-farm research is R&D beyond the farm gate. In the model, the scenarios of cost reductions in feedlots (Scenario 5), abattoirs (Scenario 6) and domestic (Scenario 7) and export (Scenario 8) marketing sectors can be treated as off-farm R&D investments.

There have been some studies comparing returns from farm-oriented research and processing and marketing research. Under the assumption of zero input substitution between the farm input and other inputs, Freebairn, Davis and Edwards (1982) concluded that the distribution of the total benefits among producers and consumers is the same whether the cost reduction occurs in the farm sector or in the marketing sector. Alston and Scobie (1983) showed that, once input substitution is allowed, producers will gain a greater proportion of total returns from research at the farm level than from research at the processing and marketing levels. This finding was also emphasized by Mullen, Alston and Wohlgenant (1989). However, all these studies are based on highly aggregated models of an agricultural industry consisting of an input supply sector, a farm sector and a joint processing and marketing sector. In the present study, each of these three sectors are further disaggregated. In the case of the Australian beef industry, exporting is an important part of the industry. In the present model, domestic and export marketing are modelled separately because they are quite different in nature. The single farm sector in the past studies is also separated into breeding, backgrounding, grass-finishing and feedlot sectors in this study. Consequently, welfare gains from different types of on-farm research and different types of off-farm research are available. As non-zero but small (0.05 and 0.1) substitution elasticities are assumed for all sectors in the present model, the welfare distribution will be different when the R&D occurs at different points of the production and marketing chain.

As can be seen from Table 5.2, farmers will receive a larger share of the total benefit from on-farm research (33.7%, 27.6% and 28.8% for Scenarios 1, 2 and 3 respectively) than from feedlot (26.8%) and processing (25.9%) research. However, the comparison between farm research and marketing research shows different results for domestic and export marketing. The domestic marketing sector research is shown to give farmers a much lower proportion of benefit (19.8%) than all types of farm production research. Thus, the results from the present model are consistent with the literature in concluding that farmers should prefer on-farm R&D than R&D in feedlots, processing and domestic marketing sectors.

An exception is export marketing research, which is shown to give farmers a larger share of the benefits (30.2%) than some types of on-farm research such as R&D in cattle backgrounding. The reason that cost reduction in export marketing gives farmers a much larger share of benefits than domestic marketing is that, in comparison to domestic marketing, the export marketing sector is much smaller in value and overseas consumers have a much more elastic demand. Since exporters and overseas consumers are consequently unable to collect benefits, the benefit flows naturally back to producers rather than to the domestic sectors.

As for Australian consumers, the preference between farm research and off-farm research is inconclusive. While they gain an overwhelmingly larger proportion of the benefits from domestic marketing research (65.6%) and relatively lower shares for weaner production research (50.8%) and export marketing research (48.3%), their shares for the other on-farm and post-farm research scenarios are very similar (55.2% to 55.4%).

Feedlotters, processors and marketers each receive a significantly larger share for research occurring in their own sector. Otherwise, these groups are mostly indifferent among other types of on-farm and off-farm research investments.

This scenario is discussed in more detail in Zhao, Griffith and Mullen (2000).

#### ***5.3.4 Research versus Promotion***

Scenarios 1 to 8 (except Scenario 4) are research scenarios relating to farm, feedlot, processing and export and domestic marketing sectors of the beef industry. Export promotions are represented by Scenarios 9 and 10, and domestic promotions are modelled by Scenarios 11 and 12.

Producers pay levies to support both research and promotion. As pointed out in Section 1, although the percentage spent on R&D has increased over the years, almost two-thirds of the research and promotion dollars for the red meat industries were spent on promotion over the years 1990/91 to 1996/97 (MRC 1996/97, AMLC 1996/97). Under the newly-formed Meat & Livestock Australia, the R&D share of the total expenditure has been increased to 49% in 1998/99 (MLA 1998/99).

Existing studies indicate that primary producers should not be indifferent about spending levy money on research versus promotion. Using a model of similar aggregation to that of Alston and Scobie (1983), Wohlgenant (1993) compared the distributions of gains from research versus promotion. With an input substitution elasticity of 0.72 for the U.S. beef industry, his

finding is that farmers gain a much larger share of benefits from production research than from promotion<sup>10</sup>, although processing/marketing research is shown to be much less preferable to farmers than promotion.

Now look at the results in Tables 5.2 for the various types of production research, processing and marketing research and promotion. Concentrate first on the farmers' shares of the total welfare gains. Again, export promotion and domestic promotion are shown to have different implications for farmers in comparison to research. In terms of the share of the total benefits, domestic promotion is less preferable to farmers (23.2% to 23.4%) than all types of on-farm research (27.6 to 33.7%) and research in the feedlot, processing and export marketing sectors (25.9% to 30.2%), but is more preferable than domestic marketing research (19.8%). In contrast, export promotion brings the farmers bigger surplus shares (31.3% to 31.6%) than all research types (19.8% to 28.8%) except for weaner production research (33.7%). In fact, to farmers, domestic marketing research has similar effects as the two types of domestic promotion, while export marketing research has a similar implication to that of export promotion. In summary, in terms of percentage share of total benefits, farmers should prefer research (except for domestic marketing research) to *domestic* promotion, but they should prefer export promotion to all research types except for weaner production research.

Wohlgenant (1993) gave an intuitive explanation of the result that producers prefer production research to promotion by examining the determinants of retail-to-farm price transmission resulting from a retail demand shift due to promotion (p646). He showed that, when input substitution is possible, the effect of an increase in retail demand is not generally passed along completely to the farm price. Although deriving similar analytical expressions is less feasible with the more disaggregated model in this study, the finding that the share of benefits to farmers is higher from a new weaner production technology than from both domestic and export promotion can be explained in a similar way.

Because domestic consumers are the other major beneficiaries for all 12 scenarios, the preference of domestic consumers would be almost opposite to that of producers. Australian consumers prefer increased efficiency in the domestic retailing sector the most since they receive 65.6% of the total benefits. Other types of research in the farm, feedlot, processing and export marketing sectors will give them lower shares of the total welfare gains (48.3%-55.4%) than domestic promotions (61.7% to 61.9%). However, export promotion results in smaller shares of benefits to domestic consumers (50.1% to 50.6%) than all research scenarios (50.8% to 65.6%) except for export marketing research (48.3%).

As for other industry participants, each will strongly prefer research or promotion in its own sector. For example, feedlots will receive 2.1% of the total gains from feedlot research, but less than 0.3% of the total benefits from all other research and promotions. Otherwise, there is no significant difference in the welfare shares to these industry groups from various types of research and promotion.

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<sup>10</sup> The total surplus changes in his three scenarios of production research, marketing research and promotion are the same. As a result, the same benefit share for a particular group from different scenarios implies equal absolute benefits in dollars.

### ***5.3.5 Domestic Promotion versus Export Promotion***

While the focus of lamb promotion has been on the domestic markets, the majority of the promotional effort for the beef industry has been on overseas markets. During 1990/91 to 1996/97, about 64% of the total promotion expenditure for the Australian red meat industries was in export markets. In 1998/99, 75.5% of the MLA beef promotion expenditure was spent on promotions in various major buyer countries, with 46.1% in Japan, 11.6% in Korea, 11.9% in South East Asia and China and 5.9% in others (MLA 1998/99).

Scenarios 9 to 12 are the four promotion investments modelled in the study. As can be seen from the results in Table 7.2-II, domestic promotion and export promotion have very different welfare implications to both producers and consumers. Cattle producers receive 31.3% to 31.6% of the total welfare gains from overseas promotion, but only 23.2% to 23.4% from domestic promotion. Conversely, Australian consumers receive larger shares of gains from domestic promotion (61.7%-61.9%) than from overseas promotion (50.1%-50.6%).

Feedlotters, processors and exporters are also shown to receive larger shares from export promotion than from domestic promotion. Feedlots' shares from the two export promotions are 0.3%, in contrast to 0.2% for the two domestic promotions. Processors and exporters receive 2.0% from export promotional investments, while their share is only 1.1% for domestic promotional investments.

The explanation for these results lies in the highly elastic demand assumed for Australian beef exports, which means that increases in market share can be achieved with little impact on price to Australia.

### ***5.3.6 Research in Grain-Finishing versus Grass-Finishing***

In the model, research into the backgrounding and feedlot sectors only directly affects the grain-finishing cattle stream (Scenarios 3 and 5), and research on reducing costs in the grass-finishing sector focuses on grassfed cattle (Scenario 2). In practice, some research projects such as those aiming to improve pasture management may reduce the costs in both backgrounding and grass-finishing sectors, and even in the breeding sector. However, research projects targeting new technologies in backgrounding cattle to meet feedlot requirements may be modelled by Scenario 3. Examples of feedlot research in Scenario 5 include research in feedlot nutrition and management.

Due to the expansion of the Japanese and other Asian markets, and the increasing standard of product specifications of grainfed beef in these markets, R&D in the grain-finishing sectors has received greater attention. Consider the seven-year, \$19 million venture of the Cooperative Research Centre for the Cattle and Beef Industry (Beef CRC) for example. A major portion of its resources are invested in research programs targeting high-quality grainfed cattle, such as the long-feed heavy grade Japanese ox (B2 and B3). These include projects on pre-boosting and backgrounding cattle in order to meet feedlot entry requirements and to increase feedlot performance. There are also projects on animal nutrition aimed at increasing the growth rate of cattle in feedlots.

Refer to the results for Scenarios 2, 3 and 5 in Table 7.2. Because of the non-zero but small input substitution elasticities in the grass-finishing, backgrounding and feedlot sectors, the farmers' shares of benefits are slightly higher for backgrounding (28.8%) and grass-finishing (27.6%) research than for feedlot research (26.8%). Thus, in terms of the shares of the total benefits, the farmers should be slightly in favour of research in the areas of backgrounding and grass-finishing than in feedlots. Note that research into more efficient production of weaners delivers an even larger share of benefits to producers.

For the feedlotters, the benefit share is, of course, higher from feedlot research (2.1%) than from research in backgrounding (0.1%) and grass-finishing (0.3%). As for other industry groups (i.e. processors, marketers and domestic and export consumers), there is almost no difference in their percentage shares of total benefits whether the research occurs in the grass-finishing or in the grain-finishing sectors.

Although the percentage distributions of benefits are not significantly different between grass-finishing research and grain-finishing research, the total welfare gains in *dollar* terms for the same 1% cost reductions are significantly different; grass-finishing research may generate up to ten times more dollars (\$13.32 million) as research in the backgrounding (\$1.74 million) and feedlot (\$1.13 million) sectors. In other words, because of their small sizes, research in the backgrounding and feedlot sectors needs to reduce the cost of other inputs by 10% in order to bring the same total welfare benefits as a 1% cost reduction in grass-finishing inputs; that is, the investment needs to be ten times more efficient in the grain-finishing sectors than in the grass-finishing sector.

This scenario is discussed in more detail in Griffith, Mullen and Zhao (2000).

### ***5.3.7 Some More Insights about the Results***

It may be worthwhile to repeat the point stated in Section 5.3.1. As we do not have information on the costs involved in bringing about the same 1% shifts in the various markets, the conclusions that can be drawn from comparing the actual dollar returns from alternative investment scenarios are limited. Thus, the above discussion and comparisons are focused on the percentage shares of the total benefits for each individual group, irrespective of total dollar benefits of different scenarios.

However, the benefits in dollar terms *can* provide valuable information *if* the data on the costs and efficiency of research and promotion could be obtained. Basically, for the same vertical *percentage* shifts in different markets, investment in a sector with larger value brings greater total welfare returns. Thus, for the same 1% initial shifts, the total welfare gains in dollars are larger for promotions of grassfed beef (\$20.38 million overseas and \$31.55 million domestically) and cost reductions in the weaner production (\$19.60 million), grass-finishing (\$13.32 million) and domestic marketing (\$23.88) sectors. In contrast, due to their smaller sector sizes, research in the backgrounding (\$1.74 million), feedlot (\$1.13 million), export marketing (\$1.88 million) and processing (\$4.69 million) sectors only results in small total welfare gains.

Complete insights into the issues can only be gained from information on (1) the cost involved in bringing about the initial research-induced supply shifts or promotion-induced

demand shifts, (2) the total welfare gains in dollars resulting from these initial shifts, and (3) the percentage shares of the total benefits to individual industry groups. Without information on the costs or efficiency of research and promotion investments in (1), comparison of welfare gains in dollars can only be made under some assumptions such as *equally efficient* investments in all sectors. For example, *if* domestic promotion is equally efficient as export promotion, in that the advertising costs of bringing about a 1% increase in the consumers' 'willingness to pay' for grassfed beef are the same in the two markets, producers would prefer the domestic grassfed beef promotion (leaving farmers \$7.36 million better-off) than the grassfed export promotion (\$6.45 million to farmers), even though the percentage share of total benefits to farmers is lower for domestic promotion (23.4%) than for export promotion (31.6%). This is simply because domestic grassfed beef has a much higher sector value and lower demand elasticity at retail than export grassfed beef does at the point of shipment.

A similar situation arises for domestic marketing versus export marketing. *If* the investments in marketing research *were* equally efficient in the two marketing sectors, producers would prefer domestic marketing research (\$4.72 million) to export marketing research (\$0.57 million), even though the shares of total benefits give the opposite preference (19.8% for domestic and 30.2% for export). Or, from a different perspective, export marketing research needs to be more than ten times as efficient ( $23.88/1.88$  gives 12.7) in order to have the same total dollar return as domestic marketing research. For producers, investment in export marketing research needs to be eight times as efficient ( $4.72/0.57$  is 8.28) as investment in domestic marketing in order for them to be indifferent about the two marketing research investments.

The ranking of preferences to farmers among the 12 alternative investment scenarios, in terms of their percentage shares of total benefits and absolute monetary benefits respectively, are given in Table 5.3. The ranking in the first column is always true even though the information on the investment costs involved in the initial 1% shifts is unavailable. The ranking in the second column is conditional on the assumption of equal efficiency across the 12 scenarios, that is, the costs of bringing about the equal 1% shifts in all scenarios are the same. Obviously, the ranking of preferences in the two columns is rather different.

More insights may be gained from the information given in Tables 5.4 and 5.5. In Table 5.4, the initial *percentage* shifts and *absolute* shifts required in each of the 12 scenarios in order to achieve the same dollar amount of *total* benefits as from a 1% cost reduction in weaner production in Scenario 1 are listed. Similar information is given in Table 5.5 in order for *farmers* to be indifferent about the alternative investment scenarios.

For example, in order to achieve the same *total* welfare benefit to society, \$19.6m, as from a 1% cost reduction in weaner production (Scenario 1), costs of cattle processing need to be reduced by 4.18% (Scenario 6) and the 'willingness to pay' by domestic grassfed beef consumers needs to increase by 0.62% (Scenario 12); in terms of actual amounts of initial shifts, these are equivalent to a 1.12 cents reduction in the cost of producing a kilogram of weaner cattle, 5.28 cents reduction in processing input costs per kilogram of live cattle, and 4.84 cents increase in consumer's 'willingness to pay' per kilogram of grassfed cattle in the domestic market.

**Table 5.3 Preferences to Farmers among the 12 Investment Scenarios**

Rank	in terms of % share of total benefits (%)	in terms of absolute benefits in dollars (\$m)
1	S. 1 (33.7)	S. 12 (7.36)
2	S. 10 (31.6)	S. 1 (6.61)
3	S. 9 (31.3)	S. 10 (6.45)
4	S. 8 (30.2)	S. 7 (4.72)
5	S. 3 (28.8)	S. 2 (3.69)
6	S. 2 (27.6)	S. 11 (2.19)
7	S. 5 (26.8)	S. 9 (1.95)
8	S. 6 (25.9)	S. 6 (1.21)
9	S. 4 (24.3)	S. 8 (0.57)
10	S. 12 (23.4)	S. 3 (0.51)
11	S. 11 (23.2)	S. 4 (0.34)
12	S. 7 (19.8)	S. 5 (0.29)

Similarly, referring to Table 5.5, in order for *farmers* to be indifferent about investments in weaner production technology (Scenario 1) and in export grainfed beef promotion (Scenario 9), the cost of creating a technology that reduces the weaner production cost by 1% needs to be the same as the advertising expenditure that increases the Japanese consumers' 'willingness to pay' for Australian grainfed beef by 3.39%; in terms of absolute shifts, they are equivalent to a cost reduction in producing weaners of 1.12 cents per kilogram and an increase in 'willingness to pay' for export grainfed beef of 19.18 cents per kilogram. Thus, it is dependent upon the investment costs in bringing about the 1% and 3.39% (or 1.12 cents and 19.18 cents) shifts in the relevant markets as to which of the two investment scenarios is preferable to producers.

The information on the required *absolute* shifts in Tables 5.4 and 5.5 provides a different perspective because the absolute amounts relating to the same 1% vertical shifts in different markets could be very different due to different price levels at different points of the chain. In the case of Scenario 1 versus Scenario 12, a 1% vertical shift in weaner supply is 1.12 cents ( $w_l = \$1.12/\text{kg}$ ) and a 1% vertical shift in domestic grassfed beef demand is 7.81 cents ( $p_{sd} = \$7.81/\text{kg}$ ). While the study by Wohlgenant (1993) was based on a comparison of benefits resulting from *equal absolute* shifts in different markets and the present study is based on *equal percentage* shifts, information on returns from equal absolute initial shifts in relevant markets can be estimated from the information in Tables 5.4 and 5.5. For example, from the information on Scenario 1 and Scenario 12, a one cent initial supply shift in the weaner market brings a total benefit of \$17.5 million ( $19.60/1.12=17.5$ ) and \$5.90 million ( $6.61/1.12=5.90$ ) to farmers, while a one cent initial shift in domestic grassfed beef market results in \$4.05 million ( $19.60/4.84=4.05$ ) in total and \$0.94 million ( $6.61/7.03=0.94$ ) to

farmers<sup>11</sup>. Thus, if the cost of bringing about equal absolute shifts of one cent in the two markets were the same, weaner technology would be more preferable than domestic promotion. This is an opposite conclusion to that if the cost of 1% shifts were the same.

**Table 5.4 Percentage and Absolute Initial Shifts Required to Provide the Same *Total Returns* as from Scenario 1**

	<b>Scenario 1</b> weaner prod. research	<b>Scenario 2</b> grass-finishing research	<b>Scenario 3</b> backgrounding research	<b>Scenario 4</b> feedgrain research	<b>Scenario 5</b> feedlot research	<b>Scenario 6</b> processing research
<b>Total Returns (Smillion)</b>	19.60	19.60	19.60	19.60	19.60	19.60
<b>Initial % Shifts Required (%)</b>	1.00	1.47	11.26	13.61	17.35	4.18
<b>Initial Absolute Shifts(C/kg) *</b>	1.12	1.28	9.57	2.35	5.21	5.28
	<b>Scenario 7</b> dom. marketing research	<b>Scenario 8</b> exp. marketing research	<b>Scenario 9</b> exp. grainfed promotion	<b>Scenario 10</b> exp. grassfed promotion	<b>Scenario 11</b> dom. grainfed promotion	<b>Scenario 12</b> dom. grassfed promotion
<b>Total Returns (Smillion)</b>	19.60	19.60	19.60	19.60	19.60	19.60
<b>Initial % Shifts Required (%)</b>	0.82	10.43	3.15	0.96	2.07	0.62
<b>Initial Absolute Shifts(C/kg) *</b>	2.83	1.67	17.83	2.94	21.34	4.84

\* measured as cents per kilogram of cattle/beef inputs of the relevant sector.

Regardless of whether it is more reasonable to assume equally efficient investment in terms of the costs of achieving equal 1% initial shifts or equal one cent initial shifts, in general, from the information in Tables 5.4 and 5.5, research investments in the backgrounding, feedlot and processing sectors need to be more efficient in order to have society and producers in favour of these investments over investments in weaner producing, grass-finishing and domestic

<sup>11</sup> Ignoring rounding errors, these results, derived from Tables 5.4 and 5.5, are the same as those from running the model with equal one cent initial shifts, which is equivalent to initial percentage shifts of  $t_{x1}=1/w_1=1/121=0.89\%$  for Scenario 1 and  $n_{Qsd}=1/p_{sd}=1/781=0.13\%$  for Scenario 12.

marketing sectors and in grassfed beef promotion. Only when the information on the costs of initial shifts is available can definite conclusions be made.

**Table 5.5 Percentage and Absolute Initial Shifts Required to Provide the Same *Benefits to Farmers* as from Scenario 1**

	<b>Scenario 1 weaner prod research</b>	<b>Scenario 2 grass-finishing research</b>	<b>Scenario 3 backgrounding research</b>	<b>Scenario 4 feedgrain research</b>	<b>Scenario 5 feedlot research</b>	<b>Scenario 6 processing research</b>
<b>Returns to farmers (\$million)</b>	6.61	6.61	6.61	6.61	6.61	6.61
<b>Initial % Shifts Required (%)</b>	1.00	1.79	12.96	19.44	22.79	5.46
<b>Initial Shifts(C/kg)*</b>	1.12	1.52	11.28	3.36	6.84	6.90
	<b>Scenario 7 dom. marketing research</b>	<b>Scenario 8 exp. marketing research</b>	<b>Scenario 9 exp. grainfed promotion</b>	<b>Scenario 10 exp. grassfed promotion</b>	<b>Scenario 11 dom. grainfed promotion</b>	<b>Scenario 12 dom. grassfed promotion</b>
<b>Returns to farmers (\$million)</b>	6.61	6.61	6.61	6.61	6.61	6.61
<b>Initial % Shifts Required (%)</b>	1.40	11.60	3.39	1.02	3.01	0.90
<b>Initial Shifts (C/kg)*</b>	3.25	1.86	19.18	3.12	31.03	7.03

\* measured as cents per kilogram of cattle/beef inputs of the relevant sector.

## **6 Review, Limitations and Further Research**

### **6.1 An Equilibrium Displacement Model of the Australian Beef Industry**

In recent years, around \$100 million has been spent annually on R&D and promotion in the Australian red meat industries. The money comes from levies paid by producer groups and from government contributions for research. Producers have been questioning the pay-off from these investments. The returns from the investments is also a public policy issue since the coercive powers of government are used to underpin the levy system. Governments should also be concerned about the returns to the expenditure of public funds.

Questions of interest include, among others, the returns from research versus those from promotion, the returns from on-farm research versus those from off-farm research, and the returns from domestic promotion versus those from export promotion. Not only are the total returns from these investments of interest, but also the identification of the distribution of the total returns among groups such as cattle producers, feedlotters, processors, exporters, and domestic and export consumers will be valuable in aiding policy decisions within the industry.

In this Report, an equilibrium displacement model of the Australian beef industry was specified and simulated. The demand and supply relationships among different sectors of the industry were represented by a structural model with general functional form. The impacts of new technologies and promotion were modelled as exogenous supply or demand shifts in the relevant markets. Changes in prices and quantities were simulated for each of the exogenous scenarios, and the economic welfare implications were then estimated.

The industry was disaggregated vertically into sectors covering breeding, backgrounding, grass- or grain-finishing, processing, marketing and final consumption. The model included four end products with segregation being made on the basis of grain versus grass finishing and domestic versus export consumption. The model is more disaggregated than existing studies of the Australian beef industry. The model specification enables the analysis of technical changes in individual sectors and promotion in different markets. It also enables the identification of benefits to individual industry sectors.

In Section 3, an extensive effort was made in compiling a set of base equilibrium prices and quantities for all inputs and outputs representing the average situation for 1992-1997. Market elasticities required in the model were specified based on available empirical estimates, economic theory and subjective judgement. Integrability conditions among these elasticities were also imposed at the base equilibrium for economic consistency.

The model provides a comprehensive economic framework for studying the impacts of various research-induced new technologies and promotion expenditures. In the base model in Section 5, twelve investment scenarios were considered relating to new technologies in the grass and grain and processing and marketing sectors of the beef industry and to promotion in export or domestic markets. The study was based on 1% shifts of the supply or demand curves in the relevant markets for the 12 scenarios. For each of these scenarios, total returns in terms

of economic surplus change as well as the distribution of total returns among individual industry sectors and consumer groups were estimated.

## 6.2 Measuring Changes in Welfare

As has been recognised in the literature (for example, Slesnick 1998), complications arise regarding the measurement of economic welfare in multi-market models. In particular, care needs to be taken when there are multiple sources of equilibrium feedback in multi-product models (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 production and consumption. As a result, a single source of exogenous shock will induce endogenous shifts in both the supply and demand curves in the two markets. In this case, both the producer's profit function and the consumer's expenditure function involve multiple price changes.

In Section 4, the economic welfare implications for the various industry groups for the 12 exogenous shift scenarios were examined through the profit or expenditure functions and the associated integrals of supply or demand functions. These welfare changes were also related to graphical areas in the relevant markets. Eleven industry groups were identified in the model. They relate to factor suppliers in various sectors and final beef consumers. For ten of these groups, there is only a single price change in the relevant profit or expenditure functions. In other words, there is only one source of feedback in each of these ten markets. For these ten groups, the economic surplus changes were used as welfare measures and they were measured straightforwardly as areas off the exogenously fixed supply or demand curves. Based on the results shown in Willig (1976) and Hausman (1981) for the single market models, as the whole trapezoid areas of welfare changes were of interest in this study and the equilibrium shifts were small, the consumer surplus changes are expected to be good approximations to the preferred compensating or equivalent variation measures.

However, the two domestic beef products were assumed to be related in both supply and demand. The domestic consumers' decision problem involves two price changes and this is the case described by Thurman (1991a) as having two sources of equilibrium feedback. It was shown in Section 4 that, when integrability conditions are imposed on the Marshallian elasticities at the base equilibrium, the economic surplus measures are uniquely defined and path independent. Under the integrability conditions, the economic surplus changes can be uniquely measured either through the general equilibrium curves in a single market or via the partial equilibrium curves in individual markets.

The derivations in Section 4 also implied that, when integrability conditions are not met, the first-order terms ( $\mathbf{O}(\lambda)$ ) of the economic surplus measures may still be path independent and equal to the first-order terms of the compensating or equivalent variation measures. The integrability conditions may only affect the economic surplus measures at the second order terms ( $\mathbf{O}(\lambda^2)$ ). Since changes in economic surplus (trapezoid areas) are of the first-order magnitude ( $\mathbf{O}(\lambda)$ ), as long as the considered equilibrium displacements are small ( $\lambda$  is small), failure to satisfy integrability conditions may not result in significant errors in using economic surplus changes as welfare change measures. However, if the second-order measures of triangular 'deadweight loss' are of interest in a policy study, integrability conditions are vital and violation of them could result in significant errors. This is consistent with the empirical

observations in LaFrance (1991), who showed that the errors were insignificant in the estimation of the trapezoid area of economic surplus change when using *ad hoc* linear models.

Finally, it has been recognised in the literature (Just, Hueth and Schmitz 1982, p469; Alston, Norton and Pardey 1995, p232) that, when integrability conditions are satisfied, there are two alternative ways of calculating the welfare effects: measuring the total welfare change off the general equilibrium curves in the single market where the initial shift occurs, or measuring the individual welfare effects off the partial equilibrium curves in individual markets and adding up. Thurman (1991a) examined the welfare significance of the economic surplus areas off the general equilibrium curves in a single market when multiple sources of equilibrium feedback exist. In particular, he showed that the area off the general equilibrium demand or supply curve individually does not measure welfare to any identifiable group, but the sum of the two areas measures the total welfare change.

In this Section, it was pointed out that, in the case of multiple channels of feedback, caution also needs to be taken in measuring economic surplus areas off partial equilibrium demand or supply curves. When two markets are related through more than one source, the economic surplus change to the producers or the consumers should be measured sequentially in the two markets and then added up; that is, the surplus change based on the (same) *initial* partial equilibrium curve in the first market plus the surplus change based on the (same) *new* partial equilibrium curve in the second market. It is wrong to calculate changes in surplus areas based on different partial equilibrium curves in the same market, as has been done in some past studies. It was shown with an example that the error in doing so could be significant (of the order of  $O(\lambda)$ ).

### 6.3 Partial v General Equilibrium Models

The model developed in this study is a partial equilibrium model that concentrated on the interaction among different sectors within the Australian beef industry. The economy-wide implications, including interaction with other agricultural industries, were ignored. In reality, the beef industry is related in production to other livestock and crop industries such as the sheep industry and the wheat industry. Also, most meat consumers regard beef, lamb, chicken and pork as close substitutes. An innovation in the beef industry will result in a fall in beef prices in the first instance. As second round effects, the supply of lamb and the demand for lamb, chicken and pork will also be affected, which results in price changes in these other industries. These changes in other industries will also feedback to induce further changes in the beef industry. A model that takes account of these interactions with other meat industries is of a more general equilibrium nature and would be more realistic in the context of the current structure of Australian agriculture.

Development of a complete general equilibrium model would require more resources than were available for this study. In addition to the increased data and resource requirements in building such a general equilibrium model, an important restriction comes from the complication involved in the welfare measures in multi-product models. As pointed out above, the welfare measures are complicated when more than two sources of equilibrium feedback are involved in multiple product situations (Thurman 1991a; LaFrance 1991; Alston, Norton and Pardey 1995; Slesnick 1998). The special conditions of this model that allow the consumer surplus changes to be measured sequentially as the trapezoid areas off the partial

equilibrium demand curves in the two markets have been noted. They were expected to be good approximations to the exact compensating or equivalent variation measures, as long as the equilibrium shifts considered are small and only one exogenous change is considered at one time.

However, for more general equilibrium models that involve more than two products related in both demand and supply, or for equilibrium models that involve multiple technical changes and market distortions, the off-the-curve economic surplus measures as demonstrated in Section 4 become more complicated or impossible. In these cases, the estimated changes in prices and quantities using EDM will still be good approximations, but the welfare measures will be difficult. An analytical approach that is more theoretically sound would be necessary. Martin and Alston (1994) and Alston, Chalfant and Piggott (1999) have used an exact approach for measuring the impacts of technical changes and promotions. It involves the explicit specification of profit and expenditure functions and the inclusion of technical change and promotion variables in these functions. This is a more theoretically consistent approach that can be used for more general equilibrium issues involving multiple sources of feedback and simultaneous exogenous changes.

## **6.4 Some Key Assumptions**

### ***6.4.1 The Nature of Supply Shifts and Functional Forms***

There have been concerns in the EDM literature about the assumptions relating to functional forms and types of exogenous shifts of demand and supply curves (for example, Alston and Wohlgenant 1990; Hurd 1996; and Lindner and Jarrett 1980). Zhao, Mullen and Griffith (1997) and Zhao (1999), found that when the exogenous shifts considered in EDMs are small and when parallel exogenous shifts are assumed, the functional forms of the demand and supply curves are irrelevant in obtaining good approximations of both the price and quantity changes and the economic surplus changes. However, the results also indicate that, when proportional shifts are assumed, significant errors are possible in the measures of welfare changes from using the wrong functional forms. Finally, in the case of parallel shifts, only local linearity is required of the demand and supply curves to have the EDM results exactly correct, and hence the restriction in some past studies that supply curves had to have elasticities greater than one in order to have positive intercepts was shown to be unnecessary.

### ***6.4.2 Competitive Conditions in the Australian Beef Industry***

In this study we have assumed that the Australian beef industry is characterised by perfectly competitive behaviour along the production and marketing chain. This has meant that in the specification of the equilibrium displacement model, prices are assumed to be equal to marginal costs. Once the assumption of perfect competitive market is relaxed, the estimated returns from R&D and promotion are expected to be different (Huang and Sexton 1996; Alston, Sexton and Zhang 1996).

There have been increasing concerns about the competitive structure of the Australian food marketing chain (ACCC 1999; Australian Parliament 1999). Empirical evidence for the Australian meat industries (Chang and Griffith 1998; Zhao, Griffith and Mullen 1998; Hyde and Perloff 1998) indicated that the domestic beef market may be consistent with competitive

behaviour on the selling side. But several submissions to the recent Joint Select Committee on the Retailing Sector (e.g. NFF 1999) suggested that this may not be the case on the buying side in the domestic market. Zhao, Griffith and Mullen (1998) also showed some evidence that the export market for Australian beef may not be competitive due to policy interventions in the US and Japanese markets. Presumably market power in the processing and marketing sectors would allow these sectors to capture more of the benefits from new technologies or promotion, particularly that occurring in their sector, at the expense of beef producers and consumers.

The rapidly changing structure of the Australian beef industry has highlighted the need for some detailed case studies about the competitive behaviour of different components of the beef marketing chain, and the implication of this for evaluating returns from R&D and promotion investments.

## 6.5 The Twelve Investment Scenarios Compared

From the base model results summarised in Table 5.2 in Section 5, the majority of the welfare gains for all 12 scenarios accrue to domestic consumers (48.3% to 65.6%) and cattle producers (19.8% to 33.7%). This is largely due to the significant gross revenues in the domestic retail and cattle breeding sectors and the less than perfect weaner supply and domestic demand elasticities. Overseas consumers and domestic retailers are the other two groups who gain significant shares, receiving 5.1% to 11.7% and 3.6% to 6.8%, respectively, for the 12 scenarios. The shares of benefits to feedlotter, processors, exporters and feedgrain producers are mostly less than 3% in all scenarios, due to the assumption of elastic factor supply in these sectors and competitive markets.

In terms of the farmers' share from alternative investment scenarios, they should generally prefer on-farm research (33.7%, 27.6% and 28.8% shares for Scenarios 1, 2 and 3, respectively) to off-farm research such as R&D in feedlotting, processing and domestic marketing sectors (26.8%, 25.9% and 19.8% shares respectively). An exception is export marketing research which gives farmers 30.2% of the total benefits, even higher than for some on-farm research scenarios.

In terms of promotion versus research, the two domestic promotion scenarios were shown to provide farmers with smaller shares of benefits (23.2% and 23.4%) than all research scenarios (shares of 25.9% to 33.7%) except for domestic marketing research (share of 19.8%). In contrast, export promotion scenarios (shares of 31.3% and 31.6%) were preferred in terms of benefit shares to all research types (shares of 19.8% to 28.8%) except for weaner production research (33.7% share). In addition, while research into grain-finishing (26.8% share) and grass-finishing (shares of 27.6% to 28.8%) were shown to provide farmers with similar benefit shares, overseas beef promotion (shares of 31.3% and 31.6%) would provide farmers with larger shares of total benefits than domestic promotion (shares of 23.2% and 23.4%).

Of course, the preference of a particular industry group for alternative investment scenarios can be very different in terms of absolute monetary gains from that in terms of percentage shares of total benefits, as the total benefits are different for different scenarios. For example, for the same initial 1% shifts in alternative scenarios, the total welfare gains in dollars are much larger from promotion of grassfed beef (\$31.55m domestically and \$20.38m overseas)

and research-induced cost reductions in weaner production (\$19.60m) and domestic marketing (\$23.88m) than from research-induced cost reductions in backgrounding (\$1.74m) and feedlots (\$1.13m).

Because information on the costs of bringing about the 1% shifts in the various markets was not considered in this study, the comparison of welfare gains in dollars among alternative investment scenarios can only be made under certain assumptions about the efficiency of investments. For example, if it is assumed that the costs of bringing about the 1% shifts in all 12 scenarios are the same, farmers' preferences can be ranked based on the estimated dollar benefits given in Table 5.2. In this case, grassfed beef promotion in both domestic and overseas markets (\$7.36m and \$6.45m) was shown to be just as preferable to farmers as weaner production research (\$6.61m), while 1% cost reductions in sectors of small value such as backgrounding (\$0.51m), feedlotting (\$0.29m), export marketing (\$0.57) and processing (\$1.21m) were shown to provide farmers much smaller dollar returns. As shown in Table 5.3, the ranking of the preferences for farmers was very different in terms of their percentage shares of the total benefits and in terms of their absolute benefits in dollars.

Given that the information on the costs of R&D and promotion investments is unavailable, the initial percentage and absolute shifts required in all 12 scenarios that are necessary to achieve the same dollar benefits as from Scenario 1, in total and to farmers respectively, were also provided in Tables 5.4 and 5.5 of Section 5. These results can be used, along with external information on the costs of bringing about these required initial shifts, to decide which scenario is preferable. For example, in order for farmers to be indifferent about investing their money in weaner production research, feedlot research or domestic grassfed beef promotion, the required investments in reducing the cost of weaner production by 1%, or reducing the cost of feedlot inputs by 22.79%, or increasing the domestic consumers' willingness to pay for grassfed beef by 0.90%, need to be the same.

Sensitivity of EDM results to uncertainty in market parameters is currently receiving considerable attention in the literature (Davis and Espinoza 1998; Griffiths and Zhao 2000). A simulation approach to a comprehensive sensitivity analysis in EDM applications was reported in Zhao, Griffiths, Griffith and Mullen (2000). The uncertainty in elasticities was represented with subjective probability distributions and the implied probability distributions for welfare measures was obtained via Monte Carlo simulation. That approach was adopted in Zhao (1999) but is not reported here due to space considerations. Briefly, for a specified joint subjective distribution for all market parameters, the means, standard deviations and 95% probability intervals for some of the welfare measures in the base results were estimated. Preferences among alternative investment scenarios were shown to be robust in terms of the *percentage shares* of the total benefits to individual groups. However, the comparison in terms of the *absolute* dollar benefits, under the assumption of equally efficient investments in the 1% shifts in all sectors, was shown to be quite sensitive to the assumed parameter values. Some useful measures for the sensitivity of results to individual parameters were also proposed using estimated response surfaces.

In summary, the equilibrium displacement model developed in this study provides a rigorous and consistent economic framework for analysing total welfare changes and their distribution among industry groups from various exogenous changes affecting the Australian beef industry. This information on benefits can be used in a cost-benefit analysis of different

investments along with information about the costs of bringing about the initial shifts in demand and supply functions. It can be used for individual R&D or promotion project evaluations, or for comparisons among broad types of research and promotion investments, if costs of alternative investment scenarios are available. It can also be used to simulate the effects of various government interventions such as tax or price policies. It is disaggregated both vertically and horizontally to a greater extent than previous models, thus enabling studies of exogenous changes occurring at individual industry sectors.

## **6.6 Limitations and Further Research**

### **6.6.1 Dynamics**

As reviewed in detail in Section 2.5.5, the equilibrium displacement modelling approach used in this study is a comparative static analysis in which two snapshot situations are compared. The new technologies in all sectors and promotion in different markets have been assumed to result in the initial shifts in the supply or demand curves instantly after the investments. In reality, while some promotion campaigns and some nutritional or management R&D may have prompt effects, a longer time lag is often involved in the effects of more basic research. Often, there are time lags between the R&D investments, the research outcomes and the adoption of the technology. Adoption and disadoption of a technology is also a long process following certain patterns. Research costs including maintenance costs are often incurred over a period of time. Similarly, the promotional costs and the impacts on the consumers' willingness to pay may also occur over a period of time.

In addition, it often takes several years for an industry, especially the cattle industry, to completely adjust to an initial shock to reach a new equilibrium. Just, Hueth and Schmitz (1982, p65-66) illustrated how to measure the annual welfare implications for the years after the initial shock and before the new equilibrium, using supply curves of different lengths of run. In this study, it was assumed that a medium-run time frame is needed for the beef industry to fully adjust to the initial shocks, and medium-run elasticities have been chosen for the base model. Thus, based on the length-of-run analysis by Just, Hueth and Schmitz (1982), the welfare gains estimated in the current study relate to the *annual benefit for the years on and after reaching the new equilibrium*. The annual benefits for the years during the equilibrium adjustment can be calculated using shorter time-run elasticity values associated with the periods between the starting point and each year.

A complete evaluation of a research or promotion investment and any comparison among alternative investment scenarios should take into account the sequence of all costs and benefits over time in relation to the above factors. These benefit and cost flows can then be summarised using net present values (NPV) or internal rates of return (IRR) with the appropriate discount rate.

### **6.6.2 A Complete Benefit/Cost Framework**

In this study, 1% shifts of the relevant supply or demand curves for alternative investment scenarios were simulated. The total welfare benefits and their percentage distributions among the various industry groups were estimated. However, the investment costs required to bring about the 1% initial shifts, or the issues regarding the efficiency of the R&D and promotion

investments, were not examined. In other words, this study only provides part of the information for a complete cost-benefit analysis of alternative investments in the Australian beef industry.

However, the model specified in this study has provided a framework for a complete cost-benefit analysis once the data on the investment efficiency or costs are available. For example, if the model is to be used for evaluation of a particular research program, the technical aspects of the research or new technology can be closely studied to estimate the direct impact in terms of productivity change or cost reduction. The implied amount of supply shift in the relevant market can then be estimated and used as input to an EDM (for example, Lemieux and Wohlgenant 1989). Probability of research success, rate and pattern of adoption and the flow of research costs can also be accounted for. A similar procedure is required for assessing a particular promotional program, which may start at quantifying its direct effect on consumers' perception of the products.

If the model is to be used for evaluation and comparison of broad categories of research-induced technologies and promotion to address general policy issues in priority-setting, information about investment efficiency is necessary. Eliciting the expected amounts of supply or demand shifts based on the same amount of monetary investments in different scenarios would be difficult. Econometric models may be required for estimating such direct impacts (Scobie, Mullen and Alston 1991; Mullen and Cox 1995; Cox, Mullen and Hu 1997). Data on research expenditures and the associated productivity, or promotion expenditures and the changes in demand, would be required. The resulting benefits from alternative investment scenarios will be comparable when the initial shifts in all scenarios relate to the same investment cost. In addition, the final appraisal of alternative investment scenarios will need to take into account not only the economic objectives in terms of efficiency, but also the social objectives and even environmental concerns.

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## Appendix 1. Derivation of Integrability Conditions

In this appendix, the properties of cost, revenue, profit and utility functions are discussed in turn and used to derive the required properties for the demand and supply functions and their implications for the market parameters in the EDM model specification.

### A1.1 Cost Functions and Output-Constrained Input Demand

Consider first the properties of the cost function  $C(w, y)$  of any multi-output technology as defined in Equation (2.3.3). To be a cost function,  $C(w, y)$  needs to be positive for  $y > 0$ , nondecreasing in  $w$ , concave and continuous in  $w$ , linearly homogenous in  $w$ , equal to zero when  $y=0$  (as a  $n \times 1$  vector) and nondecreasing in  $y$  (Chambers 1991, p262). When  $C(w, y)$  is twice-continuously differentiable, the comparative static properties of the derived output-constrained input demands in Equation (2.3.6) are characterised by the requirements that (i) the derived demands  $x(w, y) = \nabla_w C(w, y)$  be homogenous of degree zero in  $w$ ; (ii) the Hessian matrix  $\nabla_{ww} C(w, y) = \nabla_w x(w, y)$  be symmetric and negative semidefinite; (iii) the gradient of marginal costs  $\nabla_y C(w, y)$  be homogenous of degree 1 in  $w$ ; and (iv)  $(\partial^2 C / \partial w_i \partial y_j) = (\partial^2 C / \partial y_j \partial w_i)$  ( $i=1, \dots, k; j=1, \dots, n$ ) (Chambers 1991, p262). The definition of gradient  $\nabla$  is obvious from the discussion). These are the four conditions that input demands for the six industry sectors in Equations (2.4.5)-(2.4.8), (2.4.19)-(2.4.22), (2.4.28)-(2.4.32) and (2.4.41)-(2.4.46) in the model need to satisfy in order to be integrable allowing recovery of the "proper" cost functions in Equations (2.3.16)-(2.3.21). As market elasticity values are required to solve the displacement model in Equations (2.4.1)-(2.4.58)', the implications of the above integrability conditions for the elasticities are examined below.

First,  $x = x(w, y) = (x_1(w, y), \dots, x_k(w, y))'$  homogenous of degree zero (HD(0)) in  $w$  implies that for any  $\lambda > 0$ ,

$$(A.1.1) \quad x_i(\lambda w, y) = x_i(w, y) \quad (i = 1, \dots, k) \quad (\text{homogeneity}).$$

The necessary and sufficient condition for a function  $f(z) = f(z_1, \dots, z_k)$  to be HD(m) is that

$$\sum_{j=1}^k z_j \frac{\partial f(z)}{\partial z_j} = m f(z) \quad (\text{Euler's Theorem, Berck and Sydseter 1992, p15}).$$

Thus,  $x(w, y)$  is

$$\text{HD}(0) \text{ in } w \text{ if and only if } \sum_{j=1}^k \frac{\partial x_i(w, y)}{\partial w_j} w_j = 0, \text{ or } \sum_{j=1}^k \frac{\partial x_i(w, y)}{\partial w_j} \frac{w_j}{x_i(w, y)} = 0 \quad (i = 1, \dots, k).$$

That

$$(A.1.1)' \quad \sum_{j=1}^k \tilde{\eta}_{ij}(w, y) = 0 \quad (i = 1, \dots, k) \quad (\text{homogeneity}),$$

where  $\tilde{\eta}_{ij}(w, y)$  is the constant-output input demand elasticity of  $x_i$  with respect to a change in the input price  $w_j$  ( $i, j = 1, \dots, k$ ). Using Allen-Uzawa's definition of elasticity of input substitution (McFadden 1978, p79-80)

$$(A.1.2) \quad \tilde{\eta}_{ij}(w, y) = s_j(w, y) \sigma_{ij}(w, y) \quad (i, j = 1, \dots, k),$$

Equation (A.1.1)' can be written as

$$(A.1.1)'' \quad \sum_{j=1}^k s_j(w, y) \sigma_{ij}(w, y) = 0 \quad (i = 1, \dots, k) \quad (\text{homogeneity})$$

where  $s_j(\cdot) = (w_j x_j / C)$  is the share of the  $j$ th input in total cost and  $\sigma_{ij}(w, y)$  is the Allen-Uzawa elasticity of substitution between the  $i$ th and  $j$ th inputs ( $i, j = 1, \dots, k$ ).

Second, by definition the Hessian matrix can be written as

$$H = \nabla_{ww} C(w, y) = \nabla_w x(w, y) = \left( \frac{\partial x_i(w, y)}{\partial w_j} \right)_{k \times k} = \left( \eta_{ij}(w, y) \frac{x_i(w, y)}{w_j} \right)_{k \times k}.$$

When the homogeneity condition is satisfied, the columns of  $H$  are linearly correlated satisfying  $\sum_{j=1}^k \frac{\partial x_i(w, y)}{\partial w_j} w_j = 0$  ( $i = 1, \dots, k$ ). This implies that  $H$  is singular, or

$$|H| = 0.$$

$H$  is symmetric implies that

$$(A.1.3) \quad \frac{\partial x_i(w, y)}{\partial w_j} = \frac{\partial x_j(w, y)}{\partial w_i} \quad (i, j = 1, \dots, k) \quad (\text{symmetry}), \quad \text{or}$$

$$\tilde{\eta}_{ij}(w, y) \frac{x_i}{w_j} = \tilde{\eta}_{ji}(w, y) \frac{x_j}{w_i} \quad (i, j = 1, \dots, k) \quad (\text{symmetry}), \quad \text{or}$$

$$(A.1.3)' \quad s_i(w, y) \tilde{\eta}_{ij}(w, y) = s_j(w, y) \tilde{\eta}_{ji}(w, y) \quad (i, j = 1, \dots, k) \quad (\text{symmetry}).$$

Using Equation (A.1.2), the above symmetry condition becomes

$$\sigma_{ij}(w, y) \frac{w_j x_j}{C} \frac{x_i}{w_j} = \sigma_{ji}(w, y) \frac{w_i x_i}{C} \frac{x_j}{w_i}, \quad \text{or}$$

$$(A.1.3)'' \quad \sigma_{ij}(w, y) = \sigma_{ji}(w, y) \quad (i, j = 1, \dots, k) \quad (\text{symmetry}).$$

In other words, in terms of input substitution, the symmetry condition simply means that the Allen-Uzawa substitution elasticity is symmetric.

$H$  is negative semidefinite (NSD) if and only if all eigenvalues of  $H = (b_{ij})_{k \times k}$  are nonpositive, or if and only if  $(-1)^m H_m \geq 0$  where  $H_m$  is the  $m$ th principal minor of  $H$  ( $m = 1, \dots, k$ ). That is, the principal minors of  $H$  alternate between nonpositive (when  $k$  is odd) and nonnegative (when  $k$

is even). As is already shown in Equation (2.4.4), the  $k$ th principal minor  $H_k = |H| = 0$ ;  $H$  is NSD if and only if

$$(A.1.4) \quad (-1)^m H_m = (-1)^m \begin{vmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, k-1) \quad (\text{concavity})$$

where  $b_{ij} = \frac{\partial x_i(w, y)}{\partial w_j}$  ( $i, j = 1, \dots, k$ ).

In terms of demand elasticities, for  $m = 1, \dots, k$ ,

$$H_m = \left| \left( \eta_{ij} \frac{x_i}{w_j} \right)_{m \times m} \right| = \left( \prod_{i=1}^m \frac{x_i}{w_i} \right) \left| (\eta_{ij})_{m \times m} \right|.$$

Thus, as  $\prod_{i=1}^m \frac{x_i}{w_i} \geq 0$ ,  $H$  is NSD iff  $H_\eta = (\eta_{ij})_{k \times k}$  is NSD, or, in terms of principal minors of  $H_\eta$  (as it can be shown that  $H_\eta$  is also singular),  $H$  is NSD iff

$$(A.1.4)' \quad (-1)^m H_{\eta m} = (-1)^m \begin{vmatrix} \tilde{\eta}_{11} & \tilde{\eta}_{12} & \cdots & \tilde{\eta}_{1m} \\ \tilde{\eta}_{21} & \tilde{\eta}_{22} & \cdots & \tilde{\eta}_{2m} \\ \vdots & \vdots & & \vdots \\ \tilde{\eta}_{m1} & \tilde{\eta}_{m2} & \cdots & \tilde{\eta}_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, k-1) \quad (\text{concavity}).$$

Similarly, as  $H_{\eta m} = \left| (\tilde{\eta}_{ij})_{m \times m} \right| = \left| (s_j \sigma_{ij})_{m \times m} \right| = \left( \prod_{j=1}^m s_j \right) \left| (\sigma_{ij})_{m \times m} \right|$  and  $\left( \prod_{j=1}^m s_j \right) \geq 0$ ,  $H$  is NSD if and only if  $H_\sigma = (\sigma_{ij})_{k \times k}$  is NSD, or, because  $H_\sigma$  is also singular under homogeneity,

$$(A.1.4)'' \quad (-1)^m H_{\sigma m} = (-1)^m \begin{vmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1m} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2m} \\ \vdots & \vdots & & \vdots \\ \sigma_{m1} & \sigma_{m2} & \cdots & \sigma_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, k-1) \quad (\text{concavity}).$$

Now consider Conditions (iii) and (iv). Under the assumptions of separable inputs and outputs and constant returns to scale, the cost function can be written as  $C(w, y) = g(y) \hat{c}(w)$  as in Equations (2.3.4) and (2.3.5). Thus,  $\frac{\partial C(w, y)}{\partial y_j} = g'_j(y) \hat{c}(w)$  ( $j = 1, \dots, n$ ). This implies that

Condition (iii) that  $\nabla_y C(w, y) = \left( \frac{\partial C}{\partial y_1}, \frac{\partial C}{\partial y_2}, \dots, \frac{\partial C}{\partial y_n} \right)$  are HD(1) in  $w$  is equivalent to the unit cost function  $\hat{c}(w)$  being HD(1) in  $w$ . This, given the separable cost function, is equivalent to

a cost function  $C(w, y)$  being HD(1) in  $w$ . As in general  $f(z)$  is HD( $m$ ) in  $z$  implies  $\nabla_z f(z)$  is HD( $m-1$ ) in  $z$  (Berck and Sydseter 1992, p15), a HD(1)  $C(w, y)$  means that  $x(w, y) = \nabla_w C(w, y)$  is HD(0) in  $w$ . In other words, under the three assumptions given at the beginning of Section 2.3, Condition (iii) implies condition (i) in terms of integrability requirements in input demands. Also, when the cost function is assumed twice-continuously-differentiable, Condition (iv) is always satisfied. Thus, the integrability conditions for the input demands in the model are reduced to Conditions (i) and (ii), or, specifically, homogeneity, symmetry and concavity conditions in Equations (A.1.1), (A.1.3) and (A.1.4), or their two equivalent forms in Equations (A.1.i)' and (A.1.i)'' ( $i = 1, 3, 4$ ).

## A1.2 Revenue Functions and Input-Constrained Output Supply

To be a multi-output revenue function for a given input bundle  $x$ ,  $R(p, x)$  needs to be nonnegative, nondecreasing in output price  $p$ , HD(1) in  $p$ , convex and continuous in  $p$ , and nondecreasing in  $x$  (Chambers 1991, p263). Also, if  $R(p, x)$  is differentiable in  $p$ , the input-constrained output supply can be derived (Chambers 1991, p264) as

$$y_j(p, x) = \frac{\partial R(p, x)}{\partial p_j} \quad (j = 1, \dots, n).$$

Based on the above properties, the comparative static properties for a twice-continuously differentiable  $R(p, x)$  and the derived output supplies are that (i)  $y(p, x)$  be HD(0) in  $p$ ; (ii) the Hessian matrix  $\nabla_{pp} R(p, x) = \nabla_p y(p, x)$  be symmetric and positive semidefinite (PSD); (iii)  $\nabla_x R(p, x)$  be HD(1) in  $p$ ; and (iv)  $(\partial^2 R(p, x) / \partial x_i \partial p_j) = (\partial^2 R(p, x) / \partial p_j \partial x_i)$  ( $i = 1, \dots, k; j = 1, \dots, n$ ) (Chambers 1991, p265).

Similar to the analysis of cost function (thus derivation is not repeated here), under the three assumptions made at the beginning of Section 2.3 (ie. profit maximization, input and output separability and constant returns to scale), the above comparative static properties are exhausted by the following homogeneity, symmetry and convexity restrictions, or their equivalent forms.

The homogeneity condition is given by

$$(A.1.5) \quad y_j(\lambda p, x) = \lambda y_j(p, x) \quad (\forall \lambda > 0; j = 1, \dots, n) \quad (\text{homogeneity}), \text{ or}$$

$$(A.1.5)' \quad \sum_{j=1}^n \tilde{\varepsilon}_{ij}(p, x) = 0 \quad (i=1, \dots, n) \quad (\text{homogeneity}),$$

where  $\varepsilon_{ij}(p, x)$  is the input-constrained output supply elasticity of  $y_i$  with respect to a change in output price  $p_j$  ( $i, j = 1, \dots, k$ ). Using Allen-Uzawa's definition of elasticity of product transformation (McFadden 1978, p79-80), ie.

$$(A.1.6) \quad \tilde{\varepsilon}_{ij}(p, x) = \gamma_j(p, x) \tau_{ij}(p, x)$$

where  $\gamma_j(\cdot) = (p_j y_j / R)$  is the share of the  $j$ th output in total revenue and  $\tau_{ij}(p, x)$  is the Allen-Uzawa elasticity of product transformation between the  $i$ th and  $j$ th outputs ( $i, j = 1, \dots, n$ ), homogeneity can also be written as

$$(A.1.5)'' \quad \sum_{j=1}^n \gamma_j(p, x) \tau_{ij}(p, x) = 0 \quad (i=1, \dots, n) \quad (\text{homogeneity}).$$

The symmetry condition is given by

$$(A.1.7) \quad \frac{\partial y_i(w, y)}{\partial p_j} = \frac{\partial y_j(w, y)}{\partial p_i} \quad (i, j = 1, \dots, n) \quad (\text{symmetry}), \quad \text{or}$$

$$(A.1.7)' \quad \gamma_i(p, x) \tilde{\epsilon}_{ij}(p, x) = \gamma_j(p, x) \tilde{\epsilon}_{ji}(p, x) \quad (i, j = 1, \dots, n) \quad (\text{symmetry}).$$

Using Allen-Uzawa's elasticity of substitution, the symmetry condition becomes

$$\tau_{ij}(p, x) \frac{p_j y_j}{R} \frac{y_i}{p_j} = \tau_{ji}(p, x) \frac{p_i y_i}{R} \frac{y_j}{p_i}, \quad \text{or}$$

$$(A.1.7)'' \quad \tau_{ij}(w, y) = \tau_{ji}(w, y) \quad (i, j = 1, \dots, n) \quad (\text{symmetry}).$$

In other words, the symmetry condition simply implies symmetry of Allen-Uzawa product transformation elasticities.

The convexity condition requires that the Hessian matrix

$$H = \nabla_{pp} R(p, x) = \nabla_{pY} p(p, x) = \left( \frac{\partial y_i(p, x)}{\partial p_j} \right)_{n \times n}$$

is PSD. It can be shown that  $H$  is PSD iff  $H_\epsilon = (\tilde{\epsilon}_{ij})_{n \times n}$  is PSD, or  $H_\tau = (\tau_{ij})_{n \times n}$  is PSD.

Similar to the case of cost function, it can also be shown that under the homogeneity condition, all three matrices  $H$ ,  $H_\epsilon$  and  $H_\tau$  are singular. Thus, in terms of the principal minors of these matrices, the convexity condition is equivalent to

$$(A.1.8) \quad H_m = \begin{vmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, n-1) \quad (\text{convexity})$$

where  $b_{ij} = \frac{\partial y_i(p, x)}{\partial p_j}$  ( $i, j = 1, \dots, n$ ), or

$$(A.1.8)' \quad H_{\varepsilon m} = \begin{vmatrix} \tilde{\varepsilon}_{11} & \tilde{\varepsilon}_{12} & \cdots & \tilde{\varepsilon}_{1m} \\ \tilde{\varepsilon}_{21} & \tilde{\varepsilon}_{22} & \cdots & \tilde{\varepsilon}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\varepsilon}_{m1} & \tilde{\varepsilon}_{m2} & \cdots & \tilde{\varepsilon}_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, n-1) \text{ (convexity), or}$$

$$(A.1.8)'' \quad H_{\tau m} = \begin{vmatrix} \tau_{11} & \tau_{12} & \cdots & \tau_{1m} \\ \tau_{21} & \tau_{22} & \cdots & \tau_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tau_{m1} & \tau_{m2} & \cdots & \tau_{mm} \end{vmatrix} \geq 0 \quad (m = 1, \dots, n-1) \text{ (convexity).}$$

Thus, the integrability conditions for the output supplies in Equations (2.4.13)-(2.4.16), (2.4.25)-(2.4.26), (2.4.35)-(2.4.38) and (2.4.51)-(2.4.54) in the model are satisfied if the homogeneity, symmetry and convexity conditions in Equations (A.1.5), (A.1.7) and (A.1.8), or their two equivalent forms in Equation (A.1.i)' and (A.1.i)'' ( $i = 5, 7, 8$ ), hold. These conditions will ensure the recovery of the underlying revenue functions in Equations (2.3.22)-(2.3.27).

### A1.3 Profit Functions and Exogenous Factor Supplies

A multioutput (including single output as a special case) profit function  $\Pi(p, w)$  needs to be nonnegative, nondecreasing in output prices  $p$ , nonincreasing in input prices  $w$ , convex, continuous and HD(1) in all arguments (Chambers, 1991, p269). When  $\Pi(p, w)$  is differentiable, using Hotelling's Lemma, a unique set of profit-maximizing output supplies and input demands can be derived as

$$(A.1.9) \quad y_j(p, w) = \frac{\partial \Pi(p, w)}{\partial p_j} \quad \text{and} \quad -x_i(p, w) = \frac{\partial \Pi(p, w)}{\partial w_i} \quad (i = 1, \dots, k; j = 1, \dots, n).$$

The comparative static properties for these input demands and output supplies are that (i)  $z(p, w) = (y_j(p, w), -x_i(p, w))$  are HD(0) in  $q=(p, w)$ ; and (ii) the Hessian matrix  $\nabla_q z(q) = \nabla_{qq} \Pi(q)$  is symmetric and PSD.

Similar to the cases of cost and revenue functions, the demand and supply functions in Equation (A.1.9) need to satisfy homogeneity, symmetry and convexity conditions. These conditions can be expressed in terms of market elasticities. And the exogenous input supplies of  $X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$  in Equations (2.4.1), (2.4.3)-(2.4.4), (2.4.17)-(2.4.18), (2.4.27) and (2.4.39)-(2.4.40) need to satisfy these conditions.

However, if we let  $x$  represent any one of the exogenous inputs to the model ( $x = X_1, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me}$  and  $Z_{md}$ ), the supply of  $x$  is the only equation in the model that is derived from its supplier's profit function. Other variables influencing the factor supply are assumed exogenous and kept constant. Thus, the supply of each of these factors needs to satisfy the economic restrictions associated with the demand and supply of other variables in its supplier's profit function, but not with any demand or supply specifications within the model. As a result, homogeneity and symmetry conditions do not impose restrictions on the

exogenous factor supply functions that involve any other equations in the model. The only restriction implied by a PSD Hessian is that the own-price supply elasticities are non-negative, ie.

$$(A.1.10) \quad \varepsilon_x \geq 0 \quad (x = X_l, X_{n2}, X_{s2}, F_{n2}, F_{n3}, Y_p, Z_{me} \text{ and } Z_{md}),$$

where  $\varepsilon_x$  is the own-price supply elasticity of input  $x$ .

## A1.4 Utility Functions and Exogenous Product Demands

Now examine the consumer demands for the final products of the beef industry, which are assumed exogenous to the model. Consumer theory and the relationship between the indirect utility function, expenditure function and the derived Marshallian and Hicksian demand functions can be found in many economics textbooks (eg. Varian 1992) and will not be discussed in detail here.

In brief, the indirect utility function for given income is defined as

$$v(p, m) = \max_x \{u(x): px \leq m\}$$

where  $x$  is the commodity vector,  $p$  is the price vector,  $m$  is income and  $u(x)$  is the utility function. Using Roy's identity, the Marshallian demand functions are derived as

$$x_i(p, m) = - \frac{\frac{\partial v(p, m)}{\partial p_i}}{\frac{\partial v(p, m)}{\partial m}} \quad (i = 1, \dots, n).$$

The inverse of the indirect utility function is the expenditure function, or equivalently, the expenditure function for a given utility level is given by

$$e(p, u) = \min_x \{px: u(x) \geq u\}.$$

The Hicksian demand functions can be derived as

$$h_i(p, u) = \frac{\partial e(p, u)}{\partial p_i} \quad (i = 1, \dots, n).$$

There are a set of relationships relating  $v(p, m)$ ,  $x(p, m)$ ,  $e(p, u)$  and  $h(p, u)$  (eg. see Varian 1992, p106). In particular,

$$x_i(p, m) = h_i(p, v(p, m)),$$

ie. Marshallian demand at income  $m$  is Hicksian demand at utility  $v(p, m)$ .

As the expenditure function for a given utility level is completely analogous to a cost function for a given output level, the properties of  $e(p, u)$  are similar to those of the cost function discussed earlier and will not be repeated (see for example, Varian 1992, p104). Thus, analogous to the comparative static properties for the conditional factor demand in production theory, the properties for Hicksian demand are that (i)  $h(p, u) = \nabla_p e(p, u)$  are HD(0) in  $p$ ; and (ii) Hessian matrix  $\nabla_p h(p, u) = \nabla_{pp} e(p, u)$  is symmetric and NSD.

However, unlike the case of the cost function where output is observable, Hicksian demand is not observable because utility is not directly observable. The relationship that links the derivatives of the unobservable Hicksian and the observable Marshallian demand functions is the Slutsky equation:

$$(A.1.11) \quad \frac{\partial h_i(p, u)}{\partial p_j} = \frac{\partial x_i(p, m)}{\partial p_j} + \frac{\partial x_i(p, m)}{\partial m} x_j(p, m) \quad (i, j = 1, \dots, n).$$

Using the Slutsky equation, the above comparative static properties in terms of the Marshallian demand functions are that (i)  $x(p, m)$  are HD(0) in  $(p, m)$ ; and (ii) the Slutsky matrix with elements in Equation (A.1.11) is symmetric and NSD. In terms of demand elasticities, the homogeneity condition becomes

$$(A.1.12) \quad \sum_{j=1}^n \eta_{ij} + \eta_{im} = 0 \quad (i = 1, \dots, n) \quad (\text{homogeneity}), \text{ and}$$

the symmetry condition becomes

$$(A.1.13) \quad \eta_{ij} = \frac{s_j}{s_i} \eta_{ji} + s_j (\eta_{jm} - \eta_{im}) \quad (i, j = 1, \dots, n) \quad (\text{symmetry}),$$

where  $s_i$  ( $i = 1, \dots, n$ ) is the expenditure share of the  $i$ th commodity. A NSD Slutsky Hessian matrix implies that

$$(A.1.14) \quad H_\eta = \left( \eta_{ij} \frac{x_i}{p_j} + \eta_{im} \frac{x_i x_j}{m} \right)_{n \times n} \text{ is NSD} \quad (\text{concavity}).$$

Derivation is straightforward and thus omitted.

Now come back to the implications of these conditions for the specification of the final beef demand functions in the model. As discussed in Section 2.5.3, the Marshallian economic surplus areas will be used as measures of welfare, which implies that the marginal utility of income is constant and the income effect will be ignored. Under this assumption, a symmetric and NSD Marshallian substitution matrix is equivalent to a symmetric and NSD Slutsky matrix. As the expenditure on beef is only a small proportion in the consumers' budget, this should not introduce a significant error by using the economic surplus as a welfare measure (Willig 1976).

The two types of beef are assumed non-substitutable in the export market. Thus, no integrability restrictions with the rest of the model are required for each of these export demands, except that the own-price demand elasticities are negative to be consistent with the NSD Hessian, that is

$$(A.1.15) \quad \eta_{(Qie, pie)} \leq 0 \quad (i = n, s)$$

As for the domestic demand, the two types of beef are modelled as substitutes and relate to the utility maximization of the same domestic consumer. Because other competing commodities in the consumer's budget, as well as income, are assumed exogenously constant and do not appear in the model, the integrability conditions in the context of this model relate only to the 2×2 sub-Hessian matrix of the two domestic beef products (denoted by  $x_1$  and  $x_2$  for convenience).

In particular, symmetry implies that

$$\frac{\partial x_1}{\partial p_2} = \frac{\partial x_2}{\partial p_1} \quad (\text{symmetry}), \text{ or}$$

$$(A.1.16) \quad \eta_{12} = \left(\frac{\lambda_2}{\lambda_1}\right)\eta_{21} \quad (\text{symmetry}),$$

where  $(\lambda_2/\lambda_1)$  is the relative budget shares of the two commodities, and concavity implies that

$$(A.1.17) \quad \eta_{11} \leq 0 \quad \text{and} \quad \begin{vmatrix} \eta_{11} & \eta_{12} \\ \eta_{21} & \eta_{22} \end{vmatrix} \geq 0 \quad (\text{concavity}).$$

The 2×2 sub-Hessian matrix and the 2×2 demand elasticity matrix are not necessarily singular now. For normal situations where  $\eta_{ii} < 0$ ,  $\eta_{ij} \geq 0$ , and  $|\eta_{ii}| > |\eta_{ij}|$ , Equation (A.1.17) is naturally satisfied. In these situations, homogeneity also means that

$$(A.1.18) \quad \eta_{11} + \eta_{12} = -\sum_{j=3}^n \eta_{ij} - \eta_{1m} \leq 0 \quad \text{and} \quad \eta_{21} + \eta_{22} = -\sum_{j=3}^n \eta_{ij} - \eta_{1m} \leq 0,$$

which are naturally satisfied. Complete discussion on the integrability problem and the integrability conditions for the “incomplete demand system” can be found in Epstein (1982), LaFrance and Hanemann (1989) and LaFrance (1991).

## Appendix 2. Specification of Equilibrium Prices and Quantities

In this appendix, the specification of equilibrium prices and quantities for all inputs and outputs of all industry sectors is detailed. The original data sources, assumptions made regarding the price and quantity relationships among different levels and the derivation of the unavailable data are given. Refer to Table 2.3 or Figure 2.1 for variable definitions. The resulting set of average prices and quantities for 1992-1997 are summarised in Table 3.1.

### A2.1 Quantities

The annual quantities of the four types of cattle/beef products at all production and marketing stages are required for the period of 1992 to 1997.

#### Step 1. $Q_e, Q_{ne}, Q_{se}$ and $Z_e \Rightarrow Z_{ne}, Z_{se}, Y_{ne}, Y_{se}$ and $Y_e$

$Q_e, Q_{ne}$  and  $Q_{se}$ , quantities of total export beef, grainfed export beef and grassfed export beef, respectively, measured in kilotons shipped weight, are obtained from Agriculture, Fisheries and Forestry, Australia (K. Wade, AFFA, per. comm. 1998). A data spreadsheet was obtained from the Quota Administration and Statistics Unit, AFFA that lists the annual quantities of Australian beef exports, in separate grainfed and grassfed quantities, to more than 100 countries for the period of 1992-1998. The grainfed figures in these data are based on the exporter specified grainfed amounts as indicated on the Health Certificate applications.

$Z_e$ , the total Australian export of beef in kilotons carcass weight, is taken from Table 150, Australian Commodity Statistics (ABARE 1998).

The saleable yield for converting the export carcass weight to the export shipped weight is obtained as the ratio of  $Q_e$  to  $Z_e$ . The average of this ratio for 1992-1997 is about 68%. This same yield percentage is used to derive the carcass weights for both export grainfed and export grassfed beef; that is  $Z_{ne}=Q_{ne}/0.68$  and  $Z_{se}=Q_{se}/0.68$ .

A commonly used conversion factor of 0.55 (Griffith, Green and Duff 1991) is applied to all four beef categories to convert the cattle live weights to beef carcass weights. In particular,  $Y_{ne}=Z_{ne}/0.55$ ,  $Y_{se}=Z_{se}/0.55$  and  $Y_e=Y_{ne}+Y_{se}$ .

#### Step 2. $Z_d \Rightarrow Y_d$ and $Y$

$Z_d$ , the total domestic beef consumption in kilotons carcass weight, is obtained from Table 150, Australian Commodity Statistics (ABARE 1998). Live weight total domestic beef quantity  $Y_d$  is derived using the 0.55 conversion percentage, ie.  $Y_d=Z_d/0.55$ . The total cattle live weight is calculated as  $Y=Y_d+Y_e$ .

#### Step 3. Derivation of Average Slaughtering Weights $WPH(Y_{ne})$ and $WPH(Y_n)$

The total domestic beef quantity is given in Step 2. However there is no published information available on the separate quantities for grainfed and grassfed domestic

consumption. The only information is an estimated figure of domestic grainfed quantity for 1994 in a MRC research report (MRC 1995).

In this MRC commissioned study, the total domestic grainfed production was derived from the information on numbers of grainfed cattle slaughtered by major retailers and factored up by their estimated market share in comparison with the butchers. Then, the domestic feedlot-finished cattle was assumed to equal the throughput of major feedlots servicing the domestic grainfed market and the residual assumed to be grain supplemented. As a result, from their discussions with the national beef retail managers of Woolworths and Coles and with a major Sydney retailer, and based on the information from the AMLC commissioned Nielsen Survey and from LMAQ and NSW saleyard reports, they estimated that the total number of domestic grainfed cattle is in the order of 1.2 million head, of which 390,000 head are fed in major feedlots and the residual of 811,000 head grain supplemented. Based on this information, they estimated the number of cattle slaughtered and the total carcass weight for each market segment for 1994 (Chart 3.1 and 3.2, MRC 1995).

In the current study, information on separate domestic grainfed and grassfed cattle for the period of 1992-1997 is required. The slaughtering weight per head for the major feedlot finished cattle in 1994 from the MRC study is taken and assumed unchanged for other years. This, together with the cattle turn-off number in major feedlots described in Step 4 below, is used to derive the domestic grainfed (major feedlot finished for the purpose of this study) cattle quantity.

Specifically, in Table A2.1, the number of cattle slaughtered, the total carcass weight and the average carcass weight per head for the various market segments for 1994 are assembled based on the information in the above mentioned MRC report (MRC 1995). These market segments include domestic feedlot finished ( $y_{nd}(\text{feedlot})$ ), domestic grain supplemented ( $y_{sd}(\text{suppl.})$ ), domestic grassfed ( $y_{sd}(\text{grass})$ ), export grainfed ( $y_{ne}$ ) and export grassfed ( $y_{se}$ ) cattle. For the purpose of this study, the domestic grainfed  $Y_{nd}$  only includes  $y_{nd}(\text{feedlot})$ , ie.  $Y_{nd}=y_{nd}(\text{feedlot})$  and  $Y_{sd}=y_{sd}(\text{grass})+y_{sd}(\text{suppl.})$ . The slaughtering numbers and carcass weights marked with  $(.)^*$  are taken from MRC (Chart 3.1 and 3.2, 1995). An assumption is made that the average slaughtering weight for total domestic grainfed cattle ( $y_{nd}(\text{feedlot})+y_{sd}(\text{suppl.})$ ) derived from the MRC figures is the same for its two components ( $y_{nd}(\text{feedlot})$  and  $y_{sd}(\text{suppl.})$ ). Based on this assumption, the figures in  $(.)^{***}$  are derived. In particular, the average carcass weight for  $y_{ne}$  is 332kg and for  $y_n(\text{feedlot})$  is 292kg per head. In live weight,  $WPH(Y_{ne})=332/0.55=604\text{kg(l.w.)}$  and  $WPH(Y_n)=292/0.55=531\text{kg(l.w.)}$ . These figures are used in the derivation of other data below.

#### **Step 4. $N$ , $N_n$ and $WPH(Y_n) \Rightarrow Y_n$ and $Y_s$**

The total number of cattle slaughtered,  $N$ , for each year of 1992-1997 is taken from the Australian Commodity Statistics (Table 150, ABARE 1998). The cattle 'off-feed' numbers from the major feedlots are obtained from feedlot survey information (C. Toyne, ABARE, per. comm. 1998). Using the average weight per head for feedlot finished cattle in 1994 for all other years, the total live weight of feedlot finished cattle can be derived as  $Y_n=(N_n)(WPH(Y_n))$ . The total live weight of grassfed cattle (including grain-supplemented) can be obtained accordingly as  $Y_s=Y-Y_n$ .

**Step 5.  $Y_n, Y_s, Y_{ne}$  and  $Y_{se} \Rightarrow Y_{nd}, Y_{sd}, Z_{nd}$  and  $Z_{sd}$**

Domestic grainfed and grassfed quantities can be calculated as  $Y_{nd}=Y_n-Y_{ne}$  and  $Y_{sd}=Y_s-Y_{se}$ . Using the conversion factor of 0.55 as discussed in Step 1, the carcass weight for the two domestic products is calculated as  $Z_{nd}=0.55Y_{nd}$  and  $Z_{sd}=0.55Y_{sd}$ .

**Step 6.  $R_{(Zd/Qd)}$  -- Domestic Saleable Yield Percentage**

The quantities for domestic retail cuts are not reported in published sources. A saleable yield percentage  $R_{(Zd/Qd)}$  is used to convert the carcass weights to the weights of saleable cuts.  $R_{(Zd/Qd)}$  needs to be consistent with the various retail cuts that are included in the measurements of the prices and quantities. In the model, the major cuts that comprise a beef carcass are included in the calculation of domestic retail beef quantities and prices. They include rump steak, sirloin, topside, chuck, blade and mince. Based on a study by Griffith, Green and Duff (1991), these cuts comprise 72% of the weight of a beef carcass. Thus a yield percentage  $R_{(Zd/Qd)}=0.72$  is specified. The derivation of the associated retail price  $P_d$  is given in Section A2.2 in this Appendix.

**Step 7.  $Z_{nd}$  and  $Z_{sd} \Rightarrow Q_{nd}$  and  $Q_{sd}$**

Based on the discussion above in Step 6, the domestic retail beef quantities are calculated as  $Q_{nd}=0.72Z_{nd}$  and  $Q_{sd}=0.72Z_{sd}$ .

**Step 8.  $WPH(Y_{ne}), Y_{ne}$  and  $N_n \Rightarrow N_{ne}$  and  $N_{nd}$**

Using the average slaughtering weight per head ( $WPH(Y_{ne})$ ) and the total slaughtering weight for export grainfed cattle ( $Y_{ne}$ ), the cattle numbers for the export grainfed beef are derived as  $N_{ne}=Y_{ne}/WPH(Y_{ne})$ . The domestic feedlot-finished cattle number is then calculated as  $N_{nd}=N_n-N_{ne}$ .

**Step 9. Derivation of  $WPH(F_{n1e}), WPH(F_{n1d}), WPH(X_{ne})$  and  $WPH(X_{nd})$**

Data on cattle quantities at feeder and weaner levels are not available from published sources. They are derived from information on the average per head weights of export quality feeders ( $WPH(F_{n1e})$ ) and weaners ( $WPH(X_{ne})$ ) and domestic quality feeders ( $WPH(F_{n1d})$ ) and weaners ( $WPH(X_{nd})$ ). As summarised in Table 2.2, the cattle weight requirements at different production stages for the various Japanese, Korean and domestic grainfed market segments are provided in MRC (1995, p93-102). These include feeder weights after backgrounding and weaner weights before backgrounding. Market shares for the four Japanese grainfed categories are also given in MRC (1995, p57). Percentages of Japanese and Korean components in the total export of grainfed beef are from the data provided by AFFA (K. Wade, AFFA, per. comm. 1998). Based on this information, a spreadsheet was established to derive the average per head weights for grainfed export and domestic cattle at feeder and weaner levels for each year of 1992-1997. The derivation for the 1992-1997 average figures is outlined in Table A2.2. The mid-points of the weight ranges for various market segments are weighted by their market shares to derive the average feeder and weaner weights per head for export and domestic markets.

**Table A2.1 Derivation of Average Slaughtering Weights for Various Market Segments**

	<b>Cattle Number</b> (‘000 heads)	<b>Total Carcass Weights</b> (kt c.w.)	<b>WPH(Weight Per Head)</b> (kg c.w.)	<b>WPH(Weight Per Head)</b> (kg l.w.)
<b>y<sub>nd</sub>(feedlot)</b>	390*	81.9***	210**	382***
<b>y<sub>sd</sub>(suppl.)</b>	811*	170.3***	210**	382***
<b>y<sub>nd</sub>(feedlot) + y<sub>sd</sub>(suppl.)</b>	1201*	252.2*	210***	382***
<b>y<sub>sd</sub>(grass)</b>	2419*	425*	176***	320***
<b>y<sub>ne</sub></b>	782*	260*	332***	604***
<b>y<sub>se</sub></b>	3842*	881.5*	229***	416***
<b>y</b>	8244*	1818*	221***	402***
<b>Y<sub>s</sub> = y<sub>sd</sub>(grass) + y<sub>sd</sub>(suppl.) + y<sub>se</sub></b>	7072***	1476.8***	209***	380***
<b>Y<sub>n</sub> = y<sub>nd</sub>(feedlot) + y<sub>ne</sub></b>	1172***	341.9***	292***	531***

\* MRC (1995);

\*\* Assuming that the feedlot finished cattle for domestic market have the same average slaughtering weight as the grain supplemented cattle for domestic market;

\*\*\* Derived from data in (.)<sup>\*</sup> and (.)<sup>\*\*</sup>.

### Step 10. $WPH(F_{n1e}), WPH(F_{n1d}), N_{ne}$ and $N_{nd} \Rightarrow F_{n1e}$ and $F_{n1d}$

The feeder quantities for export and domestic markets are calculated as

$$F_{n1e} = (WPH(F_{n1e}))(N_{ne}) \text{ and } F_{n1d} = (WPH(F_{n1d}))(N_{nd}).$$

### Step 11. $WPH(X_{ne}), WPH(X_{nd}), N_{ne}, N_{nd}$ and $N_s \Rightarrow X_{n1}$ and $X_{s1}$

Total weaner quantities for feedlot finishing are derived as  $X_{n1} = (WPH(X_{ne}))(N_{ne})$

+  $WPH(X_{nd})(N_{nd})$ . As discussed in Chapter 2, it is assumed in this study that the weaner cattle are not differentiated in quality regardless of whether they are for grain or grass finishing.

Thus, the average weaner weight per animal for grass-finishing is assumed as the same as that for grain-finishing. The average weight for weaners for grain-finishing is calculated as

$WPH(X_{n1}) = X_{n1}/N_n$ , and the quantity for weaners for grass-finishing is derived as

$$X_{s1} = WPH(X_{n1})(N_s).$$

**Table A2.2 Derivation of Average Feeder and Weaner Weights Per Head**

	Japan				Korean		Domestic
	B <sub>3</sub>	B <sub>2</sub>	B <sub>1</sub>	Yearling	K <sub>1</sub>	Fullset	
<b>Feeder* (kg):</b>							
weight range	380-420	400-500	400-500	290-350	250-430	330-470	330-350
mid-point	400	450	450	320	340	400	340
<b>Weaner* (kg):</b>							
weight range	250-280	210-240	190-240	170-220	150-170	160-190	170-220
mid-point	265	225	215	195	160	175	195
<b>Sub-group weights*</b>	0.18	0.37	0.34	0.11	0.5	0.5	1
<b>Weighted Average***:</b>							
feeder		426.7kg			370kg		340kg
weaner		225.5kg			167.5kg		195kg
<b>Exp. Market Shares (92-97 Av)**</b>		0.92			0.08		n/a
<b>WPH***:</b>							
feeder					<b>WPH(F<sub>nlc</sub>) = 422kg</b>		<b>WPH(F<sub>nlc</sub>) = 340kg</b>
weaner					<b>WPH(X<sub>nc</sub>) = 221kg</b>		<b>WPH(X<sub>nc</sub>) = 195kg</b>

\* MRC (1995)

\*\* AFFA (1998)

\*\*\* Derived from figures in (.)<sup>\*</sup> and (.)<sup>\*\*</sup>.**Step 12. Derivation of  $F_{n2}$** 

Feedgrain consumption  $F_{n2}$  is estimated from the “per kilogram liveweight gain feedgrain consumption” calculated from the data in a feedlot case study of the Beef CRC (Meppem 1995). In this study, the feed cost per kilogram liveweight gain for cattle on feed 150 days was \$1.02. The feed composition was 88% of feedgrain, 10% of roughage and 2% of additives, and the prices of the three components were \$150, \$110 and \$1000 per tonne respectively. From these data, the feedgrain consumption per kilogram liveweight gain was calculated as 5.51 kilograms. The annual feedgrain consumption was calculated by multiplying this amount by the total liveweight gain each year; that is,

$$F_{n2} = 5.51 * (Y_{ne} + Y_{nd} - F_{n1e} - F_{n1d}).$$

Details of the derivation is in Zhao and Griffith (2000).

## A2.2 Prices

The prices for the four types of cattle/beef at all production and marketing stages and the prices for feedgrain for the period of 1992 to 1997 are given in Zhao and Griffith (2000). The original data sources, assumptions made regarding the price relationships and the derivation of all prices are given below. The resulting average prices for all inputs and outputs for 1992-1997 are listed in Table 5.1.

### Step 1. $v_d$ , $v_{e-str}$ , $v_{e-hfr}$ and $v_{e-cow}$

The Australian Commodity Statistics (ABARE 1998) publishes annual saleyard prices for domestic yearling, export ox (301-350kg, c.w.) and export cow (201-260kg, c.w.). Another source for finished live cattle prices is The Land newspaper (NLRs 1998), which reports weekly 'over the hook' (OTH) prices for various local and export cattle categories. In particular, during 92-96, it reported the OTH prices for two domestic yearling/steer grades (140-180 and 180-220), two export steer grades (240-320 and 320-400), two export heifer grades (180-250 and 250-320) and three export cow grades (150-180, 180-220 and 220+). Since 1997, even more categories for both domestic and export markets are reported. For example, prices on cattle to specific countries such as Japan, Korea, EU and US are reported from 1997. The annual averages of these weekly prices are obtained from the National Livestock Reporting Services (A. Galea, NLRs, per. comm. 1998).

However, before November 1997, the prices reported do not differentiate between grainfed and grassfed cattle. Only since November 1997 are separate grassfed and grainfed cattle prices reported for various domestic, Korean and Japanese categories.

In order to specify the four finished cattle prices according to export/domestic and grassfed/grainfed for 1992 to 1997, the aggregated domestic prices ( $v_d$ ), export ox/steer prices ( $v_{e-str}$ ), export heifer prices ( $v_{e-hfr}$ ) and export cow prices ( $v_{e-cow}$ ) were obtained from the above sources. Then using the weekly information on separate grainfed and grassfed prices since November 1997, a grainfed price premium for each category was obtained through regressing over the weekly observations. The four required prices  $v_{ne}$ ,  $v_{se}$ ,  $v_{nd}$  and  $v_{sd}$  for the period of 1992-1997 were derived using these price premium results.

As there are inconsistencies in the NLRs reported categories for 1992-1996 and 1996-1997, the domestic finished cattle prices,  $v_d$ , were taken from the saleyard yearling prices in ABARE (Table 143, 1998). The domestic yearling saleyard prices published by ABARE (1998) were very similar to the two yearling/steer prices by NLRs (A. Galea, NLRs, per. comm. 1998).

Similarly, for consistency purposes,  $v_{e-str}$  and  $v_{e-cow}$  were taken from the export quality ox (301-350kg) and cow (201-260kg) prices in ABARE (Table 143, 1998). They were very similar to the prices in the relevant categories reported by NLRs (1998).  $v_{e-hfr}$  were taken from the export heifer (180-250kg) prices for 1992-1996 and export heifer (170-230kg) prices for 1997 from NLRs (A. Galea, NLRs, per. comm. 1998).

## Step 2. Saleyard Grainfed Price Premiums for Domestic ( $r_{Y(dom)}$ ) and Japanese ( $r_{Y(JP)}$ ) Markets

Twenty weekly OTH price observations during 1998 for grainfed and grassfed cattle for two domestic categories and two Japan categories were collected from The Land newspaper (NLRs 1998a). The grainfed prices were regressed on the relevant grassfed prices in each of the above four categories. When the intercept was allowed to be non-zero in the regressions, three out of the four regressions showed statistically insignificant intercepts, but all four categories showed very strong significance of the grassfed price variable. Thus a proportional price premium was assumed, and the regressions were run again without intercepts. Remarkably, the two local categories showed the same price parameters of 1.11 (t-values are 118 and 121 respectively) and the two Japanese grades have price parameters of 1.082 and 1.085 (t-values are 125 and 82) respectively. Therefore, 11% and 8% were assumed as the grainfed price premiums for the domestic and Japanese markets, ie.  $r_{Y(dom)}=11\%$  and  $r_{Y(JP)}=8\%$ .

## Step 3. $v_{e-str}$ , $v_{e-hfr}$ , $v_{e-cow}$ and $r_{Y(JP)} \Rightarrow v_{ne}$ and $v_{se}$

As can be seen in Table 2.1, during 1992-1997, on average 14% of the Australian export beef are grainfed. In the export grassfed category, more than one-third was to the US market. The majority of the beef to the US is low quality manufacturing beef such as cows. For example, almost all beef to the US during 1996 and 1997 was low quality frozen meat rather than chilled (AMLC 1996/97).  $v_{e-cow}$  is assumed to account for the US's share of the total grassfed export price. An average of  $v_{e-str}$  and  $v_{e-hfr}$ , denoted  $v_{e-noncow}$ , was taken as the price for export cattle excluding cows. Then using the 8% grainfed premium for the cattle to Japan, separate grainfed and grassfed export prices for export cattle excluding cows were derived from the aggregated prices  $v_{e-noncow}$ . That is,  $v_{e-noncow-grassfed} = v_{e-noncow}/(1+r_{Y(JP)}*\rho_{(n/noncow)})$  and  $v_{e-noncow-grainfed} = (1+r_{Y(JP)})(v_{e-noncow-grassfed})$ , where  $\rho_{(n/noncow)}$  is the proportion of grainfed cattle of the total export cattle excluding the US segment, and the grainfed premium  $r_{Y(JP)}=0.08$ . Note that Japan accounted for 92% of the total grainfed export for the modelled time period. Finally, the export grassfed price for finished cattle was the weighted average of  $v_{e-noncow-grassfed}$  and  $v_{e-cow}$ , ie.  $v_{se} = \rho_{(US/se)}v_{e(cow)} + (1-\rho_{(US/se)})v_{e-noncow-grassfed}$ , where  $\rho_{(US/se)}$  was the proportion of US component in the total grassfed export cattle obtained from AFFA (K. Wade, AFFA, per. comm., 1998). As cows are not part of the grainfed segment,  $v_{ne}=v_{e-noncow-grainfed}$ . Details of the derivation are in Zhao and Griffith (2000).

## Step 4. $v_d$ and $r_{Y(dom)} \Rightarrow v_{nd}$ and $v_{sd}$

Using the grainfed price premium specified in Step 2, the domestic grassfed and grainfed prices for finished cattle were calculated from the aggregated domestic price  $v_d$  as  $v_{sd}=v_d/(1+r_{Y(dom)}*\rho_{(nd/d)})$  and  $v_{nd}=(1+r_{Y(dom)})v_{sd}$ , where  $\rho_{(nd/d)}=Y_{nd}/Y_d$  is the proportion of feedlot finished cattle in the domestic market and  $r_{Y(dom)}=0.11$  is the domestic grainfed cattle premium.

## Step 5. $u_d$ , $v_d$ and $\Delta_{ud-vd} \Rightarrow u_{nd}$ and $u_{sd}$

The domestic processed beef carcass prices ( $u_d$ ) were taken from the monthly averages of the wholesale price survey data in The Australian Meat Industry Bulletin (Nielson Marketing

Research 1997a). There was no information published on separate grainfed and grassfed wholesale prices. We assumed that the costs of slaughtering and processing cattle per kilogram into beef carcass was the same for both grainfed and grassfed. This implies that the two domestic categories have the same price mark-up as the observed aggregated price difference  $\Delta_{ud-vd} = u_d - v_d / 0.55$  where  $\Delta_{ud-vd}$  is measured as per kilogram carcass weight. That is, the domestic wholesale price for grainfed carcass is  $u_{nd} = v_{nd} / 0.55 + \Delta_{ud-vd}$  and for grassfed carcass is  $u_{sd} = v_{sd} / 0.55 + \Delta_{ud-vd}$ .

**Step 6.  $v_e$  and  $\Delta_{ud-vd} \Rightarrow u_e, u_{ne}$  and  $u_{se}$**

Information on export beef carcasses is not often reported. Unlike the domestic market where the cattle are slaughtered in abattoirs and then cut and packed into retail cuts in supermarkets and local butcher shops, the cattle for export are often slaughtered, cut, boned, trimmed, processed and then packed into boxes within abattoirs. Physically the export marketing sector may be simply the boning and packing rooms in abattoirs. The model is structured with a separate export marketing sector in order to be consistent with the domestic market for the joint processing sector. As the carcass quantities for export beef are converted from live weight in the same way as for domestic beef (ie. with a 55% conversion factor), it is reasonable to assume that the cost for slaughtering and processing per kilogram of export cattle to beef carcass is the same as that of domestic cattle. Under this assumption, the export carcass prices are calculated as  $u_{ne} = v_{ne} / 0.55 + \Delta_{ud-vd}$ ,  $u_{se} = v_{se} / 0.55 + \Delta_{ud-vd}$  and  $u_e = v_e / 0.55 + \Delta_{ud-vd}$ .

**Step 7.  $p_e$  and  $\Delta_{pne-pse} \Rightarrow p_{ne}$  and  $p_{se}$**

The prices for shipped weight export beef were obtained from the unit values of Australian export beef and veal in ABARE (Table 146, 1998). The prices are reported in financial years. The calendar year prices for  $p_e$  are estimated as the averages of prices of each two adjacent financial years.

Information on separate grainfed and grassfed export shipped weight prices was not available. A price premium was estimated based on the prices in principal overseas markets reported in Table 145 in ABARE (1998). If the 'Japan boneless chilled' price in this table is taken as an export-grainfed price indicator, 'Japan boneless frozen' price as a good-quality or non-cow grassfed export price, and 'US boneless frozen' as a US cow/manufacturing beef price, the price differences between the grainfed and the two grassfed types were \$2.8 and \$2.6 per kg (f.o.b.) on average for 1992-1997. As the information only serves as a rough guide, the difference between the f.a.s. (free alongside ship) and f.o.b. (free on board) prices, ie. the loading charges, is ignored. Roughly one-third of export-grassfed beef is US manufacturing beef. Consequently a \$2.6 price premium was assumed for the export market, ie.  $\Delta_{pne-pse} = \$2.6/\text{kg}$  (shipped weight). The grainfed and grassfed prices were then calculated as  $p_{se} = p_e - 2.6 * \rho_{(ne/e)}$  and  $p_{ne} = p_{se} + 2.6$ , where  $\rho_{(ne/e)} = Y_{ne} / Y_e$  is the proportion of grainfed beef in total export. As the same quantity conversion percentages (ie. 55% and 68%) were used for both grainfed and grassfed, the grainfed proportion was the same at live, carcass and shipped weight levels.

### Step 8. $p_d$ and $\Delta_{pnd-psd} \Rightarrow p_{nd}$ and $p_{sd}$

The retail beef prices reported by ABARE (Table 144, 1998) are price averages of selected beef cuts that do not include some lower quality cuts. As discussed in Step 6 of A2.1, six major retail cuts were included in the domestic retail quantity and price calculation, which gives a domestic saleable yield percentage  $R_{(Zd/Qd)}=72\%$ . The weights for the six cuts were taken from Griffith, Green and Duff (1991); they were: 9.4% for rump steak, 15.3% for sirloin, 13.5% for top side, 19% for chuck, 15.7% for blade, and 27.1% for beef mince. The prices for these cuts were taken from the national averages of the monthly retail selling prices published in the Australian Meat Industry Bulletin (Nielsen Marketing Research 1997b). The domestic retail price  $p_d$  was calculated as the weighted average price of the six cuts.

A grainfed premium was needed in order to derive the grainfed and grassfed prices from the aggregated price  $p_d$ . Australia has no domestic grading system that could provide the information on quantity or price of grainfed beef that is sold through the retail outlets. Based on talks with people from the industry (for example, B. Gaden, NSW Agriculture, per. comm. 1998), a grainfed premium of \$2.5 per kilogram was assumed. That is  $\Delta_{pnd-psd}=\$2.5/\text{kg}(\text{retail cuts})$ .

The domestic retail grainfed and grassfed beef prices for the quantities in Step 7 of A2.1 were calculated as  $p_{sd}=p_e-2.5*\rho_{(nd/d)}$  and  $p_{nd}=p_{sd}+2.5$ .

### Step 9. $s_{n1d}$ and $s_{n1e}$

The Land newspaper (NLRS 1998b) reports the weekly feeder cattle prices in three categories: domestic feeder steers under 320kg, domestic feeder heifers under 320kg and export feeder steers over 400kg. The annual averages of these prices was obtained from NLRS (A. Galea, NLRS, per. comm. 1998). The average of the two domestic feeder prices was used as domestic feeder price  $s_{n1d}$ , and the over 400kg price as export feeder price  $s_{n1e}$ .

### Step 10. $w_1$

The Land newspaper (NLRS 1998c) also reports weekly the weaner prices in the CALM system in terms of location, weight range, average weight, whether it is for restock and the price in c/kg live weight and \$/head. As described in Step 11 of A2.1 in this Appendix, the average weight for all the weaners was 208kg live weight. Around 100 weaner price observations from the CALM report, that were for restock and had reasonable weight ranges, were chosen and entered in a spreadsheet. Average weaner prices ( $w_1$ ) was calculated for each year and then for the whole 1992-1997 period.

### Step 11. $s_{n2}$

The feed barley prices reported by ABARE (Table 45, 1998) were used as the feedgrain prices for the cattle feedlots. Barley is the preferred feed in cattle feedlots. The financial year prices of every adjacent two years were averaged to approximate the calendar year figures.

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