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The Specification, Estimation and Validation of a Quarterly Structural Econometric Model of the Australian Grazing Industries

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Contents

List of Tables

List of Figures

1. Introduction

The extensive livestock industries have historically been a major component of Australia's agricultural sector. Since 1980, livestock commodities have contributed an average 52% of the annual gross value of Australian agricultural production. The corresponding average export values have been approximately 60%, of which wool and meat contributed an average value of 35% and 25% respectively (ABARE 1998). Over the same period, the national sheep and beef cattle populations averaged 137.2 and 21.8 million head, while the total area of sown pastures was an average 28.75 million hectares.

Cyclical variation in supply and demand is a prominent feature of the Australian extensive livestock industries. Regular variations in livestock production occur because animal breeding decisions are based as much on the biological constraints associated with seasonal and pasture growth cycles as on responses to price changes. These constraints inhibit the ability of producers to adapt production plans to changing economic conditions and so they impose a strong degree of regularity in livestock production cycles (Vere, Griffith and Bootle 1993). The typically low short-term supply price elasticities for livestock products (Griffith *et al.* 2000) are evidence of the strength of such constraints. Livestock production decisions are also recursive in that current decisions reflect those of previous periods which together determine future outputs. Regularity in the livestock production cycles in turn influence the patterns of supply for livestock products throughout the year. Production is also affected by longer-term variations resulting from the attempts by producers to adjust to new production technologies and to changing industry conditions.

Irregularly occurring external events and policies also have significant impacts within and across the Australian livestock industries. Beef production has been adversely affected by periodic export price collapses and by the introduction of regulations relating to animal welfare and feedlots. Australia's beef exports have recently been threatened by issues such as pesticide contamination in feedlots, bacterial infections in Japanese meat products, and domestic over-supply in the USA. In the lamb industry, heavy supply increases in the early 1970's and 1980's due to wool industry policy resulted in prolonged low prices and proposals for the introduction of lamb price stabilisation policies. An important external event which has caused concern to lamb producers has been the introduction of the Closer Economic Relations with New Zealand policy in 1985. The pigmeat industry has a less competitive market structure because of its dominance by large, integrated production units. While this structure has provided some protection from large price fluctuations, this industry too has recently faced potentially serious threats from pork imports and exotic disease outbreaks. In the wool industry, the effects of over-supply encouraged by price support and the deregulation of the industry in early 1991 resulted in immediate and significant price falls.

The importance of all sources of cyclical variability, events and policies in determining economic activity in the Australian livestock industries emphasises the need for detailed and timely knowledge of their economic behaviour. This requirement can only be realistically met by the development of rigorous quantitative economic models of the industry's structures and operations. To this end, the economics research section of NSW Agriculture has been involved in the development and application of several econometric models of the Australian livestock industries to enable a better understanding of industry operations.

Particular attention has been given to the structural econometric type of industry model in which the supply, demand and price determination relationships are determined simultaneously. This focus follows the belief that in industries where internal variability and external factors are important, the structural model best provides a systematic basis for analysing and forecasting industry behaviour, and evaluating the industry impacts of events and policies. The models that have been constructed have mainly been estimated from quarterly data because of the typical high seasonality evident in Australian livestock production, consumption and price patterns. It is also because of the requirement for quarterly forecasts by livestock industry organisations and because those remaining policy decisions affecting the livestock industries are often made and adjusted throughout the year, particularly in import markets.

One feature of the quarterly NSW Agriculture models to date is that they have had a single industry focus (e.g., beef, lamb and pig) and have been used for analyses only within those industries. As such, it has not been possible to undertake cross-industry analyses, except in a somewhat simplistic way, by for example, including the farm and retail prices of competing products as explanatory variables in the supply and demand functions for individual products. This shortcoming has been an important constraint because the Australian livestock industries are highly competitive and feature strong joint relationships in both the supply of and the demand for livestock products. The main problem with the use of individual industry models in this context is that some of the important relationships between livestock commodities are necessarily treated as being exogenous.

For example, in explaining the retail demand for one type of meat (e.g., beef), the prices of competing meats (lamb, pork and chicken) are assumed to be exogenous. Similarly, the farm wool price is exogenous to the production system in an Australian lamb industry model since that price is principally determined in the much larger wool growing industry. In reality, both these price effects are not truly exogenous since it is known that there is a strong degree of substitution between meat products at the retail level (Piggott *et al.* 1996), hence retail prices tend to move together, and wool and sheepmeats are joint outputs from the sheep production system. The individual industry model does not have the mechanism to allow for quantity and price adjustments between the livestock industries with the result being that cross-industry issues might not able to be accurately analysed.

The development of a generalised model of the livestock industries (and the inclusion of a wool industry component) was therefore considered to be a necessary extension of this modelling research. This paper details the development of an integrated quarterly structural econometric model of the Australian grazing industries. The model's purpose is to provide an improved basis for livestock industry analyses, particularly where cross-industry issues are concerned. The model incorporates revised and updated versions of the Australian lamb model (Vere, Griffith and Bootle 1994), and expanded models of the Australian beef and pig industries that incorporate the basic structures of the Griffith and Goddard (1984) and Griffith and Gellatly (1982) models of these industries. A new addition is a model of the Australian wool and mutton industries which has been developed over the past two years.

The perceived value in constructing such a model results from the additional information that is made available to the solution of the individual model components. It is expected that linking models of individual industries would enhance the explanatory powers of each model because this allows a greater level of interaction between all the explanatory variables in determining the values of each set of endogenous variables. In integrating these models, all that is required is that the list of endogenous variables is expanded to include all those in each of the models, and that the list of behavioural equations and identities is similarly expanded.

Overall, this integrated model is based on the same modelling philosophy and processes that underlie the earlier individual industry models, as detailed in the following section. The model has a fully integrated structure in which the values of the individual industry variables are determined by interaction with those of the other industries. For two reasons, this type of model is expected to enable improved economic analyses of the operations of the Australian livestock industries to be undertaken. The first is that the simultaneous-equations methodology on which structural econometric modelling is based is well recognised as being a logical approach to estimating economic relationships where the values of two or more variables are jointly dependent within each time unit for which observations are available (Ezekiel and Fox 1967). The second is that the model's integrated structure directly enables the cross-industry effects of issues and events to be simultaneously evaluated.

An important impetus to the finalisation of this model has been the need to undertake improved economic analyses of the impacts of weeds in Australian grazing systems. Each year, weeds cause substantial economic costs to the Australian livestock industries in terms of lost production, product contamination and resource degradation. The costs of weeds in grazing systems also have socio-economic effects where many livestock producers are affected because of reduced market supplies and higher product prices.

Vere, Jones and Griffith (1997a;b) described the development of an integrated economic model for evaluating weed impacts and the benefits of improved weed management in Australian crop and livestock production systems. The completion of this model has been an initiative of the Cooperative Research Centre for Weed Management Systems (CRC) which was established in 1995 with the objective of reducing the costs of weeds in Australian agriculture. In the livestock industry context, the model has two main components. First, farm-level models establish the effects of weeds in grazing systems and the output and revenue changes from improved weed control. Second, an integrated Australian livestock industries model determines the aggregate industry equivalents of the farm-level changes. By incorporating both the production and marketing sectors of the livestock industries, this modelling system enables the impacts of weeds and the benefits of improved weed control to be accurately evaluated. The two important economic issues facing the CRC in relation to pasture weeds are the relative impacts of the target weeds and the potential benefits to producers and the livestock industries from improved weed management. The application of this modelling system provides economic information that will assist the CRC to determine the extent to which its research activities have successfully addressed these issues.

In Section 2, the general approach to structural econometric modelling is discussed in terms of the purposes of these models and the considerations on which they are based. The specifications of the individual component livestock models are detailed in Section 3 with reference to the past research which is relevant to each model's development. Section 4 contains the estimation results for each model, while the corresponding validation results are given in Section 5. The final section provides a summary of the paper and discusses some areas for the further improvement, development and application of the model.

2. Structural Econometric Modelling in the Australian Livestock Industries

Various organisations including NSW Agriculture and the Australian Bureau of Agricultural and Resource Economics (ABARE) have been involved in the development of econometric models of the industries comprising the Australian agricultural sector. In most instances, these models have been developed for specific purposes such as forecasting, production technology evaluation and policy impact assessments. For example, ABARE has used econometric models to provide a consistent basis for the annual National Outlook Conference forecasts and for the analysis of domestic and trade policy issues. Section 2.3 contains a number of examples of the issues to which the NSW Agriculture models have been applied in the livestock industries. The following two sections outline the general theory on which the construction of the structural econometric model (SEM) is based, the purposes of model construction and the philosophical considerations which have been central to NSW Agriculture's livestock sector modelling.

2.1 Modelling Purposes

The principal objective in the development of a structural econometric model (SEM) of a livestock industry is to identify the sequences of industry decision making and to quantify the relative importance of the factors that underlie them. As such, the structure of the typical SEM closely follows the microeconomic theory of equilibrium between supply and demand. After Labys and Pollak (1984, p. 38), the SEM can be considered to be "... a formal representation of a commodity market or industry where the behavioural relationships selected reflect the underlying economic laws".

The purpose of the SEM is to quantify the industry's operations by simultaneously solving a set of equations that represent the main industry variables and their linkages. This purpose indicates that the SEM seeks to explain decisions made within the industry, such as the number of animals to be bred, the quantity of meat to produce, the amount of meat to consume and the price to be paid for consumption. To capture these decisions, the model must incorporate the economic theories that describe production and consumption behaviour. The SEM is therefore a model in which the behavioural relationships are estimated empirically from actual industry data.

Because the SEM utilises actual data to quantify the industry's supply, demand and price determination processes, it provides a systematic and comprehensive method for analysing and forecasting industry behaviour (Labys and Pollak 1984). To be useful for these purposes, the model must be capable of capturing the industry's sequence of decision making which includes the inventory investment, production and marketing decisions of producers, as well as the purchasing decisions of consumers. It must also be able to accurately quantify the factors on which this decision sequence is based. Figure 1 illustrates the linkages between these industry processes. Labys (1988) stated that the main stages of a SEM's development are to determine the model's purposes, to select the appropriate model structure, to specify the industry's relationships, to estimate the model's parameters from an historical data set, and to validate and simulate the model. Griffith (1993) detailed these procedures as follows.

(i) Selecting the variables to include in the model. This procedure includes the selection of both the endogenous or internal variables which reflect the important decision points in the industry (e.g., production, consumption and prices), and the exogenous or external variables which explain how the decisions are to be made (e.g., pasture areas, weather, other prices and incomes). Endogenous variables are determined within the model by association with the exogenous variables. In this model, the values of all the endogenous variables are simultaneously determined when the model is solved. The values of the exogenous variables are not influenced by the endogenous variables within the context of the modelling system. Some variables such as weather and policy events will be truly exogenous to the system, while others such as lagged endogenous variables and competing farm and retail prices will have stronger associations with the endogenous variables.

(ii) Hypothesising relationships between the variables. This procedure concerns the formation of the relationships between each endogenous variable and the explanatory variables and perhaps, other endogenous variables, to explain how industry decisions are determined. The variables selected and the form of the relationship follow the relevant economic theories, knowledge of the industry structure, and institutional factors and policies. Of particular concern are the patterns of causality between the selected variables and whether these patterns are lagged or simultaneous. The hypotheses relate to the level of explanation provided by each explanatory variable, the direction of impact (+ or -) on the dependent variable, and the particular form of the hypothesised relationship.

Figure 1: Variables and Linkages in a Livestock Industry Model

(iii) Combining the individual economic relationships into the model. This procedure requires knowledge of the industry and the economic theory of price determination to link the individual behavioural relationships into the industry model. In most instances, the characteristics of the industry are such that price is determined by balancing supply (the aggregate of production, imports and opening stocks) and demand (the aggregate of domestic consumption, exports and closing stocks). There is a range of options for specifying the price determination process in agricultural industries that may have to be compared to ascertain the most appropriate specification for individual models (Vere and Griffith 1995b).

(iv) Statistically estimating the model from actual industry data. This procedure involves the collation of actual data on prices and quantities that best reflect the variables defined in ***(i)***, and utilising econometric methods on these data to transform the theoretical model into an empirical model. This transformation process is mainly based on statistical tests on the individual equations, while another factor that may have an influence is the availability and reliability of actual data which correctly measures the economic variables.

(v) Validating the model. This procedure involves testing whether the estimated model is a valid representation of the actual process, which has generated the values of the endogenous variables. It is based on statistical tests of the behaviour of the complete model once all the individual equations are linked together. If the model does not validate in an acceptable manner, weak components can be identified and refined and the validation process repeated. It is only when the developed model is rigorously tested, and found to be an accurate representation of the industry, that it can be confidently used for industry analysis. Model validation is probably the most important component of the development and testing procedure.

Following this process, a validated SEM can then be applied in three major areas of livestock industry analysis, i.e., in testing hypotheses concerning industry behaviour, in forecasting future values of industry variables and in evaluating the industry impacts of policies or of exogenous events such as droughts and technology adoption.

2.2 Modelling Philosophy

The modelling philosophy on which this integrated livestock industry model was constructed embraces two aspects of cyclical behaviour in the Australian livestock industries. The first recognises the regular cyclical variations of different frequencies that determine economic activity in an industry. These mainly concern changes in seasonal conditions that influence pasture growth and livestock breeding patterns. However, they also relate to the demand by consumers for different forms of livestock products throughout the year. Therefore, the biology of animal production systems and the preferences of consumers combine to induce seasonal patterns in livestock production, consumption and prices within the industry. There may be some longer-term cyclical activity that reflects the time taken to change enterprises on mixed farms such as from wool to lambs or from wheat to lambs. Given the pervasive nature of seasonality in the Australian livestock industries, empirical behavioural models such as the SEM are required to measure this behaviour for efficient industry analysis.

The second aspect is that in spite of the seasonality inherent in livestock production systems and consumer preferences, livestock producers and meat consumers will continue to respond reasonably predictably to economic changes based on the theory that governs their activities. Thus the regular effects of the seasonal patterns tend to be disrupted to some extent by events and changes in the set of external factors which influence the livestock industries. It is now well established that these factors do exert major influences on economic activity. For example, at the lamb consumption level, changes in the retail prices of competing meats (beef, pork and chicken) and changes in the income levels of consumers all combine to influence the demand for lamb (Fisher 1979; Vere and Griffith 1988). At the lamb production level, changes in the returns from wool and wheat influence decisions about the numbers of ewes mated to British breed rams. Changes in pasture quality also influence the length of time that lambs are on farm and their weights and fat scores (Freebairn 1973; Vere and Griffith 1988). Again, the SEM is an appropriate mechanism for incorporating the effects of seasonal changes in a livestock industry model.

An additional consideration follows the proposal of Jarvis (1974) that livestock are similar to capital goods that are retained by producers whilst ever their productive value exceeds their slaughter value. This proposition holds that livestock classes cannot be treated homogeneously in econometric models. Animals of different ages, sex and breeding abilities will have different economic functions and producers will make different economic decisions concerning their use. Productive values will thus be affected differently by exogenous shocks to the production system.

The main implication of the Jarvis proposition for the development of an econometric model is that livestock need to be disaggregated as far as possible to enable a better understanding of the decisions of livestock producers. However, Kaine-Jones (1988) has noted that the availability of such disaggregated livestock data is usually limited.

The livestock industries also appear to be basically competitive in their marketing and pricing structures. Zhao, Griffith and Mullen (1996; 1998) found that the lamb and beef industries had competitive pricing patterns in the domestic market, the beef industry was non-competitive in the export market and the pig industry was also non-competitive. Griffith (2000) found all Australian domestic meat markets to be competitive. So although concern about the lack of competition in meat pricing and processing has been the subject of a large number of inquiries by government and industry groups over the last 25 years, that concern now appears to have abated somewhat. Given these developments, a competitive market structure is assumed in the model specifications that are detailed below.

Another characteristic of these livestock industries is the importance of export markets. Beef and mutton exports averaged more than 60% of total production over the 1990's, while the proportion of wool exported exceeded 90%. The export markets for lamb and pigmeat are now much more important than they previously have been. Given these industry characteristics, a particular focus of the present modelling research has been to explain export demand in the major markets for the various products, and to account for the nature of the price transmission process which links together domestic and international trade price formation.

Therefore in industries where external factors are important, including those factors mentioned above, models specifically designed to incorporate the industry's economic fundamentals and the influence of the outside factors are required to explain how past economic decisions were made and to predict into the future. The expectation is that an economic model of an industry, which has been estimated and validated using historical data, will provide a sound basis for industry analysis. Since all of the major Australian livestock industries are influenced significantly by events in the external economic environment, there has been a large investment made by research organisations in constructing economic models which attempt to explain industry behaviour. The modelling research undertaken by NSW Agriculture and ABARE are examples of this investment. Because underlying industry structures tend to change over time, the models need to be regularly updated and re-estimated and re-validated so that the most recent expression of these economic relationships can be used for analysis. These views underlie this philosophy as to how improved analyses can be undertaken in Australian livestock industries.

The SEM's of the Australian livestock industries that have formed the basis of this integrated model closely conformed to these objectives and requirements. The modelling purpose has been to quantify the operations of the individual industries through the solution of sets of equations that represent the major variables in the supply, demand and price formation processes and their linkages within and across the industries. The models' outputs are (i), estimates of the behavioural equations and elasticities as indications of the responsiveness of the endogenous variables to changes in the levels of their determinants, and (ii), the validation process which simulates the values of each of the endogenous variables over the estimation sample period and compares each of the predicted series with the actual data. Where the diagnostic criteria are satisfied, the model can be considered to be an accurate representation of the industry's operations in that it can reproduce the actual history of the industry, given that the model's estimation sample period represents the normal flow of events affecting the industry.

2.3 Previous Research

The livestock industry modelling research undertaken by NSW Agriculture previously has resulted in the development of a set of models that have been applied in the analysis of a range of industry issues. This model inventory includes quarterly models of the Australian lamb industry (Griffith, Vere and Findlay 1986; Vere *et al.* 1994), the Australian beef industry (Griffith and Goddard 1984), and the Australian pig industry (Griffith and Gellatly 1982). State-level models of the New South Wales lamb industry (Vere and Griffith 1988) and pig industry (Griffith 1993) have also been constructed. Griffith and Goddard (1984) developed a quarterly model of the Australian beef industry, while the development of an annual model of the Australian dairy industry has been detailed in Griffith, Lattimore and Robertson (1993). Some examples of the applications of these models are in forecasting, in production technology evaluation and in policy impact assessments in the lamb and beef industries (Vere and Griffith 1990; 1991; 1995a;b; Farquharson and Griffith 1991; Griffith and Kaine-Jones 1987a;b; Griffith, Vere and Bootle 1995; Griffith and Vere 2000). They have also been applied in assessing the potential effects of exotic diseases and pigmeat imports on the Australian pig industry (Griffith 1988; 1993), and of domestic dairy policies on international trade (Griffith *et al.* 1993). As previously indicated, the models have been most recently used in evaluating the economic impacts of pasture weeds in Australian grazing systems (Vere *et al.* 1997a;b; Jones and Vere 1998).

The Australian and New South Wales lamb industries have been a particular focus of the authors' research because it had received little modelling attention relative to the beef and pig industries. There had also been a demand from the lamb industry for economic information on issues such as price stabilisation, production forecasting and production technology assessment. The second and third issues were researched under grants from the Meat Research Corporation between 1989 and 1992 (Vere, Griffith and O'Halloran 1992; Vere, Bootle and Griffith 1992).

Two important issues were addressed in the development of the Australian lamb industry model which have been instrumental in the development of the integrated model. The first was in modelling the biological constraints and lags associated with the breeding ewe inventories. The second issue was in investigating the process of farm lamb price determination and in evaluating how it influenced the model's ability to forecast farm prices. These specificational procedures and their results are briefly revisited here because they were central considerations in the development of the lamb models and thus have implications for the subsequent development of this integrated industry model.

Modelling the lamb breeding inventories

Because the breeding inventory represents the lamb industry's production capacity, production decisions must first involve decisions regarding breeding ewe matings intentions. This means that current decisions to breed must incorporate past decisions and these together influence future production. The latter decisions partly determine lamb slaughterings, which with average lamb slaughter weight determine lamb production.

The conventional procedure for specifying breeding inventory relationships in livestock models is to treat the inventory system as a set of identities, with some of the components of these identities being explained by behavioural equations. For example, the closing stock of a certain class of livestock is usually defined to be the opening stock of this class, minus slaughterings and deaths of this class, plus additions to this class. For livestock types in aggregate (pigs, sheep and cattle), such identities can be constructed since data are available on total numbers and total slaughterings, and natural increase variables can be calculated. Further, for cattle, inventory identities for different classes can be constructed because slaughterings and numbers data are available for each of the various classes of cattle (Reeves *et al.* 1980; Griffith and Goddard 1984).

However, for sheep and pigs, slaughterings data are not available separately for breeding stock, so breeding inventories cannot be defined. Thus, recognition that decisions to alter output must first involve decisions to change the level of breeding stock requires that these breeding inventories have to be estimated as a set of behavioural equations. Lamb breeding inventories are usually specified as functions of the opening inventory of breeding ewes with a predetermined lag, farm prices for lamb and other products, the area and quality of pastures and seasonal conditions. It is well established that livestock breeding decisions in extensive production systems are largely unresponsive to changes in lagged farm prices (e.g., Freebairn 1973; Fisher and Munro 1983; Griffith *et al.* 2000), and this is particularly so with lamb (Vere *et al.* 1993). The low supply price elasticities for lamb emphasise the importance of breeding constraints in lamb supply response, and the need for their explicit incorporation into the lamb industry model.

In their model of the New South Wales lamb industry, Vere and Griffith (1988) made three adjustments to Freebairn's (1973) definition of lamb production capacity as being the opening inventory of intended ewe matings to British breed rams. The first adjustment was to disaggregate this inventory into the three main ram types (short wool, long wool and Corriedales and Polwarths) because it was found that supply response differed for each category (Reynolds and Gardiner 1980) and the distribution of these breeds varied considerably around Australia. This distinction is a surprising omission in the Kaine-Jones (1988) sheep industry supply response model since sheep breeding intentions data on a disaggregated basis have long been available through the Australia Bureau of Statistics (ABS).

The second adjustment allocated the progeny proportions contributed by the individual ram breeds to overall lamb production. This was incorporated into a third adjustment to reflect the time lags between breeding decisions and lamb output, as well as the important differences in these lags between the ram breeds. Together, these adjustments enabled the definition of the ewe breeding inventory-lamb production capacity variable. An additional adjustment had to be made to derive a quarterly series for this variable because the breeding data are collected annually each March 31st and so it was necessary to ensure that the quarterly allocation of breeding intentions equals the March 31st estimate. In the New South Wales model (Vere and Griffith 1988), these adjustments significantly improved the model's simulation and validation, and so these procedures were followed closely in the development of the Australian lamb industry model.

Modelling the farm price determination process

The form of the farm price determination process is also an important issue in model specification. Other econometric studies into the operations of various agricultural industries have utilised different mechanisms for determining the price equilibrium conditions. A common approach has been to estimate relationships for production, consumption and stock behaviour and then to determine prices by balancing supply and demand (Labys and Pollak 1984). This specification is considered to be appropriate in industries in which stocks are important (such as grains) and hence, in which stock changes readily affect prices. In a prominent departure from this traditional specification, Heien (1977) considered that the focus on stocks behaviour reduced the model's ability to accurately determine prices because the residual nature of the stocks variable made its equation also liable to measurement error, as were the resulting prices. Heien proposed price dependent demand in lieu of the market balance specification because the supplies of most farm products were largely predetermined and the remaining quantity variation either came from stocks or demand. Other mechanisms such as excess demand, retail price transmission and price dependent production have also been used to determine farm prices (Vere and Griffith 1995b). All of these alternatives are consistent with the underlying assumption of a competitive market structure.

However, none of this research had empirically examined the effects of alternate price determination specifications on a SEM's validation performance. This is an important issue in model specification since a model's value for industry analysis is determined by the quality of its validation results. In applications such as price forecasting, attempts to improve a model's price forecast accuracy first requires improvement to be made in the specification of the price mechanism (Popkin 1975). Vere and Griffith (1995b) examined the effects of five price determination options on the ability of their Australian lamb industry model to simulate and then forecast farm lamb prices. The options were the traditional market balance, retail price dependent demand, retail price transmission, excess demand and the traditional market balance with an exogenous price spread. The results of these experiments highlighted the influence of the farm price determination specification on the model's simulation performance, with the final option being preferred.

ABARE has also pursued an active research program in structural livestock industry modelling. Much of this research was undertaken in the 1970's and 1980's with a focus on the Australian beef industry and its export trade, and on the supply side of the Australian sheep industry. Examples of this research are found in Longmire and Main (1978); Reynolds and Gardiner (1980); Reeves, Longmire and Reynolds (1980); Longmire, Main and Reynolds (1980), and Reeves and Longmire (1982). These models then formed the basis of the Econometric Model of Australian Broadacre Agriculture (EMABA) which became the main quantitative mechanism used by ABARE for policy evaluation and forecasting in Australia's broadacre agricultural industries.

The motivation for the development of the EMABA model "arose from a need to acknowledge explicitly in broadacre policy and forecasting work the important simultaneous interactions between broadacre activities" (Dewbre, *et al.* 1985a, p. 4). EMABA's structure was also largely based on the general principles discussed in Section 2.1. The documented version of the model (in 1985) contained 225 equations and therefore embodied the same number of endogenous variables to represent annual demand, supply and price determination in the three main broadacre agricultural sectors, cattle (beef and dairy), sheep and crops. The model was strongly orientated to the livestock industries and to the export demand for Australian livestock products in particular. It was estimated from annual data over the relatively short sample period 1961-62 to 1981-82.

2.4 General Modelling Procedures

Each of the models described in the following section has a similar structure that incorporates the same general specificational procedures. That is, the initial focus is on the breeding inventory (a synonymous term to breeding intentions) specification because the entire industry process which involves the supply and demand for livestock products is initiated by producers' breeding decisions. As discussed in Section 2.3, the decision to breed livestock is itself a complicated process which is constrained by both biological and economic influences. Time lags between breeding decisions and outputs are the result of these influences and they vary between the different types of livestock in terms of the time required for mating, gestation and the finishing of young animals. These considerations emphasise the importance of the accuracy of the breeding inventory specification in the representation of the remaining components of the model, and in the complete model's simulation performance (Vere *et al.* 1993). The values of the inventory elasticities of supply in the estimated equations (i.e., slaughterings) are an indication of this importance.

Hence, each model is based on a block-recursive simultaneous system starting with a breeding inventory block which recursively enters the simultaneously determined production, demand and price blocks. Since the breeding inventories of intended matings are determined solely by past values of the explanatory variables, the breeding block enters the production block with a lag. This and the demand and price blocks are jointly determined by current period values of the endogenous variables (Figure 2 illustrates this general structure). While this base recursive structure is common to each model, there are some notable differences, particularly in the beef and the sheep and wool industry models where the export components are most important.

3. Specification of the Integrated Model

Descriptions of the structures of the models that are incorporated in the integrated grazing industry model are given in this section. All variable names, definitions and sources are given in Appendix A.

3.1 Specification of the Australian Beef Industry Model

In the mid-1980's, Griffith and Goddard (1984) noted that there had been little structural modelling in the Australian beef industry. Prior to then, Throsby (1974) had developed the first quarterly Australian beef industry model with equations explaining the beef cattle breeding inventory, production, domestic and export demand, and farm and retail prices. This model was considered to have important conceptual and statistical problems, which limited its value for industry analysis (Griffith and Goddard 1984). The quarterly Australian beef model of Longmire and Main (1978), represented a major improvement on Throsby's model, but it too had shortcomings. A later annual version of this model was considered to be more theoretically sound (Reeves *et al.* 1980), but there was little published evidence of its validation performance or its applications to industry issues.

Goddard, Martin and Griffith (1980) estimated a nine-equation quarterly SEM of the Australian beef industry, which emphasised Australia's trade with North America. The model contained seven equations explaining cattle breeding inventories, beef production, per capita consumption, farm beef prices, exports to North America and imports of Australian beef into both Canada and the USA. Identities determined exports to other destinations, and the Australian beef export price as the equality of the export supply to and the import demand by North America. This model produced reasonably sound estimates that were adequately reproduced under a dynamic simulation. Further refinements of this model were reported in Griffith and Goddard (1984). The later model comprised five blocks for the beef cattle breeding inventory, beef production, domestic demand, export demand and price formation.

The current beef industry model retains the base structure of the Griffith and Goddard model. Table 1 contains the current model's specification details, while Figure 2 illustrates the model's flow structure. In the inventory block, demographic identities determine the closing inventories of female cattle (heifers and cows), male cattle (steers and bulls) and young cattle (vealers and calves). Unlike the situation for sheep and pigs, these inventories can in principle, be specified exactly because of the availability of slaughter data for all cattle types. Values for the closing inventories are calculated from a system of identities based on the annual ABS records and the biological characteristics of the beef production process. For each cattle type, the closing inventories are defined to be the previous period's closing inventory, plus additions, less slaughterings and deaths (equations 1.1, 1.2, 1.3). For the vealer and calf inventory, the levels of promotion of young cattle to the two adult classes are also subtracted. A further identity defines the quarterly number of calves born as being an estimated proportion of the cow and heifer inventory lagged three quarters (equation 1.4). As will be discussed later, there are substantial problems with the ABS data on calf births and inventories (Dewbre *et al.* 1985b, pp. 5-7). In this model, variables representing calf promotions to the adult herd and the calving ratio (designated as CPROM and CRAT) are estimated to ensure the inventory identities balance.

Slaughterings equations for each of the three cattle types are specified behaviourally in the production block. The separate equations for the slaughter of cows and heifers, steers and bulls and vealers are given as functions of their closing inventories in the previous period, farm prices for beef and wool and seasonal conditions (equations 1.5, 1.6, 1.7). Lagged dependent variables are also included as partial adjustment mechanisms to account for the discrepancy between the actual and desired slaughterings levels due to the influence of feed and management constraints. The average slaughter weights of adult cattle and vealers are determined endogenously (equations 1.8, 1.9), while overall beef and veal production is determined by an identity comprising average slaughter weight and slaughter numbers (equation 1.10).

The domestic demand block contains an equation for the per capita consumption of beef and veal which is determined by the own retail beef price, those for other meats and income levels (equation 1.11). An identity defines the total domestic demand for beef as being the product of per capita beef consumption and the Australian population (equation 1.12). The main difference in the specification of this and the previous beef models relates to the export demand block. While this model retains the same domestic supply and demand and export market structure as the Griffith and Goddard model, it now includes a section for the Australian-Japanese beef trade. Australia's beef exports to Japan have grown substantially over the last 20 years, from an average 8% of annual total

Table 1: Specification of the Australian Beef Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Inventory	INCHAU	cow and heifer inventory	1.1 (identity)	0.975 * INCHAU(-1) + (CPROM/2) * INVLAU(-1) – SLCHAU
	INSBAU	steers and bulls inventory	1.2 (identity)	0.975 * INSBAU(-1) + (CPROM/2) * INVLAU(-1) – SLSBAU
	INVLAU	vealer inventory	1.3 (identity)	NOB - SLVLAU + (0.975 – CPROM) * INVLAU(-1)
	NOB	calves born	1.4 (identity)	CRAT * INCHAU(-3)
Production	SLCHAU	cow and heifer slaughter	1.5 (OLS)	INCHAU(-1), SLCHAU(-1), PIAU(-1)
	SLSBAU	steer and bull slaughter	1.6 (OLS)	INSBAU(-1), PABFAU(-1), SLSBAU(-1), DUM74
	SLVLAU	vealer slaughter	1.7 (2SLS)	INVLAU(-1), PABFAU, PIAU, SLVLAU(-1)
	WTBFAU	average beef slaughter weight	1.8 (OLS)	PIAU, TIME65
	WTVLAU	average vealer slaughter weight	1.9 (OLS)	PIAU, TIME65
	PRODBF	beef and veal production	1.10 (identity)	(WTVLAU * SLVLAU) + WTBFAU * (SLSBAU + SLCHAU)
Demand	DCBFAU	per capita beef consumption	1.11 (2SLS)	PRBFAU, PRPKAU, PRLBAU, YPCAU, DUM74, TIME65
	DMBFAU	total beef demand	1.12 (identity)	DCBFAU * POPNAU
Export	EXBEEF	total Australian beef exports	1.13 (identity)	(PDBFAU + STBFAU(-1) – DMBFAU - STBFAU)/1.5
	USBIMP	total US beef imports; (a) no quota; (b) quota	1.14 (OLS)	(a) UPRATIO, YPCUS, STBFUS(-1) (b) USREG
	EXBFAUS	Australian beef exports to US; (a) no quota; (b) quota	1.15 (2SLS)	(a) USBIMP, PRATIO (b) USRESG, PRATIO(-1)

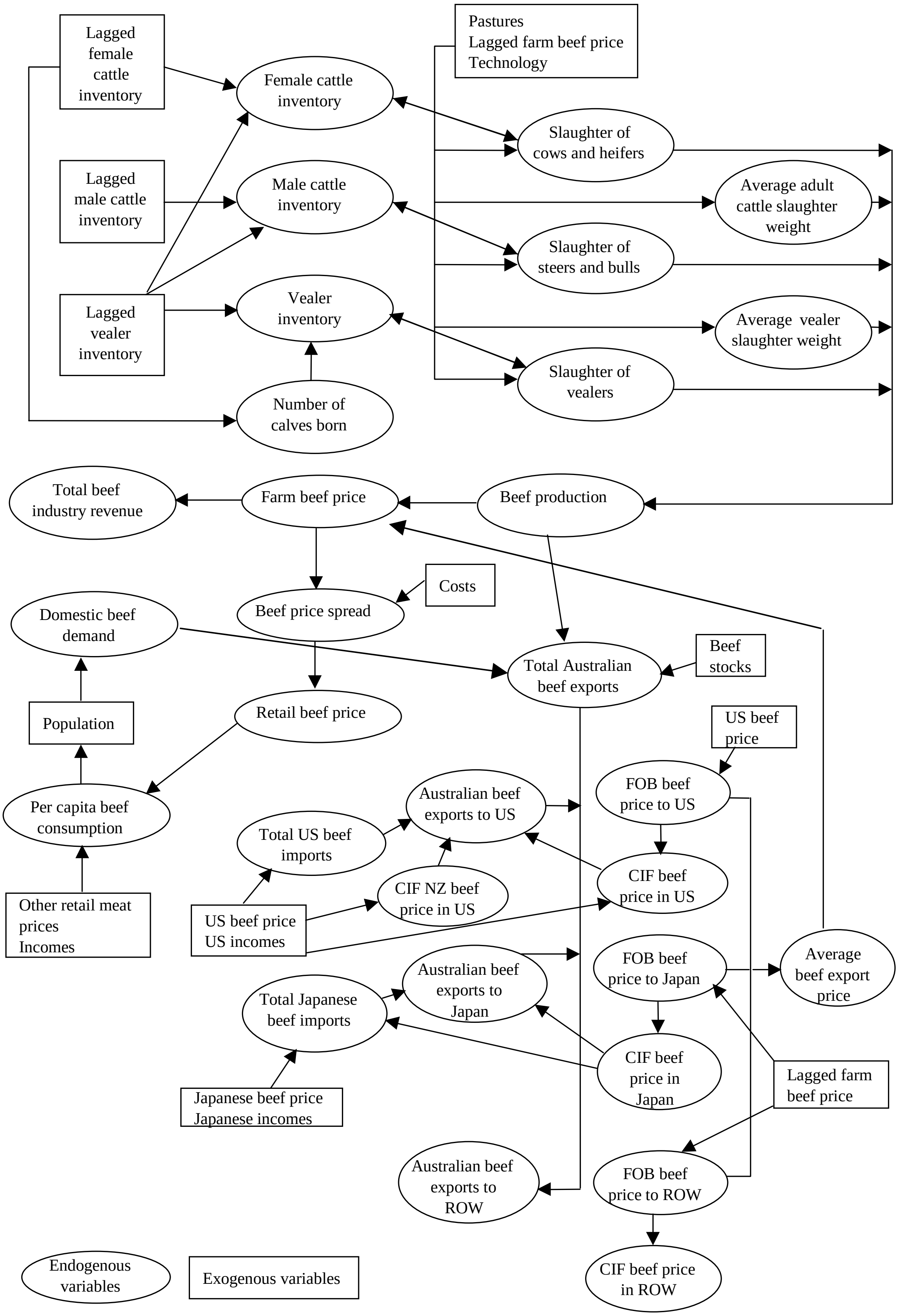
[a] constant term and seasonal dummy variables omitted.

Table 1 cont: Specification of the Australian Beef Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Export (cont.)	IMBFJAP	total Japanese beef imports	1.16 (OLS)	PB2JAP, YPCJAP, STKBFJP(-1)
	EXBFAJP	Australian beef exports to Japan	1.17 (2SLS)	IMBFJAP, PXBJPCF, DUM74
	EXBFROW	Australian beef exports to ROW	1.18 (identity)	EXBEEF – EXBFAUS – EXBFAJP
Price and revenue	PABFAU	farm beef price	1.19 (2SLS)	PREXBF, PDBFAU, PABFAU(-1), DUM74
	PRBFAU	retail beef price	1.20 (identity)	PABFAU + MMBFAU
	MMBFAU	beef price spread	1.21 (OLS)	PABFAU(-1), WAGEAU
	PREXBF	Australian beef export price in all markets	1.22 (identity)	(PXBFAUS * EXBFAUS + PXBFAJP * EXBFAJP + PXBFROW * EXBFROW) /EXBEEF
	PXBUSCF	CIF price of Australian beef in US; (a) no quota; (b) quota	1.23 (OLS)	(a) PWBFUS (b) PWBFUS
	PXBFAUS	FOB price of Australian beef in US	1.24 (identity)	(1 - 0.033) * (PXBUSCF/XRUSAU) * (CPIUS/CPIAUN) – FRBFAU
	PXBJPCF	CIF price of Australian beef in Japan	1.25 (identity)	(((1 + 0.033) * (PXBFAJP) + FRBFAJP) * XRAUJAP)) * (CPIAUN/CPIJAP)
	PXBFAJP	FOB price of Australian beef in Japan	1.26 (OLS)	PABFAU(-1), PXBFAJP(-1), DUM74
	PXBRWCF	CIF price of Australian beef to ROW	1.27 (identity)	(((1 + 0.033) * (PXBFROW) + FRBFAU) * XRUSAU)) * (CPIAUN/CPIUS)
	PXBFROW	FOB price of Australian beef to ROW	1.28 (OLS)	PABFAU(-1), PXBFROW(-1), DUM74
	USPNZ	CIF New Zealand beef price in US; (a) no quota; (b) quota	1.29 (OLS)	(a) PWBFUS (b) – $\triangle$ PWBFUS
	TRBFAU	beef industry revenue	1.30 (identity)	PDBFAU * PABFAU

[a] constant term and seasonal dummy variables omitted.

Figure 2: Structural Diagram of the Australian Beef Industry



exports over the 1970's, to 21% over the 1980's. Since 1990, Japan has accounted for an average 31% of Australia's beef exports.

Total beef exports are separated into trade with the USA, Japan and the rest of the world (ROW). This variable is derived from a market balance identity (equation 1.13), while exports of beef to the USA are determined as Australia's share of total US beef imports. Separate policy regimes are specified for when the US meat import legislation was and was not effective. Aggregate US beef imports from all sources are specified to be a function of US income levels and the US price and stocks of manufacturing grade beef (equation 1.14). This specification holds when the import legislation was not effective, while the negotiated restraint level provides the upper limit to total US beef imports when the quota was effective. US imports of Australian beef (equation 1.15) are determined by total US beef imports, and the relative prices of Australian and New Zealand beef which is Australia's closest competitor in the USA. Again, the negotiated restraint level becomes effective when the quota was on, while the variable explaining total US beef imports is used when the quota was off. Also, during the effective quota period, the US beef stocks level is included as a measure of US supply, and hence, the extent to which actual imports approached the restraint level.

The Japanese beef trade is represented by an equation for total Japanese imports of beef from all sources (equation 1.16) which are determined by the Japanese domestic retail beef price, Japanese income and personal expenditure levels and the opening Japanese stocks of beef. Japanese imports of Australian beef (equation 1.17) are determined by total beef imports, the ratio of the Australian and US beef prices in Japan and a dummy variable for the suspension of the Australian-Japanese beef trade in 1974:4. An identity gives exports to the ROW as being total exports less Australian beef exports to the USA and Japan (equation 1.18).

In the model's price formation process, the central price is an average free-on-board (FOB) export price for Australian beef. This is defined as being the weighted average of the FOB export prices to the USA, Japan and the ROW, weighted according to the quantities of beef exported to these broad market sectors (equation 1.22). This is because prices in other regions, principally in the USA, combine to determine the FOB price and it in turn determines prices in the Australian market. The cost-insurance-freight (CIF) equivalents of the FOB prices are also calculated because these prices are important determinants of the demand for Australian beef in the major export markets.

Each of the CIF and FOB export prices for Australian beef in the USA, Japan and the ROW are endogenous variables in the model (equations 1.23, 1.24, 1.25, 1.26, 1.27, 1.28), where the FOB prices are defined as being the CIF prices adjusted for relative exchange and freight rates. Because of New Zealand's importance as a competitor to Australia's beef trade in the USA, the New Zealand CIF beef export price in the USA in the quota and non-quota periods is specified to be a function of the US manufacturing beef price (equation 1.29). No account is taken of New Zealand's beef trade with Japan. In this version of the model, the US and Japanese domestic beef prices are exogenous variables.

The Australian saleyard beef price is specified to be a function of the weighted average FOB export price and current period beef production (equation 1.19). The domestic price spread for beef is given as a function of the costs of providing market services (wages), production as a throughput measure, current and lagged prices as test of price levelling behaviour, and a time trend to reflect the introduction of cost-saving technology in beef processing (equation 1.21). Retail beef prices are determined by the addition of the farm price to the price spread (equation 1.20). With the inclusion of an identity defining total beef industry revenue (equation 1.30), this model has 30 endogenous variables.

3.2 Specification of the Australian Lamb Industry Model

Griffith and Vere (1981) developed the first complete quarterly SEM of the Australian lamb industry. Previous models had concerned either lamb supply or demand, and there had been no attempts to link both sides of the industry, e.g., in the sheep supply response models of Reynolds and Gardiner (1980) and Kaine-Jones (1988), or in Fisher's (1979) analysis of retail meat demand. There had also been a tendency to consider lamb as a minor component of the broader sheep and wool industry or retail meat market rather than as a separate entity in itself. As a result, the quantitative aspects of the lamb industry's operations and performance had been inadequately analysed. The Griffith and Vere model and the later versions reported in Griffith, Findlay and Vere (1986) and Vere *et al.* (1994) remain the only complete SEM's which incorporate both the supply and demand sides of the Australian lamb industry.

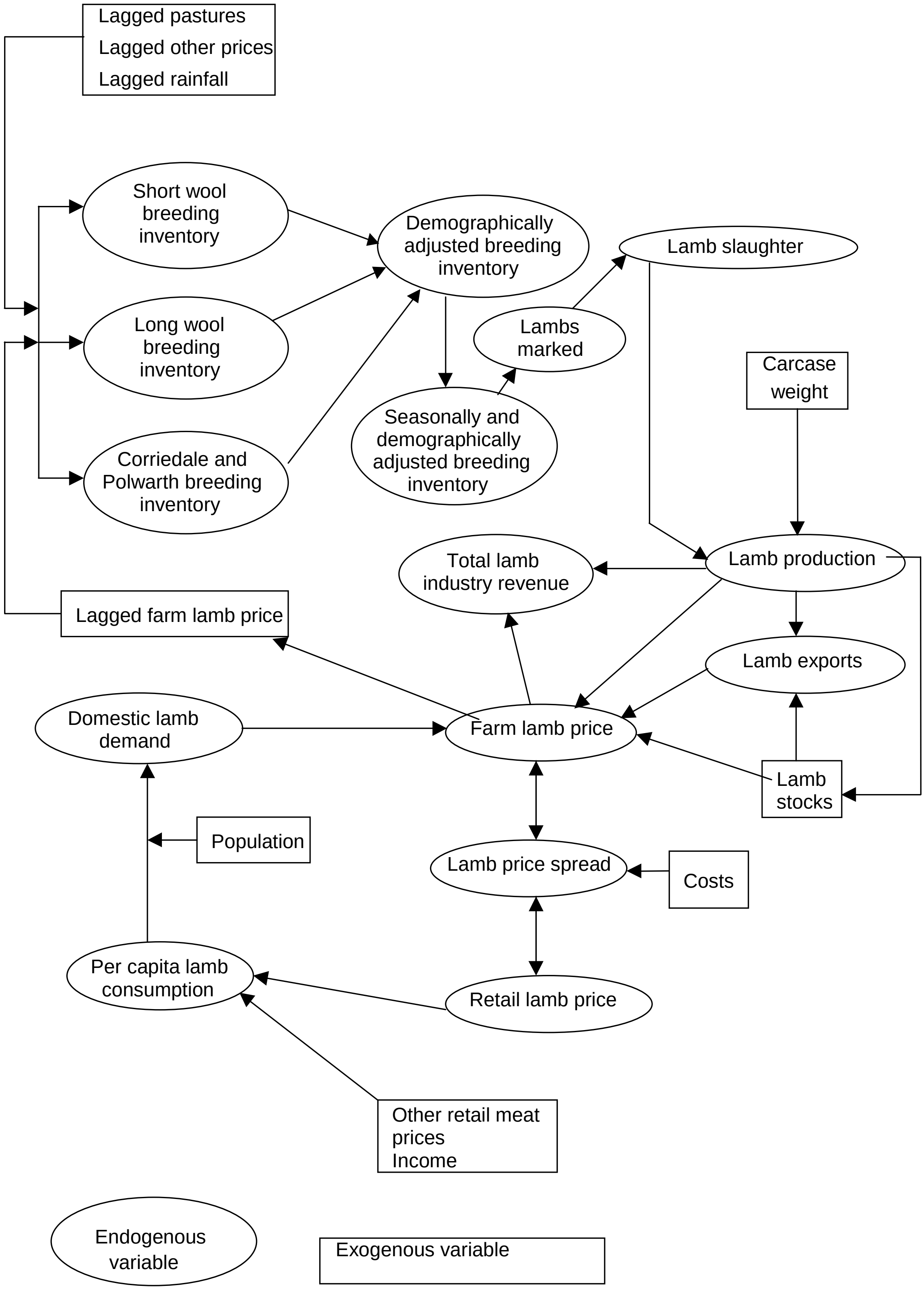
Details of the specification, estimation and validation of this model are given in Vere *et al.* (1994) and are retained in this integrated SEM (Table 2; Figure 3). The model contains 15 endogenous variables that are represented by eight behavioural and seven definitional equations. The breeding block contains behavioural equations for producers' intentions to mate ewes to short wool (equation 2.1), long wool (equation 2.2) and Corriedale and Polwarth rams (equation 2.3), the number of lambs marked (equation 2.6), and two identities that represent two adjusted production

Table 2: Specification of the Australian Lamb Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Inventory	INSWAU	short wool breeding ewe inventory	2.1 (OLS)	INSWAU(-4), PALBAU(-4)/PGWOOL(-4), PALBAU(-4)/PGWHAU(-4), DMDT(-4)
	INLWAU	long wool breeding ewe inventory	2.2 (OLS)	INLWAU(-4), PALBAU(-4)/PGWOOL(-4), PALBAU(-4)/PGWHAU(-4)
	INCPAU	Corriedale and Polwarth breeding ewe inventory	2.3 (OLS)	INCPAU(-4), PALBAU(-4)/PGWOOL(-4), PALBAU(-4)/PGWHAU(-4), DMDT(-4)
	AUSBI	demographically adjusted inventory	2.4 (identity)	δ^{SW} INSWAU + δ^{LW} INLWAU + δ^{CP} INCPAU + 1-δ^{LW} INLWAU(-8) + 1-δ^{CP} INCPAU(-8)
	AUSBX	AUSBI with seasonal adjustment	2.5 (identity)	(AUSBX(-1) + AUSBX(-2) + AUSBX(-3) + AUSBX(-4))/4
	LAMBMK	lambs marked	2.6 (2SLS)	AUSBI, PIAU, LAMBMK(-1)
Production	SLLBAU	lamb slaughter	2.7 (OLS)	LAMBMK(-1), SLLBAU(-4)
	PDLBAU	lamb production	2.8 (identity)	SLLBAU * WTLBAU
Demand	DCLBAU	per capita lamb consumption	2.9 (2SLS)	PRLBAU, PRPKAU, PRBFAU, PRCHAU, YPCAU, DUM74
	DMLBAU	total lamb demand	2.10 (identity)	DCLBAU * POPNAU
Exports	NXLBAU	net lamb exports	2.11 (OLS)	PDLBAU, PDIFLBAU(-1), STLBAU(-1), DUM74
Price and revenue	PALBAU	farm lamb price	2.12 (identity)	PDLBAU + STLBAU(-1) – DMLBAU – NXLBAU – STLBAU
	PRLBAU	retail lamb price	2.13 (identity)	PALBAU + MMLBAU
	MMLBAU	lamb price spread	2.14 (2SLS)	PRLBAU, WAGEAU, MMLBAU(-1), DUM74
	TRLBAU	lamb industry revenue	2.15 (identity)	PDLBAU * PALBAU

[a] constant term and seasonal dummy variables omitted.

Figure 3: Structural Diagram of the Australian Lamb Industry



capacity variables (equations 2.4, 2.5). The equations include lagged dependent variables as partial adjustment mechanisms which recognise that biological and economic constraints are likely to inhibit the full adjustment of breeding decisions to price changes (Vere and Griffith 1988). Hence, the number of ewes desired at the end of a particular period is likely to differ from actual ewe numbers in that period. Price ratios and seasonal conditions also influence ewe-breeding decisions

The breeding inventories define the lamb industry's breeding capacity and thus set the limit to lamb slaughter which is approximated by the number of lambs marked. The number of lambs marked is determined by the current period adjusted lamb breeding capacity variable (AUSBI) and improved pasture areas. The production block contains a lamb slaughterings function (equation 2.7) expressed in terms of the total number of lambs marked lagged one quarter, lagged slaughterings and quarterly dummy variables. An identity which determines lamb production (equation 2.8) from the lamb numbers slaughtered multiplied by the average weight of each lamb completes the model's supply side.

In the demand block, per capita lamb consumption is determined from a behavioural equation that is expressed as a function of retail meat prices, disposable income and dummy variables (equation 2.9). Total demand (equation 2.10) is per capita consumption multiplied by the Australian population. Net lamb exports (equation 2.11) are given by current production, closing stocks, export price and dummy variables. The price block comprises the farm lamb price which is derived from the solution of the market balance identity (equation 2.12) and the retail price of lamb (equation 2.13) which is defined as the farm price plus the price spread (equation 2.14). Total lamb industry revenue is then defined as the product of lamb production and farm price (equation 2.15).

3.3 Specification of the Australian Pig Industry Model

Prior to the studies of West (1980) and Griffith and Gellatly (1982), there had been little structural econometric modelling in the Australian pig industry. Earlier work by Gruen *et al.* (1967), Hill (1968) and Richardson and O'Connor (1978) basically used simple two-equation lagged supply systems which first estimated the number of sows, and then incorporated this estimate into a slaughterings equation. These models were limited because they did not allow for all components of supply and there was no linkage of supply with the demand side of the pig industry.

West's annual pig industry model was converted into a quarterly equivalent by Griffith and Gellatly (1982), and most recently revised and updated by Griffith (1993). In both the latter models (as for the beef and lamb industry models), the economic relationships in the pig industry were specified in four blocks to represent breeding decisions, and the production, demand, and price formation processes. The first two blocks, inventory and production, together represented the factors directly determining the supply of pigmeat. Decisions made about the number of pigs in the current period were represented in the inventory section that reflected past breeding decisions. In this specification, the number of pigs at the end of any period was a major element in the later-period production decisions, pig numbers slaughtered and the average slaughter weight. The latter two variables together determined the level of production.

In the earlier model versions, the dynamic interactions between the sow inventory and production decisions were modelled by specifying the opening breeding sow inventory to be the main determinant of the closing (current period) inventory. The former inventory provided the basis for determining the size of the natural increase in the current period. In part, the natural increase determined closing pig numbers, which in turn, was the major determinant of the next period's slaughterings. The farm pig price was determined by equating supply and demand, while the retail price of pigmeat was formed by the addition of a price spread to the farm price. Because most pigmeat is consumed domestically, with exports rarely reaching significant levels, the demand for pigmeat was specified as being the product of per capita consumption and the national population.

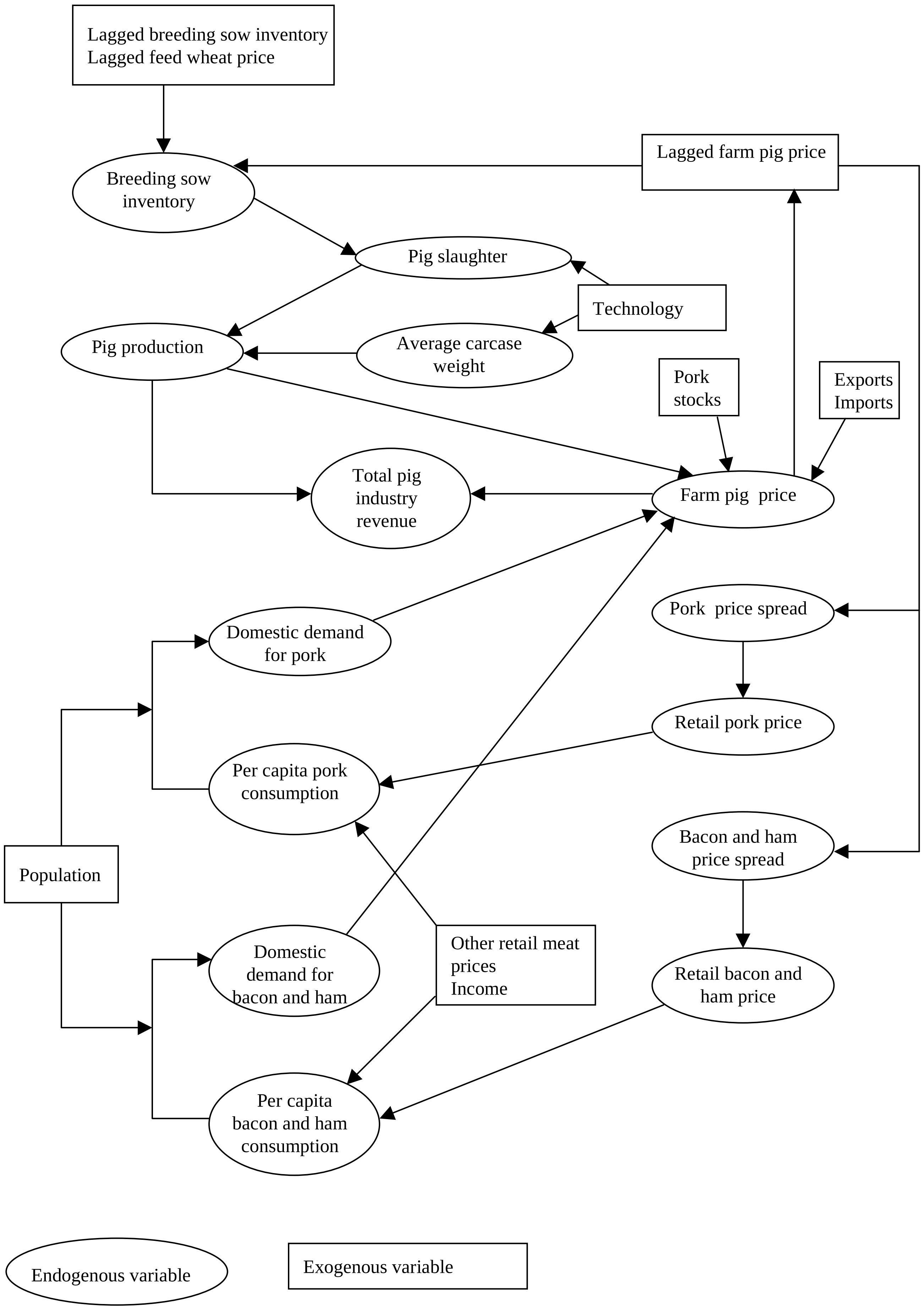
The current version of the model contains 14 endogenous variables, seven of which are represented by behavioural equations and seven by identities (Table 3; Figure 4). In the inventory block, a behavioural equation is specified for total sow numbers, because as with the breeding ewe inventories, there are no data on the slaughter of sows. Current period sow numbers are specified as a function of those at the end of the previous period, the saleyard pigmeat price, a feed cost index during previous periods, and a dummy variable that takes a value of one when wheat quotas were operating during the early 1970's (equation 3.1). The cost of feed is the major cost faced by pig producers, and this is proxied by the farm wheat price, since the wheat market determines prices in the broader feed grains market. The time between the decision to increase the sow herd and the size of the pig slaughter is represented by four-quarter lags on the farm price and feed cost variables. This lag involves a four-month gestation and a period of nine months before the gilts are mature enough to be mated. Also, a lagged dependent variable is specified as a partial adjustment mechanism to account for the divergence between the actual and desired sow numbers at the end of any period.

Table 3: Specification of the Australian Pig Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Inventory	SOWSAU	sow breeding inventory	3.1 (OLS)	SOWSAU(-1), PAPGAU(-2), PGWHAU(-2), DUMWQ(-4)
Production	SLPGAU	pig slaughter	3.2 (OLS)	SOWSAU(-2), TIME65
	WTPGAU	average pig slaughter weight	3.3 (OLS)	WTPGAU(-1), TIME65
	PDPGAU	pig production	3.4 (identity)	SLPGAU * WTPGAU
Demand	DCPKAU	per capita pork consumption	3.5 (2SLS)	PRPKAU, PRBFAU, PRCHAU, YPCAU
	DMPKAU	total pork demand	3.6 (identity)	DCPKAU * POPNAU
	DCBHAU	per capita bacon and ham consumption	3.7 (2SLS)	PRBANW, PRBFAU, YPCAU, DCBHAU(-1)
	DMBHAU	total bacon and ham demand	3.8 (identity)	DCBHAU * POPNAU
Price and revenue	PAPGAU	farm pigmeat price	3.9 (identity)	DMPKAU + DMBHAU + EXPIG – STKPGAU – IMPKAU – IMBHAU – PDPGAU
	PRPKAU	retail pork price	3.10 (identity)	PAPGAU + MMPKAU
	MMPKAU	pork price spread	3.11 (2SLS)	PAPGAU(-1), WAGEAU, MMPKAU(-1)
	PRBANW	retail bacon and ham price	3.12 (identity)	PAPGAU + MMBHAU
	MMBHAU	bacon and ham price spread	3.13 (2SLS)	PAPGAU(-1), WAGEAU
	TRPGAU	pig industry revenue	3.14 (identity)	PDPGAU * PAPGAU

[a] constant term and seasonal dummy variables omitted.

Figure 4: Structural Diagram of the Australian Pig Industry



Slaughterings and average slaughter weight are behavioural equations in the production block, while production is defined exactly as slaughtering times weight. Pig slaughterings are specified as a function of sows six months ago, and a time trend for the effects that improvements in breeding and veterinary care have on slaughter. In the earlier versions of this model, economic factors such as saleyard prices and feed costs were assumed to determine both the extent to which the pig slaughter rate approaches the slaughter limit (the total pig numbers at the end of the previous period) and the timing of the decision to slaughter. However, given the continuing growth in the number of large intensive piggeries and the proportion of total output that they make up, and the rapid movement towards a single sized market pig, here the pig slaughterings function is held to be mainly a biological relationship with available pig numbers as proxied by sow numbers.

In the pig industry, the average slaughter weight (equation 3.3) is largely predetermined by the demand of processors for pigs of a certain size and fat depth. There are large price penalties for producers who do not meet the preferred weight and fat grids. In addition, other factors determine average slaughter weight, including changes in farm management practices, feeding and housing techniques, and consumer tastes for bacon, ham and pork. A partial adjustment mechanism is used to proxy these constraints on achieving the desired slaughter weight. The model's supply side is completed by an identity combining pig slaughterings and average slaughter weight to determine total pig production (equation 3.4).

In the demand block, the per capita consumption of pork and bacon and ham are now estimated separately by behavioural equations (Griffith 1986a;b) and the total consumption for each product is defined from identities. A behavioural equation expresses the per capita consumption of pork to be a function of its own retail price, the retail prices of other meats and income levels (equation 3.5). The total demand for pork is defined as per capita pork consumption multiplied by population (equation 3.6). The per capita consumption of bacon and ham has a similar functional specification to that for pork, in which it is expected that the retail prices of pork and beef and consumer incomes will be significant determinants (equation 3.7). The total consumption of bacon and ham is also defined as per capita consumption multiplied by population (equation 3.8).

The farm price for pigmeat is determined from the market balance identity (equation 3.9) and the retail price of pork (equation 3.10) is defined as the farm pigmeat price plus the pork price spread (equation 3.11). Similarly, the retail price of bacon (equation 3.12) is defined as the farm pigmeat price plus the bacon price spread (equation 3.13). The equations for the two price spreads are specified behaviourally in the price block, and saleyard and both retail prices are defined from identities. The two margins are considered to be mainly determined by marketing costs (Griffith 1974), in which wages are by far the most important (PJT 1978). The lagged farm price is included to test for the presence of price levelling behaviour. Total pig industry revenue is also calculated as the product of farm price and output (equation 3.14).

3.4 Specification of the Australian Wool Industry Model

While there have been many published economic studies of various issues in the Australian wool industry which have used econometric models, there have been few attempts to develop full structural models of this industry. Hitherto, the main complete wool industry model has been ABARE's EMABA model (Dewbre *et al.* 1985a;b). In this annual model, the sheep and wool supply system module contained equations for sheep numbers and slaughter, wool and mutton production and live sheep exports. Domestic greasy wool and mutton prices were derived from market balance identities. Other equations represented the stock-buying activities of the Australian Wool Corporation (AWC) and wool stocks held within the industry during the period in which the wool price support scheme did not operate. Wool export quantities were derived from a balance equating production and opening and closing stocks, and this was then regressed on the average greasy wool price and a real aggregate income series for the six main wool importing countries. There was no attempt to disaggregate the wool export market, or to explain export price formation in the different markets.

The mutton component of the EMABA model contained endogenous variables representing adult sheep slaughter and average sheep slaughter weight, mutton production, domestic demand and exports of mutton and live sheep. The farm mutton price was determined from a market balance identity. Other endogenous mutton prices in the model were the retail mutton price, the mutton price spread and the average export mutton price. Overall, the EMABA model contained about 30 equations that represented the production, disposal and price formation processes in the Australian wool industry.

Connolly, MacAulay and Piggott (1987) examined the revenue effects of wool price stabilisation resulting from AWC price support, between 1974 and 1984, on six grades of Australian wool using a quarterly SEM of the Australian wool industry (previously developed by Connolly 1990).

The results suggested that wool industry revenue was slightly higher than it would have been without price intervention by the AWC for the combing grades of wool and the converse for carding wool. In another study, Connolly (1992) specified an annual SEM of the world wool trade in which the world demand for wool products (except carpet wool) in the seven main wool consuming regions was linked to the wool production, stock-holding and export activities of the main international wool producers. The model's structure was developed around seven separate wool demand regions with equations explaining each region's total raw wool demand, and the shares and prices of the individual wool exporters in each regional market. The export modules were linked to a livestock inventory model of the Australian sheep industry to allow the effects of changes in wool export demand to be incorporated into the production decisions of wool producers. The model was dynamically simulated over the short period of 1981 to 1989 and validated on the basis of comparisons of the actual and predicted values of the endogenous variables.

This (NSW Agriculture) model's wool industry component represents both the wool and mutton production and consumption processes of the Australian sheep industry. It has a similar structure to the other NSW Agriculture livestock models in that industry activity is initiated through producers' decisions to join Merino and other breeding ewes and that the consequences of these decisions flow through recursively to all other activity in the sheep and wool industry. Figure 5 depicts the variables and linkages that are incorporated in this wool industry model. Those variables that are endogenous to the lamb model are marked with an asterisk (*).

The main breeding intentions inventory for wool production relates to Merino ewes and this is specified similarly to the British breed inventories in the lamb model, i.e, to be a function of past breeding decisions, relative farm prices and seasonal and pastoral conditions (Table 4; equation 4.1). The inventory is also based on four-period lags. The overall sheep breeding inventory is given by the sum of the Merino and British breed breeding ewe inventories (equation 4.2), while the wether population is determined behaviourally because of its importance in total sheep numbers (equation 4.4). Two identities define the total sheep population (equation 4.3) and the balance of lambs marked which are retained as adult replacements (equation 4.5).

Wool production capacities are represented by three definitional equations for the fine, medium and broad micron categories in which the main determinants are the breeding capacity variables for each micron range and seasonal conditions. The fine wool inventory (20 micron and under) is defined as being 21% of the Merino breeding inventory as this has been the historical proportion of fine wool in total Merino wool production (equation 4.6). The remaining Merino breeding inventories represent woolgrowers' decisions to produce medium wool (21 to 25 micron, equation 4.7), while the inventory for broad wool production decisions is given as the aggregate of the three British breed ewe inventories (equation 4.8). These breeding inventories are the wool industry's main production capacity variables. Total wool production (equation 4.9) is defined as the aggregate of fine, medium and broad wool production (equations 4.10, 4.11, 4.12). The respective lagged inventories, greasy wool prices and seasonal conditions determine these wool production types.

The disposal of the Australian wool clip is modelled through the industry's export, stock-holding and domestic demand activities. Wool stocks are modelled to represent the total stock-holdings of the various Australian wool marketing authorities both during and outside the period in which the wool Reserve Price Scheme (RPS) operated (1974 to 1991). Stock-holdings under the RPS are specified to be a function of the ratio of the farm wool price to the eastern wool market indicator price since the former price also represents the average auction price that was the trigger for AWC intervention in the market. The farm price is the main determinant of stock-holdings outside the period of the RPS (equation 4.13), although it has been noted that these stocks were historically minimal and difficult to explain econometrically (Dewbre e*t al.* 1985). Because of data problems, the stock-holdings of private traders are assumed to be included in the total wool stocks variable. The domestic demand for wool is not defined endogenously because of the poor quality of the data on this variable (because of the very large proportion of wool production that is exported).

Wool exports are represented by three equations, which explain the individual demands for Australian wool in the European Community, Japan and the ROW (equations 4.19, 4.20, 4.21). These demands are determined by the respective CIF prices of Australian wool, the prices of cotton and synthetics and importing country real income or consumer expenditure levels. An identity defines the total demand for Australian wool in all export markets (equation 4.18).

The main requirement of the wool export price section has been to endogenise the average greasy wool price (equation 4.24) relative to the expected average wool price over all export markets. This is because expected export prices in the major destinations are considered to be the main determinants of the average price received by Australian woolgrowers. Here, the former price is exogenous and is defined as being the average export price for wool over all markets two quarters into the future. In turn, the average farm wool price determines the fine wool price equivalent (equation 4.25). A broad micron wool price was not included in the model endogenously because of difficulties in estimating a satisfactory equation for this variable. The

Table 4: Specification of the Australian Wool Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Inventory	INMEAU	Merino breeding inventory	4.1 (OLS)	INMEAU(-4), PGWOOL(-4) /PGWHAU(-4), PGWOOL(-4) /PAMTAU(-4), DMDT(-4)
	TOTEWL	total breeding ewe inventory	4.2 (identity)	INMEAU + INSWAU + INLWAU + INCPAU
	SHEEP	Australian sheep population	4.3 (identity)	SHEEP(-1) + LAMBAL – SDEATH – SLSHEEP – LSHPEX
	WETHAU	Australian wether population	4.4 (OLS)	PGWOOL(-4)/PGWHAU(-4), WETHAU(-4)
	LAMBAL	lambs not slaughtered	4.5 (identity)	LAMBMK – SLLBAU
	BIFINE	fine wool breeding inventory	4.6 (identity)	INMEAU * 0.21
	BIMED	medium wool breeding inventory	4.7 (identity)	INMEAU * 0.79
	BIBROAD	broad wool breeding inventory	4.8 (identity)	INSWAU + INLWAU + INCPAU
Production	PDWLAU	total wool production	4.9 (identity)	PDWLFNE + PDWLMED + PDWLBRD
	PDWLFNE	fine micron wool production	4.10 (OLS)	BIFINE(-2), PGRW19(-1), DMDT(-3), PDWLFNE(-1)
	PDWLMED	medium micron wool production	4.11 (OLS)	BIMED(-3), PGWOOL(-1), TIME65, PDWLMED(-1)
	PDWLBRD	broad micron wool production	4.12 (OLS)	BIBROAD(-6), PGWOOL(-4), DMDT(-4), PDWLBRD(-1)
	STKWLAU	wool stocks; (a) RPS on; (b) RPS off	4.13 (OLS)	(a) WPRATIO, STKWLAU(-1), TIME65 (b) PGWOOL(-1), STKWLAU(-1)
	SLSHEEP	adult sheep slaughter	4.14 (OLS)	PGWOOL(-1), SHEEP(-1), SLSHEEP(-1)

[a] constant term and seasonal dummy variables omitted.

Table 4 (cont.): Specification of the Australian Wool Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Production (cont.)	WTSHAU	average adult sheep slaughter weight	4.15 (OLS)	PIAU, TIME65
	PDMTAU	mutton production	4.16 (identity)	SLSHEEP * WTSHAU
Demand	DMUTAU	total mutton demand	4.17 (identity)	STKMUT(-1) + PDMTAU – STKMUT – EXUTAU
Export	WLEXPT	total wool exports	4.18 (identity)	WLXEEC + WLXJAP + WLXROW
	WLXEEC	wool exports to the EC	4.19 (2SLS)	PWLMEEC, YPCUS, PRPOLY, PWLXNZ, WLXEEC(-1)
	WLXJAP	wool exports to Japan	4.20 (2SLS)	PWLMJAP, PCEXJAP, PRPOLY(-1), WLXJAP(-1), TIME65
	WLXROW	wool exports to ROW	4.21 (2SLS)	PWLMRW, YPCUS, WLXROW(-1)
	EXMTAU	total mutton exports	4.22 (OLS)	STKMUT(-1), PMUTDIF
	LSHPEX	live sheep exports	4.23 (OLS)	PAMTAU(-1), PGWOOL(-1), LSHPEX(-1)
Price and revenue	PGWOOL	average greasy farm wool price	4.24 (2SLS)	EPWLXP, PGWOOL(-1)
	PGRW19	19 micron greasy farm wool price	4.25 (2SLS)	PGWOOL, PGRW19(-1)
	PAMTAU	farm mutton price	4.26 (2SLS)	PGWOOL, PALBAU
	PWLEXP	average export wool price	4.27 (identity)	(WLXJAP * PWLXJAP + WLXEEC * PWLXEEC + WLXROW * PWLXRW) / WLEXPT
	PWXLEEC	FOB wool export price to the EC	4.28 (OLS)	PGWOOL(-2), PWLXEEC(-1)

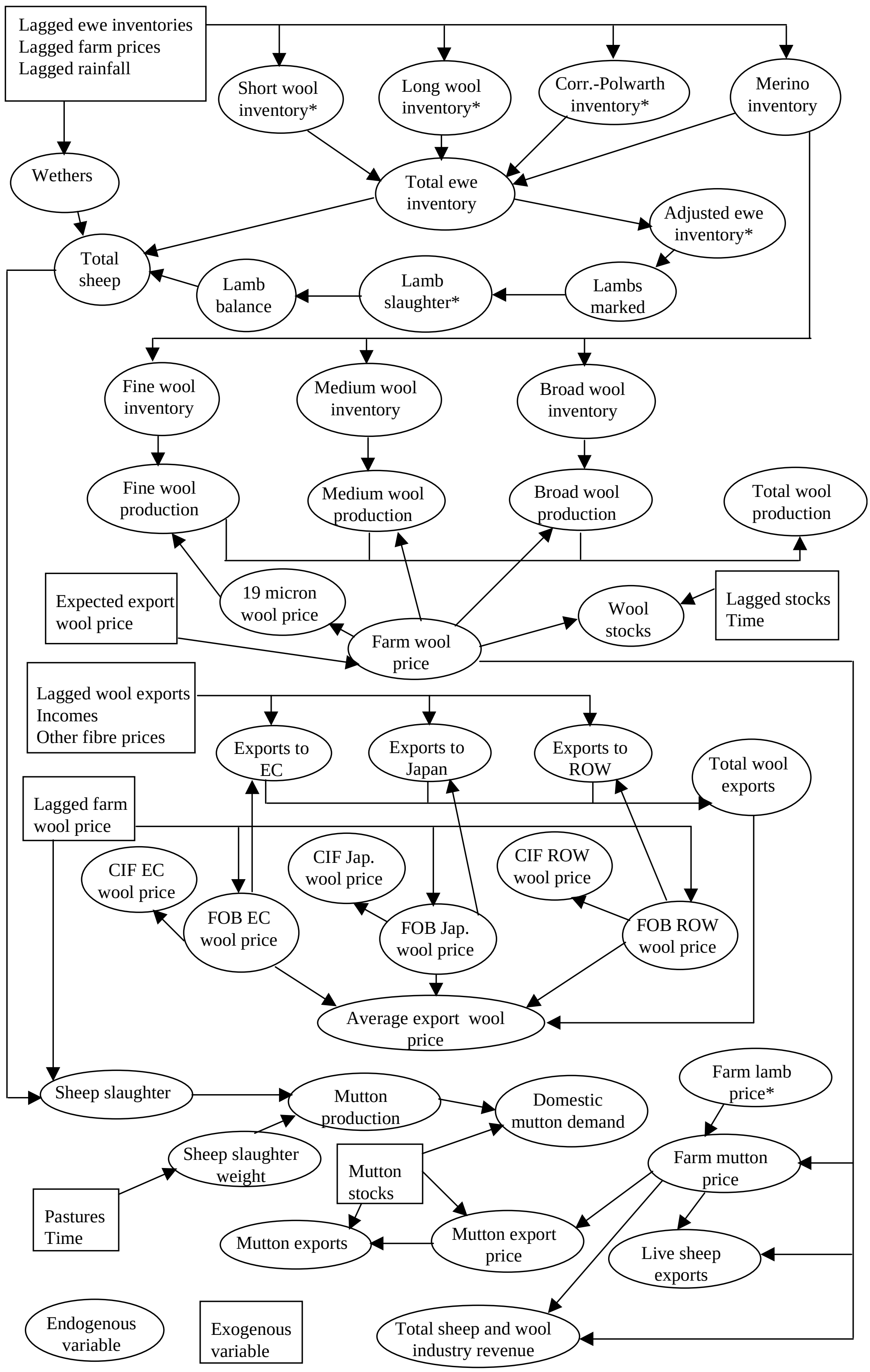
[a] constant term and seasonal dummy variables omitted.

Table 4 (cont.): Specification of the Australian Wool Industry Model

Block	Dependent variable	Variable name	Equation/ estimator	Explanatory variables [a]
Price and revenue (cont.)	PWLXJAP	FOB wool export price to Japan	4.29 (OLS)	PGWOOL(-2), PWLXJAP(-1), DUMRP1
	PWLXRW	FOB wool export price to ROW	4.30 (OLS)	PGWOOL(-2), PWLXRW(-1), DUMRP1
	PWLMEEC	CIF wool export price to the EC	4.31 (identity)	((1.033) * (PWLXEEC) + (FRBFAU)) * (XRAUGR) * (CPIAUN/CPIEEC)
	PWLMJAP	CIF wool export price to Japan	4.32 (identity)	((1.033) * (PWLXJAP) + (FRBJAP)) * (XRAUJAP) * (CPIAUN/CPIJAP)
	PWLMRW	CIF wool export price to ROW	4.33 (identity)	((1.033) * (PWLXRW) + (FRBFAU)) * (XRUSAU) * (CPIAUN/CPIUS)
	PRXMUT	average mutton export price	4.34 (2SLS)	PAMTAU, PRXMUT(-1), STKMUT
	TRWLAU	wool industry revenue	4.35 (identity)	((PGWOOL * PDWLAU + PAMTAU * PDMTAU + PXLSHP * LSHPEX))

[a] constant term and seasonal dummy variables omitted.

Figure 5: Structural Diagram of the Australian Wool Industry



average price for all Australian exported wool is determined by the weighted averages of the prices to the three principal destinations (equation 4.27). In each of these markets, the FOB price is given as a function of the lagged greasy farm wool price (equations 4.28, 4.29, 4.30). The CIF wool export price equivalents are defined in terms of the home currencies with adjustments for insurance premiums, freight and exchange rates (equations 4.31, 4.32, 4.33).

The model's mutton production section is specified with two behavioural equations to explain the slaughter of adult sheep (equation 4.14) and their average slaughter weight (equation 4.15) which together define mutton production (equation 4.16). Per capita consumption of mutton has not been included as an endogenous variable because there are no reliable published data for the retail mutton price after 1983. The total domestic demand for mutton is derived from a market balance identity that equates production, stocks and exports (equation 4.17) while the farm mutton price is determined by the farm prices for wool and lamb (equation 4.26).

Over the past decade, nearly two-thirds of Australian mutton production has been exported with the Middle East, South Africa and Japan being the major markets. Mutton exports represent about 15% of Australia's total red meat exports and this is more than four times the annual quantity of lamb exported. Mutton exports are determined behaviourally by opening mutton stocks and a price differential between the farm and average export mutton prices (equation 4.22). The average export price for mutton is determined by the farm mutton price and opening stocks (equation 4.34), while live sheep exports are determined by lagged greasy wool and farm mutton prices (equation 4.23). An identity for total sheep industry revenue completes the wool and mutton section of the model (equation 4.35).

3.5 Specification of the Integrated Australian Grazing Industries Model

This model combines the full structures of the component models detailed in Sections 3.1 to 3.4 into a single integrated livestock industry model. As indicated in the Introduction, model integration is considered to be beneficial for industry analyses because of the additional information that is made available to the model solution. If the validation performance of the integrated model approximates or improves on those for the individual models, it should offer an improved basis for forecasting and other analyses because it better captures the important cross-industry effects. Indications of the benefits of this approach were established in a separate study by integrating the two lamb industry models, and by further linking this model with the Australian pig industry model. In the main, the linked models retained the levels of explanatory power of the component models, but importantly, they allowed the direct incorporation of cross-industry considerations, rather than through less formal links such by including the prices of competing meats in the meat consumption equations.

4. Estimation of the Integrated Model

A major consequence of the decision to develop a quarterly SEM is that the data requirement increases directly with the scope and complexity of the model. In terms of number of explanatory variables, an over-riding issue is that there is now increasingly less investment in primary data collection and publication by agencies such as ABS and ABARE. Many of the series that were available even 10 years ago are no longer published (Griffith 1993). A further problem has emerged from structural changes in livestock selling methods. For example in the pig market, the majority of sales are made on a direct-to-plant basis but these sales are not reported publically. The reported pig saleyard price used in this research is rapidly becoming a residual market price, and so it suffers from more variability than the direct sale prices.

Data frequency is also an important issue. Many of the crucial inventory series are only collected annually by ABS, and procedures have to be developed to convert these into quarterly series. In some cases (breeding ewe mating intentions), industry expert opinion has been used in the past to generate consistent quarterly series (Vere *et al.* 1993). Elsewhere, data series have been linearly interpolated. Some export data, such as export values to particular markets, are only available annually and various procedures have had to be tested to derive sensible quarterly export price series. These data limitations have in many cases forced a re-specification of the preferred model structure.

In each model component, the behavioural equations were estimated by ordinary least squares (OLS) regression or by two-stage least squares (2SLS) regression where the latter equations contained current period endogenous variables as explanatory variables. All behavioural equations were estimated using quarterly data covering the period 1970:1 to 1996:4 using the TSP (version 4.3B) econometric package. Where necessary, the estimated equations were corrected for first-order autocorrelation using the maximum likelihood iterative technique. The integrated model contains 94 endogenous variables, of which 30 are contained in the beef model, 15 in the lamb model, 14 in the pig model and 35 in the wool model. The endogenous variables are represented by 51 behavioural and 43 definitional equations (identities).

All behavioural equations were specified with a linear functional form. While there are many factors to consider in choosing a particular functional form (Tomek and Robinson 1990, Chapter 15), in this case the need for simplicity and ease of comparison across equations was a primary consideration. There are however, good reasons for the use of double-log functions (Dewbre *et al.* 1985a, p. 6), and work is proceeding on a formal comparison. The equation estimates for each model are contained in Tables 5 to 11. Each equation was evaluated according to the adjusted coefficients of determination (adjusted R^2), the significance and sign of each of the estimated coefficients, the Durbin-Watson (DW) and Durbin (h) autocorrelation statistics, the standard error of the endogenous variable estimate (SEE) expressed as a proportion of the mean of the dependent variable, and the estimated value of the autocorrelation coefficient (rho) and its associated t-statistic value. Where relevant, the short and longer-term elasticities on the major explanatory variables are calculated. All estimates are derived from the transformed data where first-order autocorrelation corrections were necessary, and all price and value variables were converted into real terms by dividing by the appropriate consumer price index (CPI).

The estimation results for the behavioural equations are reported for the blocks in the composite model's structure rather than the full results for each of the component models. Because the results for each equation are identical for both the individual and the integrated models, block reporting of the results enables similarities and differences between the estimates to be more readily observed, e.g., the importance of retail prices and income levels in the various meat consumption equations. Also, comment is made only on those results that either strongly confirm or differ from the expectations in their specification, and instances that require additional modelling attention.

4.1 Breeding Inventory and Livestock Population Estimates

Each of the sheep breeding inventory equations display highly significant lagged dependent variable effects and are generally unresponsive to price changes (Table 5). The lagged dependent variable coefficients in each of these equations indicate the capital stock nature of the breeding base through which previous breeding decisions are transmitted into current decisions (Jarvis 1974). All of the short-term price elasticities are small and are consistent with past observations concerning the inelastic short-term nature of price response in extensive livestock production (Griffith *et al.* 2000). The large coefficients on the lagged dependent variables generate much larger price elasticities in the longer-term, particularly in relation to the lamb and wheat price ratios, and suggest very long adjustment lags.

The results demonstrate the importance of the biological constraints in livestock production systems which have been

Table 5: Breeding and Livestock Population Inventory Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
INSWAU	INSWAU(-4)	0.982	104.13	
	PALBAU(-4)/PGWOOL(-4)	-0.179	-0.66	-0.02; {-1.30}
	PALBAU(-4)/PGWHAU(-4)	0.213	1.35	0.06; {3.34}
	DMDT(-4)	0.036	0.57	
	Adjusted R^2 = 0.99; DW = 2.23; SEE [b] = 0.12; Rho = 0.28 (2.93); N = 111			
INLWAU	INLWAU(-4)	0.965	81.70	
	PALBAU(-4)/PGWOOL(-4)	-0.194	-1.32	-0.06; {-1.68}
	PALBAU(-4)/PGWHAU(-4)	0.134	1.59	0.09; {2.52}
	Adjusted R^2 = 0.98; DW = 2.25; SEE [b] = 0.17; Rho = 0.46 (5.11); N = 111			
INCPAU	INCPAU(-4)	0.950	90.23	
	PALBAU(-4)/PGWOOL(-4)	-0.128	-1.35	-0.06; {-1.15}
	PALBAU(-4)/PGWHAU(-4)	0.136	2.36	0.13; {2.65}
	DMDT(-4)	-0.021	-0.86	
	Adjusted R^2 = 0.99; DW = 2.08; SEE [b] = 0.14; Rho = 0.19 (2.09); N = 111			
INMEAU	INMEAU(-4)	0.984	86.25	
	PGWOOL(-4)/PGWHAU(-4)	0.418	3.58	0.10; {6.21}
	PGWOOL(-4)/PAMTAU(-4)	-0.093	-5.60	-0.07; {-4.42}
	DMDT(-4)	0.446	2.38	
	Adjusted R^2 = 0.99; DW = 1.95; SEE [b] = 0.08; N= 112			
SOWSAU	SOWSAU(-1)	0.832	5.27	
	PAPGAU(-2)	0.00008	1.68	0.03; {0.18}
	PGWHAU(-2)	-0.00007	-0.96	-0.02; {-0.13}
	DUMWQ(-4)	0.007	1.83	
	Adjusted R^2 = 0.76; DW = 2.03; SEE [b] = 0.06; Rho = 0.77 (3.92); N = 115			
WETHAU	WETHAU(-4)	0.980	114.24	
	PGWOOL(-4)/PGWHAU(-4)	0.397	3.96	0.10; {5.16}
	Adjusted R^2 = 0.99; DW = 2.33; SEE [b] = 0.10; Rho = 0.25 (2.70); N = 110			
LAMBMK	AUSBI	0.624	3.89	0.32; {0.61}
	LAMBMK(-1)	0.483	5.64	
	PIAU	0.247	2.73	
	DUMQ1	-21.439	-15.37	
	DUMQ2	-17.067	-51.23	
	DUMQ3	-15.967	-59.08	
	Adjusted R^2 = 0.98; DW = 2.11; SEE = 0.09; N = 111			

[a] constant term omitted; [b] given as proportion of dependent variable mean

observed to have a far greater influence on breeding decisions than producers reactions to changes in prices and other economic variables (Rucker, Burt and LaFrance 1984; Vere *et al.* 1993). This means that sheep and wool producers are unable to readily adjust production decisions in the short term because of the restrictions imposed by the breeding process, i.e., the partial adjustment process equating actual and desired breeding ewe levels at the end of any period is slow. In each of the lamb inventories, there are few pastoral and seasonal effects which also indicates the extent to which producers are committed to lamb production once the initial breeding decisions have been made. Seasonal effects are significant in the Merino inventory, while pasture areas are an important determinant of the numbers of lambs marked each quarter.

The breeding sow inventory estimate also has a strong lagged dependent variable effect. The small price elasticities of supply indicate that pig-breeding decisions are largely unresponsive to product prices and input costs.

4.2 Slaughter and Slaughter Weight Estimates

Livestock slaughter levels are also mainly determined by the respective lagged breeding inventories and except for pig slaughterings, also display significant lagged dependent variables (Table 6). Most of the quarterly dummy variables

Table 6: Slaughter and Slaughter Weight Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
SLLBAU	LAMBMK(-1)	0.062	1.80	0.17; {0.32}
	SLLBAU(-4)	0.472	5.50	
	DUMQ1	-1.329	-2.35	
	DUMQ2	-0.511	-3.67	
	DUMQ3	-0.144	-1.79	
	Adjusted R^2 = 0.56; DW = 2.14; SEE [b] = 0.16; Rho = 0.48 (5.01); N = 111			
SLPGAU	SOWSAU(-2)	2.211	6.31	0.68
	TIME65	0.004	9.19	
	DUMQ1	-0.116	-19.64	
	DUMQ2	-0.025	-3.71	
	DUMQ3	-0.017	-3.03	
	Adjusted R^2 = 0.84; DW = 1.89; SEE [b] = 0.16; Rho = 0.81 (14.22); N = 116			
WTPGAU	WTPGAU(-1)	0.747	10.30	
	TIME65	0.050	3.57	
	DUMQ1	1.587	5.58	
	DUMQ2	2.117	9.14	
	DUMQ3	1.433	5.49	
	Adjusted R^2 = 0.99; DW = 2.00; SEE [b] = 0.01; Rho = -0.23 (-2.04); N = 115			
SLCHAU	INCHAU(-1)	0.012	2.71	0.22; {2.09}
	SLCHAU(-1)	0.896	22.72	
	PIAU(-1)	0.003	0.69	
	DUMQ1	0.112	5.42	
	DUMQ2	0.156	7.61	
	DUMQ3	0.0007	0.04	
	Adjusted R^2 = 0.86: DH = 0.65; SEE [b] = 0.10; N= 108			
SLSBAU	INSBAU(-1)	0.065	2.97	0.38; {0.59}
	SLSBAU(-1)	0.366	3.99	
	PABFAU(-1)	-0.0009	-2.22	-0.10 {-0.15}
	PIAU	0.010	1.21	
	DUMQ1	-0.039	-1.19	
	DUMQ2	0.116	3.28	
	DUMQ3	0.069	2.12	
	Adjusted R^2 = 0.55: DH = -0.90; SEE [b] = 0.12; N = 108			

are significant (relative to the fourth quarter) in all functions which indicates the high degree of seasonality in these variables. Prices were not specified in either of the slaughter functions for lambs and pigs since these functions were assumed to be mainly technical relationships resulting from the breeding inventory functions in which farm product prices are important determinants (Griffith 1993).

There are significant farm beef price effects in both the male cattle and vealer slaughter functions. The current period price in the latter function indicates the short-term nature of vealer production.

Pasture areas are a positive determinant of the slaughter of steers and bulls but are negative in relation to vealers. The latter result suggests that producers only retain vealers under good pasture conditions. The slaughter of female cattle is highly responsive to the beef breeding capacity variable in the longer term. Also, the significant time trend in the pig slaughter function indicates the steady advances in production technology in the pig industry which is evidenced by the domination of the large, integrated production units. There are no price variables and hence no price elasticities in the lamb and pig slaughter functions for the reasons stated above. The slaughter weights of cattle and vealers are mainly determined by the level of improved pastures and the time trend which is also significant in the pig slaughter weight equation.

Table 6 (cont.): Slaughter and Slaughter Weight Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
SLVLAU	INVLAU(-1)	0.017	3.67	0.29; {0.89}
	SLVLAU(-1)	0.673	7.26	
	PABFAU	-0.0004	-1.41	-1.35; {-4.14}
	PIAU	-0.011	-1.78	
	DUMQ1	0.188	4.67	
	DUMQ2	0.359	8.25	
	DUMQ3	0.592	17.07	
	Adjusted R^2 = 0.93; DW = 2.11; SEE [b] = 0.13; Rho = -0.30 (-3.28); N = 107			
WTBFAU	PIAU	4.084	3.14	
	TIME65	0.261	3.89	
	DUMQ1	-4.819	-1.70	
	DUMQ2	-12.365	-3.99	
	DUMQ3	-3.248	-1.16	
	Adjusted R^2 = 0.47; DW = 1.86; SEE [b] = 0.07; Rho = 0.29 (3.12); N = 108			
WTVLAU	PIAU	1.121	1.49	
	TIME65	-0.032	-0.84	
	DUMQ1	6.279	2.45	
	DUMQ2	-1.509	-0.59	
	DUMQ3	-12.283	-4.80	
	Adjusted R^2 = 0.33; DW = 2.03; SEE [b] = 0.14; N = 108			
SLSHEEP	SHEEP(-1)	0.014	3.32	0.49: {1.97}
	PGWOOL(-1)	-0.003	-3.90	-0.17; {-0.71}
	SLSHEEP(-1)	0.753	15.78	
	DUMQ1	-0.862	-4.92	
	DUMQ2	-1.821	-10.53	
	DUMQ3	-1.324	-8.28	
	Adjusted R^2 = 0.81; DH = 0.10; SEE [b] = 0.15; N = 112			
WTSHAU	PIAU	0.051	0.34	
	TIME65	0.003	0.43	
	DUMQ1	-0.596	-2.55	
	DUMQ2	-1.253	-4.78	
	DUMQ3	-1.241	-5.35	
	Adjusted R^2 = 0.38; DW = 1.88; SEE [b] = 0.10; N = 112			

[a] constant term omitted; [b] given as proportion of dependent variable mean

4.3 Per Capita Meat Consumption Estimates

The main features of the meat consumption estimates are the strong influences of own-price and the prices of other meats at retail, and the relatively weak income effects in the beef, pork and lamb demand functions (Table 7). In contrast, the bacon and ham consumption function has a weaker own-price effect and a strong income effect in all time periods. Each of the fresh meat functions has significant own-price effects and at least two competing retail meat prices as major determinants. Consistent with the theoretical homogeneity condition (although not imposed in this model), the short-term elasticities indicate that fresh meat consumption is more responsive to own-price changes than to changes in the retail prices of other meats.

The pork consumption function has significant and positive seasonal effects that indicate that the demand for this meat is consistent throughout the year until the fourth quarter. The overall importance of chicken price as a demand determinant of lamb and pork indicates the strong growth in chicken consumption over the past 30 years, although it was not significant in the beef consumption function. It is surprising that consumer incomes are only significant in relation to the consumption of bacon and ham and weakly negative for beef. As previously indicated, per capita mutton consumption was not estimated because a reliable retail mutton price series is not available.

Table 7: Per Capita Meat Consumption Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
DCLBAU	PRLBAU	-0.021	-11.75	-1.54
	PRBFAU	0.008	8.64	0.87
	PRPKAU	0.004	2.19	0.38
	PRCHAU	0.015	6.79	0.74
	YPCAU	0.0006	1.56	0.22
	DUM74	0.730	2.89	
	DUMQ1	-0.065	-0.51	
	DUMQ2	0.039	0.28	
	DUMQ3	0.254	2.45	
	Adjusted R^2 = 0.93; DW = 1.40; SEE [b] = 0.06; N = 116			
DCPKAU	PRPKAU	-0.008	-3.00	-1.59
	PRBFAU	0.002	1.30	0.41
	PRCHAU	0.006	2.25	0.65
	YPCAU	0.0001	0.45	0.12
	DUMQ1	0.319	3.47	
	DUMQ2	0.547	5.26	
	DUMQ3	0.433	6.17	
	Adjusted R^2 = 0.57; DW = 1.99; SEE [b] = 0.38; Rho = 0.67 (9.74); N = 115			
DCBHAU	PRBANW	-0.003	-0.84	-0.07; {-0.13}
	PRBFAU	0.001	3.43	0.19; {0.34}
	YPCAU	0.002	12.96	1.43; {2.65}
	DCBHAU(-1)	0.460	10.53	
	Adjusted R^2 = 0.90; DW = 1.88; SEE [b] = 0.10; N = 115			
DCBFAU	PRBFAU	-0.036	-9.13	-1.38
	PRPKAU	0.011	0.97	0.37
	PRLBAU	0.026	3.54	0.64
	YPCAU	0.002	1.57	0.33
	DUM74	2.349	2.61	
	DUMQ1	1.442	3.01	
	DUMQ2	1.367	2.59	
	DUMQ3	1.475	4.17	
	TIME65	-0.052		
	Adjusted R^2 = 0.83; DW = 2.03; SEE [b] = 0.09; Rho = 0.30 (3.33); N= 111			

[a] constant term omitted; [b] given as proportion of dependent variable mean

4.4 Wool Production and Stock-holdings Estimates

Only wool production is determined from behavioural equations since the production of beef, lamb and pork is represented by identities (Table 8). Fine, medium and broad micron wool production depends mainly on the lagged levels of the respective breeding inventories and lagged greasy wool prices, although the production elasticities with respect to price changes are very small in both the short and long terms. These results are similar to those for the lamb inventories that demonstrate that wool production is also largely predetermined by the biological constraints imposed by the sheep breeding processes. The highly significant dummy variables indicate the seasonal nature of wool production. The wool stock-holding equations mainly reflect the differences in price response between the free market and price support periods in the Australian wool industry. The free market period has a highly elastic long-term response to the previous period's farm wool price.

4.5 Meat and Wool Export Estimates

The export functions for lamb and for the non-quota periods for beef exports to the USA have insignificant price determinants and small price elasticities (Table 9). The ratio of the Australian and New Zealand CIF prices is a significant determinant of US beef imports from Australia for those periods in which the US beef import quotas operated. The unremarkable lamb exports function estimates may be largely due to the past residual nature of lamb exports and also to problems involved in defining a

Table 8: Wool Production and Stocks Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
PDWLFNE	BIFINE(-2)	0.675	1.11	
	PGRW19(-1)	0.001	1.89	0.03; {0.23}
	PDWLFNE(-1)	0.853	15.67	
	DMDT(-3)	0.598	2.45	
	DUMQ1	-1.164	-0.86	
	DUMQ2	-11.382	-18.42	
	DUMQ3	8.448	3.05	
	Adjusted R^2 = 0.95; DW = 1.95; Rho = -0.33 (-2.88); SEE [b] = 0.05; N = 110			
PDWLMED	BIMED(-3)	0.863	1.68	
	PGWOOL(-1)	0.019	3.92	0.07; {0.35}
	PDWLMED(-1)	0.806	13.94	
	TIME65	0.040	2.82	
	DUMQ1	12.772	1.73	
	DUMQ2	-36.229	-11.00	
	DUMQ3	48.685	10.92	
	Adjusted R^2 = 0.96; DW = 1.87; SEE [b] = 0.05; Rho = -0.48 (-4.91); N = 110			
PDWLBRD	BIBROAD(-6)	0.999	5.54	
	PGWOOL(-4)	0.006	2.11	0.04; {0.14}
	PDWLBRD(-1)	0.734	14.89	
	DMDT(-4)	0.498	1.11	
	DUMQ1	-20.316	-20.85	
	DUMQ2	-24.904	-30.17	
	DUMQ3	1.457	2.10	
	Adjusted R^2 = 0.97; DH = 1.19; SEE [b] = 0.06; N = 111			
STKWLAU (no RPS)	STKWLAU(-1)	0.989	45.62	
	PGWOOL(-1)	0.035	3.67	0.08; {7.27}
	Adjusted R^2 = 0.98; DW = 0.61; SEE [b] = 0.04; Rho = 0.63 (5.26); N = 41			
STKWLAU (with RPS)	STKWLAU(-1)	0.877	15.14	
	WPRATIO	6.297	0.96	0.08; {0.61}
	TIME65	0.393	1.41	
	Adjusted R^2 = 0.85; DW = 1.85; SEE [b] = 0.58; Rho = 0.86 (13.73); N = 66			

[a] constant term omitted; [b] given as proportion of dependent variable mean

representative export price series given the diversity of the two main lamb export markets in the Middle East and the USA. The growing strength of Australia's lamb trade to the USA suggests the need to disaggregate this variable to explicitly accommodate the separate markets.

Australia's beef exports to the USA are more dependent on US meat import legislation than on import price relativities, although total US beef imports are negatively related to real income changes. Some estimation problems remain with the levels of autocorrelation in these functions that cannot be corrected because of the split samples over which these functions were estimated. Price effects are similarly weak in the Japanese beef import market that is mainly determined by the overall level of Japanese beef imports from all sources. This demand is significantly affected by current Japanese income levels and has a high short-term income elasticity.

The three wool export equations have consistent price and income effects in representing the demand for wool in the importing countries. Each function displays a negative own-price response (which is only significant in the Japanese market) and a strongly positive consumer income-expenditure effect. The price of polyester is a significant determinant of the import demand for Australian wool in the EC. The farm-export mutton price differential has an important effect on the levels of mutton exports, while the lagged dependent variable and the lagged greasy wool price export are the main determinants of live sheep exports.

Table 9: Meat and Wool Export Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
NXLBAU	PDLBAU	0.221	2.57	
	PDIFLBAU(-1)	-0.005	-0.21	-0.01
	STLBAU(-1)	0.637	3.23	
	DUMQ1	-1.241	-1.29	
	DUMQ2	-0.703	-0.57	
	DUMQ3	-2.153	-2.58	
	Adjusted R^2 = 0.64; DW = 2.26; SEE [b] = 0.20; Rho = 0.77 (13.09); N = 111			
EXBFAUS (no quota)	USBIMP	0.720	7.72	
	PRATIO(-1)	24.915	0.85	0.35
	Adjusted R^2 = 0.61; DW = 0.68; SEE [b] = 0.08; N = 44			
EXBFAUS (with quota)	USREG	0.408	12.58	
	PRATIO(-1)	-74.094	-7.92	-0.99
	Adjusted R^2 = 0.72; DW = 0.77; SEE [b] = 0.12; N = 67			
USBIMP (no quota)	YPCUS	-0.005	-2.79	-0.69
	UPRATIO	-262.771	-4.09	-0.70
	STBFUS(-1)	-0.202	-2.28	
	Adjusted R^2 = 0.27; DW = 0.54; SEE [b] = 0.14; N = 72			
USBIMP (with quota)	USREG	0.367	9.16	
	Adjusted R^2 = 0.56; DW = 0.24; SEE [b] = 0.14; N = 68			
IMBFJAP	PB2JAP	0.005	0.96	0.25
	YPCJAP	0.033	5.36	1.77
	STKBFJP(-1)	0.210	4.43	
	DUMQ1	-11.102	-3.25	
	DUMQ2	2.715	0.70	
	DUMQ3	-0.686	-0.20	
	Adjusted R^2 = 0.76; DW = 2.06; SEE [b] = 0.26; Rho = 0.46 (5.25); N = 111			
EXBFAJP	IMBFJAP	0.439	21.58	
	PXBJPCF	-0.0001	-0.62	-0.05
	DUM74	2.883	0.41	
	Adjusted R^2 = 0.91; DW = 1.46; SEE [b] = 0.19; N = 111			

4.6 Price Transmission Estimates

Most of the farm and export price equations explain a high proportion of quarterly variation in their respective series (Table 10). The exception is the farm mutton price equation estimate that is mainly determined by the current farm greasy wool price. An important result is the elastic nature of the farm beef price in relation to the average export beef price. This is also the case with the strong linkage between the expected average export wool price and farm wool price that in turn becomes the main determinant of the FOB prices in the three wool export markets. The importance of these linkages is that it reflects the notion that beef producers and woolgrowers base their production decisions on export rather than domestic prices.

4.7 Domestic Price Spread Estimates

The estimated farm-retail meat price spreads each have reasonably high multiple correlation coefficients and several significant determinants (Table 11). Wages, as the main component of marketing costs, have some significance in each equation, but there are no time trend effects to indicate the adoption of cost-saving methods based on improved meat processing methods.

Table 9 (cont.): Meat and Wool Export Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
WLXEEC	PWLMEEC	-0.009	-0.82	-0.12; {-0.24}
	YPCUS	0.003	2.04	0.98; {2.02}
	WLXEEC(-1)	0.514	5.94	
	PRPOLY	0.093	2.15	
	DUMQ1	-10.502	-3.43	
	DUMQ2	-10.016	-2.43	
	DUMQ3	-17.750	-6.08	
	Adjusted R^2 = 0.41; DW = 2.05; SEE [b] = 0.13; N = 111			
WLXJAP	PWLMJAP	-0.0008	-2.77	-0.39; {-0.97}
	PCEXJAP	0.004	2.16	1.01; {2.52}
	PRPOLY(-1)	11.587	0.78	0.06; {0.15}
	WLXJAP(-1)	0.601	7.08	
	DUMQ1	0.514	0.30	
	DUMQ2	-0.577	-0.33	
	DUMQ3	-0.412	-2.59	
	TIME65	-0.632	-3.09	
	Adjusted R^2 = 0.86; DW = 1.64; SEE [b] = 0.11; N = 111			
WLXROW	PWLMRW	-0.027	-2.77	-0.20; {-0.35}
	YPCUS	0.004	3.37	1.18; {2.05}
	WLXROW(-1)	0.432	3.63	
	DUMQ1	-10.291	-2.17	
	DUMQ2	-12.587	-2.62	
	DUMQ3	-23.107	-5.76	
	Adjusted R^2 = 0.54; DH = 0.76; SEE [b] = 0.11; N = 110			
EXMTAU	PMUTDIF	0.153	8.56	-0.31
	STKMUT(-1)	0.459	2.95	
	DUMQ1	0.914	0.70	
	DUMQ2	-5.208	-3.51	
	DUMQ3	-4.498	-3.19	
	Adjusted R^2 = 0.73; DW = 2.14; SEE [b] = 0.74; N = 110			
LSHPEX	PAMTAU(-1)	0.0001	0.23	0.004; {0.044}
	PGWOOL(-1)	0.0001	1.23	0.03; {0.28}
	LSHPEX(-1)	0.901	8.64	
	Adjusted R^2 = 0.82; DW = 1.84; SEE [b] = 0.15; Rho = 0.81 (5.53); N = 109			

[a] constant term omitted; [b] given as proportion of dependent variable mean

Table 10: Price Transmission Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
PABFAU	PDBFAU	0.055	0.61	0.21; {0.75}
	PREXBF	0.216	1.22	0.25; {0.92}
	PABFAU(-1)	0.727	3.25	
	DUM74	-21.804	-2.00	
	Adjusted R^2 = 0.78; DW = 2.04; SEE [b] = 0.09; Rho = 0.43 (4.96); N = 111			
PXBUSCF (no quota)	PWBFUS	2.663	29.24	0.99
	Adjusted R^2 = 0.92; DW = 1.14; SEE [b] = 0.08; N = 72			
PXBUSCF (with quota)	PWBFUS	2.577	17.93	0.92
	Adjusted R^2 = 0.83; DW = 1.12; SEE [b] = 0.14; N = 68			
PXBFAJP	PABFAU(-1)	0.278	7.26	0.14; {0.77}
	PXBFAJP(-1)	0.815	24.25	
	Adjusted R^2 = 0.93; DH = 1.91; SEE [b] = 0.05; N = 108			
PXBFROW	PABFAU(-1)	0.444	6.57	0.29; {0.81}
	PXBFROW(-1)	0.639	11.61	
	Adjusted R^2 = 0.91; DH = -1.36; SEE [b] = 0.08; N = 108			
USPNZ (no quota)	PWBFUS	2.035	15.63	0.72
	Adjusted R^2 = 0.77; DW = 0.53; SEE [b] = 0.13; N = 72			
USPNZ (with quota)	PWBFUS	1.546	10.14	0.01
	Adjusted R^2 = 0.60; DW = 0.59; SEE [b] = 0.15; N = 68			
PGWOOL	EPWLXP	0.529	4.87	0.59; {1.19}
	PGWOOL(-1)	0.498	4.49	
	DUMQ1	-5.703	-0.87	
	DUMQ2	-34.632	-4.86	
	DUMQ3	-21.665	-3.84	
	Adjusted R^2 = 0.74; DW = 2.13; SEE [b] = 0.09; Rho = 0.44 (3.26); N = 103			
PGRW19	PGWOOL	0.345	0.75	0.14; {0.60}
	PGRW19(-1)	0.768	7.88	
	Adjusted R^2 = 0.70; DW = 2.07; SEE [b] = 0.23; Rho = 0.39 (4.49); N = 99			
PWLXEEC	PGWOOL(-2)	0.118	2.42	0.11; {0.52}
	PWLXEEC(-1)	0.783	11.72	
	Adjusted R^2 = 0.83; DH = 3.61; SEE [b] = 0.09; N = 108			
PWLXJAP	PGWOOL(-2)	0.161	3.40	0.13; {0.63}
	PWLXJAP(-1)	0.796	15.49	
	DUMRP1	7.789	1.43	
	Adjusted R^2 = 0.85; DH = 2.21; SEE [b] = 0.09; N = 108			
PWLXRW	PGWOOL(-2)	0.438	6.08	0.38; {0.63}
	PWLXRW(-1)	0.388	4.27	
	DUMRP1	-8.965	-1.48	
	Adjusted R^2 = 0.81; DH = 3.25; SEE [b] = 0.11; N = 108			
PAMTAU	PGWOOL	0.139	2.12	0.76
	PALBAU	-0.078	-0.28	-0.17
	DUMQ1	0.126	0.04	
	DUMQ2	10.334	1.51	
	DUMQ3	8.935	1.54	
	Adjusted R^2 = 0.23; DW = 1.92; SEE [b] = 0.17; Rho = 0.943 (29.97); N = 111			
PRXMUT	PAMTAU	1.345	3.70	0.50
	STKMUT	-1.699	-1.87	
	DUMQ1	-15.574	-2.15	
	DUMQ2	-6.021	-0.65	
	DUMQ3	37.526	4.40	
	Adjusted R^2 = 0.43; DW = 1.97; SEE [b] = 0.31; Rho = 0.525 (6.44); N = 109			

[a] constant term omitted; [b] given as proportion of dependent variable mean

Table 11: Domestic Price Spread Estimates: 1970:1 to 1996:4

Dependent variable	Explanatory variables [a]	Coefficient value	t-statistic	Elasticities
MMLBAU	PRLBAU	0.068	1.55	0.10; {0.28}
	WAGEAU	0.048	1.06	0.05; {0.14}
	MMLBAU(-1)	0.649	11.02	
	DUM74	-92.874	-9.13	
	Adjusted R^2 = 0.71; DW = 2.03; SEE [b] = 0.05; N = 112			
MMPKAU	PAPGAU(-1)	0.154	3.57	0.08; {0.46}
	WAGEAU	0.057	1.05	0.05; {0.26}
	MMPKAU(-1)	0.822	17.02	
	Adjusted R^2 = 0.85; DH = 0.13; SEE [b] = 0.04; N = 116			
MMBHAU	PAPGAU(-1)	0.311	3.12	0.09; {1.12}
	WAGEAU	0.229	1.76	0.11; {1.25}
	MMBHAU(-1)	0.914	23.28	
	Adjusted R^2 = 0.85; DH = -1.64; SEE [b] = 0.05; N = 116			
MMBFAU	PABFAU(-1)	0.690	9.19	0.22
	WAGEAU	0.205	1.58	0.12
	DUMQ1	6.637	3.82	
	DUMQ2	12.281	6.97	
	DUMQ3	6.715	4.42	
	Adjusted R^2 = 0.71; DW = 1.82; SEE [b] = 0.03; Rho = 0.92 (24.32); N = 111			

[a] constant term omitted; [b] given as proportion of dependent variable mean

5. Validation of the Integrated Model

5.1 Purposes

By definition, a model is a representation of reality. The purpose of model validation is to determine whether the estimated model is an *adequate* representation of an industry's operations, i.e., whether the estimated model sufficiently represents the economic processes that have generated the values of the endogenous variables. While the model is partly validated during the estimation process through the statistical tests on the behavioural equations, the validation or solution of the entire model requires that the set of behavioural equations be integrated with each other and the set of identities over the estimation period.

There are two main issues in model validation. First, the confidence with which an industry model can be used to explain historical behaviour, to forecast future values, and to evaluate the effects of events and policies depends on the extent to which the estimated model is able to satisfy a range of statistical criteria. These criteria establish the model's explanatory power when it is simulated in a fully-integrated context, by examining the correlation between the actual data and the series of predicted (solved) values for each of the endogenous variables, and the sources of error in the estimation process. Second, the data sample period over which the model is estimated should be long enough to capture the normal flow of events that affect an industry. These events result from regular cycles (e.g., livestock breeding and product demand patterns), seasonal changes (e.g., droughts), exogenous influences (e.g., trade barriers) and domestic policy changes (e.g., the deregulation of the Australian wool industry in early 1991). Here, the 30-year quarterly data period over which each of the models was estimated incorporates many such events which have regularly and/or periodically affected the Australian livestock industries. Where the estimated model adequately satisfies the validation criteria and the sample period requirements, it can then be considered to be a sound representation of the industry's operations in the absence of unanticipated structural change.

Each of the models was validated using a dynamic, historical, control simulation routine over the full estimation sample period. The *dynamic* element of this process utilises the solution values for the lagged dependent variables instead of actual values in predicting the quarterly values of the endogenous variables, as well as the actual exogenous data and the actual parameter estimates from the sample period. A dynamic simulation provides a more exacting test of the model's stability and hence its capacity to follow the sequence of recorded events than a static simulation that uses the actual data on the lagged variables. Essentially this is because estimation errors occurring in one period are automatically transferred into the following period under a dynamic simulation routine. This aspect is particularly demanding of a model in predicting variables such as prices which, under competitive industry conditions, are determined by the intersection of the estimated supply and demand schedules which themselves contain a degree of measurement error. The terms *historical* and *control* refer to the use of actual data and actual parameter estimates over the actual past instead of synthetic and/or forecast data. This is important because the main objective of model validation is to explain the actual past.

The algorithm used to simulate the model is based on the Newton method for solving sets of simultaneous equations. This method requires that there is a separate equation or identity for every endogenous variable, but these may be either typical equations where the endogenous variable is on the left-hand side or in implicit form (such as the market balance identities from which the farm lamb and pig prices are determined).

The four summary validation statistics reported are derived from the comparison of the predicted and the actual values of the endogenous variables. The squared correlation coefficient (R^2) indicates the model's ability to explain quarterly changes in the endogenous variables when all current and lagged period interactions are explicitly incorporated in the model simulation. As with single-equation estimation, a high R^2 is desirable. In Tables 12 to 15, the R^2 of the underlying structural equation is included for comparison with the simulation R^2. Ideally, the values of these coefficients should be close to each other to confirm the strength of the base equation. The actual on predicted (A/P) coefficient is a measure of the correlation between the actual and predicted values where a value close to one indicates that both the series display similar variability. A value greater than one indicates that the predicted series is more stable than the actual data - a problem which may arise when quarterly data have to be constructed from annual series. The converse holds for an A/P coefficient with a value less than one. A value for Theil's (1961) U_2 coefficient less than one indicates that the model provides a better forecast of the endogenous variable than a naïve or no-change forecast. The error decomposition statistics measure the amount of simulation error that is attributable to bias in the predicted values relative to the actual data.

5.2 General Model Validation Results

Tables 12 to 15 contain the dynamic validation results for each of the component models. Results are reported for both the individual models and for the integrated model within which all the components interact dynamically. This comparison is made to examine the extent to which the integration process affects the validation performances of the component models. As previously indicated, measurement errors in the supply and demand variables that determine commodity price predictions are likely to be greater in a larger model. Significant differences in the validation results for the price variables between the component and the composite models could have implications for the use of either model for purposes such as forecasting.

The dynamic validation results display few differences between the individual and the integrated beef industry models (Table 12). The dynamic simulation statistics for most of both models' endogenous variables are very similar, although those for the two domestic beef consumption variables have been slightly reduced through integration. The main reason for this appears to be that two of the main determinants in the behavioural function for per capita beef consumption (lamb and pork retail prices) are also endogenous variables in the integrated model. Under this dynamic simulation routine, measurement errors in these variables will compound and so adversely effect the simulation of the dependent variable moreso than in the individual beef industry model in which the prices of the other meats competing in demand were exogenous. The simulation of total beef demand is similarly affected as it is a product of per capita consumption and population. There is substantial bias in the vealer inventory and slaughter variable simulations, whilst both models predict a much more stable total US beef import series than is actually so.

In contrast to beef, the integration of the lamb industry model has adversely affected its simulation performance in almost half of the 14 endogenous variables (Table 13). While the lamb-breeding inventory estimates are unaffected because of the strength of the respective lagged dependent variables, the values of the dynamic simulation statistics for the production and domestic demand variables are significantly reduced. The problem with the two demand variables might have a similar explanation to that for beef, i.e., additional error is likely to have been introduced through the right-hand side endogenous variables. However, this explanation is less valid for the lamb slaughter and production variables because none of the determinants are endogenous elsewhere in the model.

The strength of the (adverse) effects of the integration process on parts of the lamb model was investigated by re-solving the model without the wool industry component. For each of the lamb consumption and production variables, the simulation statistics were almost identical to those of the individual lamb model. This indicates that the operations of the smaller lamb industry are being significantly affected by activity in the larger wool and mutton industry. Because lamb tends to be a secondary product in many Australian sheep production systems (Vere and Griffith 1982), the increased endogenisation of the determinants of the major lamb industry variables is likely to cause simulation problems by additional error introduction. For example, on the lamb supply side, this would result from the elastic long-term responses to the farm prices for wool, wheat and mutton which are important determinants of lamb breeding decisions and thence lamb slaughterings and production through the lagged production capacity variable. In particular, the farm wool price is endogenous in the model. Therefore changes in this price will have a greater than proportional effect on lamb breeding decisions and the subsequent lamb slaughter, over long validation sample periods. Also, the lamb consumption estimates could be similarly affected by the endogenous retail prices for beef and pork.

These findings demonstrate the importance of market fundamentals in model simulation performance. In the case of lamb, lamb supply is own-price and cross-price inelastic in the short run but has a high long-term price elasticity. Also, the domestic demand for lamb is own-price elastic and the cross-price elasticity with beef is close to unity. Thus shifts in the supply or demand curves for lamb, caused by shocks from say the wool or beef sectors, would have a significant influence on lamb quantities but little influence on lamb prices, in the long run. Conversely, in the short run, shifts in lamb supply or demand introduced through model integration would have a major influence on both prices and quantities.

While the pig industry is also relatively small, pork is a specialist product and is not as directly affected as lamb by activity in the other livestock industries. This is evidenced by the minimal differences in the pork model's simulation performance when it is integrated into the larger model (Table 14). However, only the pig slaughter and slaughter weight functions have simulation R^2 values that approximate those of the underlying structural equations. Both models predict more stable sow inventory and pig slaughterings series than is evident in the actual data.

The wool industry model's dynamic simulation performance is one of the strengths of the integrated model. In most instances, the integrated and individual wool models' simulation statistics are very similar and so this model has

Table 12: Dynamic Validation of the Australian Beef Industry Model: 1970:1 to 1996:4

Endogenous variable		Individual beef industry model				Integrated beef industry model			
	R^2 of structure [a]	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.
INCHAU	identity	0.92	0.02	0.15	0.95	0.92	0.02	0.15	0.95
INSBAU	identity	0.70	0.04	0.21	0.70	0.70	0.04	0.21	0.70
INVLAU	identity	0.76	0.13	0.87	1.15	0.76	0.13	0.87	1.15
NOB	identity	0.91	0.08	0.16	1.08	0.91	0.08	0.16	1.08
SLCHAU	0.86	0.51	0.09	0.01	0.87	0.51	0.09	0.01	0.87
SLSBAU	0.53	0.51	0.06	0.00	1.07	0.51	0.06	0.00	1.07
SLVLAU	0.93	0.90	0.12	0.62	1.04	0.90	0.12	0.62	1.04
WTBFAU	0.47	0.57	0.03	0.00	1.00	0.57	0.03	0.00	1.00
WTVLAU	0.33	0.33	0.12	0.00	0.95	0.33	0.12	0.00	0.95
PRODBF	identity	0.63	0.05	0.03	0.91	0.62	0.05	0.03	0.91
DCBFAU	0.79	0.82	0.06	0.05	1.08	0.71	0.06	0.00	1.01
DMBFAU	identity	0.69	0.05	0.06	1.05	0.51	0.06	0.00	0.95
EXBEEF	identity	0.49	0.08	0.00	0.76	0.48	0.09	0.03	0.61
USBIMP	0.55	0.33	0.07	0.00	1.73	0.33	0.07	0.00	1.73
EXBFAUS	0.72	0.37	0.07	0.02	0.74	0.37	0.07	0.02	0.74
IMBFJAP	0.75	0.88	0.11	0.00	0.99	0.88	0.11	0.00	1.00
EXBFAJP	0.91	0.89	0.09	0.00	1.01	0.90	0.09	0.00	1.01
EXBFROW	identity	0.36	0.24	0.00	0.35	0.42	0.27	0.01	0.31
PABFAU	0.90	0.91	0.05	0.03	1.10	0.91	0.05	0.00	1.09
PRBFAU	identity	0.86	0.03	0.12	1.19	0.86	0.03	0.12	1.18
MMBFAU	0.71	0.63	0.03	0.10	1.40	0.62	0.03	0.12	1.40
PREXBF	identity	0.89	0.04	0.30	1.02	0.90	0.04	0.26	1.01
PXBUSCF	0.83	0.84	0.06	0.00	0.96	0.84	0.06	0.30	0.96
PXBFAUS	identity	0.82	0.08	0.31	0.78	0.82	0.08	0.31	0.78
PXBJPCF	identity	0.94	0.05	0.01	1.03	0.94	0.05	0.01	1.03
PXBFAJP	0.93	0.69	0.05	0.03	1.01	0.70	0.05	0.03	1.10
PXBRWCF	identity	0.79	0.05	0.01	1.02	0.80	0.05	0.00	1.02
PXBFROW	0.91	0.76	0.06	0.02	1.14	0.79	0.06	0.02	1.14
USPNZ	0.60	0.76	0.08	0.00	1.14	0.76	0.08	0.00	1.14
TRBFAU	identity	0.66	0.07	0.00	1.00	0.70	0.07	0.00	0.99

[a] R^2 of structural equation for comparison; [b] regression coefficient of actual on predicted values

not been adversely affected through model integration (Table 15). Many of the endogenous variables have simulation R^2 values that are at least 75% of the R^2 values of the underlying structural equations. Also, the good simulation results for most of the production identities are noteworthy since many of the behaviourally determined endogenous inventory and production variables are components of these identities. Examples are the total breeding ewe, total sheep, lamb balance and total wool production identities that contain right-hand side variables determined from behavioural equations.

The main weak spots in the wool model are with the total and the EC wool export variables that simulate relatively poorly in terms of simulation R^2, although these variables have satisfactory A/P coefficients. These results were not anticipated because good quality quarterly data on these variables are available from the industry. The farm and export mutton price variables do not simulate well and this is mainly due to problems in defining satisfactory data series for these variables. Mutton is a relatively neglected industry in terms of available statistics. For example, Australian retail mutton prices have not been recorded since the mid-1980's. Also, quarterly mutton export price series appear to be only available for the Japanese market, which ranks in importance behind the Middle East and US markets. Given such data problems, it is doubtful if better estimates of these variables could be obtained.

Table 13: Dynamic Validation of the Australian Lamb Industry Model: 1970:1 to 1996:4

Endogenous variable		Individual lamb industry model				Integrated lamb industry model			
	R^2 of structure [a]	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.
INSWAU	0.99	0.97	0.07	0.43	0.92	0.97	0.07	0.28	0.91
INLWAU	0.98	0.91	0.09	0.30	0.96	0.89	0.09	0.19	0.94
INCPAU	0.99	0.95	0.12	0.28	1.21	0.94	0.13	0.37	1.18
AUSBI	identity	0.75	0.05	0.34	1.01	0.58	0.05	0.14	0.88
AUSBX	identity	0.97	0.05	0.23	0.98	0.96	0.06	0.10	0.97
LAMBAL	identity	0.97	0.06	0.00	0.99	0.96	0.07	0.03	0.98
SLLBAU	0.56	0.54	0.05	0.01	1.21	0.34	0.06	0.01	0.96
PDLBAU	identity	0.44	0.05	0.01	1.02	0.24	0.06	0.17	0.76
DCLBAU	0.93	0.67	0.06	0.00	1.34	0.57	0.07	0.01	1.18
DMLBAU	identity	0.26	0.06	0.00	0.85	0.11	0.06	0.00	0.58
PALBAU	identity	0.58	0.12	0.00	0.65	0.50	0.13	0.02	0.65
PRLBAU	identity	0.63	0.04	0.00	0.77	0.47	0.05	0.09	0.71
MMLBAU	0.71	0.39	0.04	0.01	0.96	0.33	0.04	0.02	0.87
NXLBAU	0.64	0.25	0.13	0.03	0.74	0.22	0.14	0.04	0.67
TRLBAU	identity	0.71	0.10	0.02	0.66	0.69	0.10	0.01	0.68

[a] R^2 of structural equation for comparison; [b] regression coefficient of actual on predicted values

Table 14: Dynamic Validation of the Australian Pig Industry Model: 1970:1 to 1996:4

Endogenous variable		Individual pig industry model				Integrated pig industry model			
	R^2 of structure [a]	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.	R^2	Theil's U_2 stat.	Bias error	A/P [b] coeff.
SOWSAU	0.76	0.61	0.03	0.00	1.62	0.59	0.03	0.00	1.60
SLPGAU	0.84	0.76	0.04	0.00	1.24	0.76	0.04	0.00	1.24
WTPGAU	0.99	0.97	0.01	0.02	1.00	0.97	0.01	0.02	1.00
PDPGAU	identity	0.92	0.03	0.00	1.11	0.92	0.03	0.00	1.11
DCPKAU	0.57	0.31	0.10	0.00	0.69	0.29	0.10	0.01	0.71
DMPKAU	identity	0.48	0.10	0.00	0.84	0.47	0.10	0.01	0.85
DCBHAU	0.90	0.80	0.06	0.00	1.05	0.80	0.06	0.00	1.07
DMBHAU	identity	0.89	0.06	0.00	1.05	0.88	0.06	0.00	1.06
PAPGAU	identity	0.29	0.14	0.00	0.38	0.30	0.13	0.00	0.41
PRPKAU	identity	0.52	0.05	0.00	0.62	0.42	0.04	0.03	0.66
MMPKAU	0.85	0.40	0.04	0.01	0.77	0.53	0.05	0.01	0.86
PRBANW	identity	0.50	0.05	0.04	0.68	0.42	0.06	0.09	0.68
MMBHAU	0.87	0.31	0.06	0.05	0.72	0.21	0.07	0.09	0.65
TRPGAU	identity	0.07	0.13	0.00	0.10	0.04	0.12	0.00	0.09

[a] R^2 of structural equation for comparison; [b] regression coefficient of actual on predicted values

Table 15: Dynamic Validation of the Australian Wool Industry Model: 1970:1 to 1996:4

Endogenous variable		Individual wool industry model				Integrated wool industry model			
	R^2 of structure [a]	**R^2**	**Theil's U_2 stat.**	**Bias error**	**A/P** [b] **coeff.**	**R^2**	**Theil's U_2 stat.**	**Bias error**	**A/P** [b] **coeff.**
INMEAU	0.99	0.87	0.11	0.12	1.01	0.86	0.11	0.11	1.01
TOTEWL	identity	0.94	0.07	0.12	1.04	0.92	0.08	0.13	1.01
WETHAU	0.99	0.90	0.09	0.01	0.95	0.90	0.09	0.01	0.95
SHEEP	identity	0.99	0.01	0.38	1.02	0.99	0.01	0.23	1.01
LAMBMK	0.98	0.97	0.04	0.00	0.99	0.95	0.06	0.03	0.98
BIFINE	identity	0.87	0.11	0.12	1.01	0.86	0.11	0.11	1.01
BIMED	identity	0.87	0.11	0.12	1.01	0.86	0.11	0.11	1.01
BIBROAD	identity	0.96	0.06	0.11	0.96	0.96	0.06	0.09	0.96
PDWLAU	identity	0.88	0.05	0.04	0.98	0.85	0.06	0.05	0.96
PDWLFNE	0.95	0.73	0.08	0.02	0.89	0.73	0.08	0.02	0.89
PDWLMED	0.96	0.84	0.06	0.05	0.94	0.84	0.06	0.04	0.94
PDWLBRD	0.97	0.93	0.04	0.01	0.98	0.87	0.05	0.05	0.94
STKWLAU	0.85	0.96	0.07	0.03	1.03	0.96	0.07	0.03	1.03
WLEXPT	identity	0.37	0.07	0.00	1.01	0.37	0.07	0.00	1.00
WLXJAP	0.79	0.73	0.08	0.00	1.04	0.73	0.08	0.00	1.04
WLXEEC	0.41	0.20	0.10	0.00	0.86	0.20	0.10	0.00	0.86
WLXROW	0.55	0.50	0.11	0.00	1.10	0.50	0.11	0.00	1.10
PWLEXP	identity	0.66	0.07	0.00	1.47	0.66	0.07	0.00	1.47
PWLXJAP	0.85	0.49	0.09	0.00	1.52	0.49	0.09	0.00	1.52
PWLXEEC	0.83	0.43	0.09	0.01	1.45	0.43	0.09	0.01	1.45
PWLXRW	identity	0.67	0.07	0.00	1.18	0.67	0.07	0.00	1.18
PWLMJAP	identity	0.76	0.08	0.00	0.97	0.76	0.08	0.00	0.97
PWLMEEC	identity	0.68	0.07	0.01	1.13	0.68	0.07	0.01	1.13
PWLMRW	0.81	0.78	0.13	0.00	1.14	0.78	0.06	0.00	1.14
PGWOOL	0.74	0.73	0.08	0.00	1.09	0.73	0.08	0.00	1.09
PGRW19	0.70	0.61	0.14	0.00	2.52	0.61	0.14	0.00	2.52
SLSHEEP	0.81	0.74	0.09	0.01	1.19	0.74	0.09	0.01	1.19
WTSHAU	0.38	0.17	0.03	0.00	1.02	0.17	0.03	0.00	1.02
PDMTAU	identity	0.78	0.08	0.01	1.16	0.78	0.08	0.00	1.16
DMUTAU	identity	0.46	0.24	0.54	0.53	0.46	0.24	0.54	0.53
EXMTAU	0.73	0.48	0.14	0.01	1.34	0.48	0.14	0.01	1.34
PRXMUT	0.43	0.30	0.17	0.00	0.90	0.29	0.18	0.00	0.88
PAMTAU	0.23	0.16	0.25	0.00	1.16	0.17	0.25	0.00	1.20
LSHPEX	0.84	0.59	0.11	0.00	1.20	0.59	0.11	0.00	1.20
TRWLAU	identity	0.82	0.10	0.01	1.14	0.81	0.10	0.00	1.15

[a] R^2 of structural equation for comparison; [b] regression coefficient of actual on predicted values

6. Summary

6.1 Summary of Current Progress

This paper provides details of the specification, estimation and validation of a quarterly structural econometric model of the Australian livestock and grazing industries as at September, 2000. The model's development closely follows the structural modelling procedures previously adopted in NSW Agriculture and represents an aggregation of that research into a single entity. The model contains a total of 94 endogenous variables representing the production, consumption and price formation processes of the Australian beef, sheep and wool, lamb and pig industries. Each of the component models and the integrated model is specified as a system of equations that simultaneously generates equilibrium solution values for the endogenous variables. The supply and demand blocks of each model are linked by an equilibrium balancing condition in which current prices influence decisions concerning livestock supply and demand.

The underlying rationale behind the development of this model was that a fully integrated system would capture the important cross-industry relationships in the Australian livestock sector more effectively than the existing single industry models, and that this could potentially benefit the results of analyses using the model. This is because the endogenous variables for each component industry interact to simultaneously determine each other's solution values for every period in the estimation sample. Given the satisfaction of a range of statistical criteria, the estimated model was thus expected to provide an improved economic mechanism for the purposes indicated in Section 3. That is, for testing hypotheses regarding livestock industry behaviour, for forecasting the future values of industry variables and for evaluating the impacts of events, policies and technologies which affect the Australian livestock industries.

The structure of this model differs from the authors' previous and most other related research on the important basis that it endogenises the functions of the separate industries into a single integrated system. Most other Australian livestock models have had a single industry focus in which the activities of the related industries were largely assumed to be exogenous. In reality, these activities are usually interdependent. A pertinent example of this issue is found in the earlier lamb industry models in which the average farm wool price was an important exogenous variable in the breeding ewe inventory equations (Vere and Griffith 1988; Vere *et al.* 1993). However, this price is a major factor in decision making over the entire sheep and wool industry, particularly in lamb production through its influence on first-cross ewe breeding and their subsequent use in second-cross lamb production. Similar arguments apply in modelling retail meat demand where the prices of competing meats are necessarily exogenous in single industry models. In both examples, these deficiencies can be overcome by model integration as this endogenises more of the variables that are known to influence production and consumption decisions. This process is thus expected to result in a more realistic representation of the operations of the livestock industries.

The central *a priori* considerations on which this model's specification is based are discussed in Section 2. These are that extensive livestock production in Australia is characterised by a high degree of seasonality in both supply and demand. Production follows seasonal changes in pasture growth which strongly influence livestock breeding patterns. Breeding itself is bound by biological constraints that generate time lags between breeding (joining, gestation and growing out) and the sale of products. Both these factors explain the well-observed price inelastic nature of livestock production in the short term. Seasonality is also found on the demand side of the Australian livestock industries because of quarterly changes in the flows of products onto the markets. Also, the capital good nature of the livestock resource (Jarvis 1974) is generally recognised and requires that livestock inventories be disaggregated so that the different economic decisions concerning the different livestock categories can be properly represented in the model. These considerations have been accommodated wherever possible in the current model's development.

Section 3 presents details of the individual model's specifications that closely follow the previously established procedures. Consistency with economic theory has been a foremost requirement. The main advances from the authors' previous models are the re-specification of the beef export trade block to include the Japanese market and additional export prices, and the introduction of a newly developed model of the wool and mutton industry. This model now represents all the major extensively produced livestock products.

The remainder of the paper contains the model's estimation and dynamic validation results. The overall estimation results are generally good with most of the equations displaying sound statistical properties (high R^2 values, correctly signed and significant coefficients and low autocorrelation). Three-quarters of the 51 structural equations have R^2 values greater than 0.75. Also, most of the elasticity estimates are consistent with expectations, although the low income elasticities in most of the meat consumption functions are not. In some instances, variables with insignificant coefficient estimates were retained if their inclusion in the structural equation was justified on theoretical grounds and where it improved the model validation results. The main features of the estimation results are discussed in Section 4.

The validation process is the true test of the model's potential value for industry analyses. It is often possible to obtain good estimates of either an industry's production or consumption processes, but combining and solving them in a system is usually a much more demanding task. Model validation determines the extent to which the estimated model represents the industry operations that generate the values of the endogenous variables. This is particularly so when a model has been dynamically validated because the dynamic simulation routine uses the solved values for the endogenous variables rather than the actual data. Hence, simulation errors are carried forward into the solution for the following periods. Major errors will cause the simulation to get "off track" and result in unsatisfactory model validation criteria. The results indicate a generally good model validation performance with a high proportion of the 94 endogenous variables explaining more than half of the variation in their respective series. Also, most of the dynamic simulation R^2 values are close to those of the behavioural equations. However, there are several endogenous variables with low simulation R^2 values that indicate problems in replicating the actual data for these variables.

6.2 Current Limitations

This integrated model is regarded as a major improvement on the previous individual component industry models on which it is largely based. The cross-commodity impacts have been endogenised, export demand behaviour has been enhanced and a new sheep model has been added to explain activity in the wool and mutton industries. The individual estimated equations generally reflect theoretical expectations, the estimated elasticities are consistent with previous research and the complete model provides a generally good model validation performance.

However, some limitations remain. In the beef model, the domestic prices in the US and Japanese markets are exogenous. Thus while changes in these markets cause changes in import demand for Australian beef and through that, changes in prices and quantities in the Australian market, the opposite is not the case. There is no mechanism for changes in Australian export demand to have any impact in the US or Japanese domestic markets. Australian beef imports are small in relation to total demand in the US market and are about half the total Japanese market demand, but Australia is a major supplier to both markets and imports are increasing as a proportion of total demand. The potential for two way causal impacts should be available. Domestic supply and demand data for the US and Japanese markets are currently being sourced and this limitation should be addressed during the next year.

In the wool model, the process by which export and domestic prices are linked provides a workable solution but one which could be improved. The notion that wool producers base their production decisions on expected export prices rather than current farm prices is linked to the capital good nature of the livestock resource. This is particularly relevant in the wool industry since returns are largely a function of wool quality which is usually derived from breeding programs. Thus, it makes economic sense for wool producers to base decisions on long-term price trends rather than current prices. However this relationship has proven to be difficult to satisfactorily model without treating the expected price as exogenous. Further work is required to fully endogenise this price linkage.

Improvements in the validation of particular variables, such as beef, lamb and wool export quantities, may be found by the structural model enhancements as noted above. Other improvements, such as the more precise specification of the growing Australian-US lamb export trade, and price determination in the pigmeat and mutton markets, will mainly depend on either obtaining better data and/or better estimates of the base structural equations.

Additional ways of validating the model would be useful in confirming its specification and solution processes. For example, impact testing is often adopted to examine how a model responds to either a one-off or a sustained external shock. In imposing such a shock on an exogenous variable, the model is solved with the variable's new values and the time paths of all the endogenous variables are tracked to examine whether and how (in terms of the time taken) the model returns to an equilibrium set of values. Out of sample validation is also sometimes adopted to examine how a model responds to observations of variables that are outside the estimation sample. Both these types of experiments are currently being undertaken.

Finally, data collection mechanisms do not always closely follow industry marketing practice. Thus, while to varying degrees different types of livestock are sold direct to processors on a contractual over-the-hook basis, sufficiently long data series of these types of transactions are not yet available to enable their inclusion in the econometric estimation process. In the model described here, farm level prices are generally defined to be saleyard prices because that market is well reported. Our expectation is that saleyard prices and contract prices will generally move together on a quarterly basis, so this omission should not be too limiting. As more over-the-hooks price data become available, it is envisaged that these series will be integrated into the modelling of the farm level price formation processes.

6.3 Plans for Applying the Model

Overall, the proposed uses for this integrated model are similar to those to which the individual industry models have previously been applied (Section 2.3). It is expected that this model will allow improved economic analyses of the effects of issues in Australia's livestock industries since model integration endogenises more of the variables that are known to influence livestock sector economic activity. Combining single industry SEMs into an integrated system thus provides the opportunity to more realistically represent the causal relationships between variables within and across the industries. The attraction of this process is that it allows the joint analysis of industry issues to be directly undertaken. This is considered to be an important advantage in analysing competitive industries, such as those for Australian livestock, which exhibit strong interdependent relationships in the production and disposal of livestock products. Therefore the model will help to overcome the problem that has been experienced in many previous livestock industry economic studies based on the use of individual industry SEMs in which some of the important relationships between variables were assumed to be exogenous. For example, the model will directly allow the impacts of a production-expanding technology in the beef industry to be jointly evaluated in terms of responses in the other livestock industries. Of particular interest in this situation will be the cross effects on the consumption and prices of lamb and pork where an increase in the supply of beef reduces beef prices and increases beef consumption.

Also, the model will enable the cross-industry effects of potential government policy in individual industries to be evaluated. Analyses such as these will provide important information to government and industry bodies to assist policy making and R&D decisions. The model will also allow joint forecasting to be undertaken across the meat industries. Improved forecasts are expected to result because the model allows the direct interaction of each industry's set of variables in determining forecast values. Further, the model will provide a source of estimates of the quantity, price and elasticity parameters that are required in livestock industry evaluations that utilise economic surplus analysis. The CRC for Cattle and Beef Quality is an example of a major livestock industry research program that will utilise this model for economic analyses.

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Appendix A: Data Definitions and Sources

Endogenous Variables

AUSBI: Australian adjusted breeding ewe inventory incorporating the seasonal allocation of mating intentions, (millions, calculated);

AUSBX: Australian total adjusted breeding ewe inventory, (millions, calculated);

BIBROAD: broad wool breeding ewe inventory, Australia, (millions, calculated);

BIFINE: fine wool breeding ewe inventory, Australia, (millions, calculated);

BIMED: medium wool breeding ewe inventory, Australia, (millions, calculated);

DCBFAU: per capita consumption of beef, Australia, (kg, calculated);

DCBHAU: per capita consumption of bacon and ham, Australia, (kg, calculated);

DCLBAU: per capita consumption of lamb, Australia, (kg, calculated);

DCPKAU: per capita consumption of pork, Australia, (kg, calculated);

DMBFAU: total consumption of beef and veal, Australia, (kt, AMLC);

DMBHAU: total consumption of bacon and ham, Australia, (kt, AMLC);

DMLBAU: total consumption of lamb, Australia, (kt, AMLC);

DMPKAU: total consumption of pork, Australia, (kt, AMLC);

DMUTAU: consumption of mutton, Australia, (kt, AMLC);

EXBFAJP: Japanese beef imports from Australia, (kt, ALIC);

EXBFAUS: Australian beef exports to US, (kt, AMLC);

EXBFROW: Australian exports of beef and veal to ROW, (kt, calculated);

EXBEEF: Australian exports of beef and veal, (kt, AMLC);

EXMTAU: Australian exports of mutton, (kt, AMLC);

IMBFJAP: Japanese beef imports from all sources, (kt, ALIC);

INCHAU: number of cows and heifers, Australia, interpolated, (millions, ABS);

INCPAU: number of ewes intended to be mated to Corriedale and Polwarth rams, Australia, interpolated, (millions, ABS);

INLWAU: number of ewes intended to be mated to long wool rams, Australia, interpolated, (millions, ABS);

INMEAU: number of ewes intended to be mated to Merino rams, Australia, interpolated, (millions, ABS);

INSBAU: number of steers and bulls, Australia, interpolated, (millions, ABS);

INSWAU: number of ewes intended to be mated to short wool rams, Australia, interpolated, (millions, ABS);

INVLAU: number of calves, Australia, interpolated, (millions, ABS);

LAMBAL: balance of lambs not slaughtered, Australia, (millions, calculated);

LAMBMK: number of lambs marked, Australia, (millions, ABS);

LSHPEX: Australian live sheep exports, ('000, AMLC);

MMBFAU: price spread for beef, Australia, (c/kg, calculated);

MMBHAU: price spread for bacon and ham, Australia, (c/kg, calculated);

MMLBAU: price spread for lamb, Australia, (c/kg, calculated);

MMPKAU: price spread for pork, Australia, (c/kg, calculated);

NXLBAU: Australian exports of lamb, (kt, AMLC);

NOB: number of cattle births, Australia, (millions, ABS);

PABFAU: saleyard beef price, 301-350 kg. dressed weight, Australia, (c/kg, ABARE);

PALBAU: saleyard lamb price, 16-19 kg. dressed weight, Australia, (c/kg, ABARE);

PAMTAU: saleyard mutton price, 22 kg. dressed weight, Australia, (c/kg, ABARE);

PAPGAU: saleyard pigmeat price, 60-73 kg. dressed weight, Australia, (c/kg, ABARE);

PDLBAU: lamb production, Australia, (kt, AMLC);

PDMTAU: mutton production, Australia, (kt, AMLC);

PDPGAU: pigmeat production, Australia, (kt, AMLC);

PDWLAU: greasy wool production, all microns, Australia, (kt, WI);

PDWLBRD: greasy wool production, broad microns, Australia, (kt, WI);

PDWLFNE: greasy wool production, fine microns, Australia, (kt, WI);

PDWLMED: greasy production, medium microns, Australia, (kt, WI);

PGWOOL: average greasy wool price, Australia, (c/kg, NCWSBA);

PGRW19: average greasy fine wool price, Australia, (c/kg, WI);

PRBANW: retail price of bacon and ham, New South Wales, (c/kg, ABARE);

PRBFAU: retail price of beef, Australia, (c/kg, ABARE);

PREXBF: average Australian export price, (c/kg, calculated);

PRXMUT: mutton export price, Australia, (c/kg, Japanese series, ABARE);

PRLBAU: retail price of lamb, Australia, (c/kg, ABARE);

PRODBF: production of beef and veal, Australia, (kt, AMLC);

PRPKAU: retail price of pork, Australia, (c/kg, ABARE);

PWLEXP: Australian average export wool price in all markets, (c/kg, FOB, calculated);

PWLMEEC: CIF equivalent of PWLXEEC, (c/kg);

PWLMJAP: CIF equivalent of PWLXJAP, (c/kg);

PWLMRW: CIF equivalent of PWLXRW, (c/kg);

PWLXEEC: Australian average export wool price in EEC, (c/kg, FOB, calculated);

PWLXJAP: Australian FOB average export wool price in Japan, (c/kg, calculated);

PWLXRW: Australian FOB average export wool price in ROW, (c/kg, calculated);

PXBFAJP: Australian FOB beef export price to Japan, (c/kg, AMLC):

PXBFAUS: Australian FOB beef price in US, (c/kg, AMLC);

PXBFROW: Australian FOB beef export price in ROW, (USc/kg, calculated);

PXBRWCF: Australian CIF beef export price in ROW, (yen/kg, calculated);

PXBJPCF: Australian CIF beef export price in Japan, (yen/kg, calculated);

PXBUSCF: Australian CIF beef export price in US, (USc/kg, calculated);

SHEEP: total number of sheep, Australia, (millions, ABS);

SLCHAU: slaughterings of cows and heifers, ('000, ABS);

SLLBAU: slaughterings of lambs, Australia, (millions, ABS);

SLPGAU: slaughterings of pigs, Australia, (millions, ABS);

SLSBAU: slaughterings of steers and bulls, Australia, ('000, ABS);

SLSHEEP: adult sheep slaughter, Australia, (millions, AMLC);

SLVLAU: slaughterings of calves, Australia, ('000, ABS);

SOWSAU: inventory of breeding sows, Australia, (millions, AMLC);

STKWLAU: closing greasy wool stocks, Australia, (kt, WI);

TOTEWL: total breeding ewe inventory, Australia, (millions, calculated);

TRBFAU: total beef industry revenue, ($millions, calculated);

TRLBAU: total lamb industry revenue, ($millions, calculated);

TRPGAU: total pig industry revenue, ($millions, calculated);

TRWLAU: total wool industry revenue, ($millions, calculated);

USBIMP: US imports of beef from all sources, (kt, USDA);

USPNZ: price of New Zealand beef in US, (c/kg, NZMWB);

WETHAU: number of wethers, Australia, (millions, ABS);

WLEXPT: Australian wool exports to all destinations, (kt, WI);

WLXEEC: Australian wool exports to the EEC, (kt, WI);

WLXJAP: Australian wool exports to Japan, (kt, WI);

WLXROW: Australian wool exports to ROW, (kt, calculated);

WTBFAU: average beef slaughter weight, (kg, calculated);

WTPGAU: average pig slaughter weight, (kg, calculated);

WTSHAU: average adult sheep slaughter weight, (kg, calculated);

WTVLAU: average veal slaughter weight, (kg, calculated).

Exogenous Variables

CPIAUN: consumer price index, Australia, (UN Statistical Bulletin);

CPIBG: consumer price index, Belgium, (UN Statistical Bulletin);

CPIFR: consumer price index, France, (UN Statistical Bulletin);

CPIGR: consumer price index, Germany, (UN Statistical Bulletin);

CPIIT: consumer price index, Italy, (UN Statistical Bulletin);

CPIJAP: consumer price index, Japan, (UN Statistical Bulletin);

CPINE: consumer price index, Netherlands, (UN Statistical Bulletin);

CPINZ: consumer price index, New Zealand, (UN Statistical Bulletin);

CPIUK: consumer price index, UK, (UN Statistical Bulletin);

CPIUS: consumer price index, United States, (UN Statistical Bulletin);

CPROM: promotion of calves to the adult cattle herd, (estimated);

CRAT: ratio of calves born to breeding cows, (estimated);

DMDT: dummy variable for periods of drought;

DUM74: dummy variable, 1974 (4) = 1, 0, elsewhere;

DUMQ1: seasonal dummy variable, quarter 1 = 1, 0, elsewhere;

DUMQ2: seasonal dummy variable, quarter 2 = 1, 0, elsewhere;

DUMQ3: seasonal dummy variable, quarter 3 = 1, 0, elsewhere;

DUMRP1: dummy variable for period of Wool Reserve Price Scheme (WPRS), (1 = WPRS not operating);

DUMRP2: dummy variable for period of Wool Reserve Price Scheme (WPRS), (1 = WPRS operating);

DUMWQ: dummy variable for period of wheat quota, (1 = quota operating);

EXPIG: Australian exports of pork, (kt, AMLC);

EXPWL: expected average wool export price two quarters ahead, (calculated);

FRBFJP: freight rate for beef to Japan, (c/kg, carton weight, AMLC);

FRBFUS: freight rate for beef to US, (c/kg, carton weight, AMLC);

INCAU: household disposable income, Australia, ($'000), ABS;

MIWOOL: eastern wool market indicator, (c/kg clean, WI);

MTXVAL: value of mutton exports, Australia, ($millions, AMLC);

NZWLEX: New Zealand wool exports, (kt, WONZ);

OTHEWE: number of non-breeding ewes, Australia, (millions, ABS):

PB2JAP: wholesale domestic beef price in Japan, (yen/kg; ALIC);

PCEXBG: personal expenditure, Belgium, (billions home currency, IMF);

PCEXFR: personal expenditure, France, (billions home currency, IMF);

PCEXGR: personal expenditure, Germany, (billions home currency, IMF);

PCEXIT: personal expenditure, Italy, (billions home currency, IMF);

PCEXJAP: personal expenditure, Japan, (billions home currency, IMF);

PCEXNE: personal expenditure, Netherlands, (billions home currency, IMF);

PCEXUK: personal expenditure, UK, (billions home currency, IMF);

PCEXUS: personal expenditure, US, (billions home currency, IMF);

PCLWOOL: clean wool price, Australia, (c/kg, WI);

PDIFLBAU: lamb export-farm price differential, (calculated);

PDVLAU: veal production, Australia, (kt, AMLC);

PGWHAU: average export price of wheat, ($/tonne),

PIAU: area of improved pastures, Australia, (million ha, ABS);

POPNAU: Australian population, (millions, ABS);

PMUTDIF: mutton farm/export price differential, (calculated);

PRATIO: Australian/New Zealand export beef price ratio in US, (calculated);

PRCHAU: retail price of chicken, Australia, (c/kg, ABARE);

PRCOT: world cotton price, (US c/kg, ABARE);

PRPOLY: world polyester price, (US c/kg, ABARE);

PWBFUS: US manufacturing beef price, Omaha series, (US c/kg, AMLC);

PWLXNZ: average New Zealand wool export price, (NZ c/kg, calculated);

RAMS: number of rams, Australia, (millions, ABS):

SHARE: Australia's share of total US beef imports, (%, AMLC);

STBFAU: closing beef and veal stocks, Australia, (kt, AMLC);

STKBFJP: Japanese beef stocks, (kt, ALIC);

STKPGAU: closing pigmeat stocks, Australia, (kt, AMLC);

STLBAU: stocks of lamb, Australia, (kt, AMLC);

TIME65: time trend, 1 in 1965 (3), 2 in 1965 (4), etc.

UPRATIO: US/Australian export beef price ratio in US, (calculated);

USREG: negotiated restraint level for US beef imports, (kt, AMLC);

WAGEAU: wages paid in meat processing sector, ($/week),

WPRATIO: farm greasy wool price/market indicator ratio, Australia, (calculated);

XRAUBG: exchange rate, Australia-Belgium, ($AUD, RBA Bulletin);

XRAUFR: exchange rate, Australia-France, ($AUD, RBA Bulletin);

XRAUGR: exchange rate, Australia-Germany, ($AUD, RBA Bulletin);

XRAUIT: exchange rate, Australia-Italy, ($AUD, RBA Bulletin);

XRAUJAP: exchange rate, Australia-Japan, ($AUD, RBA Bulletin);

XRAUNE: exchange rate, Australia-Netherlands, ($AUD, RBA Bulletin);

XRAUUK: exchange rate, Australia-UK, ($AUD, RBA Bulletin);

XRUSAU: exchange rate, Australia-US, ($AUD, RBA Bulletin);

YPCAU: per capita income, Australia, ($AUD '000, ABS);

YPCJAP: per capita income, Japan, ($US '000, OECD);

YPCUS: per capita income, USA, ($US '000, OECD).

Sources

Agriculture and Livestock Industries Corporation (ALIC, Japan);
Australian Bureau of Agricultural and Resource Economics (ABARE);
Australian Bureau of Statistics (ABS);
Australian Meat and Live-stock Corporation, Meat and Livestock Australia (AMLC, MLA); International Monetary Fund (IMF);
National Council of Wool Selling Brokers of Australia (NCWSBA);
New Zealand Meat and Wool Board (NZMWB);
Organisation for Economic Co-operation and Development (OECD);
Reserve Bank of Australia (RBA);
United Nations (UN);
United States Department of Agriculture (USDA);
Wool International (WI);
Wools of New Zealand (WONZ).