The Competitive Structure of the Australian Beef Industry:

Accounting for Trade

Xueyan Zhao, Garry R. Griffith and John D. Mullen

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Abstract

There has been a longstanding interest in the degree of competition in the Australian meat and livestock industries. Various inquiries have examined aspects of oligopsonistic pricing practices by wholesalers, processors and retailers; labour relations in meat processing; vertical integration; and foreign ownership. No consensus has emerged, but the suspicion of noncompetitive behaviour remains. In this paper, a model developed by Holloway based on the conjectural variations of noncompetitive firms is applied to Australian beef industry data. In a model without a trade sector there was strong evidence of noncompetitive behaviour. However in a model in which the domestic and export markets were treated as being separate, there was evidence that the domestic market was competitive while the export market was not. These findings have important implications for the choice of conceptual frameworks to model this industry.
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Introduction

There has been concern over a long period of time about the degree of competition in the Australian meat and livestock industries and the implications this has for structure, conduct and performance. A large number of government, parliamentary and industry inquiries have examined aspects of oligopsonistic pricing practices by wholesalers, processors and retailers; labour relations in meat processing; vertical integration; foreign ownership; and the provision and quality of market information (see reviews in Industry Commission and Bureau of Agricultural Economics 1981). In the early years the questions asked related to whether governments should intervene to modify industry structure, conduct or performance, while in later years, alongside developments in competition policy, the questions had changed to how to encourage microeconomic reform in these industries.

Meat industry structure and practices have changed considerably over the past 25 or so years, and many early criticisms are now unfounded. In particular, there are now better systems for describing products and providing this information to suppliers and purchasers of meat. Many of the smaller, older abattoirs have been closed down or rebuilt. In fact, many structural aspects of the meat industry were reported favourably upon by the Industry Commission. However, other aspects were not. The meat processing sector has been consistently singled out as a high cost sector which would benefit from reform of regulatory constraint and labour relations. Alternatively, many analysts now believe that the supermarkets wield an unacceptable degree of market power in these industries, and additionally, the Australian Meat and Live-Stock Corporation still licences meat exporters. Hence the suspicion of noncompetitive behaviour in the meat and livestock industries remains.

On another level, a growing share of public and producers’ funds have been used in recent years to finance research in the meat processing sector and promotion in retail meat markets as well as livestock production research. Mullen, Alston and Wohlgenant and Wohlgenant (1993) have demonstrated that under competitive conditions producers receive a smaller share of the benefits from processing research and promotion than they do from traditional production research activities. This arises because of input substitution between farm and non-farm inputs. If input suppliers to the processing sector can capture an even larger share of the benefits from new processing technology or generic promotion because of the exercise of market power, then the profitability of processing research or promotion needs to be higher to justify the investment of producer levies in these activities ahead of investment in production research.

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1 Similarly, processors and retailers bear a smaller share of the incidence of levies imposed at the point of sale of farm products than do producers.

2 Presuming that when there is a lack of competition in processing, the distribution of benefits from new technology and promotion are skewed further away from producers.
A number of recent evaluations of the distribution of benefits from research and promotion activities in the Australian livestock industries have used equilibrium displacement modelling (EDM) (see for example, Mullen, Alston and Wohlgenant; Piggott; Mullen and Alston; Piggott, Piggott and Wright; Hill, Piggott and Griffith). In all of these studies, a competitive market has been assumed. Freebairn, Davis and Edwards suggested how imperfect competition might be modelled, and Huang and Sexton, and Alston, Sexton and Zhang have recently developed a general oligopoly/oligopsony model to analyse the distribution of returns to research. Mullen and Alston (p.60) specifically recommended that “...an assessment has to be made of the competitive nature of the marketing chain in the lamb industry.” However, little empirical work has been done in relation to the Australian livestock industries and the results are ambiguous. Hyde and Perloff found that the domestic retail meat market was competitive for beef, lamb and pork and that market power had not increased over time. Conversely, Griffith, Green and Duff found that short run price levelling was a pervasive characteristic of these markets, a factor which is inconsistent with competitive market behaviour, and Chang and Griffith found that although beef farm, wholesale and retail prices were cointegrated, and thus moved together over time, the retail price could be considered to be weakly exogenous to the farm and wholesale prices. This could be an indication of market inefficiency.

Hence, whether interest lies with general questions of structure, conduct and performance within the livestock industries or with more specific questions about the distribution of the benefits from new production and processing technologies and from promotion, it is critical to know whether the Australian meat and livestock industries can be characterised as perfectly competitive. Thus the initial task is to test for the existence of non-competitive behaviour, rather than to examine the consequences of imperfect competition for the distribution of the benefits of research. In this paper, a model developed by Holloway is applied to Australian beef industry data to examine this issue\(^3\). The contributions of the research are to generate new knowledge on the competitive structure of the Australian beef industry, to apply the model to a situation where trade is a critical part of the industry, and to improve the sufficiency conditions derived in the original paper.

**The Underlying Conceptual Model**

Holloway extended Gardner’s model of equilibrium in a food marketing system based on perfect competition to a conjectural-variations oligopoly with endogenous entry of firms. An important parameter is \(\theta_i\), the elasticity of total industry output conjectured by each identical firm \(i\). Given an industry demand curve, an aggregate output identity as the sum of each firm’s output and the firm’s conjecture function, the first order condition for profit maximisation by the firm can be written as:

\[
P_x(1 + \theta_i/\eta) = C(P_a, P_b)
\]

where \(P_x\) is the retail price of the food product \(x\), \(\eta\) is the own-price elasticity of demand for \(x\) at retail, and \(C(.)\) is the firm’s unit marginal cost defined over \(P_a\) and \(P_b\) which are the prices of the farm commodity input \(a\) and a marketing services input \(b\), used to produce \(x\). If \(\theta_i \equiv \theta = 0\), then (1) represents the perfectly competitive solution of price equal to marginal cost; if \(\theta_i \equiv \theta

\(^3\) The beef industry is the largest and most export-oriented of the Australian livestock industries and best illustrates the points raised in this paper.
\( = 1 \), the equation represents the monopoly solution of marginal revenue equal to marginal cost. Thus the value of \( \theta \) indicates the degree of competition in the market for product \( x \).

Unfortunately, \( \theta \) cannot be measured easily. Holloway derived a set of equivalent conditions for \( \theta = 0 \), from the equilibrium model, that are empirically testable. This model included the industry demand curve for \( x \), the aggregate output identity for \( x \), the equilibrium condition in (1), a firm entry condition, two firm input demand schedules for \( a \) and \( b \), two aggregate input quantity identities, and two inverse supply functions for \( P_a \) and \( P_b \). This ten equation model was then expressed in proportional changes denoted by superscript (*) to allow solution for a new equilibrium following an exogenous shift in demand or supply conditions (Holloway’s equations (11) to (20), p. 982).

To simplify his system of equations and facilitate the development of testable hypotheses about the level of competition, Holloway adopted three assumptions about parameter relationships commonly made in past studies (in particular Wohlgenant 1989). These were (i) that the supply of the farm commodity \( a \) is predetermined during a year and hence is exogenous, (ii) that the supply of marketing inputs is perfectly elastic (which means \( P_b \) is exogenous), and (iii) that the exogenous retail demand shift variable \( N^* \) can be estimated as a linear combination of known elasticities and values of individual demand shifters such as income, population, and the prices of competitive goods.

Holloway then focused on Gardner’s retail-farm price ratio \( R = P_x / P_a \). In proportional change terms and in relation to one of the exogenous variables, say \( N^* \), this ratio can be expressed as:

\[
R^* / N^* = (P_x^* / N^*) - (P_a^* / N^*) \quad \text{or as} \quad E_{R,N} = E_{P_x,N} - E_{P_a,N}
\]

These last three terms are elasticities of the retail-farm price ratio, the retail price and the farm price, respectively, with respect to the exogenous demand shift variable \( N^* \). Similar expressions to those in (2) exist for the other exogenous variables \( a^* \) and \( P_b^* \), to give \( E_{R,a} \) and \( E_{R,P_b} \), respectively. These expressions can be written in expanded form in terms of all the parameters of the model including \( \theta \) (Holloway’s equations (21) to (23), p. 983), and from these Holloway derived testable hypotheses about how farm and retail prices and the price spread responded to changes in demand and supply conditions were the market competitive, ie were \( \theta = 0 \).

Necessary and almost sufficient conditions for perfect competition in food markets were found to be each of the following:

\[
(3) \quad E_{P_x,N} = -E_{P_x,a} \\
(4) \quad E_{P_a,N} = -E_{P_a,a} \\
(5) \quad E_{R,N} = -E_{R,a}
\]

These are equivalent conditions for \( \theta = 0 \). Thus under perfect competition, and the three assumptions listed above, the proportional effects on the retail price, the farm price and their ratio, of shifts in retail level demand and farm level supply are equal in magnitude and opposite in sign (Holloway, p.984).

Holloway showed that the farm price condition (4) is sufficient to infer \( \theta = 0 \) but did not recognise that the ratio condition (5) is also sufficient for \( \theta = 0 \). Examining the proof of Holloway’s proposition (p.985), it can be shown that (5) is sufficient for \( \theta(\sigma_\omega-\cdots) \).
\[ \frac{\eta}{(\theta+\eta)} = 0, \]
where \( \sigma \) is the elasticity of substitution between the farm input and the marketing input, \( \omega_b \) is the cost share of the marketing input, and \( \Phi \) is an aggregate term of various elasticities and cost shares. Following Holloway’s reasoning for \( (\theta+\eta) \neq 0 \) and \( \Phi \neq 0 \), it follows that \( \theta(\sigma \omega_b - \eta) = 0 \). Given that \( \sigma \omega_b \geq 0 \), and \( \eta \leq 0 \), the term \( (\sigma \omega_b - \eta) \) must be non-negative. Thus the only possibility of \( \sigma \omega_b - \eta = 0 \) is when both \( \sigma = 0 \) and \( \eta = 0 \). Holloway has shown that a perfectly inelastic demand \( \eta = 0 \) infers \( \theta = 0 \). Thus (5) is indeed sufficient to infer \( \theta = 0 \), or perfect competition.

For the retail price condition, Holloway showed that (3) is sufficient only for \( \sigma \theta = 0 \). Thus, if there is independent evidence that \( \sigma \neq 0 \), (3) is sufficient for competition. If there is no such evidence about \( \sigma \), he showed that \( E_{P_x P_b} \neq 0 \) infers \( \sigma \neq 0 \), where \( E_{P_x P_b} \) is the proportional effect on the retail price with respect to a change in the price of marketing services. Thus:

(6) \[ E_{P_x P_b} \neq 0 \]
is a joint sufficient condition, together with (3), to infer competition in the retail price equation.

Therefore "... a test of competition reduces to a test of the validity of a linear restriction imposed across the coefficients of \( N^* \) and \( \alpha^* \) in a regression on \( R^* \)" (Holloway, p.984), or equivalently on \( P_x^* \) or \( P_a^* \). In Holloway’s notation, the models to be estimated are:

(7) \[ P_x^* = \beta_{N N}^* N^* + \beta_{N a}^* a^* + \beta_{N b}^* P_b^* + \epsilon_x \]
(8) \[ P_a^* = \beta_{N N}^* N^* + \beta_{a a}^* a^* + \beta_{a b}^* P_b^* + \epsilon_a \]
(9) \[ R^* = \beta_{N N}^* N^* + \beta_{a a}^* a^* + \beta_{a b}^* P_b^* + \epsilon_R \]

where the \( \beta \)s are coefficients to be estimated, the \( \epsilon \) are stochastic errors and all variables are defined in the current period. The conditions for competition outlined in (3) to (5) amount to tests of:

(3)' \[ \beta_{N N} = -\beta_{a a} \]
(4)' \[ \beta_{N N} = -\beta_{a a} \quad \text{and} \]
(5)' \[ \beta_{N N} = -\beta_{b a} \]
in (7) to (9), respectively, while the condition in (6) amounts to a test of:

(6') \[ \beta_{a b} \neq 0. \]

Empirically, if any of the F-tests for the restrictions embedded in the equivalent hypotheses (3)'-(5)', that the demand shift and supply shift variables be equal but of opposite sign, are significant, this implies at least one piece of evidence that the industry is not competitive. On the other hand, if none of the F-tests are significant, and the test for the hypothesis that \( \beta_{a b} \neq 0 \) is rejected, or there is other evidence that \( \sigma \neq 0 \), then the empirical data are consistent with competitive behaviour.

**Alternative Models for the Australian Beef Industry**
**Base model**

Our base model was a direct application of Holloway's model embedded in (7) - (9) to the Australian beef industry. Domestic retail beef price, average saleyard cattle price and total beef production data were used for $P_x$, $P_a$ and $a$, respectively, and an index of marketing and processing costs was used for $P_b$. $N^*$ was calculated as a linear combination of Australian retail prices of competitive goods, income and population and their relevant elasticities. Definitions and data descriptions for the variables in (7)-(9) for the base model are summarised in Table 1.

**Aggregated model**

One important assumption of the Gardner, Wohlgenant (1989) and Holloway analyses, and therefore of the base model, was that the product was produced and consumed domestically. Holloway recognised that international trade plays an important role in many food-marketing systems, but argued that the complexities of introducing a foreign marketing sector were outside the scope of his paper. While ignoring trade effects may not significantly influence analyses of United States food markets, this will not be the case for the Australian beef industry. For example, exports of beef and veal from the United States averaged about 7 per cent of production in the three years to 1996 (and imports averaged about 10 per cent), but for Australia exports of beef and veal exceeded 64 per cent of production in the same period (AMLC 1996). Thus the production of beef in Australia is driven by both domestic and export demand. However, the demand shifter $N^*$ in the base model is constructed from domestic market information only.

Two alternative models are estimated in an attempt to measure beef market behaviour in a trade environment. For the first model domestic and export markets were aggregated as illustrated in Table 2. Input variables were represented by the average saleyard cattle price, total beef production and the marketing cost index as in the base model. However, the 'retail' product $X$ was defined as the sum of domestic demand ($X_d$) and export demand ($X_e$), ie $X = X_d + X_e$, and the 'retail' price of $X$ as the weighted average of the domestic retail price and the export price:

$$P_x = (P_d X_d + P_e X_e)/(X_d + X_e) = \rho_d P_d + \rho_e P_e$$

where $\rho_d$ and $\rho_e$ are the proportions of domestic and overseas consumption for each year. The demand shifter was constructed as the weighted average of the domestic demand shifter and an overseas demand shifter:

$$N_{ag}^* = \rho_d N_d^* + \rho_e N_e^*$$

The domestic demand shifter $N_d^*$ was calculated from the Australian market information as in the base model in Table 1. The export demand shifter $N_e^*$ was calculated from demand conditions in the United States and Japanese markets. Exports to these two countries have accounted for 70-80 per cent of total Australian beef exports since 1970 (ABARE 95). The demand shifter for 1977-94 was a weighted average of demand shifters for these two markets. Due to data limitations in the Japanese meat market before 1977 and the fact that only a small proportion of beef exports were destined for Japan during this early period, only the United
States market data were used to calculate the export demand shifter for 1970-76. Specification of the aggregated model is detailed in Table 2.

**Separated domestic and export markets**

While there is some degree of substitution possible between enduses of beef, increasingly cattle destined for the domestic butcher and supermarket trade are differentiated from cattle destined for the various overseas target markets (NSW Agriculture). Production for export markets is often contracted before the cattle are fattened, slaughtered and processed. Therefore a second approach to modelling trade is to assume that the domestic and export markets for the Australian beef industry are separable.

The domestic sector was modelled using domestic retail price, saleyard cattle price for lighter cattle and beef production for domestic consumption. The domestic demand shifter was calculated from the domestic market information as in the base model. The export sector was modelled using the unit value of export beef, saleyard price for heavier cattle and beef production for export. Again, the demand shifter from the overseas markets was calculated from the United States and Japanese market conditions as in the Table 2. Details of the separate models are summarised in Table 3.

**Data Requirements**

**Raw data sources**

In terms of the raw Australian data needed, average farm price of all beef cattle, and the average price of domestic trade and export type cattle and the retail prices of beef, lamb, pork and chicken were obtained from ABARE (1995) and ABS (1993b). The quantities of beef and veal produced, consumed domestically and exported in total and to the specified markets and total export value were obtained from AMLC (1993) and ABARE (1995). Household disposable income and population were obtained from various ABS publications (ABS 1993a,c) and ABARE (1995).

To calculate the export market demand shifters, United States retail pork price, per capita income and population were collected from USDA. Similarly, Japanese retail prices of pork, chicken and eggs (were collected from LIPC, while population, per capita GNP and the two exchange rates were derived from IMF data. Data were collected for the period 1970 to 1994, except that Japanese retail prices were unavailable prior to 1977 as shown in Table 2.

**Data transformations**

Two quite important data adjustments were required. First, Wohlgenant (1989) and Holloway used farm prices for livestock adjusted for byproduct values, but a consistent series for Australian byproduct values used in Griffith, Green and Duff was only available for the period 1980 to 1988. To extrapolate byproduct values prior to 1980 and after 1988, the ratio of the byproduct value to the farm price was calculated for each meat, and the resulting values for 1980-1982 were averaged and extrapolated for 1970 to 1979, while the values for 1986-1988
were averaged and extrapolated for 1989 to 1994. The subsequent byproduct values were deducted from the farm price taking account of the dressing percentages of each meat.

Similarly in Australia there is no published index of marketing costs for meat products. Information from the ABS (1994) industry performance data for Retail Trade (Table 32) and Manufacturing (Table 16) was examined and it was found that, excluding raw materials, the cost proportions were labour (about 75 per cent over the period 1990/91 to 1993/94), depreciation (about 10 per cent), interest (about 10 per cent) and other operating expenses (mainly power - about 5 per cent). Thus the relevant wage rate (ABS 1993d), a price index for electricity (ABS 1992) and an overdraft rate (ABARE 1995) were converted into common-based indexes and combined using weights (75:10:15) to form an index of marketing and processing costs.4

Following Holloway, all prices were in nominal form since the normal homogeneity conditions for prices do not necessarily hold in the general imperfectly competitive model.

Demand elasticities

Finally, a set of cross-price and income elasticities was required to calculate the demand shift variables. For the Australian shifter, $N_d^*$, a survey of previous empirical estimates revealed that most of the estimated elasticity values were based on quarterly data, and those that were based on annual data were quite dated and incomplete (the most recent being BAE (1985) and Murray). We re-estimated the required elasticities for the domestic demand shift variable using the most recent data available. A set of linear demand functions in the logs of the variables were specified and estimated as a SUR system. Restrictions of homogeneity and symmetry were tested and rejected, but more complicated demand systems models were not pursued. To calculate $N_e^*$, meat demand elasticities were required for Japan and the United States. Elasticities for Japan were estimated in the same manner as for Australia since those available in ABARE (1991) were not strictly appropriate. Elasticities for the United States market were obtained from Wohlgenant (1989). These elasticity values are reported in Table 4.

Results

Equations (7) - (9) for the base model described in Table 1 were estimated in SHAZAM and checked in TSP. For space reasons the unrestricted estimates are not provided but can be obtained from the authors. The results for the restricted estimates, with (3)'-(5)' imposed, along with the test statistics are provided in Table 5. The $R^2$ are reasonable for these percentage change types of models, although the DW estimates indicate the possible presence of autocorrelation.5 In the farm and retail price equations, the coefficients on the demand shift variable are positive and significant, while the coefficients on the farm supply shift variable and the marketing cost variable are negative and significant. In the ratio equation, the signs are reversed and the variables are still significant. The restriction is strongly rejected for the retail

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4 Alternate weightings were tested but did not influence the results.
5 The three equations were re-estimated with an autocorrelation correction, but the rho coefficients were not significant so the OLS estimates were retained. This procedure was followed for all models. As a final check on the possible effects of autocorrelation, likelihood ratio tests were conducted on the models estimated with autocorrelation corrections, and the results were identical to the OLS models.
price equation, although not for either the farm price or ratio equations. This is very strong evidence that the beef market in this particular specification is non-competitive.

Results of the restricted estimates for the aggregated model are reported in Table 6. This specification provided strong and consistent evidence that the beef market is non-competitive. Each of the F tests strongly rejects the hypothesis that the retail demand and farm supply coefficients are equal and opposite in sign.

Finally, the results for the disaggregated model in which the domestic and export markets are treated as being separable are reported in Table 7. The restriction on elasticities is not rejected at even the 10 per cent level for any of the domestic market equations, and the hypothesis that $\beta_{x_b}=0$ is strongly rejected. Thus no evidence is found against any of the three sufficient conditions for perfect competition, and competitive behaviour is implied in the domestic beef market. Conversely, there is strong and consistent evidence that the export beef market is non-competitive. Two of the F tests reject the hypothesis that the retail demand and farm supply coefficients are equal and opposite in sign.

**Conclusions and Implications**

In this paper, a model developed by Holloway based on the conjectural variations of noncompetitive firms was used to assess the level of competition in the Australian beef industry. New evidence about the competitive structure of the beef industry was generated, the modelling framework was extended to account for the influence of trade, and the sufficiency conditions for testing for competitive behaviour were improved and clarified.

In a model ignoring trade adapted from Holloway, strong evidence was found of noncompetitive market behaviour in the Australian beef industry. However the Australian beef industry has a large export sector. When the model was respecified to account for trade, the findings about competitive behaviour were found to be sensitive to how the domestic and export markets for beef were modelled: (a) when the two markets were aggregated, the aggregate market was noncompetitive, But (b) when the domestic beef market was completely quarantined from the export market, the farm supply of beef being defined as only that destined for the domestic market, there was no evidence of non-competitive behaviour. These results are consistent with the lack of evidence of market power in meat retailing in the Sydney market provided by Hyde and Perloff and by Chang and Griffith. However there was strong evidence that the export market has been non-competitive.

The implication that the domestic beef market has been competitive but the export beef market has not been, raises two interesting questions:

- why the difference? and
- how is the beef industry best modelled in the future?

In the Introduction several features of the livestock industries in Australia that might lead to the emergence of market power were identified. These included barriers to entry in the form of government regulation and union power. The analysis reported above sheds no light as to why the domestic and export markets are different nor where the market power resides.

If union power is a significant source of non-competitive behaviour, then the assumption that the supply of marketing inputs is perfectly elastic is untenable and further work is required to derive testable hypotheses about competition which do not require this assumption. However Zhao, Griffith and Mullen found little evidence of non-competitive behaviour in the Australian
lamb and pig industries which operate under similar labour conditions to the beef industry. Moreover, labour conditions have been similar in domestic and export sectors although there is an increasing trend to specialised export plants. Hence it seems unlikely that the findings presented here for the beef industries can be explained by the exercise of union power.

Additionally, both domestic and export sectors share processing inputs (with each other and with other livestock species) and would appear to rely on few specialised inputs. They share the common feature that there are barriers to entry into processing partly arising from fixed assets and partly from statutory regulation of capacity.

There are two features of the Australian beef export sector that may at least partly explain this finding of non-competitive behaviour. First, access to export markets is restricted under licensing arrangements operated by the statutory Australian Meat and Livestock Corporation. These licences are issued when exporters have in place quality assurance processes and meet minimum quality assurance standards. The Corporation also manages the flow of product into export markets which have quantitative restrictions. Second, there is a much greater degree of vertical integration between the production, processing and marketing of export beef than of domestic beef (MRC).

Our finding that the export sector was characterised by non-competitive behaviour was based on a model in which the domestic and export sectors were assumed to be separable. A more theoretically sound approach than that attempted in this paper may be to go back to the underlying structural model, disaggregate the retail demand into domestic and export components and derive a new set of testable hypotheses in terms of domestic retail price, export price, domestic and export demand shifters, etc. However, as Holloway recognised, modelling a large number of diverse markets for which data are limited, is a challenging exercise.

An important implication for future research should the findings reported here prove to be robust is that in modelling the Australian beef industry differences in conduct in the domestic and export sectors of the industry need to be recognised.

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Table 1. Specification of the Base Model

<table>
<thead>
<tr>
<th>Model Structure:</th>
<th>[ X_d ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>X_d</td>
</tr>
<tr>
<td>b</td>
<td>X_d</td>
</tr>
</tbody>
</table>

Retail price $P_x$: Australian retail price of beef, average of prices of selected cuts in each of the state capitals;

Farm price $P_a$: Australian saleyard price of beef, weighted average of prices of yearling, ox and cow in each state weighted by state production;

Retail-farm price ratio $R$: \[ R = \text{retail price/farm price}; \]

Farm supply $a$: Australian production of beef and veal;

Other input price $P_b$: derived marketing cost index, weighted average of wage rate, electricity price and interest rate (75:10:15).

Demand shifter $N^*$: \[ N_d^* = \eta_{lb}^{(a)} P_{lb}^* + \eta_{lp}^{(a)} P_{pk}^* + \eta_{bc}^{(a)} P_{ch}^* + \eta_{by}^{(a)} Y_{aus}^* + \text{POP}_{aus}^* \]

where, \[ \text{.}^* \] proportional change of the variable (.);

$P_{lb}$, $P_{pk}$ and $P_{ch}$: Australian retail prices of lamb, pork and chicken, respectively, average of prices of selected cuts in each of the state capitals;

$\eta_{lb}^{(a)}$, $\eta_{lp}^{(a)}$, $\eta_{bc}^{(a)}$ and $\eta_{by}^{(a)}$: Australian beef demand elasticities with respect to retail prices of lamb, pork and chicken, and income;

$Y_{aus}$: Australian per capita disposable income;

$\text{POP}_{aus}$: Australian population.
Table 2. Specification of the Aggregated Model

<table>
<thead>
<tr>
<th>Model Structure:</th>
<th>X = X_d + X_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail price P_x:</td>
<td>P_x = \rho_d P_d + \rho_e P_e</td>
</tr>
<tr>
<td>where,</td>
<td></td>
</tr>
<tr>
<td>P_d:</td>
<td>Australian retail price as in the base model;</td>
</tr>
<tr>
<td>P_e:</td>
<td>unit value of Australian export beef;</td>
</tr>
<tr>
<td>\rho_d, \rho_e:</td>
<td>proportions of beef domestic consumption and export;</td>
</tr>
<tr>
<td>Farm price P_a:</td>
<td>as in the base model;</td>
</tr>
<tr>
<td>Retail-farm price ratio R:</td>
<td>R_ag = aggregate retail price/farm price;</td>
</tr>
<tr>
<td>Farm supply a:</td>
<td>as in the base model;</td>
</tr>
<tr>
<td>Other input price P_b:</td>
<td>as in the base model;</td>
</tr>
<tr>
<td>Demand shifter N:</td>
<td>N_ag* = \rho_d N_d* + \rho_e N_e*</td>
</tr>
<tr>
<td>where,</td>
<td></td>
</tr>
<tr>
<td>N_d*:</td>
<td>as in the base model;</td>
</tr>
<tr>
<td>\rho_d, \rho_e, \rho_{US}, and \rho_{JP}:</td>
<td>proportions of domestic consumption, total export, export to the US and export to Japan with respect to total beef production;</td>
</tr>
<tr>
<td>P_{pk}^{(US)}, Y_{US} and POP_{US}:</td>
<td>retail price of pork, per capita income and population in the US;</td>
</tr>
<tr>
<td>P_{pk}^{(JP)}, P_{ch}^{(JP)} and P_{eg}^{(JP)}:</td>
<td>Japanese retail prices of pork, chicken and egg;</td>
</tr>
<tr>
<td>Y_{JP} and POP_{JP}:</td>
<td>per capita income and population in Japan;</td>
</tr>
<tr>
<td>\eta_{bp}^{(US)}, \eta_{by}^{(US)}:</td>
<td>US beef demand elasticities with respect to retail price of pork and income;</td>
</tr>
<tr>
<td>\eta_{bp}^{(JP)}, \eta_{bc}^{(JP)}, \eta_{be}^{(JP)} and \eta_{by}^{(JP)}:</td>
<td>Japanese beef demand elasticities with respect to retail prices of pork, chicken, egg and income.</td>
</tr>
</tbody>
</table>
Table 3. Specification of the Separated Domestic and Export Markets

<table>
<thead>
<tr>
<th>Model Structure</th>
<th>Domestic Market</th>
<th>Export Market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a_d</td>
<td>a_e</td>
</tr>
<tr>
<td></td>
<td>b_d</td>
<td>b_e</td>
</tr>
<tr>
<td>X_d</td>
<td>X_e</td>
<td></td>
</tr>
</tbody>
</table>

- Retail price $P_x$: as in the base model; unit value of exported beef as in Table 2;
- Farm price $P_a$: saleyard cattle price for domestic consumption; saleyard cattle price for export;
- Retail-farm price ratio $R$: $R_d = \text{domestic retail price/}
  \text{domestic cattle price};$ $R_e = \text{export unit value/}
  \text{export cattle price};$
- Farm supply $a$: beef production for domestic consumption; beef production for export;
- Other input price $P_b$: as in the base model; as in the base model;
- Demand shifter $N^*$: $N_d^*$ in Table 2. $N_e^*$ in Table 2.

Table 4. Elasticity Values Used

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Australian domestic market</th>
<th>United States export market</th>
<th>Japanese export market*</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{bp}$</td>
<td>0.50</td>
<td>0.10</td>
<td>0.48</td>
</tr>
<tr>
<td>$\eta_{bc}$</td>
<td>0.39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\eta_{bl}$</td>
<td>0.72</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\eta_{by}$</td>
<td>0.47</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Pork, chicken and egg prices were specified in the Japan beef demand equation, but only pork was significant.
Table 5. Base Model Results - Restricted Estimates

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Elasticity of Retail demand</th>
<th>Farm supply</th>
<th>Marketing cost</th>
<th>R²</th>
<th>D-W</th>
<th>F(1,21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail price</td>
<td>0.504**</td>
<td>-0.504**</td>
<td>-0.288</td>
<td>0.44</td>
<td>1.66</td>
<td>10.79**</td>
</tr>
<tr>
<td></td>
<td>(5.12)</td>
<td>(-5.12)</td>
<td>(-1.14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm price</td>
<td>1.290**</td>
<td>-1.290**</td>
<td>-2.233**</td>
<td>0.61</td>
<td>2.01</td>
<td>2.91</td>
</tr>
<tr>
<td></td>
<td>(6.13)</td>
<td>(-6.13)</td>
<td>(-4.14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price ratio</td>
<td>-0.786**</td>
<td>0.786**</td>
<td>1.946**</td>
<td>0.59</td>
<td>2.51</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(-5.28)</td>
<td>(5.28)</td>
<td>(5.10)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in parentheses are t statistics. ** significant at 1%; * significant at 5%.
Critical one tailed t values are t_{0.10}(21)=1.32; t_{0.05}(21)=1.72; t_{0.01}(21)=2.52.
Critical F values are F_{0.10}(1,21)=2.96; F_{0.05}(1,21)=4.32; F_{0.01}(1,21)=8.02.
Critical DW_{0.05}(3,24) values are D_L=1.10; D_U=1.66.

Table 6. Aggregated Model Results - Restricted Estimates

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Elasticity of Retail demand</th>
<th>Farm supply</th>
<th>Marketing cost</th>
<th>R²</th>
<th>D-W</th>
<th>F(1,21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail price</td>
<td>1.152**</td>
<td>-1.152**</td>
<td>-0.692**</td>
<td>0.81</td>
<td>1.79</td>
<td>10.10**</td>
</tr>
<tr>
<td></td>
<td>(9.89)</td>
<td>(-9.89)</td>
<td>(-3.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm price</td>
<td>1.424**</td>
<td>-1.424**</td>
<td>-1.544**</td>
<td>0.53</td>
<td>1.92</td>
<td>10.35**</td>
</tr>
<tr>
<td></td>
<td>(5.20)</td>
<td>(-5.20)</td>
<td>(-2.93)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price ratio</td>
<td>-0.272</td>
<td>0.272</td>
<td>0.851*</td>
<td>0.17</td>
<td>1.95</td>
<td>5.22*</td>
</tr>
<tr>
<td></td>
<td>(-1.34)</td>
<td>(1.34)</td>
<td>(2.17)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values in parentheses are t statistics. ** significant at 1%; * significant at 5%.
Critical one tailed t values are t_{0.10}(21)=1.32; t_{0.05}(21)=1.72; t_{0.01}(21)=2.52.
Critical F values are F_{0.10}(1,21)=2.96; F_{0.05}(1,21)=4.32; F_{0.01}(1,21)=8.02.
Critical DW_{0.05}(3,24) values are D_L=1.10; D_U=1.66.
### Table 7. Separated Model Results - Restricted Estimates

<table>
<thead>
<tr>
<th>Market segment</th>
<th>Dependent variable</th>
<th>Elasticity of Retail demand</th>
<th>Farm supply</th>
<th>Marketing cost</th>
<th>R²</th>
<th>D-W</th>
<th>F(1,21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic market</td>
<td>Retail price</td>
<td>0.711**</td>
<td>-0.711**</td>
<td>-0.496**</td>
<td>0.85</td>
<td>2.39</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(12.71)</td>
<td>(-12.71)</td>
<td>(-3.89)</td>
<td></td>
<td>r=-0.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Farm price</td>
<td>1.556**</td>
<td>-1.556**</td>
<td>-2.617**</td>
<td>0.76</td>
<td>2.46</td>
<td>1.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8.45)</td>
<td>(-8.45)</td>
<td>(-6.24)</td>
<td></td>
<td>r=-0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Price ratio</td>
<td>-0.845**</td>
<td>0.845**</td>
<td>2.121**</td>
<td>0.62</td>
<td>2.30</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-5.21)</td>
<td>(5.21)</td>
<td>(5.74)</td>
<td></td>
<td>r=-0.20</td>
<td></td>
</tr>
<tr>
<td>Export market</td>
<td>Retail price</td>
<td>1.065**</td>
<td>-1.065**</td>
<td>-0.473</td>
<td>0.39</td>
<td>2.14</td>
<td>4.82*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.92)</td>
<td>(-3.92)</td>
<td>(-0.71)</td>
<td></td>
<td>r=-0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Farm price</td>
<td>0.652*</td>
<td>-0.652*</td>
<td>-0.504</td>
<td>0.20</td>
<td>1.88</td>
<td>5.38*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.49)</td>
<td>(-2.49)</td>
<td>(-0.78)</td>
<td></td>
<td>r=0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Price ratio</td>
<td>0.413**</td>
<td>-0.413**</td>
<td>0.031</td>
<td>0.24</td>
<td>2.02</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.55)</td>
<td>(-2.55)</td>
<td>(0.08)</td>
<td></td>
<td>r=-0.09</td>
<td></td>
</tr>
</tbody>
</table>

Values in parentheses are t statistics. ** significant at 1%; * significant at 5%.
Critical one tailed t values are $t_{0.10}(21)=1.32; t_{0.05}(21)=1.72; t_{0.01}(21)=2.52$.
Critical F values are $F_{0.10}(1,21)=2.96; F_{0.05}(1,21)=4.32; F_{0.01}(1,21)=8.02$.
Critical DW_{0.05}(3,24) values are $D_L=1.10; D_U=1.66$. 

18