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Testing for pre-committed quantities of Australian meat demand

Kara Tighe, Nicholas Piggott, Oscar Cacho, Stuart Mounter and Renato Villano†

Pre-committed consumption represents the portion of demand that is determined by non-price and non-income factors. This study uses quarterly data to estimate a Generalised Almost Ideal Demand System (GAIDS) to test for the existence of pre-committed meat consumption in Australia. Two specifications are estimated to evaluate the impact of seasonal and time trend factors on pre-committed demand. Evidence is found for the existence of pre-committed chicken consumption when jointly estimated with seasonal and time trend factors. Results support improved demand modelling of Australian meat consumption using the GAIDS and provide insights into how Australian meat demand is affected by price, expenditures, pre-committed consumption, seasonality, and trends.

Key words: Australian meat demand, Generalised Almost Ideal Demand System, pre-committed demand.

1. Introduction

Aggregate Australian meat demand has been studied extensively using a range of consumer demand models (Cashin 1991; Hutasuhut 1995; Vere and Griffith 1995; Piggott *et al*. 1996; Vere *et al*. 2000; Griffith *et al*. 2001; Wong *et al*. 2015). Wong *et al*. (2015) reported that changes in consumer tastes, trade restrictions, and meat classifications contributed to significant changes in the proportions of meat types consumed over the past 50 years in Australia. Changes in consumer tastes played a significant role in a shift away from lamb, beef and mutton consumption towards higher proportions of pork and chicken. In an earlier study, Piggott *et al*. (1996) reported producer-funded advertising campaigns had a positive effect on Australian beef demand and a negative effect on chicken demand. Mounter *et al*. (2012) tested for the impact of improved eating quality on Australian meat demand following the introduction of a beef eating quality grading scheme in 1999. They stated that results varied across model specifications and were inconclusive.

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These studies point to the existence of non-price and non-income shifters of Australian meat demand. Pre-committed quantities represent the portion of consumer demand that is independent of price and income effects (Bollino 1987). If pre-committed demands for Australian meat do exist, failing to account for them in consumer demand models may result in misallocation of pre-committed effects to other factors included in the model (Tonsor and Marsh 2007). Understanding how new information and product changes impact meat consumption patterns is important for both policy development and industry stakeholder investment decisions. In addition to the impacts of seasonal and time trend variables, farm animal welfare, eating quality, and advertising investment are all pertinent and plausible shifters of Australian consumer meat demand. The dynamic nature of these variables makes ongoing exploration and estimation of the determinants of meat demand paramount for effective and informed decision-making by consumers and industry alike. Estimation of a GAIDS of Australian meat demand is the first step to better model and understand any non-discretionary demand shift variables and may provide a suitable method to test for their impact on Australian meat consumption patterns.

To date, the literature on pre-committed meat demand has largely focused on the United States. Piggott and Marsh (2004) and Piggott *et al.* (2007) found that US consumers have significant pre-committed levels of beef, pork, and chicken consumption. These pre-committed quantities accounted for a significant proportion of total US meat consumption. In their analysis of pre-committed meat and fish demand in the United States and Japan, Tonsor and Marsh (2007) found that US consumers have significant pre-committed levels of beef and pork consumption, while Japanese consumers have significant pre-committed levels of beef and fish consumption. Both studies demonstrated the existence of pre-committed demand in the presence of seasonal and time trend factors. This study estimates a GAIDS of Australian meat consumption to meet two novel objectives. Firstly, the GAIDS is estimated to test for the existence of pre-committed constant quantities of meat consumption among Australian consumers. Secondly, the GAIDS is estimated with pre-committed quantities augmented to include a constant component and seasonal and time trends to investigate whether pre-committed quantities are seasonal and trending. This study aims to provide insights into how Australian meat demand is affected by price, income, and pre-committed consumption, as well as the nature of pre-committed quantities.

2. Demand model

The GAIDS (Bollino 1987) allows for the estimation of both pre-committed and supernumerary quantities of each good within the demand system. Here, the pre-committed quantity represents the portion demanded of a good that is independent of price and income effects. Thus, the remaining supernumerary quantity represents the portion demanded that is dependent on price and income effects. The GAIDS specification that incorporates pre-committed constant quantities only is referred to as the GAIDS throughout this study and is estimated to test for the presence of constant pre-committed meat demand in Australia. The GAIDS specification that modifies pre-committed quantities to be a linear function of seasonal and time trend variables is referred to as the GAIDS+ and is estimated to determine whether pre-committed quantities are influenced by seasonal and time trend variables. This analysis follows the approach of Bollino (1987), Piggott and Marsh (2004) and Tonsor and Marsh (2007) and derives the generalised expenditure function as:

$$E(\mathbf{p},u) = E^0(\mathbf{p},\mathbf{C}) + E^*(\mathbf{p},u) = \mathbf{p}'\mathbf{C} + E^*(\mathbf{p},u), \tag{1}$$

where $\mathbf{p}$ is a N-vector of prices, $\mathbf{C}$ is an N-vector of pre-committed quantity parameters and u is utility. $E^0(\mathbf{p}, \mathbf{C}) = \mathbf{p}'\mathbf{C}$ identifies the pre-committed portion of total expenditures, and $E^*(\mathbf{p}, u)$ is the remaining, or supernumerary expenditures, allocated across the N goods. Applying dual properties and Shephard's lemma, the demand function:

$$q_i(\mathbf{p},u) = C_i + q_i^*(\mathbf{p},u),$$

represents the pre-committed (C_i) and the supernumerary $q_i^*(\mathbf{p},u)$ quantities demanded of each good $q_i(\mathbf{p}, u)$. The share form of the demand functions for the GAIDS is expressed as:

$$w_i = \frac{C_i \times P_i}{M} + \left(\frac{M^*}{M}\right) \times \left[\alpha_i + \sum_{j=1}^{n} \gamma_{ij} \times \ln(p_i) + \beta_i \times \ln\left(\frac{M^*}{P}\right)\right], \tag{2}$$

where:

$$M^* = \left(M - \sum_{i=1}^{n} C_i \times P_i\right),$$

represents supernumerary expenditure, M denotes total expenditure and the non-linear price index vector is defined as:

$$\ln(P) = \alpha_0 + \sum_{j=1}^{n} \alpha_j \times \ln(p_j) + (1/2) \times \sum_{k=1}^{n}\sum_{j=1}^{n} \gamma_{kj} \times \ln(p_k) \times \ln(p_j), \tag{3}$$

and total pre-committed expenditure is expressed as $\sum_{i=1}^{n} C_i \times P_i$.

To estimate the GAIDS with seasonal and time trend components, Alston *et al.* (2001) propose modifying the pre-committed quantities of the share equations via a translating procedure to incorporate seasonality and time trend variables. Pre-committed quantities for the GAIDS+ specification are defined as:

$$\widehat{C_i} = C_{i0} + \sum_{k=1}^{3} \theta_{ik} \times qt_k + \tau_i \times t + \varphi_i \times t^2, \tag{4}$$

where the C_{i0} parameters to be estimated represent the pre-committed quantity of each good that is not influenced by the incorporated demand shift variables during the sample period; θ_{ik} are seasonality parameters for the respective quarterly dummy variables qt_k; and τ_i and φ_i are trend parameters for the respective linear (t) and quadratic (t^2) time trends. Incorporating the demand shift variables in this way maintains the desired theoretical properties of the GAIDS by ensuring the estimated economic effects remain invariant to units of measurement (Alston *et al.* 2001). No additional restrictions on the demand shift parameters are necessary. The share form of the GAIDS+ that incorporates the demand shift variables can be expressed as:

$$w_i = \frac{\widehat{C_i} \times P_i}{M} + \left(\frac{M^*}{M}\right) \times \left[\alpha_i + \sum_{j=i}^{n} \gamma_{ij} \times \ln(p_i) + \beta_i \times \ln\left(\frac{M^*}{P}\right)\right], \tag{5}$$

where:

$$M^* = \left(M - \sum_{i=1}^{n} \widehat{C_i} \times P_i\right),$$

$$\widehat{C_i} = C_{i0} + \sum_{k=1}^{3} \theta_{ik} \times qt_k + \tau_i \times t + \varphi_i \times t^2.$$

Theoretical demand restrictions can be imposed in the GAIDS and GAIDS+ using the same parameter restrictions as the AIDS (Deaton and Muellbauer 1980): homogeneity is imposed by $\sum_{j=1}^{n} \gamma_{ij} = 0$; adding-up by $\sum_{i=1}^{n} \beta_i = 0$ and $\sum_{i=1}^{n} \alpha_i = 1$; and symmetry $\gamma_{ij} = \gamma_{ji} \forall_{i \neq j}$.

3. Data

The demand model was estimated using quarterly Australian consumption and price series data for lamb, beef, chicken, and pork, for the period 1996 (1)-2016 (4). The quantity variables presented in Table 1 correspond to quarterly per capita consumption in kilograms of carcase weight. Quarterly

Table 1 Summary statistics of quarterly data used to estimate the demand model 1996 (1)-2016 (4)

Variable	Mean	SD	Min.	Max.
Lamb consumption (kg per capita)	2.58	0.33	1.90	3.34
Beef consumption (kg per capita)	8.15	1.38	4.96	10.62
Chicken consumption (kg per capita)	9.27	1.69	6.34	12.51
Pork consumption (kg per capita)	5.83	0.83	4.41	7.58
Retail lamb price ($ per kg)	9.41	3.94	3.86	15.66
Retail beef price ($ per kg)	12.24	4.30	5.84	20.59
Retail chicken price ($ per kg)	4.39	1.02	2.74	5.83
Retail pork price ($ per kg)	8.36	2.81	4.11	13.04
Lamb expenditure share	0.11	0.01	0.09	0.13
Beef expenditure share	0.46	0.05	0.35	0.56
Chicken expenditure share	0.20	0.02	0.15	0.26
Pork expenditure share	0.23	0.03	0.17	0.32

Sources: ABARES (2017), ABS (2017), and own estimates

total apparent consumption data were provided by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 2017) and divided by quarterly population statistics (ABS, 2016a) to form per capita consumption estimates. During the sample period, per capita consumption averaged 2.58, 8.15, 9.27, and 5.83 kg per quarter for lamb, beef, chicken, and pork, respectively. Retail price estimates were provided by the ABARES (2017) and deflated using the ABS food and beverage consumer price index (ABS, 2017) to form real price estimates.

Figure 1 plots the price indices of the four meat types during the sample period. All meat prices increased over the period. The largest relative price rise was for lamb, which increased at a rate of 1.5 per cent per quarter, followed by beef (1.1 per cent), pork (0.9 per cent), and chicken (0.2 per cent).

Figure 2 plots the expenditure share estimates of representative Australian households over the sample period. The largest percentage of total meat expenditure, on average, was allocated to beef (48 per cent), followed by pork (23 per cent), chicken (19 per cent), and lamb (11 per cent). Figure 2 also captures an increase in expenditure share for chicken and pork at the expense of beef, and to a lesser extent lamb, over the sample period.

4. Estimation procedures

This study employs the best available data to model Australian meat demand. However, inherent data limitations, such as the highly aggregated nature of the quarterly consumption data and changes to government data collection procedures during the study period, mean the data need to be treated with caution. This needs to be noted as a characteristic of the Australian data set moving forward for other studies. Initial checks for structural change within the time series per capita consumption and price data for each meat were investigated using breakpoint analysis. Structural change was tested for using

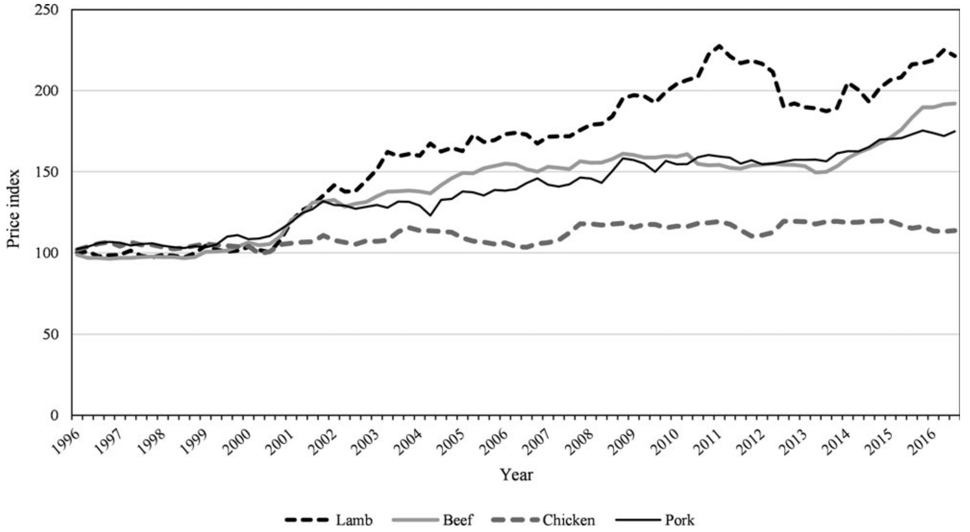

Figure 1 Price indices (1996 = 100) of Australian meat 1996 (1)-2016 (4).

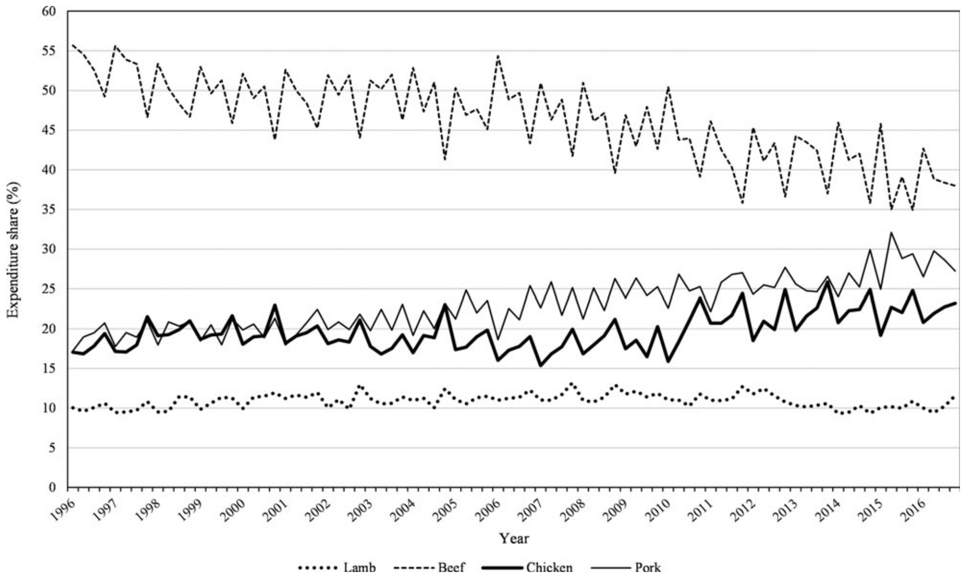

Figure 2 Australian meat expenditure shares 1996 (1)-2016 (4).

the ‘breakpoints’ procedure in the R package ‘strucchange’ (Zeileis *et al.* 2002). Briefly, this analysis tests for structural changes compared to a simple OLS regression by searching for the largest reduction in residual sums of squares between candidate models. This is moderated by comparison with the Bayesian information criteria to eliminate overfitting. This new approach was used to check the quality of the data and to better understand the impact of procedural data changes and aggregation on the individual time series.

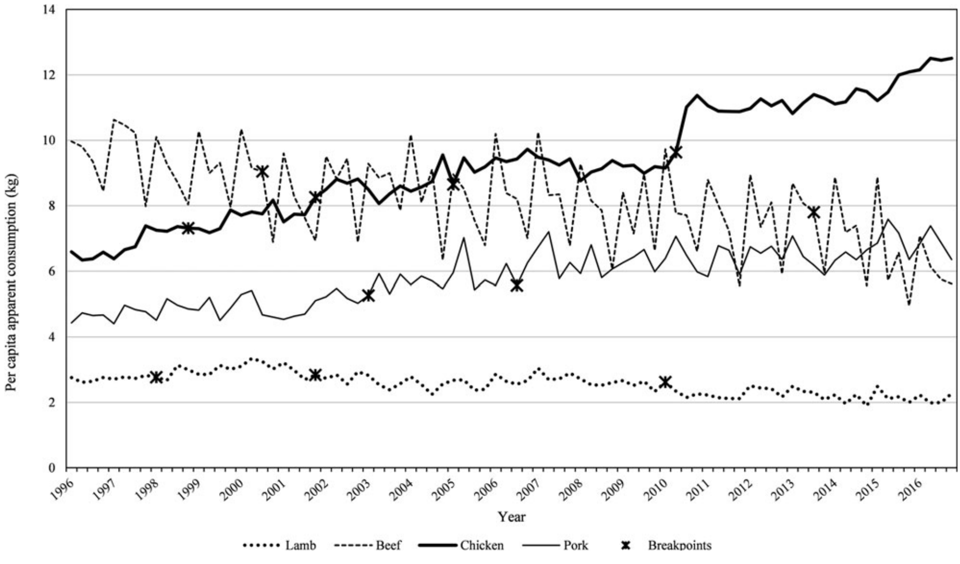

Figure 3 Per capita consumption series breakpoints 1996 (1)-2016 (4).

Results from these analyses were used to help determine breakpoints in each series that may be accounted for via dummy variables. The breakpoint analysis was undertaken in R version 3.3.3 (R Core Team, 2017) using the package 'strucchange' (Zeileis *et al*. 2002, 2003; R Core Team, 2017). Twelve breakpoints were identified in the per capita consumption time series and another twelve in the meat price time series. These breakpoints are plotted in Figures 3 and 4.

Breakpoints were cross-referenced with changes in quarterly trade stockpile volumes. The largest changes in stockpile volumes did not coincide with any of the breakpoints identified. One of the breakpoints identified coincides with changes to government data collection procedures. A coverage exercise to review the quality of the sampling frame for the ABS chicken production series was undertaken in 2010 (ABS, 2016b). This produced an expanded coverage from the September quarter 2010 and is visible in Figure 3. However, the underlying cause for all other breakpoints could not be definitively assigned to procedural change or plausible shifts in consumer tastes or preference. As per Piggott *et al*. (2007), to address the structural changes identified in the data set, breakpoints were incorporated into the models as dummy variables. To avoid convergence problems, only two dummy variables were included in the models at one time. Several combinations of breakpoints were tested, with a focus on quarters that contained multiple breakpoints. The inclusion of the dummy variables did not improve model outcomes beyond the results presented.

As per previous studies on aggregate Australian meat demand (Martin and Porter 1985; Alston and Chalfant 1991; Cashin 1991; Piggott *et al*. 1996;

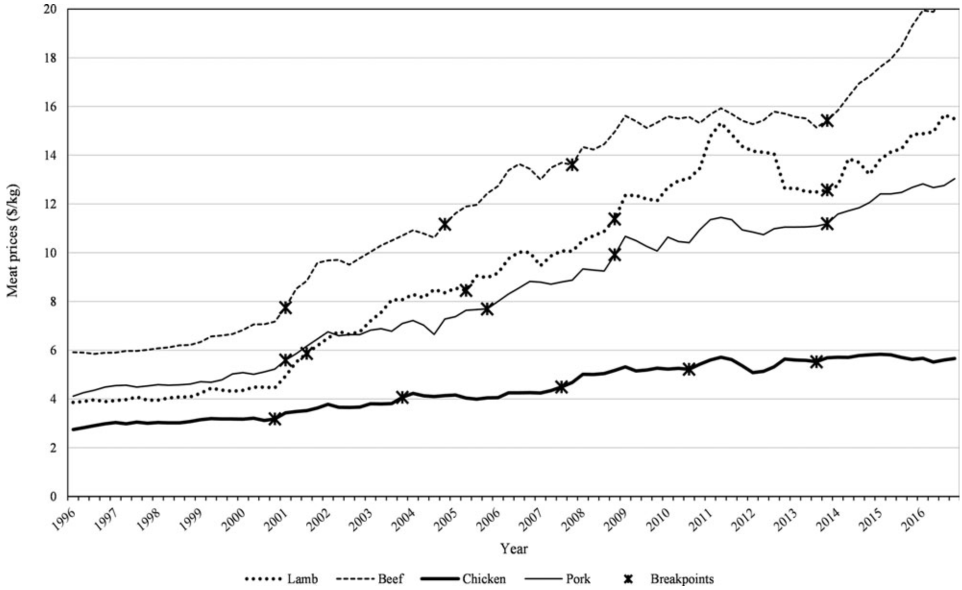

Figure 4 Meat price series breakpoints 1996 (1)-2016 (4).

Griffith *et al.* 2001; Mounter *et al.* 2012), meat is treated as weakly separable, so that consumption of each meat depends only on meat group expenditure and meat prices. This assumption makes elasticities conditional on meat expenditures and can impact the sensitivity of elasticities (Edgerton 1997). This needs appropriate consideration when interpreting elasticities. For example, responsiveness of beef consumption to changes in incomes is impacted by two elasticities, the elasticity of beef consumption to meat expenditures and the elasticities of beef consumption to changes in income. In this paper, we are concerned solely with the former interpretation of elasticities, for example the responsiveness of beef consumption to meat expenditures. Previous studies also included mutton as an independent variable in the group of meats modelled. This study excluded mutton from the model due to its declining percentage of total meat consumption over the sample period, from 6 per cent in 1996 to <0.5 per cent in 2016.

Models were estimated using iterative SUR non-linear estimation techniques in SAS/STAT software version 9.4 (SAS Institute Inc., 2015). Homogeneity and symmetry restrictions were imposed as a maintained hypothesis in all of the models. To avoid singularity of the error covariance matrix, one equation was deleted (pork) and the remaining equations estimated (lamb, beef, and chicken). The parameters of the pork equation were subsequently recovered using the imposed theoretical restrictions noted above. Effects of time on meat demand are included in the GAIDS+ model as quarterly seasonal dummy and time trend variables.

The Bewley (1986) adjusted likelihood ratio tests are used to compare the GAIDS and GAIDS+ specifications at the 5 per cent significance level.

Following previous studies (Piggott *et al.* 1996; Piggott and Marsh 2004; Tonsor and Marsh 2007), the preferred model was then estimated using three autocorrelation corrections (Berndt and Savin 1975): a null matrix (***N–R***$^{\text{matrix}}$) wherein all elements of the ***R*** matrix are restricted to zero to specify no autocorrelation correction ($\rho_{ij} = 0\forall_{ij}$); a diagonal correction matrix (***D–R***$^{\text{matrix}}$) wherein all diagonal elements are restricted to be identical and all off-diagonal elements to be zero ($\rho_{ij} = 0\forall_{i\neq j}$ and $\rho_{ij} \neq 0\forall_{i=j}$); and a full correction matrix (***F–R***$^{\text{matrix}}$) wherein all elements are allowed to differ individually from zero ($\rho_{ij} \neq 0\forall_{ij}$). The Bewley (1986) adjusted likelihood ratio tests were calculated using:

$$\mathrm{LR_B} = 2 \times (\mathrm{LL^u} - \mathrm{LL^r}) \times \left[\frac{(\mathrm{MT} - k^{\mathrm{u}})}{\mathrm{MT}}\right], \tag{6}$$

where $\mathrm{LR_B}$ denotes the Bewley (1986) likelihood ratio test, $\mathrm{LL^u}$ ($\mathrm{LL^r}$) is the maximum log likelihood value of the unrestricted (restricted) model, M is the number of estimated equations, T is the sample size, and k^{u} is the number of parameters in the unrestricted model.

Price and expenditure elasticities for the preferred models were calculated as per Piggott and Marsh (2004) using the following formulas:

$$\eta_{ij} = -\delta_{ij} + \left(\frac{1}{Mw_i}\right)\left[\hat{c}_i p_i(1 - w_i^*) + M^*\left(\gamma_{ij} - \beta_i\left\{\frac{\hat{c}_i * p_i}{M^*} + \alpha_i + \sum_{j=1}^{n}\gamma_{ij} \times \ln(p_j)\right\}\right)\right], \tag{7}$$

and:

$$\eta_{iM} = 1 + \frac{\left[\frac{1}{M}(-\hat{c}_i p_i + (M - M^*)w_i^*) + \beta_i\right]}{w_i}, \tag{8}$$

where η_{ij} denotes the uncompensated (Marshallian) price elasticity for quantity i with respect to price j; δ_{ij} is the Kronecker delta ($-\delta_{ij} = 1$ for $i = j$, $\delta_{ij} = 0$ for $i \neq j$); and η_{iM} denotes the expenditure elasticity. The compensated (Hicksian) price elasticities were calculated using the elasticity form of the Slutsky equation:

$$\varepsilon_{ij} = \eta_{ij} + w_j\eta_{i_M}. \tag{9}$$

The Slutsky matrix is calculated for each observation post-estimation to investigate the consistency of estimated economic effects with curvature as a criterion for model selection. The non-positiveness of the eigenvalues of the matrix is checked to determine whether curvature is satisfied. For curvature to be satisfied, a necessary, but not sufficient, condition is that all

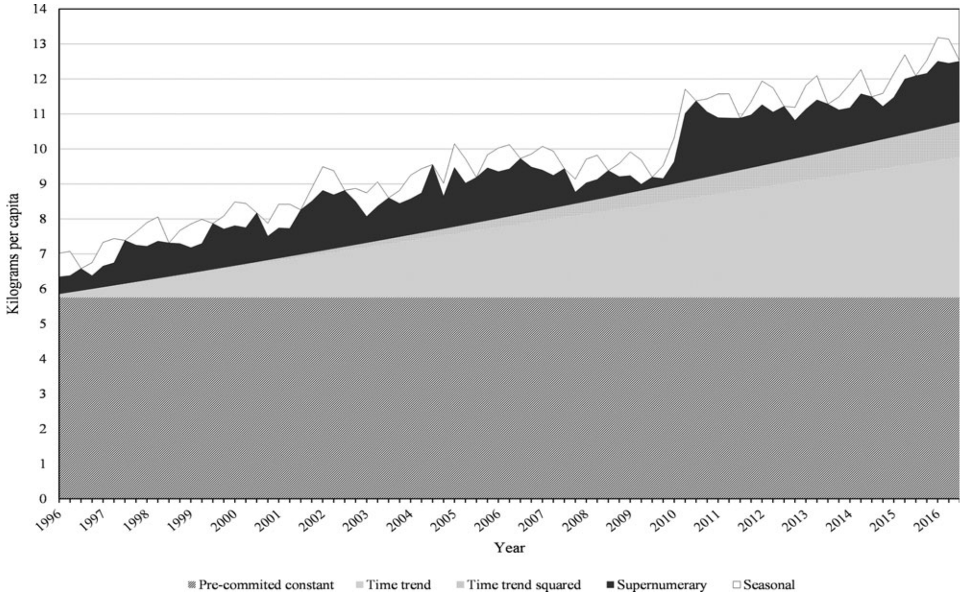

Figure 5 Underlying components of Australian chicken demand 1996 (2)-2016 (4).

compensated own-price elasticities are negative. The higher the percentage of observations found to satisfy curvature, the better the model specification conforms to economic theory.[1]

Parameter estimates combined with the in-sample data are also used to calculate predicted pre-committed and supernumerary quantities at every observation. These estimates are plotted for meats found to have statistically significant pre-committed quantities during the sample period (see Figure 5).

Previous studies on pre-committed quantities (Mafuru and Marsh 2003; Marsh *et al*. 2004; Piggott and Marsh 2004; Piggott *et al*. 2007; Tonsor and Marsh 2007) make no reference to the sign (positive or negative) of supernumerary quantities that can be derived from model estimates. As stated previously, the supernumerary quantity of a good represents the portion demanded that is dependent on price and income effects. Consistency with the income and substitution effects of demand theory would therefore imply that supernumerary quantities must be positive.

[1] An alternative approach to the determination of consistency with economic theory would be to impose the required curvature during model estimation. This approach is beyond the scope and focus of this paper, which is to establish whether pre-committed quantities exist in Australian meat consumption using standard inferences. Whether the imposition of curvature changes the inferences with respect to pre-committed quantities should certainly be explored in future work, with the caveat that forcing flexible functional forms to conform to theory can restrict them in ways that are not dictated by theory and potentially impact inferences with respect to parameters (Terrell 1996). The post-estimation approach used in this study allows ‘the data to speak’ and is used solely as a model selection criterion.

Model outcomes were assessed on statistical criteria (goodness-of-fit and likelihood ratio tests), as well as consistency with economic theory (Slutsky negative semi-definiteness, positive supernumerary quantities, and price and expenditure elasticities). Thus, models were only deemed adequate if they met both statistical and economic criteria.

5. Results

Table 2 shows the parameter estimates, standard errors, and test statistics of the GAIDS model with no autocorrelation correction. As shown, none of the constant pre-committed quantity parameter estimates are individually statistically different from zero. Further, test statistics indicate a poor model fit with an R^2 of 0.082 for lamb, 0.266 for chicken and 0.615 for beef. Thus, the GAIDS model estimates do not support the existence of a constant pre-committed quantity for any meat type.

Figures 2 and 3 show that quarterly Australian meat consumption is seasonal and that it appears to have underlying trends over time. Specifically, chicken and pork consumption appear to have positive trends, while lamb and beef have negative trends. The GAIDS specification (Table 2) indicated a model with a constant coefficient representing pre-commitment along with

Table 2 Estimated coefficients for the GAIDS model with no autocorrelation correction

Parameter	Estimate	SD
α_s	0.557	0.324
α_b	−1.375*	0.432
α_c	1.281***	0.255
β_s	−0.128	0.083
β_b	0.588***	0.138
β_c	−0.320**	0.121
γ_{ss}	0.005	0.073
γ_{sb}	0.326	0.256
γ_{sc}	−0.248	0.175
γ_{bb}	−1.901	0.971
γ_{bc}	1.044	0.560
γ_{cc}	−0.444	0.388
c_{s0}	−2.418	3.595
c_{b0}	1.905	6.215
c_{c0}	−6.828	5.950
c_{p0}	−1.087	7.061
Test statistics		
LL	740.022	
R^2 lamb	0.082	
R^2 beef	0.615	
R^2 chicken	0.266	

Note: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. The subscripts denote s for lamb, b for beef, c for chicken, and p for pork.

Table 3 Estimated coefficients for the GAIDS+ model with no autocorrelation correction

Parameter	Estimate	SD	Parameter	Estimate	SD
α_s	0.217**	0.061	θ_{s3}	−3.436	2.787
α_b	0.066	0.234	θ_{b1}	1.538	3.510
α_c	0.059	0.059	θ_{b2}	−7.053	5.814
β_s	−0.034*	0.014	θ_{b3}	−67.072	45.027
β_b	0.137*	0.056	θ_{c1}	−0.339	0.221
β_c	−0.011	0.008	θ_{c2}	−0.585	0.694
γ_{ss}	0.020	0.017	θ_{c3}	−0.621	4.102
γ_{sb}	−0.009	0.020	θ_{p1}	−0.360	1.733
γ_{sc}	0.000	0.003	θ_{p2}	−3.163	2.444
γ_{bb}	0.085	0.061	θ_{p3}	−16.537	11.992
γ_{bc}	−0.002	0.014	τ_s	0.020**	0.006
γ_{cc}	−0.002	0.019	τ_b	−0.046	0.042
c_{s0}	−0.322	0.768	τ_c	0.046**	0.012
c_{b0}	−2.075	5.077	τ_p	0.017	0.018
c_{c0}	5.928***	1.164	φ_s	-2.3×10^{-4}**	6.0×10^{-5}
c_{p0}	−4.212	3.226	φ_b	4.35×10^{-4}	4.52×10^{-4}
θ_{s1}	0.008	0.469	φ_c	1.62×10^{-4}	1.30×10^{-4}
θ_{s2}	−0.899	0.625	φ_p	2.27×10^{-4}	1.86×10^{-4}
Test statistics					
LL	870.122		R^2 beef	0.945	
R^2 lamb	0.597		R^2 chicken	0.885	

Note: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. The subscripts denote s for lamb, b for beef, c for chicken, and p for pork.

prices and expenditures led to a poor model fit. To improve model fit, a natural extension is to augment the pre-committed quantities to include seasonality with quarterly dummy variables and to capture general time trends with linear and quadratic variables as illustrated in Equation (4).

Table 3 shows the parameter estimates, standard errors and test statistics of this extended GAIDS model (hereafter referred to as GAIDS+) with no autocorrelation correction.[2] The addition of the quarterly seasonal dummy variables and time trend variables significantly improved the model fit with a substantial increase in the estimated R^2 compared with GAIDS model estimates – beef (0.945), chicken (0.885), and lamb (0.597). Parameter estimates reveal a positive and statistically significant constant pre-committed quantity for chicken of 5.928 kg per person and a positive and statistically significant linear time trend. There were also statistically significant linear and quadratic trends in lamb demand. None of the other parameters on the constant pre-committed quantities for beef, pork or lamb were individually statistically significant, nor were the parameters capturing seasonality and trends.

[2] The intercept term (α_0) was not statistically different from zero in either the GAIDS or GAIDS+. For parsimony, this term was removed from the final model specifications.

Table 4 Bewley adjusted likelihood ratio tests for significance of the GAIDS and GAIDS+

	H_0: GAIDS H_a: GAIDS+
LR_B	222.581*
df	20
$\chi_{0.05,df}$	31.410

Note: LR_B denotes the Bewley (1986) likelihood ratio test; *df* denotes the degrees of freedom; $\chi_{0.05,df}$ is the chi-square critical value of comparison; and *denotes statistical significance at the 5% level.

Table 5 Bewley adjusted likelihood ratio tests for significance of autocorrelation corrections for the GAIDS+

	H_0: $\boldsymbol{N}$–$\boldsymbol{R}^{\text{matrix}}$ H_a: $\boldsymbol{D}$–$\boldsymbol{R}^{\text{matrix}}$	H_0: $\boldsymbol{D}$–$\boldsymbol{R}^{\text{matrix}}$ H_a: $\boldsymbol{F}$–$\boldsymbol{R}^{\text{matrix}}$	H_0: $\boldsymbol{N}$–$\boldsymbol{R}^{\text{matrix}}$ H_a: $\boldsymbol{F}$–$\boldsymbol{R}^{\text{matrix}}$
LR_B	60.336*	20.945*	81.380*
df	1	8	9
$\chi_{0.05,df}$	3.841	15.507	16.919

Note: LR_B denotes the Bewley (1986) likelihood ratio test; *df* denotes the degrees of freedom; $\chi_{0.05,df}$ is the chi-square critical value of comparison; and * denotes statistical significance at the 5% level.

Table 4 shows the results of the likelihood ratio tests for the GAIDS and GAIDS+ models. The likelihood ratio test reveals the GAIDS model is rejected in favour of the GAIDS+ model. This result is consistent with the improved test statistics and the statistically significant constant pre-committed quantity and linear trend variables for chicken, and linear and quadratic trends in lamb consumption.

After establishing that the GAIDS+ model is statistically the best fit, alternative forms of autocorrelation correction are explored. Table 5 shows the results of the likelihood ratio tests for the GAIDS+ specification with a null, a diagonal and a full autocorrelation correction matrix. Results for these hypothesis tests indicate that the null and diagonal matrix corrections should be rejected in favour of the full correction matrix.

Table 6 shows the parameter estimates, standard errors, and test statistics of the preferred GAIDS+ model with a full correction autocorrelation matrix. The estimated R^2 coefficients indicate that this model provides a good fit to the Australian consumption patterns for beef (95 per cent) and chicken (95 per cent), but weaker explanatory power for lamb consumption patterns (66 per cent). A check of the supernumerary quantities revealed that they were positive at every observation. The constant components (c_{i0}'s) of pre-committed demand reveal that a highly statistically significant (at the 1 per cent level) portion of Australian chicken consumption is pre-committed. Model estimates indicate that constant pre-committed chicken consumption averages 5.756 kg per person per quarter. Pre-committed chicken consumption was estimated to have a statistically significant quarterly component in the first quarter and a statistically significant linear time trend.

Table 6 Estimated coefficients for the preferred GAIDS+ model

Parameter	Estimate	SD	Parameter	Estimate	SD
α_s	0.211***	0.052	θ_{c1}	−0.373*	0.167
α_b	0.063	0.206	θ_{c2}	−0.678	0.412
α_c	0.067	0.043	θ_{c3}	−0.693	2.282
β_s	−0.031**	0.011	θ_{p1}	−0.568	1.300
β_b	0.135*	0.046	θ_{p2}	−3.429	2.124
β_c	−0.012	0.008	θ_{p3}	−16.564	9.661
γ_{ss}	0.034*	0.015	τ_s	0.019**	0.007
γ_{sb}	−0.025	0.016	τ_b	−0.033	0.030
γ_{sc}	2.06×10^{-4}	0.002	τ_c	0.048*	0.019
γ_{bb}	0.097*	0.047	τ_p	0.020	0.015
γ_{bc}	−0.001	0.009	φ_s	-2.2×10^{-4}**	6.6×10^{-5}
γ_{cc}	−0.001	0.010	φ_b	3.01×10^{-4}	3.18×10^{-4}
c_{s0}	−0.412	0.816	φ_c	1.42×10^{-4}	1.99×10^{-4}
c_{b0}	−1.888	4.029	φ_p	1.73×10^{-4}	1.54×10^{-4}
c_{c0}	5.756***	0.778	ρ_{ss}	0.191	0.124
c_{p0}	−3.893	2.968	ρ_{sb}	−0.158*	0.062
θ_{s1}	−0.081	0.418	ρ_{sc}	−0.065	0.088
θ_{s2}	−1.193	0.654	ρ_{bs}	0.081	0.247
θ_{s3}	−5.203	3.098	ρ_{bb}	0.449**	0.125
θ_{b1}	1.124	2.688	ρ_{bc}	−0.191	0.176
θ_{b2}	−7.859	5.080	ρ_{cs}	−0.223	0.120
θ_{b3}	−72.886	38.800	ρ_{cb}	−0.012	0.060
			ρ_{cc}	0.724***	0.085

Test statistics

LL	917.689	R^2 beef	0.949
R^2 lamb	0.659	R^2 chicken	0.949

Note: *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. The subscripts denote s for lamb, b for beef, c for chicken, and p for pork.

Figure 5 illustrates how the estimated constant pre-committed, seasonal and time trend effects contributed to total quarterly chicken consumption over the sample period. Averaged across every observation, constant pre-committed, and total pre-committed quantities (comprising the constant, seasonal and time trend components) represent 64 per cent and 83 per cent of total chicken consumption, respectively. In contrast, the constant pre-committed quantities for lamb, beef, and pork demand were not statistically different from zero. This indicates that prices and meat expenditure capture the relevant components of underlying consumer demand for these meats over the sample period. Inclusion of dummy variables in the GAIDS and GAIDS+ models to account for identified breakpoints did not improve model outcomes in terms of the statistical and economic criteria noted. Rather, the inclusion of seasonal and time trends provided the best model outcomes according to these criteria. Given the frequency of breakpoints in the Australian data set, the inclusion of seasonal and time trends was found to do an adequate job of accounting for the variation present.

Table 7 GAIDS+ estimated price and expenditure elasticities

	Lamb	Beef	Chicken	Pork
Uncompensated price elasticities (η_{ij})				
Lamb	−0.728	−0.150	0.035	0.145
Beef	−0.136	−0.869	−0.014	−0.203
Chicken	−0.038	−0.324	−0.182	−0.042
Pork	0.349	−0.303	0.118	−0.675
Compensated price elasticities (ε_{ij})				
Lamb	−0.667	0.030	0.040	0.230
Beef	0.117	−0.115	0.006	0.158
Chicken	0.072	0.004	−0.173	0.111
Pork	0.478	0.081	0.128	−0.498
Expenditure elasticities (η_{i_M})	0.553	1.647	0.043	0.775

6. Elasticities

Table 7 reports average price and expenditure elasticity estimates for the preferred GAIDS+ model calculated at every observation.[3] The uncompensated (Marshallian) own-price elasticities of demand for the preferred GAIDS+ model are estimated to be −0.728 for lamb, −0.869 for beef, −0.182 for chicken and −0.675 for pork. A notable result is the relative inelastic own-price elasticity for chicken which can be explained in part by the existence of pre-committed chicken consumption. A number of discrepancies exist between the preferred GAIDS+ uncompensated and compensated cross-price elasticity estimates with respect to being substitutes and complements. Compensated cross-price elasticity estimates suggest that all meats are pairwise substitutes with each other consistent with what we might expect *a prior*. In contrast, uncompensated elasticities indicate that chicken and lamb, lamb and pork, and pork and chicken are pairwise complements. The expenditure elasticities are all positive and below unity except for beef being estimated to be 1.647. The large beef expenditure elasticity combined with the lack of any pre-committed consumption of beef reveals that the quantity of beef consumed is most responsive to increases in meat expenditures. In contrast, with an estimated elasticity of 0.043, chicken consumption is not very responsive to changes in meat expenditures. Finally, the preferred GAIDS+ model elasticity estimates are largely consistent with demand theory with 76 per cent of the observations satisfying the curvature requirements of negative semi-definiteness of the Slutsky matrix.

[3] In addition to calculating price and expenditure elasticities at every data point for the preferred GAIDS+ model, price and expenditure elasticities were calculated at the means of the sample data. Comparison of these estimates with those reported in Table 7 revealed that estimated economic effects were similar and that no meaningful changes to elasticity estimates transpired when using the alternative method.

7. Conclusions

Estimation of the GAIDS model using quarterly Australian meat data indicates the existence of statistically significant pre-committed chicken quantities by Australian consumers between 1996 and 2016 when jointly accounting for seasonality and time trend factors. These results imply that a marginal change of expenditures from supernumerary to pre-committed expenditure occurred for chicken during the sample period. This suggests that factors other than price and expenditure contribute significantly to chicken demand responses by Australian consumers during the sample period. Further, results demonstrate that seasonality and time trend factors are important considerations when estimating Australian consumer pre-committed meat demand. The absence of pre-committed quantities of lamb, beef and pork suggests that chicken is more of a staple item in Australian household diets when compared with other meats.

To improve Australian consumer meat demand modelling outcomes, future work should focus on three key data issues. First, work is needed to determine the underlying causes of Australian meat demand shifters and the breakpoints identified. While some of the breakpoints in the time series used in this study can be attributed to data collection procedural changes, without testing for specific shifters of Australian meat demand, there remains no way of knowing which of these breakpoints or structural changes occurred due to changes in consumer tastes or preferences. Second, a longer sample may alleviate problems with model convergence and may enable the inclusion of necessary dummy variables. Third, the development of a fresh salmon, or fish and seafood, variable for inclusion in the demand system is warranted. Not only do fresh salmon products sell within equivalent price ranges of some popular Australian beef and lamb cuts (Ruello & Associates Pty Ltd, 2010), approximately one-quarter of Australian consumers eat salmon once a week (Roy Morgan Research, 2016).

This study provides the first assessment of differences in Australian consumer meat demand formation when pre-committed quantities are considered. That is, Australian consumption of chicken was largely influenced by non-price and non-income factors over the sample period, while purchasing decisions for lamb, beef, and pork were driven by price and expenditure factors alone. These findings raise the question of how non-price and non-expenditure factors may influence pre-committed chicken consumption and, more generally, total Australian meat consumption. This is an understudied topic. Reasons for this result may include the diversification of chicken products available to consumers over the time period of the study in comparison with other meats, or the increase in product source information (such as free-range, organic, or welfare group-approved chicken products). The influence of any such factor needs to be investigated in terms of modifying demand modelling, for example with the development and inclusion of topic specific demand shifters in the GAIDS specification. This could greatly assist in explaining Australian meat demand factors. Future work could expand upon this study by incorporating demand shift indices in the GAIDS to evaluate the impact of other non-price and non-income factors on chicken demand. An animal welfare index may be a demand shift index worth investigation due to Australia's involvement in the live export of sheep and cattle (Munro 2015). In this context, examination of how consumer animal welfare concerns impact each meat type may provide valuable insight into the recent growth in chicken demand.

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