Food Demand Elasticities for Australia*

Mehmet Ulubasoglu,* Debdulal Mallick, Mokhtarul Wadud,
Phillip Hone and Henry Haszler

provisionally accepted at the
Australian Journal of Agricultural and Resource Economics

There is renewed interest in robust estimates of food demand elasticities at a disaggregated level not only to analyse the impact of changing food preferences on the agricultural sector, but also to establish the likely impact of pricing incentives on households. Using data drawn from two national Household Expenditure Surveys covering the periods 1998/99 and 2003/04, and adopting an Almost Ideal Demand System approach that addresses the zero observations problem, this paper estimates a food demand system for 15 food categories for Australia. The categories cover the standard food items that Australian households demand routinely. Own-price, cross-price and expenditure elasticity estimates of the Marshallian and Hicksian types have been derived for all categories. The parameter estimates obtained in this study represent the first integrated set of food demand elasticities based on a highly disaggregated food demand system for Australia, and all accord with economic intuition.

Key words: Food demand, AIDS model, Australia.

---

* We would like to thank Editor John Rolfe, an Associate Editor, and three anonymous referees for their highly encouraging and constructive comments on earlier versions of this paper. We also thank the Rural Industries Research and Development Corporation for funding the project (Project No. PRJ-00296) that gave rise to this article. We are also indebted to Margaret Dinan and Clinton Mahar from ABS, and Terry Shields, David Barrett, Helal Ahammad, and Edwina Heyhoe from ABARES for providing us with valuable information during the data collection stage, John Freebairn, Keith McLaren and George Veryikios for very useful input into this paper, and Rejaul Bakshi and Habibur Rahman for excellent research assistance.
* Corresponding author: Department of Economics, Deakin University, 70 Elgar Rd, Burwood, VIC 3125, Australia. Email: mehmet.ulubasoglu@deakin.edu.au

Food Demand Elasticities for Australia

Abstract

There is renewed interest in robust estimates of food demand elasticities at a disaggregated level not only to analyse the impact of changing food preferences on the agricultural sector, but also to establish the likely impact of pricing incentives on households. Using data drawn from two national Household Expenditure Surveys covering the periods 1998/99 and 2003/04, and adopting an Almost Ideal Demand System approach that addresses the zero observations problem, this paper estimates a food demand system for 15 food categories for Australia. The categories cover the standard food items that Australian households demand routinely. Own-price, cross-price and expenditure elasticity estimates of the Marshallian and Hicksian types have been derived for all categories. The parameter estimates obtained in this study represent the first integrated set of food demand elasticities based on a highly disaggregated food demand system for Australia, and all accord with economic intuition.

Key words: Food demand, AIDS model, Australia.

1. Introduction

Despite their central importance, robust estimates of food demand elasticities are not available for many developed economies. Reliable estimates of such elasticities are critical for formulation of various public policies and many strategic decisions undertaken at the industry level. Important examples include, setting R&D priorities, forecasting future market conditions, evaluating promotional campaigns, and assessing proposals for industry or commodity-based taxes and levies. For instance, the world-wide debate on policy responses to the increasing rate of non-communicable diseases linked to obesity is a policy evaluation process that rests on a sound understanding of food demand elasticities. Consider, in this vein, the debate on “fat taxes” and “thin subsidies” (see, among others, Nordstrom and Thunstrom 2009, Yaniv et al. 2009, and Allais et al 2010). A tax on fatty foods could change household food purchasing decisions towards the consumption of low-fat food. What impact any tax will have on household behaviour and household well-being will depend, in part, on the responsiveness of households to the rise in price of fatty foods – how large will the reduction in purchases of fatty foods be, and what foods will be purchased as substitutes? Similarly, consider “thin subsidies”. How much rise will be observed in the production and the sales of fresh vegetables and fruit if their retail prices are subsidised? Availability of sound food demand elasticity estimates can thus strongly add to policy debates and assist in informed decision-making (see Edwards and Freebairn 1981, Dixon 1982, Hill et al. 2001). Policy research without knowing the values of the relevant elasticities is analogous to calculating the expansion due to heating of a substance without knowing whether the substance is steel, concrete, or paper. Under such conditions, neither economists nor physicists can possibly get their answers right.

This paper contributes to the public policy literature by estimating a comprehensive and integrated set of food demand elasticities for 15 disaggregated food categories in Australia. Although export demand is a key component of the demand for traded goods such as grains, meats and dairy products, domestic food demand is still of considerable importance to the food supply sector and the Australian economy as a whole. Domestic food demand has been exhibiting changes in food preferences that are likely to be driven by ageing, health concerns, advertising, and a changing ethnic mix due to international migration (see Worsley 2002 and Kearney 2010), all of which could influence the responsiveness of food demand to price changes. Therefore, the evaluation of current food demand elasticities is a key consideration in the formulation of efficient policy settings in this economy.

Given this context, this paper makes three important contributions to the literature. First, own-price, cross-price and expenditure elasticities of Marshallian and Hicksian type are estimated using bi-weekly food expenditure data for 15 food categories in Australia. The food categories analysed in this study cover most of the standard food items in household shopping lists in Australia. This allows us to take into consideration the households' budgeting decisions in accord with substitution and complementarity issues. We use the Almost Ideal Demand System model as a base to estimate our elasticity estimates, and address the zero observations problem in the first stage of the estimation through parametric and semi-nonparametric methods. Second, the level of disaggregation in food items that we cover in this paper is unique for Australia. Third, we provide separate estimates of the elasticities for households with Australian-born household heads. Comparing the food demand behaviour of these households with the full sample case, we attempt to derive some inferences about how food demand might vary across households with Australian-born and foreign-born household heads.[1]

Section 2 reviews the extant literature on Australian food demand elasticities and highlights how this study differs from prior work. The data are described in Section 3, while in Section 4 we discuss the patterns in food demand and food prices in Australia. Econometric methodology is discussed in Section 5, estimation results are reported in Section 6, and conclusions and possible implications are outlined in Section 7.

2. Previous Food Demand Estimates for Australia

Table 1 provides the list of studies that have estimated Australian food demand elasticities since the 1970s, revealing five important facts. First, little is known about the values of <u>disaggregated</u> food demand elasticities for Australia. A great majority of previous studies focused on aggregate food categories, such as "food" or "meat", or specialised in only a few disaggregated items within one category, such as beef, lamb, chicken, and pork within meat. Comprehensive elasticity estimates for many of the food items that are usually seen in households' shopping lists in Australia were not made available. Second, a great majority of the studies used data from several decades ago, and almost none of the studies employed data from the 1990s and the 2000s. The nature of demand relationships could well have changed over time as evidenced by several studies. Third, almost all studies estimating Australian elasticities utilised time series data at the national level. Estimations using survey data and capturing food demand

[1] This article builds on Ulubasoglu et al. (2011), a report prepared for the Rural Industries Research and Development Corporation which estimated the Australian domestic demand elasticities for rural marketing and policy analysis.

behavior at the household level are very limited. Fourth, almost all of the studies focused on own-price elasticities. Cross-price elasticities are necessary to be able to account for possible substitution effects in evaluating the effects policies, such as a tax levy or a subsidy. Finally, past studies did not explore the implications of a changing ethnic mix on food demand, a phenomenon that is observed in many developed countries due to international migration. These contributions make our scope and contributions significantly different from those of existing studies.

Studies have drawn data from various sources including the Australian Bureau of Statistics (ABS), the Australian Bureau of Agricultural and Resource Economics (ABARE), and the Australian Meat and Livestock Corporation. Tulpule and Powell (1978) estimated expenditure elasticities using the TELES/Frisch approach, with estimates ranging between 0.1 and 0.5. Selvanathan (1991) estimated the own-price elasticity of “food” for different states, and obtained estimates that lie between 0 and -0.53. Studies by Alston and Chalfant (1987), Martin and Porter (1985), and Piggot et al. (1996) used a single equation OLS approach and estimated own-price elasticities for beef, chicken, pork, and lamb. Alston and Chalfant (1987) and Piggot et al. (1996) obtained roughly similar own-price elasticities in the range of -0.42 and -1.26, Martin and Porter’s (1985) estimates were on the higher side, ranging between -0.85 and -1.88. Bhati’s (1987) estimates for chicken, using a 2SLS approach, were similar to Alston and Chalfant’s. These studies covered the period from the 1960s to the 1980s.

Cashin (1991), and Hyde and Perloff (1998), also estimated own-price elasticities for disaggregated meat items using data that span the 1970s and 1980s, and adopted the Almost Identical Demand Systems (AIDS) methodology. Hyde and Perloff’s estimates were in the range of -1.04 and -1.71, while Cashin’s estimates were relatively lower and varied between -0.83 and -1.33.

Using a generalised addilog demand system and the 1984 Household Survey, Bewley (1987) estimated the demand elasticity for milk, and finds highly elastic estimates, -14.77 for delivered milk and -3.62 for non-delivered milk. Horticulture Australia Limited (2008), using weekly retail sales data from 2001 to 2007, estimated a demand system for horticultural products and obtained the own-price, cross-price and expenditure elasticities for nuts, fresh fruit and vegetables, including some varieties within each category. These commodities form less than 20 per cent of household food purchases in Australia.

In an uncommon approach, using the 1996 cross-country data on international price comparisons and a Florida-Slutsky-based demand model, Seale et al. (2003) provided own-price, income and expenditure elasticities for Australia along with 113 countries for eight food items classified as: beverages and tobacco, bread and cereals, dairy, fats and oils, fish, fruit and vegetables, meat, and other foods. While in terms of product coverage and disaggregation Seale et al. (2003) comes close to ours, the implications associated with cross-country demand analysis are very unclear. For instance, widely different consumer food preferences across countries may result in elasticities that are based on strong assumptions, or measurement errors might traverse across the system and contaminate the estimates.

3. Data

We use diary data reported by households on food purchases over a two-week period, available in the Household Expenditure Surveys (HES) of the ABS. The data come from the 1998/99 and 2003/04 HESs, which contain, respectively, 6859 and 6957 households that are surveyed in different quarters during the year. The most recent HES data cover the period 2009/10.[2] Not incorporating the 2009/10 survey data in this study is unlikely to change our results meaningfully, because the relationships are likely to be stable across time. Nevertheless, the 2009/10 information would be useful to validate our elasticity estimates in future studies.

Food price data for our period are available for capital cities of each state, and monthly prices are averaged into quarterly prices for concordance. Thus, variation in the price data comes from price differences across capital cities and different quarters in a year. Available information on food purchases and food prices feasibly yields 16 food categories for estimation: milk, dairy products (butter and cheese), bread, rice, beef and veal, mutton and lamb, pork, other meat, poultry, fresh fruit, fresh vegetables, preserved fruit, preserved vegetables, sugar and jam, margarine, and other foods. Detailed information on the construction of the dataset is provided in Appendix A.

4. Food Demand and Food Prices in Australia

This section discusses food demand and food prices in Australia for the 15 product categories analysed in this study. The objective is to provide a background for the elasticities to be estimated in the next section.

4.1 Food Expenditure Shares

Appendix B presents the expenditure shares of each food category (i.e., shares within the 15 food categories covered in this study) for the households surveyed in 1998/99 and 2003/04. The shares are reported by ethnicity, state, households' children status, and the age of the household head. Focusing on the 1998/99 survey, milk constitutes a significant food item with an expenditure share of around 13 per cent, not varying much across the demographic groups. Dairy products constitute approximately 9 per cent, while margarine occupies around a 4 per cent share. Bread has a mean expenditure share of 12 per cent, varying little across the demographic groups. Rice exhibits some important variability, however. Households whose heads were born in Australia spend 3 per cent on rice, whereas households with overseas-born heads spend 6 per cent. Given that rice is a staple food for ethnicities like Indians and other Asian communities, these differences seem to be unsurprising. Meat categories exhibit important characteristics. The average beef and veal expenditure share in Australian food budgets is 13 per cent. The mean expenditure share for mutton and lamb, poultry, and Other Meat is 10 per cent, 11 per cent, and 6 per cent, respectively, with relatively little variability across the demographics. However, pork does exhibit some variation across different demographic cohorts. The mean Australian expenditure share for pork is 9 per cent, with households whose heads were born in Australia consuming 8 per cent and households with overseas-born heads spending 11 per cent on pork. All other food

[2] This information became available after the completion of the project that gave rise to this study.

categories exhibit limited variability across the demographic groups, with mean expenditure shares reported as follows: Fresh fruit 7 per cent, fresh vegetables 9 per cent, preserved fruit 4 per cent, preserved vegetables 5 per cent, and sugar and jam 4 per cent.

The 2003/04 survey does not exhibit any significant changes in expenditure shares compared to the 1998/99 survey.

4.2 Food Prices

Table 2 in this article presents the average prices for 15 food categories, standard deviations of prices (in the estimation sample), and total weekly household food expenditure on the 15 categories for 1998/99 and 2003/04. Considering all 15 categories, average food prices rose by 26 per cent between the two survey periods. This is above the 17 per cent increase in the CPI over the same period in Australia. The largest increase in food prices was observed for mutton and lamb (64 per cent) and the lowest increase was for sugar and jam (3.6 per cent). Meat categories generally exhibited large rises (except poultry); average prices for the five meat categories increased by 38 per cent over the five years. Milk, bread, fresh vegetables, preserved vegetables and margarine prices registered rises of more than 20 per cent, while dairy products, fresh fruit, and sugar and jam had price increases of 10 per cent or less. All these point to changes in the absolute and relative food prices over time. Total weekly household food expenditure for the 15 food categories covered in this study increased by 24 per cent (from $41.39 to $51.22) over the five years.

5. Estimation of Food Demand Elasticities

There are many possible ways of estimating demand relationships - from using the simplest single commodity models, which are adequate for small expenditure items, to whole demand systems. In this paper a systems approach is adopted because it best represents the decisions that consumers make regarding food and other purchase decisions, and recognises the need to simultaneously meet a whole range of expenses.

Specifically, we adopt the linearised version of Deaton and Muelbauer’s (1980) AIDS methodology, which is the workhorse of many household demand systems studies. The AIDS model is based on a price index that is non-linear in parameters; so following standard practice a linear approximation has been applied to the AIDS model (see Buse 1994 and Moschini 1995). Among all the demand systems, AIDS is particularly attractive because its properties in relation to the consumers’ preferences are well-known (Barnett and Seck 2008). Accordingly, we estimate expenditure share equations for a system of 16 food categories and derive the elasticities for 15 categories. Our expenditure share equations look like:

$$W_i = \alpha_i + \sum_k \eta_{i,k} d_{i,k} + \sum_j \gamma_{i,j} \log p_j + \beta_i \log(X / P) + \mu_l S_l + u_i$$

for $i = 1, 2, \ldots, 16$, where W is the expenditure share of commodity i, p is the unit price of the commodity, j is all other commodities except i, X is the total food expenditure, P is aggregate price level, $d_{i,k}$ is k-th demographic characteristic (including the country of birth of the household head, age of the household head, household size, and the number of children under 15), and *S* stands for state of residence.

Next, we derive the own-price, cross-price and expenditure elasticities of 15 food categories. We compute the Marshallian own-price elasticities following equation (12) in Appendix C, and derive the Hicksian cross-price elasticities following Okrent and Alston (2011, p. 8). We compute the standard errors of the elasticities using the delta method. Description of the AIDS model including the theoretical constraints, and the procedural details of other derivations used in this study, is provided in Appendix C.

Zero expenditures for some food categories are the foremost estimation issue. The problem is one of non-random sampling, which results in sample selection bias leading to inconsistent OLS estimates due to skewedness of the observations towards a certain number (in this case, zero). What causes people not to buy a product which they would otherwise have bought? An important reason for zero purchases is the two-week-long survey period. During a short survey horizon, household expenditures for certain items are more likely to be zero than over a longer term. The survey horizon problem is mentioned in, among others, Heien and Wessells (1990). Zero purchases could also be preference and demographics driven, and can thus be explained by variables like ethnicity, the number of children, and proportion of meals eaten outside the home.

As a solution, we adopt the two-stage Heckman selection method. In the first stage, we estimate a probit model where the dependent variable takes 1 for positive purchases, and 0 for zero purchases. The independent variables are all of the explanatory variables of the expenditure share equation, plus a distinct variable that is to be excluded from the second stage (described below). Mills ratios calculated from the first stage for each of the food categories are then included in the respective expenditure share equations in the second stage, which are estimated jointly using Seemingly Unrelated Regressions methodology.

Regarding the distinct variable to be excluded from the second stage, most variables that would explain the zero food purchases, such as ethnicity, number of children and household size, are already included in the expenditure share equations. We are also unable to use other desired variables, such as the proportion of meals eaten outside or the presence of a pregnant woman, because this information was not available in our dataset. We follow Heien and Wessells's (1990) reasoning, who argue that if the interview period were longer, more items would be observed entering the consumer's market basket. One can reasonably say that once households go shopping, they buy not only food, but also other items like detergent, toilet paper, cling wrap, toothpaste and so on. In other words, if non-food expenditure is positive in the survey period, then there is a chance that food expenditure is positive too. If non-food expenditure is zero, then food expenditure can also be zero. We do not expect non-food expenditure to explain the expenditure shares of food items, therefore, we assume it is excludable from the second stage. Hence, we use non-food expenditure as the variable to be excluded from the second stage.

Although the two-step Heckman procedure provides an elegant solution to the censoring problem, the estimator is derived under the assumption that the disturbance in the censoring equation follows a normal distribution. This assumption may be untenable in micro data. In a robustness check, we relax the normality assumption by employing a two-step semi-nonparametric approach by Gallant and Nychka (1987) instead of a probit model. This estimator yields elasticity estimates that are, to a great extent, similar to our benchmark Heckman approach. See Appendix C for more details on the Gallant and Nychka (1987) estimator.

In an unreported analysis, we also conduct our estimations without correcting the sample selection problem. We expect that, given the elasticity formula for own-price elasticities for instance, the OLS estimate should be downwardly biased if the demand is inelastic in reality, and upwardly biased if elastic. Ten out of the 15 OLS estimates are in line with this expectation. For the remaining five food categories, which have mostly unit-elastic demand, the difference between the OLS estimates and corrected estimates is small. Of the 10 categories mentioned above, the OLS-based elasticities are, on average, 10 per cent biased compared to those obtained with correction.[3]

Another issue related to zero observations is the price data for the relevant product category. It is plausible to assume that consumers with zero consumption face the same prices as those paid by people who purchased the product in the same state and quarter. This is an assumption made in this paper.

Finally, the two surveys are pooled in the estimation process as this approach has significant advantages over utilizing them separately. This practice provides a larger degree of freedom and a greater variation in the price data, thus resulting in more meaningful measurement of consumer responses.[4] The question that may arise here is whether the 2003/04 prices should be deflated by a price index. Importantly, the AIDS model allows for explicitly imposing the homogeneity condition through a simple constraint on the coefficients. This takes care of the issue of "real" prices.[5]

6. Results

Table 3 provides the summary statistics for the explanatory variables included in the expenditure share equations. Our discussion will mainly focus on Marshallian-based own-price and expenditure elasticities and Hicksian-based cross-price elasticities, both drawn from the benchmark Heckman procedure. Note that Hicksian elasticities measure the substitution effect that is due to price changes only and exclude the income effect.

6.1 Marshallian Own-Price Elasticities for All Households

The Heckman estimation results for the Marshallian own-price and expenditure elasticities are reported in Table 4. As expected, almost all of the own-price elasticities are negative. A great majority of the estimates are statistically significant at 5 per cent or above.

[3] The magnitude of the bias reported here is the weighted mean percentage deviation (in absolute values) from the "corrected" estimates. Weights are the expenditure shares of the relevant categories. However, the reasoning concerning the bias here is based on single-equation estimation, not the system estimation.
[4] We have tested for the price stability of each commodity in the system using a Chow-type test. The results show that the change was significant at 10% level for three categories (preserved fruits, preserved vegetables, sugar and jam), significant at 5% level for one category (pork), and significant at 1% level for two categories (milk and bread). The remaining 10 categories saw no changes in the parameters between the two samples. This suggests that the parameters are, to a large extent, stable over time.
[5] We would like to thank Keith McLaren for pointing this out to us.

6.1.1 Milk, Dairy Products, Margarine

While the own-price elasticity of milk is estimated to be -0.23, the elasticity falls short of being statistically significant. The own-price elasticity for dairy products is estimated to be unit elastic, while margarine is estimated to have an elastic demand, with the own-price elasticity standing at -1.70.

6.1.2 Bread, Rice

Not surprisingly, bread's own-price elasticity is estimated to be low, standing at -0.73. Rice, on the other hand, is estimated to have an elastic demand with an own-price elasticity of -2.66. While rice is a staple item for some ethnicities, its elasticity estimate seems to be dominated by the households with an Australian-born head for whom it does not occupy a large space in total food expenditure, and hence the strong response to price changes. See below.

6.1.3 Beef and Veal, Mutton and Lamb, Pork, Poultry, Other Meat

The estimation results offer significant insights regarding own-price elasticities for different meat products. Own-price elasticities for beef and veal, mutton and lamb, and poultry are estimated to be almost the same, with estimates being roughly around -1.4. On the other hand, pork is estimated to have much higher own-demand elasticity, with an estimate of -2.20. Finally, the demand for the other meats category (which includes sausages, bacon, ham, and canned meat) is about unit-elastic, with an estimate of -0.85.

Comparatively speaking, own-price elasticity estimates for meat products are intuitive in that 'white meat' (chicken) is positioned next to the main Australian staples of beef and lamb, with pork demand being much more responsive to price changes. The fact that Australian households consider pork substitutable might explain its high elasticity estimate.

6.1.4 Fruit, Vegetables

We estimate the elasticities for fruit and vegetables for both fresh and preserved products. Once again, the estimates appear plausible and is consistent with anectodal evidence about consumer behaviour in food stores. Fresh fruit is estimated to have unit elastic demand with an elasticity estimate of -1.05, while the demand for fresh vegetables is inelastic with an elasticity standing at -0.53. Thus, consumers seem to be relatively less responsive to changes in fresh vegetable prices. Conversely, preserved fruit is estimated to have an insignificant own-price elasticity, while preserved vegetables have an elastic demand with an estimate of -1.38.

6.1.5 Sugar and Jam

The own-price elasticity for sugar and jam is estimated to be positive. A close analysis of the data suggested that this counter-intuitive result is largely driven by sugar, and importantly, by some outliers in sugar purchases – households are unlikely to purchase sugar on a weekly basis and they are likely to store this item. Modelling any dynamic influences on sugar consumption is beyond the scope of this study, given our dataset; however, eliminating from the sample 87 households whose sugar and jam purchases constitute 10 per cent or more of their food budget in 2003/04, the elasticity estimate becomes insignificant.

6.2 Marshallian Own-Price Elasticities for Households with Australian-born Heads

So far, the results cover all households in the two surveys. However, ethnicity is a potentially important factor in food demand in Australia. Preferences for commodities like milk, rice and meat can differ widely across ethnicities. While elasticities for different ethnicities are difficult to estimate due to sample size considerations, estimation for households with Australian-born heads is possible. Table 5 demonstrates that a great majority of these elasticities mimic the full sample case, although there are some important differences.

Focusing on the estimates that are different, the first notable difference is related to rice. Its own-price elasticity is -4.36 which is strikingly higher than -2.66 obtained in the full sample case. This suggests that for households with Australian-born heads, rice demand is much more price-responsive than for households with overseas-born heads. Rice is less of a staple food for households with Australian-born heads and has probably more substitutes for this group in the sample. A few other food categories also register some noteworthy variations, including dairy products, pork, sugar and jam (all with higher estimates for households with Australian-born heads), and preserved vegetables (with a lower estimate for households with Australian-born heads).

6.3 Marshallian Expenditure Elasticities for All Households and Households with Australian-born Heads

Expenditure elasticities are key behavioural parameters in policy models. Tables 4 and 5 present the expenditure elasticity estimates for all households and households with Australian-born heads, respectively. There does not appear to be any significant difference between the two samples and, therefore, our discussion will focus on the full sample.

Our expenditure elasticity estimates accord with economic intuition. All the food items are estimated to have positive and statistically significant expenditure elasticities. The demand for milk, bread, fresh fruit, fresh vegetables and margarine are estimated to be expenditure-inelastic, with the estimates ranging from 0.37 to 0.94. The demand for dairy products is in the neighborhood of unit elasticity. On the other hand, all the meat items, rice, sugar and jam, and preserved fruit/vegetables are estimated to have expenditure-elastic demand, with estimates in the range of 1.19 and 1.64. It is worth noting that milk and bread have the lowest expenditure elasticities, and beef and veal, mutton and lamb, and pork possess the highest elasticities among our estimates.

6.4 Semi-Nonparametric Estimation Results for Marshallian Elasticities

Appendix D presents the estimates computed using the semi-nonparametric method of Gallant and Nychka (1987). We calculate these elasticities for the All-Australian sample. The concordance between most of the elasticities obtained through parametric and semi-nonparametric methods is noteworthy. However, the semi-nonparametric method reinforces the fact that the sugar and jam elasticity estimate is insignificant (even without removing the outliers), suggesting that non-normality in the residuals might have affected the previous result. Also, we find the own-elasticity of rice and mutton and lamb are much higher than before, suggesting that the normality assumption in addressing the zero-observations may not be so tenable for these goods.

6.5 Hicksian Cross-Price Elasticities

Table 6 presents Hicksian cross-price elasticities derived from the Marshallian cross-price elasticities for the All-Australian sample. The key feature of Hicksian elasticities is that they facilitate predictions about the substitutability of the food categories. Most results are robust to the semi-parametric treatment as displayed in Appendix D. Note that negative cross-price elasticities imply that the relevant items are complementary, while positive elasticities imply that they are substitutes.

We estimate the response of the demand for dairy products to a change in margarine prices to be positive and significant. The response of margarine demand to price changes in dairy products is insignificant. However, both responses are insignificant with the semi-nonparametric approach, hence we find no robust evidence for substitutability between dairy products and margarine based on their prices.

Conversely, milk, dairy products and margarine are estimated to have statistically significant cross-price elasticities of varying signs with other food items, such as mutton and lamb, poultry or fresh vegetables. The data might be picking up some common bundling choices across households here, perhaps in association with two-stage budgeting decisions made during the purchase, or the amount or the timing of purchase of the food items.

Demand for bread seems to increase significantly upon an increase in the price of rice, as shown by a significant cross-price elasticity of 1.57. However, using both methods, the demand for rice does not seem to be responsive to a change in the price of bread.

We also estimate cross-price elasticities among five meat categories. The estimates are generally positive and generally significant for all groups except Other Meat. This suggests that, in Australia, the demand for different meat categories responds to changes in prices in other categories, and hence, they are substitutes.

Fresh fruit and fresh vegetables have small, negative and significant cross-price elasticities. This is probably reflective of most households' behaviour of purchasing these goods jointly from stores. On the other hand, the demand for preserved fruit and preserved vegetables seems to respond to price changes in fresh fruit and fresh vegetables, respectively, but not vice versa.

8. Conclusions

This paper computes the price responsiveness of demand for 15 food categories in Australia using HESs for the periods 1998/99 and 2003/04. Adopting an Almost Ideal Demand System approach and addressing the frequent-zero observations in the first stage through parametric and semi-nonparametric methods, we estimate the Marshallian and Hicksian own-price, cross-price and expenditure elasticities for all categories. To our knowledge, such levels of disaggregation for food elasticities are unique to our study. The food categories analysed in this study cover standard food items in household shopping lists in Australia, allowing us to account for households' budgeting decisions in accord with substitution and complementarity issues. We also estimate the elasticities for households with Australian-born heads. Comparing these estimates with the full sample case, we derive some inferences about how food demand varies across households headed by individuals with Australian and foreign origin. The underlying food demand elasticities obtained in this study generally accord with economic intuition.

Our estimates convey relevant information central to the formulation of various public policies and to strategic industry planning in the agricultural sector in Australia. Notably, the marked differences in the estimated own price elasticities of demand suggest that an inclusion of all food items in the Goods and Services Tax (GST) regime could have markedly different impacts on different food items. Our estimates indicate that any increase in food prices that resulted from a tax on all food would tend to have the largest impacts on the demand for rice and meat and would probably have little impact on the demand for milk and preserved fruit. For fresh fruit, a 10 per cent increase in consumer prices would depress final consumer demand by around 10 per cent. We note that there is potential to further update the analysis with more recent HES data for 2009/10.

References

Allais O., Bertail, P. and Nichele, V. (2010). The Effects of a Fat Tax on French Households' Purchases: A Nutritional Approach. *American Journal of Agricultural Economics* 92(1), 228-45.

Alston, J.M. and Chalfant, J.A. (1987). Weak Separability and the Specification of Income in Demand Models with Application to the Demand for Red Meats in Australia. *Australian Journal of Agricultural Economics* 31(1), 1-15.

Australian Bureau of Statistics. (1998). Average Retail Prices of Selected Items: Eight Capital Cities, Australia.

Australian Bureau of Statistics. (2003). Average Retail Prices of Selected Items: Eight Capital Cities, Australia.

Australian Bureau of Statistics. (2006). Household Expenditure Survey: 1998-99 and 2003-04, Australia.

Barnett, W.A. and Seck, O. (2008). Rotterdam Model Versus Almost Ideal Demand System: Will the Best Specification Please Stand Up? *Journal of Applied Econometrics* 23(6), 795-824.

Bewley, R. (1987). The Demand for Milk in Australia Estimation of Price and Income Effects from the 1984 Household Expenditure Survey. *Australian Journal of Agricultural Economics* 31(3), 204-18.

Bhati, U.N. (1987). Supply and Demand Responses for Poultry Meat in Australia. *Australian Journal of Agricultural Economics* 31(03), 256-265.

Buse, A. (1994). Evaluating the Linearized Almost Ideal Demand System. *American Journal of Agricultural Economics* 76(4), 781-93.

Cashin, Paul. (1991). A Model of the Disaggregated Demand for Meat in Australia. *Australian Journal of Agricultural Economics* 35(3), 263-83.

Deaton, A. and Muellbauer, J. (1980). An Almost Ideal Demand System. *The American Economic Review* 70(3), 312-26.

Dixon, P.B., Parmenter, B.R., Sutton, J., and Vincent, D.P. (1982). *ORANI: A Multisectoral Model of the Australian Economy*, North-Holland, Amsterdam.

Edwards, G.W. and Freebairn J.W. (1981). Measuring a Country's Gains from Research: Theory and Application to Rural Research in Australia. Australian Government Publishing Service, Canberra, Australia.

Gallant, A.R. and Nychka, D.W. (1987). Semi-nonparametric Maximum Likelihood Estimation. *Econometrica* 55(2), 363–390.

Heien, D. and Wessells, C.R. (1990). Demand Systems Estimation with Microdata: A Censored Regression Approach. *Journal of Business and Economic Statistics* 8(3), 365-71.

Hill, D.J.; Piggott, R.R and Griffith, G.R. (2001). Profitability of Incremental Generic Promotion of Australian Dairy Products. *Agricultural Economics* 26(3), 253-66.

Horticulture Australia Limited. (2008). Future Focus: The Australian Horticulture Plan, Horticulture Outlook: Stage 1 Report, In Horticulture Australia Limited (HAL), Australia.

Hyde, C.E, and Perloff, J.M. (1998). Multimarket Market Power Estimation: The Australian Retail Meat Sector. *Applied Economics* 30(9), 1169-76.

Kearney, John. (2010). Food consumption trends and drivers, *Phil. Trans. R. Soc*. B 27, 365(1554), 2793-2807.

Martin, W and Porter, D. (1985). Testing for Changes in the Structure of the Demand for Meat in Australia. *Australian Journal of Agricultural Economics* 29(1), 16-31.

Moschini, G. (1995). Units of measurement and the stone index in demand system estimation. *American Journal of Agricultural Economics* 77(1), 63-68.

Nordstrom, J. and Thunstromb, L. (2009). The impact of tax reforms designed to encourage healthier grain consumption. *Journal of Health Economics* 28, 622-634.

Okrent, A.M. and Alston, J.M. (2011). Demand for Food in the United States. A Review of Literature, Evaluation of Previous Estimates, and Presentation of New Estimates of Demand. Giannini Foundation Monograph No 48. April.

Piggott, N.E; Chalfant, J.A.; Alston, J.M. and Griffith, G.R. (1996). Demand Response to Advertising in the Australian Meat Industry. *American Journal of Agricultural Economics* 78(2), 268-79.

Seale, J.L; Regmi, A and Bernstein, J. (2003). *International Evidence on Food Consumption Patterns*. Economic Research Service, United States Dept. of Agriculture.

Selvanathan, S. (1991). Regional Consumption Patterns in Australia: A System-Wide Analysis. *Economic Record* 67(199), 338.

Tulpulé, A and Powell, A. A. (1978). *Estimates of Household Demand Elasticities for the Orani Model*. Preliminary Working Paper, OP-22, IMPACT Project, Industries Assistance Commission.

Ulubasoglu, M., Mallick, D., Wadud, M., Hone, P. and Haszler, H. (2011). How price affects the demand for food in Australia-Australian domestic demand elasticities for rural marketing and policy. Rural Industries Research and Development Corporation (RIRDC), Canberra, Australia. RIRDC Publication No. 11/062. October.

Worsley, A. (2002). Nutrition knowledge and food consumption: can nutrition knowledge change food behaviour?, *Asia Pacific Journal of Clinical Nutrition* 11, S579–S585.

Yaniv, G., Rosin, O and Tobol, Y. (2009). Junk-food, home cooking, physical activity and obesity: the effect of the fat tax and the thin subsidy. *Journal of Public Economics* 93, 823-830.

Table 1 Previous Estimates of Australian Food Demand Elasticities

Authors	Data	Model and Estimation	Estimates			
Tulpule & Powell (1978) [a]	1964/5 -1975/6	TELES, Expenditure, Frisch	*Expenditure Elasticities:*			
			Bread, cakes	0.1	Fruit &Veg	0.5
			Confectionary	0.4	Marg, oil, fats	0.5
			Flour, cereals	0.2	Meat products	0.5
			Food nec	0.5	Milk products	0.1
Selvanathan (1991)	1975 -1989 States	Working, ML	*Spatial Food Demand Elasticities:*			
			AU	-0.26		
			NSW	-0.4	TAS	-0.53
			QLD	-0.26	VIC	0.0
			SA	-0.29	WA	-0.45
Hyde & Perloff (1998)	1970(1) - 1988(1)	LA/AIDS	*Food Demand Elasticities:*			
			Beef	-1.41	Pork	-1.04
			Lamb	-1.71		
Piggot *et al* (1996)	1978(3) – 1988(4)	Single equation, OLS	Beef	-0.42	Lamb	-1.26
			Chicken	-0.46	Pork	-0.87
Alston & Chalfant (1987)	1968(1) – 1983(1)	Single equation, OLS	Beef	-0.42	Lamb	-1.33
			Chicken	-0.37	Pork	-1.12
Martin & Porter (1985)	1962(1) - 1983(1)	Single equation, OLS	Beef	-1.13	Mutton	1.39
			Chicken	-0.85	Pork	-1.09
			Lamb	-1.88		
Bhati (1987)	1971(1) - 1986(4)	Supply and Demand, 2SLS	Chicken meat	-0.36	Poultry meat	-0.35
Bewley (1987)	1984 Household Expenditure Survey	GADS, GLS	Delivered Milk	-14.77	Non-delivered Milk	-3.62
Seale *et al* (2003)	1996 Cross country data	FloridaSlutsky, ML, Frisch	Beverages &Tobacco	-0.314	Fish	-0.283
			Bread &Cereals	-0.115	Fruit & Veg	-0.202
			Dairy	-0.275	Meat	-0.257
			Fats& Oils	-0.136	Other Foods	-0.256
HAL (2008)	Weekly, 2001-2007	OLS	Fresh Fruit	-0.66	Vegetables	-0.58
			Nuts	-0.96		
Cashin (1991)	1967(1) - 1990(1)	LA/AIDS, ML SUR		*Aggregated*	*Disaggregated*	
			Bacon	-	-0.95	
			Beef	-1.24	-0.82	
			Chicken	-0.47	-	
			Fresh Pork	-	-1.2	
			Ham	-	-1.19	
			Lamb	-1.33	-0.99	
			Pork	-0.83	-	

(a) Reported by Dixon et al (1982, p. 185)

Table 2 Average Prices for Each Food Category

Food Category	Unit (per)	1998/99 A$	2003/04 A$
Milk	2 lt	2.533	3.171
		(0.17)	(0.10)
Dairy products	500 gr	2.791	3.090
		(0.13)	(0.15)
Bread	700 gr	2.157	2.736
		(0.17)	(0.17)
Rice	1 kg	1.556	2.027
		(0.09)	(0.09)
Beef and veal	1 kg	8.536	12.355
		(0.50)	(0.41)
Mutton and lamb	1 kg	6.442	10.563
		(0.29)	(0.27)
Pork	1 kg	6.989	9.209
		(0.32)	(0.45)
Other meat	625 gr	3.426	4.724
		(0.21)	(0.13)
Poultry	1 kg	3.509	3.927
		(0.19)	(0.21)
Fresh fruit	1 kg	2.202	2.405
		(0.42)	(0.36)
Fresh vegetables	1 kg	1.967	2.386
		(0.24)	(0.20)
Preserved fruit	625 gr	1.602	1.914
		(0.08)	(0.08)
Preserved vegetables	500 gr	1.303	1.587
		(0.13)	(0.08)
Sugar and jam	1250 gr	2.372	2.458
		(0.14)	(0.15)
Margarine	500 gr	1.761	2.344
		(0.13)	(0.06)
Total Weekly Food Expenditure		41.390	51.217
		(24.97)	(34.14)
Sample Size		6850	6957

Notes: Figures in parentheses refer to standard deviations. Prices in Australian dollars (A$).

Table 3 Summary statistics for ethnicity, household characteristics and states, 1998/99 and 2003/04

	1998/99	2003/04
Households with Children Aged between 0-15	0.591 (0.95)	0.551 (0.95)
Family size	2.620 (1.35)	2.524 (1.32)
Household head Australian born	72.20%	72.82%
Household head foreign born	27.80%	27.18%
New South Wales	29.54%	25.08%
Victoria	19.96%	22.01%
Queensland	15.88%	12.75%
South Australia	8.18%	12.42%
Western Australia	9.42%	10.48%
Tasmania	6.95%	7.98%
Northern Territory & ACT	9.94%	9.29%
Sample Size	6859	6957

Note: Figures in parentheses refer to standard deviations.

Table 4 Marshallian Own-Price and Expenditure Elasticities for All Australian Households (Heckman method)

Food Category	Own-Price Elasticity	Expenditure Elasticity
Milk	-0.233 (-1.47)	0.371*** (24.36)
Dairy products	-0.999*** (-3.23)	1.004*** (36.68)
Bread	-0.733*** (-7.43)	0.449*** (33.74)
Rice	-2.657*** (-4.28)	1.196*** (16.55)
Beef and veal	-1.353*** (-9.15)	1.636*** (57.87)
Mutton and lamb	-1.420*** (-8.38)	1.637*** (44.18)
Pork	-2.203*** (-5.03)	1.592*** (31.78)
Other meat	-0.846*** (-3.57)	1.259*** (30.49)
Poultry	-1.388*** (-4.26)	1.381*** (43.50)
Fresh fruit	-1.049*** (-9.16)	0.755*** (29.92)
Fresh vegetables	-0.526*** (-5.34)	0.888*** (42.94)
Preserved fruit	-0.439 (-0.89)	1.516*** (18.70)
Preserved vegetables	-1.383*** (-4.86)	1.230*** (21.46)
Sugar and jam	1.018** (2.03)	1.187*** (20.40)
Margarine	-1.696*** (-7.51)	0.938*** (18.82)

Notes: ***, **, and * refer to statistical significance at 1%, 5% and 10% levels, respectively. Figures in parentheses refer to the z-statistics.

Table 5 Marshallian Own-Price and Expenditure Elasticities for Households with Australian-Born Heads (Heckman Method)

Food Category	Own-Price Elasticity	Expenditure Elasticity
Milk	-0.093 (-0.55)	0.393*** (25.20)
Dairy products	-1.178*** (-3.64)	0.946*** (35.62)
Bread	-0.622*** (-6.05)	0.496*** (35.71)
Rice	-4.358*** (-6.23)	1.116*** (13.13)
Beef and veal	-1.344*** (-8.62)	1.551*** (54.56)
Mutton and lamb	-1.505*** (-8.87)	1.555*** (42.20)
Pork	-2.494*** (-5.02)	1.595*** (28.63)
Other meat	-0.805*** (-3.32)	1.207*** (27.80)
Poultry	-1.425*** (-4.05)	1.358*** (37.36)
Fresh fruit	-1.004*** (-8.08)	0.726*** (28.89)
Fresh vegetables	-0.627*** (-6.12)	0.849*** (41.10)
Preserved fruit	-0.049 (-0.10)	1.421*** (18.64)
Preserved vegetables	-1.023*** (-3.57)	1.167*** (20.86)
Sugar and jam	1.561*** (2.67)	1.189*** (16.35)
Margarine	-1.774*** (-7.68)	0.943*** (20.21)

See the Notes to Table 4.

Table 6 Hicksian Cross-Price Elasticities for All Australian Households (Heckman Method)

Food Category	**Milk**	**Dairy products**	**Bread**	**Rice**	**Beef and veal**	**Mutton & lamb**	**Pork**	**Other meat**	**Poultry**	**Fresh fruit**	**Fresh vegetables**	**Preserved fruit**	**Preserved vegetables**	**Sugar and jam**	**Margarine**
Milk		0.35** (2.07)	0.36*** (3.84)	-0.80 (-1.30)	0.26* (1.76)	0.23 (1.07)	-0.27 (-0.64)	0.06 (-0.23)	0.83*** (3.80)	-1.04*** (-6.84)	-0.67*** (-5.91)	-1.23*** (-3.05)	0.07 (0.23)	-1.85*** (-5.73)	-1.25*** (-3.95)
Dairy products	0.25*** (2.73)		0.05 (0.80)	-0.22 (-0.26)	0.09 (0.82)	0.49*** (3.01)	1.04** (2.15)	0.07 (0.26)	-0.68*** (-2.88)	0.09 (0.72)	0.03 (0.35)	0.15 (0.26)	-0.29 (-0.74)	0.75 (1.47)	0.70* (1.81)
Bread	0.367*** (3.78)	-0.04 (-0.29)		1.567** *(3.37)	0.12 (0.98)	-0.27 (-1.57)	-0.35 (-1.08)	0.56*** (3.06)	0.02 (0.14)	-0.80*** (-6.59)	-0.44*** (-4.93)	-0.01 (-0.03)	0.76*** (3.35)	-1.05*** (-4.45)	-0.31 (-1.36)
Rice	-0.03 (-0.75)	-0.08 (-0.67)	0.15*** (4.46)		0.21*** (4.02)	0.42*** (5.32)	0.24 (0.99)	0.34*** (2.61)	0.09 (0.85)	0.08 (1.34)	-0.01 (-0.22)	-0.11 (-0.35)	0.41** (2.03)	0.47* (1.75)	0.43** (2.16)
Beef and veal	0.18** (2.25)	-0.08 (-0.77)	0.11* (1.83)	0.17 (0.45)		0.36** (2.34)	0.59** (2.25)	0.22 (1.46)	0.41*** (2.89)	0.30*** (2.85)	0.04 (0.50)	-0.12 (-0.48)	-0.25 (-1.36)	-0.14 (-0.74)	0.09 (0.49)
Mutton and lamb	0.11* (1.78)	0.14* (1.71)	-0.01 (-0.31)	0.79*** (2.63)	0.30*** (3.70)		0.47** (2.25)	-0.05 (-0.44)	0.22* (1.95)	0.23*** (2.76)	0.04 (0.67)	0.24 (1.27)	-0.13 (-0.87)	-0.06 (-0.39)	0.20 (1.34)
Pork	0.02 (0.25)	0.23* (1.73)	0.02 (0.49)	0.14 (0.27	0.35*** (4.63)	0.40*** (3.48)		0.07 (0.41)	0.32** (2.08)	0.03 (0.31)	0.05 (0.71)	0.57* (1.69)	-0.25 (-1.02)	0.09 (0.34)	0.49** (2.06)
Other meat	0.01 (0.17)	-0.03 (-0.27)	0.19*** (3.95)	1.02** (2.11)	0.26*** (3.39)	0.08 (0.68)	0.15 (0.50)		-0.07 (-0.44)	0.01 (0.12)	-0.05 (-0.74)	0.36 (1.13)	0.27 (1.17)	0.24 (0.93)	-0.02 (-0.7)
Poultry	0.41*** (4.03)	-0.71*** (-3.54)	0.05 (0.65)	-0.26 (-0.35)	0.40*** (3.29)	0.28 (1.51)	0.60 (1.29)	-0.29 (-1.13)		0.31** (2.24)	0.24** (2.26)	0.32 (0.67)	-0.44 (-1.24)	-0.07 (-0.17)	0.83** (2.35)
Fresh fruit	-0.40*** (-6.59)	0.04 (0.46)	-0.28*** (-5.97)	0.84** (2.49)	0.38*** (4.92)	0.55*** (4.76)	0.33 (1.48)	0.15 (1.19)	0.41*** (3.41)		-0.14** (-2.27)	-0.16 (-0.75)	0.52*** (3.21)	-0.06 (-0.31)	-0.52*** (-3.16)
Fresh vegetables	-0.36*** (-5.03)	0.05 (0.45)	-0.19*** (-3.55)	0.39 (0.97)	0.21 (0.23)	0.31** (2.36)	0.44 (1.62)	0.05 (0.34)	0.49*** (3.38)	-0.16* (-1.66)		0.98*** (3.79)	0.24 (1.24)	-0.21 (-1.01)	-0.39** (-1.99)
Preserved fruit	-0.08* (-1.70)	0.00 (0.03)	0.08** (2.25)	-0.24 (-0.49)	0.19*** (3.65)	0.32*** (4.05)	0.59** (2.30)	0.22 (1.59)	0.24** (2.00)	-0.11* (-1.73)	0.14*** (2.99)		-0.02 (-0.11)	0.09 (0.27)	-0.03 (-0.13)
Preserved vegetables	0.04 (0.74)	-0.14 (-1.22)	0.16*** (4.45)	0.78* (1.80)	0.10* (1.80)	0.11 (1.33)	-0.14 (-0.55)	0.19 (1.45)	-0.02 (-0.18)	0.13* (1.94)	-0.00(- 0.04)	-0.06(- 0.21)		0.30 (1.16)	0.55*** (2.79)
Sugar and jam	-0.20*** (-5.00)	0.12 (1.09)	-0.08*** (-2.82)	0.81* (1.81)	0.15*** (3.50)	0.19*** (2.84)	0.25 (1.12)	0.18 (1.52)	0.12 (1.13)	-0.08 (-1.43)	-0.10** (-2.32)	0.15 (0.43)	0.29 (1.44)		0.19 (0.95)
Margarine	-0.17*** (-4.16)	0.09 (1.01)	-0.03 (-1.09)	0.71** (2.05)	0.17*** (3.74)	0.26*** (3.91)	0.54*** (2.71)	0.03 (0.29)	0.33*** (3.44)	-0.26*** (-4.87)	-0.16*** (-3.99)	-0.02 (-0.08)	0.47*** (2.92)	0.16 (0.76)	

Notes: 1. Row headings refer to the price of the respective product, and column headings to the quantity demanded of the respective product;
2. ***, **, and * refer to statistical significance at 1%, 5% and 10% levels, respectively.
3. Figures in parentheses refer to the z-statistics.

APPENDIX A

A.1 The Household Expenditure Surveys (HES)

The Australian Bureau of Statistics (ABS) conducted Household Expenditure Surveys (HESs) in 1984, 1988/89, 1993/94, 1998/99, 2003/04 and 2009/10. The detailed data from these surveys are provided in the form of HES Confidentialised Unit Record Files (CURF). This study uses the 1998/99 and 2003/04 surveys, primarily because of the compatibility between the two and the range of data they offer. Although prior surveys also include data on expenditure and other household characteristics, there are serious concordance issues with the 1998/99 and 2003/04 surveys, requiring strong assumptions to construct a larger dataset. The HES 2009/10 survey became available after the completion of the project that gave rise to this study.

The 1998/99 HES CURF contains detailed information on expenditure, income and demographic characteristics for a sample of 6,892 households in Australia, excluding special dwellings such as hospitals, institutions, nursing homes, hotels and hostels, and dwellings in remote and sparsely-settled parts of the country. Information was collected through personal interviews equally spread over the period July 1998 to June 1999 from all persons aged 15 years and over in the selected households. The household reference person is chosen by applying to all household members aged 15 years and over, the following selection criteria, in the order listed, until a single appropriate reference person is identified: i) one of the partners is in a registered or de facto marriage, with dependent children, ii) one of the partners is in a registered or de facto marriage, without dependent children, iii) a lone parent with dependent children, iv) the person with the highest income, v) the eldest person (ABS 2003-04, p. 115). It is understandable that the ABS has used the notional framework of 'reference person' without directly labelling the person as the head of the household (as they did not need to). However, the definition of the reference person seems to comply with the general perception of the household head used in various communities, and hence, is adopted in this study.

The HES conducted in 2003/04 was also integrated with a Survey of Income and Housing (SIH). Prior to 2003/04, the HES and SIH were conducted independently. The SIH included 11,361 households, and collected information on household characteristics, assets and liabilities and detailed income by source. In the HES, 6,957 households were included from the SIH sample and were asked to supply detailed information on household expenditure, loans and financial stress. The surveys were conducted throughout Australia from July 2003 to June 2004 on a sample of dwellings not recently included in an ABS household survey. The sample excluded non-private dwellings, such as hospitals, nursing homes, hotels, hostels, and dwellings defined as very remote or indigenous communities.

Information on household characteristics and the detailed weekly expenditure for various household items are recorded in the household and expenditure level data files. In both 1998/99 and 2003/04, the data include information on state or territory and area of residence, type of dwelling, tenure type, landlord type, household type and composition, household reference person, household income, costs, demography and expenditures. The

1998/99 and 2003/04 HES samples were independent of each other. Respondents from the earlier sample were not part of the 2003/04 sample.

In both the HESs of 1998/1999 and 2003/04, information on consumption expenditures was collected from all persons aged 15 years and over in the households included in the samples. These expenditure data were reported by individuals in a household who were required to record in a diary all their expenditure over a two-week period. Although there may be obvious disadvantages of relying on food purchases over only a two-week period, it is expected, based on average consumption patterns of the Australian households, that food expenditure over a span of a fortnight is likely to encompass most of the major food categories. The maximum total household weekly expenditure in the HES database increased by 19% (from $199 to $235), while the minimum stayed at zero in both surveys. On the other hand, total weekly household food expenditure for the 15 food categories covered in this study increased by 24% (from $41.39 to $51.22) over the five years.

A.2 Price data

Despite a wide range of information collected by the ABS on households' expenditure, income and demographic characteristics, data on prices that households pay are not available from the HES databases. Price data are required for estimation on demand elasticities and, hence, these had to be collected from other source(s). The ABS collects price data for about 100,000 items for compiling the CPI but they are not released, even for generic items. Hence, although prices and price indexes are available for aggregate sectors or subsectors, data on prices at the disaggregated level for various household items are limited. The most detailed data on prices are available for capital cities from the ABS publication entitled *Average Retail Prices of Selected Items, Eight Capital Cities* (ABS Catalogue No. 6403). These average prices are obtained as geometric means of prices for specified grades, qualities, brands, and so on, charged by a number of retailers in each city. These prices are collected for about 55 categories of goods used by Australian households, including food and beverages. Note that average prices in Australia for this study are the weighted averages of the states' prices where the weights are the population shares of each state.

The process of obtaining the price information changed over the two surveys for some food items. In 1998/99, prices for fresh fruit and vegetables were collected weekly, while those for milk, fresh meat, bread, fish, petrol and alcohol were collected monthly. Prices for all other items were collected during the mid-month of each quarter. In 2003/04, prices for milk, butter, bread, fresh meat, fresh fruit and vegetables, margarine, and alcohol were obtained each month at regular intervals and were averaged to obtain quarterly prices. Prices for all other items were collected during the mid-month of each quarter. All these prices were averaged to obtain quarterly prices.

A.3 Database for Estimation

In the HES databases of 1998/99 and 2003/04, expenditure on more than 600 items is listed including expenditures on housing, fuel, food, clothing, furnishings, health, transport, personal care and recreation. Information on households' expenditure is reported for 125 food items. Of these, we identified 42 food expenditure items with the corresponding price data available. Then, we aggregated these items into 16 categories for a feasible elasticity estimation. These categories are: milk, dairy products (butter & cheese), bread, rice, beef & veal, mutton & lamb, pork, other meat, poultry, fresh fruit, fresh vegetables, preserved fruit, preserved vegetables, sugar & jam, margarine, and other foods. The 'other foods' category included in the system estimation is not analysed because of the heterogeneity of food items in this category (which includes biscuits, breakfast cereals, flour, canned and bottled fish seafood, chocolates confectionary, eggs, marmalades/jam, tea, coffee, sauces & salad dressing, canned spaghetti & baked beans, and baby food). We were unable to include alcoholic and non-alcoholic beverages in our categorisation, and hence, estimate their elasticities, due to unavailability of price data, or lack of concordance between the specific categories for which price data are available and the categories available in the HES databases.

The unit price for each food item was defined as per the publication on average retail prices (ABS Catalogue No. 6403). Several additional household level demographic variables that are likely to affect households' spending behaviour were also included in our database. These include the number of family members aged between 0 to 15 years, the age of the household head, family size and ethnic background. To control for the effects of the ethnic background of the household head, we use three categories: whether the household heads were born in Australia, in other English speaking countries, or in other countries. Total food expenditure of each household, to be used at the first stage of our model estimation, was obtained through aggregating the expenditure on all the 16 categories.

A.4 Data Concordance

Developing an appropriate set of price data to match the expenditure categories of the households is generally difficult, mainly due to lack of exact concordance among the expenditure categories and the items classified in the price data catalogues. Fortunately, the same 10-digit commodity codes were used in both the 1998/99 and 2003/04 HES expenditure databases, which precludes any need for concordance of commodity categories between these databases. We match the expenditure items with the classifications used in the price data using the description of each commodity. The prices were matched with expenditures according to the time period (i.e., quarter) and the state and the territory of the surveyed households. As per information available on location in the HES CURFs, households residing in ACT and NT were assigned the average prices of their capital cities.

A.5 Data Limitations

Acquiring information on prices can be a problem because they are mostly available as averages over multiple products, depending on the level of aggregation of commodities and locations within a city or state. Thus, they may not accurately portray the actual prices paid by the households for a given food item. Also, the ABS considers average retail prices in major Australian cities as representative for measuring price changes over time (ABS Catalogue no. 6403) and regards such prices as approximate indicators of the price levels. Therefore, the prices may not reflect the price differences within a region, state or commodity group. Moreover, at the data compilation stage, prices for generic categories of food were obtained by taking simple averages of the disaggregated items, which may potentially have led to imprecision in the prices. Further, in the HES CURFs, the ABS reduced the level of detail for many data items for the sake of maintaining confidentiality. Finally, in the basic CURF, which is used in this study, households residing in ACT and NT have been assigned a combined location, ACT/NT.

APPENDIX B

Table B1 Expenditure Shares for Each Food Category by Demographics, 1998/99

Food Category	By Ethnicity of HHS Head			By State							By Children under 15		By Age of Household's Head		
	All	**Australian-born**	**Foreign-born**	**NSW**	**VIC**	**QLD**	**WA**	**SA**	**TAS**	**NT & ACT**	**Yes**	**No**	**Below 35**	**Between 35-55**	**Above 55**
Milk	0.126 (0.12) [6324]	0.127 (0.12) [4589]	0.122 (0.12) [1735]	0.122 (0.12) [1735]	0.124 (0.11) [1279]	0.133 (0.13) [1001]	0.133 (0.12) [594]	0.139 (0.13) [515]	0.134 (0.13) [449]	0.129 (0.14) [631]	0.131 (0.12) [2221]	0.123 (0.12) [4103]	0.154 (0.15) [1609]	0.118 (0.11) [2898]	0.112 (0.09) [1817]
Dairy products	0.086 (0.06) [5141]	0.083 (0.06) [3757]	0.092 (0.07) [1384]	0.092 (0.07) [1384]	0.087 (0.06) [1065]	0.082 (0.05) [834]	0.085 (0.06) [479]	0.089 (0.07) [415]	0.091 (0.07) [366]	0.083 (0.06) [510]	0.080 (0.05) [1880]	0.089 (0.06) [3261]	0.092 (0.06) [1229]	0.084 (0.06) [2450]	0.083 (0.06) [1462]
Bread	0.122 (0.10) [6428]	0.122 (0.10) [4661]	0.122 (0.10) [1767]	0.122 (0.10) [1767]	0.124 (0.09) [1297]	0.123 (0.11) [1016]	0.114 (0.09) [598]	0.130 (0.11) [520]	0.136 (0.10) [458]	0.108 (0.09) [640]	0.114 (0.09) [2200]	0.126 (0.11) [4228]	0.130 (0.12) [1588]	0.120 (0.10) [2934]	0.119 (0.09) [1906]
Rice	0.041 (0.06) [1554]	0.029 (0.04) [997]	0.061 (0.08) [557]	0.061 (0.08) [557]	0.041 (0.06) [323]	0.037 (0.05) [231]	0.037 (0.04) [158]	0.037 (0.06) [116]	0.029 (0.02) [88]	0.042 (0.06) [184]	0.040 (0.06) [625]	0.041 (0.06) [929]	0.051 (0.08) [368]	0.040 (0.06) [793]	0.032 (0.04) [393]
Beef and veal	0.133 (0.10) [3350]	0.133 (0.10) [2455]	0.135 (0.10) [895]	0.135 (0.10) [895]	0.127 (0.09) [680]	0.143 (0.10) [547]	0.123 (0.10) [317]	0.137 (0.11) [258]	0.120 (0.09) [222]	0.137 (0.09) [370]	0.113 (0.08) [1174]	0.144 (0.11) [2176]	0.132 (0.10) [746]	0.129 (0.10) [1589]	0.142 (0.10) [1015]
Mutton and lamb	0.103 (0.08) [2209]	0.105 (0.08) [1706]	0.098 (0.08) [503]	0.098 (0.08) [503]	0.104 (0.08) [482]	0.100 (0.07) [302]	0.093 (0.07) [219]	0.120 (0.10) [170]	0.087 (0.06) [160]	0.099 (0.06) [208]	0.090 (0.06) [750]	0.110 (0.08) [1459]	0.110 (0.09) [417]	0.097 (0.07) [1043]	0.108 (0.08) [749]
Pork	0.091 (0.07) [1384]	0.081 (0.05) [901]	0.111 (0.09) [483]	0.111 (0.09) [483]	0.086 (0.06) [279]	0.085 (0.06) [245]	0.085 (0.06) [132]	0.088 (0.06) [106]	0.068 (0.05) [78]	0.098 (0.08) [139]	0.092 (0.08) [472]	0.091 (0.07) [912]	0.094 (0.07) [267]	0.094 (0.08) [660]	0.085 (0.06) [457]
Other meat	0.064 (0.05) [3323]	0.065 (0.05) [2492]	0.062 (0.05) [831]	0.062 (0.05) [831]	0.059 (0.04) [678]	0.072 (0.05) [563]	0.069 (0.05) [345]	0.065 (0.07) [259]	0.062 (0.06) [240]	0.062 (0.05) [319]	0.058 (0.04) [1320]	0.069 (0.06) [2003]	0.072 (0.06) [780]	0.062 (0.05) [1628]	0.062 (0.05) [915]
Poultry	0.110 (0.08) [3403]	0.108 (0.08) [2386]	0.115 (0.09) [1017]	0.115 (0.09) [1017]	0.108 (0.07) [707]	0.100 (0.07) [498]	0.112 (0.08) [358]	0.121 (0.09) [277]	0.100 (0.07) [216]	0.115 (0.09) [367]	0.101 (0.07) [1330]	0.117 (0.09) [2073]	0.123 (0.09) [825]	0.107 (0.07) [1690]	0.105 (0.08) [888]
Fresh fruit	0.070 (0.07) [4990]	0.069 (0.07) [3580]	0.074 (0.07) [1410]	0.074 (0.07) [1410]	0.068 (0.07) [1032]	0.068 (0.07) [823]	0.072 (0.07) [459]	0.059 (0.04) [373]	0.064 (0.05) [327]	0.076 (0.08) [504]	0.060 (0.05) [1776]	0.076 (0.07) [3214]	0.071 (0.07) [1106]	0.066 (0.06) [2325]	0.076 (0.07) [1559]
Fresh vegetables	0.089 (0.07) [5909]	0.088 (0.07) [4264]	0.092 (0.07) [1645]	0.092 (0.07) [1645]	0.081 (0.05) [1195]	0.089 (0.07) [954]	0.087 (0.07) [564]	0.081 (0.06) [460]	0.088 (0.06) [400]	0.101 (0.07) [594]	0.078 (0.05) [2030]	0.095 (0.07) [3879]	0.090 (0.07) [1384]	0.085 (0.06) [2729]	0.096 (0.07) [1796]
Preserved fruit	0.042 (0.04) [2268]	0.042 (0.04) [1737]	0.041 (0.04) [531]	0.041 (0.04) [531]	0.041 (0.04) [450]	0.041 (0.05) [391]	0.041 (0.04) [215]	0.041 (0.04) [150]	0.043 (0.03) [161]	0.045 (0.05) [226]	0.035 (0.03) [899]	0.046 (0.05) [1369]	0.045 (0.04) [491]	0.038 (0.04) [1099]	0.045 (0.04) [678]
Preserved vegetables	0.046 (0.04) [2788]	0.047 (0.03) [2109]	0.045 (0.04) [679]	0.045 (0.04) [679]	0.044 (0.03) [545]	0.045 (0.04) [433]	0.045 (0.03) [291]	0.048 (0.04) [228]	0.049 (0.03) [187]	0.050 (0.04) [271]	0.041 (0.03) [1148]	0.050 (0.04) [1640]	0.053 (0.04) [654]	0.043 (0.03) [1381]	0.047 (0.04) [753]
Sugar and jam	0.036 (0.03) [3141]	0.036 (0.03) [2254]	0.036 (0.03) [887]	0.036 (0.03) [887]	0.036 (0.03) [648]	0.034 (0.03) [524]	0.036 (0.03) [287]	0.034 (0.03) [255]	0.044 (0.03) [226]	0.032 (0.02) [277]	0.028 (0.02) [1156]	0.040 (0.03) [1985]	0.034 (0.03) [618]	0.031 (0.02) [1472]	0.043 (0.03) [1051]
Margarine	0.039 (0.03) [2960]	0.040 (0.03) [2276]	0.037 (0.03) [684]	0.037 (0.03) [684]	0.036 (0.02) [601]	0.037 (0.03) [425]	0.037 (0.03) [266]	0.043 (0.05) [251]	0.050 (0.03) [225]	0.035 (0.03) [281]	0.033 (0.03) [1110]	0.043 (0.04) [1850]	0.040 (0.04) [605]	0.035 (0.02) [1422]	0.045 (0.04) [933]
Sample	**6859**	**4952**	**1907**	**2026**	**1369**	**1089**	**646**	**561**	**477**	**682**	**2296**	**4563**	**1746**	**3095**	**2018**

Figures within the first parentheses refer to the standard deviation of the series, and the second parentheses to the number of observations. Zero expenditures are included in the calculation of mean expenditure shares.

Table B2 Expenditure Shares for Each Food Category by Demographics, 2003/04

Food Category	By Ethnicity of HHS Head			By State							By Children under 15		By Age of Household's Head		
	All	Australian-born	Foreign-born	NSW	VIC	QLD	WA	SA	TAS	NT & ACT	Yes	No	Below 35	Between 35-55	Above 55
Milk	0.136	0.140	0.124	0.130	0.130	0.143	0.137	0.153	0.133	0.135	0.146	0.131	0.164	0.136	0.115
	(0.12)	(0.13)	(0.11)	(0.12)	(0.11)	(0.12)	(0.14)	(0.14)	(0.11)	(0.13)	(0.12)	(0.13)	(0.15)	(0.12)	(0.10)
	[6201]	[4540]	[1661]	[1524]	[1357]	[794]	[661]	[774]	[514]	[577]	[1971]	[4230]	[1289]	[2039]	[2050]
Dairy products	0.091	0.090	0.093	0.089	0.095	0.088	0.090	0.094	0.088	0.092	0.080	0.096	0.101	0.087	0.089
	(0.07)	(0.07)	(0.07)	(0.06)	(0.08)	(0.07)	(0.07)	(0.06)	(0.06)	(0.07)	(0.05)	(0.08)	(0.08)	(0.07)	(0.07)
	[5050]	[3711]	[1339]	[1231]	[1101]	[656]	[520]	[651]	[415]	[476]	[1659]	[3391]	[991]	[1724]	[1657]
Bread	0.142	0.143	0.137	0.151	0.144	0.132	0.130	0.141	0.148	0.132	0.142	0.141	0.158	0.136	0.132
	(0.11)	(0.11)	(0.11)	(0.12)	(0.11)	(0.10)	(0.09)	(0.10)	(0.11)	(0.10)	(0.10)	(0.11)	(0.13)	(0.09)	(0.10)
	[6356]	[4628]	[1728]	[1608]	[1390]	[807]	[668]	[784]	[519]	[580]	[2004]	[4352]	[1308]	[2099]	[2116]
Rice	0.041	0.027	0.067	0.050	0.043	0.038	0.034	0.037	0.027	0.039	0.041	0.041	0.048	0.041	0.035
	(0.06)	(0.03)	(0.09)	(0.08)	(0.06)	(0.06)	(0.04)	(0.06)	(0.02)	(0.04)	(0.07)	(0.06)	(0.07)	(0.06)	(0.05)
	[1350]	[878]	[472]	[363]	[307]	[177]	[124]	[135]	[92]	[152]	[534]	[816]	[264]	[503]	[390]
Beef and veal	0.141	0.139	0.146	0.147	0.132	0.149	0.142	0.136	0.127	0.151	0.118	0.151	0.146	0.133	0.151
	(0.10)	(0.10)	(0.11)	(0.11)	(0.10)	(0.11)	(0.10)	(0.10)	(0.08)	(0.10)	(0.09)	(0.11)	(0.12)	(0.09)	(0.11)
	[3085]	[2244]	[841]	[758]	[670]	[401]	[355]	[367]	[252]	[282]	[969]	[2116]	[509]	[1105]	[1095]
Mutton and lamb	0.116	0.115	0.117	0.123	0.124	0.095	0.110	0.114	0.102	0.124	0.099	0.123	0.130	0.107	0.120
	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.07)	(0.08)	(0.09)	(0.08)	(0.10)	(0.08)	(0.10)	(0.11)	(0.08)	(0.09)
	[2013]	[1545]	[468]	[494]	[442]	[241]	[234]	[218]	[188]	[196]	[636]	[1377]	[291]	[686]	[769]
Pork	0.094	0.084	0.114	0.103	0.094	0.096	0.091	0.086	0.079	0.093	0.084	0.098	0.091	0.095	0.095
	(0.08)	(0.06)	(0.09)	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.08)	(0.08)	(0.08)	(0.07)
	[1326]	[898]	[428]	[312]	[274]	[197]	[167]	[134]	[108]	[134]	[408]	[918]	[158]	[466]	[535]
Other meat	0.070	0.071	0.068	0.068	0.069	0.079	0.074	0.068	0.070	0.063	0.063	0.074	0.073	0.069	0.069
	(0.06)	(0.06)	(0.05)	(0.05)	(0.06)	(0.07)	(0.06)	(0.05)	(0.06)	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)	(0.05)
	[3280]	[2478]	[802]	[792]	[696]	[427]	[383]	[400]	[281]	[301]	[1177]	[2103]	[590]	[1154]	[1064]
Poultry	0.117	0.114	0.125	0.116	0.122	0.106	0.125	0.117	0.108	0.120	0.110	0.121	0.138	0.114	0.110
	(0.09)	(0.09)	(0.10)	(0.09)	(0.10)	(0.07)	(0.09)	(0.09)	(0.08)	(0.09)	(0.09)	(0.09)	(0.11)	(0.09)	(0.08)
	[3329]	[2345]	[984]	[794]	[751]	[403]	[394]	[388]	[261]	[338]	[1181]	[2148]	[663]	[1142]	[1035]
Fresh fruit	0.061	0.059	0.068	0.070	0.058	0.062	0.061	0.054	0.052	0.061	0.051	0.066	0.062	0.055	0.068
	(0.06)	(0.06)	(0.06)	(0.08)	(0.05)	(0.06)	(0.06)	(0.05)	(0.07)	(0.05)	(0.05)	(0.07)	(0.06)	(0.05)	(0.07)
	[4863]	[3539]	[1324]	[1229]	[1049]	[620]	[515]	[573]	[397]	[480]	[1562]	[3301]	[862]	[1631]	[1746]
Fresh vegetables	0.087	0.086	0.089	0.088	0.085	0.086	0.086	0.084	0.086	0.091	0.072	0.093	0.084	0.084	0.094
	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.06)	(0.07)	(0.06)	(0.06)	(0.06)	(0.05)	(0.07)	(0.07)	(0.07)	(0.07)
	[5726]	[4190]	[1536]	[1413]	[1229]	[748]	[632]	[705]	[471]	[528]	[1799]	[3927]	[1111]	[1905]	[1968]
Preserved fruit	0.045	0.046	0.043	0.044	0.048	0.046	0.039	0.047	0.044	0.044	0.034	0.051	0.050	0.040	0.050
	(0.05)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.06)	(0.04)	(0.04)	(0.03)	(0.05)	(0.05)	(0.04)	(0.05)
	[2104]	[1607]	[497]	[528]	[461]	[301]	[198]	[239]	[189]	[188]	[711]	[1393]	[348]	[714]	[772]
Preserved vegetables	0.047	0.047	0.046	0.046	0.046	0.045	0.044	0.053	0.047	0.047	0.041	0.050	0.053	0.045	0.046
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)	(0.03)	(0.05)	(0.05)	(0.04)	(0.04)
	[2748]	[2063]	[685]	[663]	[594]	[363]	[336]	[349]	[222]	[221]	[1017]	[1731]	[510]	[963]	[882]
Sugar and jam	0.032	0.032	0.033	0.031	0.031	0.032	0.029	0.036	0.040	0.026	0.023	0.037	0.029	0.027	0.040
	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.06)	(0.04)	(0.03)	(0.02)	(0.04)	(0.03)	(0.03)	(0.05)
	[2736]	[1958]	[778]	[686]	[618]	[354]	[254]	[368]	[240]	[216]	[906]	[1830]	[409]	[932]	[1045]
Margarine	0.037	0.037	0.037	0.039	0.037	0.035	0.037	0.037	0.034	0.038	0.027	0.042	0.034	0.032	0.043
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)	(0.02)	(0.04)	(0.03)	(0.03)	(0.03)
	[2499]	[1909]	[590]	[621]	[565]	[292]	[251]	[344]	[224]	[202]	[824]	[1675]	[400]	[838]	[947]
Sample	**6957**	**5066**	**1891**	**1745**	**1531**	**887**	**729**	**864**	**555**	**646**	**2096**	**4861**	**1483**	**2249**	**2302**

Figures within the first parentheses refer to the standard deviation of the series, and the second parentheses to the number of observations. Zero expenditures are included in the calculation of mean expenditure shares.

APPENDIX C
Econometric Methodology

C.1 The Almost Ideal Demand System

Below we discuss our estimation of price and expenditure elasticities of food demand by the Almost Ideal Demand System (AIDS) of Deaton and Muellbauer (1980). AIDS satisfies the axioms of choice such as monotonicity, transitivity and continuity. It is simple to estimate because the functional form is consistent with known household-budget data. It aggregates over consumers perfectly without resorting to parallel linear Engel curves. The homogeneity and symmetry restrictions can also be tested through linear restrictions on fixed parameters (see Deaton and Muellbauer 1980). The separability assumption enables to estimate the food demand system separate from the rest of the consumers' budget.

The price elasticity is defined as the percentage change in quantity demanded for one percentage change in price. The expenditure (income) elasticity is defined similarly as the percentage change in quantity demanded for one percentage change in expenditure (income).

To specify the estimating equation, let W_i be the expenditure share of commodity *i* in total food expenditure of household *n*, and is given by $W_i = \frac{p_i q_i}{X}$, where p_i and q_i are, respectively, the unit price and the quantity of food category *i* purchased, and X is the total food expenditure of the household. For simplicity and without loss of generality, we omit the subscript for household. Rearranging the term as $q_i = \frac{W_i X}{p_i}$, the own-price elasticity of food category *i* is derived as:

$$\varepsilon_{i,i} = \frac{\partial \ln q_i}{\partial \ln p_i} = -1 + \frac{\partial W_i}{\partial \ln p_i} \frac{1}{W_i} . \qquad (1)$$

In what follows, we derive the expressions for $\frac{\partial W_i}{\partial \ln p_i}$. We also see below that this is the key term in our estimation of the expenditure elasticity.

One-stage estimation

In one-stage estimation, we ignore the sample selection problem due to frequent zero observations of expenditure on food categories (we come back to this issue in two-stage estimation to correct the bias in estimation). We explicitly write the expenditure share equation as:

$$W_i = \alpha_i + \sum_j \gamma_{i,j} \ln p_j + \beta_i \ln(X / P) + u_i \text{ , for } i = 1, 2, \ldots\ldots, 16 \qquad (2)$$

where P is the aggregate price level (which is the weighted average of prices of all food categories constructed as a Laspeyres index using the mean budget share of each category as the weight). Equation (2) shows that in each equation, price of all food categories are included. The above equation is augmented by household characteristics (following the literature) as:

$$W_i = \alpha_i + \sum_k \eta_{i,k} d_{i,k} + \sum_j \gamma_{i,j} \ln p_j + \beta_i \ln(X / P) + u_i \text{ ,} \qquad (3)$$

where $d_{i,k}$ is k-th demographic characteristic of the household and are the same in equations for all food categories. In our estimation, $d_{i,k}$ includes household size, age of the household head, number of dependents aged between 0-15 years, and two dummies for the origin of birth of the household head (Australian, and other English-speaking countries with the rest of the world being the base category). In addition, the state dummies are also included to account for regional variations in the consumption pattern.

In the above system of equations, the restrictions that the expenditure shares add up to unity ($\sum_i W_i = 1$) require that $\sum_i \alpha_i = 1$, $\sum_i \beta_i = 0$, $\sum_i \eta_{i,k} = 0$ and $\sum_k \gamma_{k,j} = 0$. The homogeneity restriction is satisfied by the condition $\sum_k \gamma_{j,k} = 0$. In addition, the symmetry condition is satisfied by the restriction that $\gamma_{i,j} = \gamma_{j,i}$.

It is straightforward to derive $\frac{\partial W_i}{\partial \ln p_i} = \gamma_{i,i}$ from equation (3). Hence, the price elasticity in equation (1) is rewritten as:

$$\varepsilon_{i,i} = \frac{\partial \ln q_i}{\partial \ln p_i} = -1 + \frac{\gamma_{i,i}}{W_i}, \qquad (4)$$

where W_i is evaluated at its mean value. The standard error of $\varepsilon_{i,i}$ is derived by the "delta method," which is described in standard econometrics textbooks.

Two-stage estimation

To overcome the sample selection problem due to frequent zero observations of expenditure on food categories, we employ the two-stage Heckman procedure. More specifically, the following equation is estimated in the first stage:

$$I_i = \alpha_i + \sum_k \eta_{i,k} d_{i,k} + \sum_j \gamma_{i,j} \ln p_j + \beta_i \ln(X / P) + \delta_n NFE_n + e_i$$

$$= \boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i} + e_i , \qquad (5)$$

where I_i is an indicator function defining the purchasing decision of commodity *i* by a household, and NFE_n is the total non-food expenditure of the *n*-th household. The inverse-Mills ratio is obtained by estimating equation (5):

$$\lambda_i = \frac{\phi(\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i})}{\Phi(\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i})} = \frac{\phi_i(\cdot)}{\Phi_i(\cdot)} , \qquad (6)$$

for $I_i = 1$ (or $W_i > 0$), and

$$\lambda_i = \frac{\phi_i(\cdot)}{1 - \Phi_i(\cdot)} \qquad (7)$$

for $I_i = 0$ (or $W_i = 0$).

Here $\phi_i(\cdot)$ is the normal density function and $\Phi_i(\cdot)$ is the cumulative normal distribution. Now we augment equation (3) by adding the inverse-Mills ratio to account for the selection bias arising from non-purchasing decision made by households:

$$W_i = \alpha_i + \sum_k \eta_{i,k} d_{i,k} + \sum_j \gamma_{i,j} \ln p_j + \beta_i \ln(X / P) + \varphi_i \lambda_i + u_i \ . \qquad (8)$$

It is important to mention that NFE_n is excluded from equation (8) for identification purposes. All the classical AIDS restrictions are applied in the estimation of equation (8), except the coefficient of λ_i (given that each equation in the system has its own λ_i).

Given the above bias correction, $\frac{\partial W_i}{\partial \ln p_i}$ now becomes

$$\frac{\partial W_i}{\partial \ln p_i} = \gamma_{i,i} + \varphi_i \frac{\partial \lambda_i}{\partial \ln p_i}. \quad (9)$$

The first term on the right-hand side of the equality measures the price response of food demand which also includes the bias due to zero purchase, where this bias is corrected by the second term on the right-hand side.

To explicitly define equation (9), suppose that θ_i is the proportion of consumers for which $W_i > 0$, and that $(1-\theta_i)$ has $W_i = 0$. Then we have

$$\frac{\partial \lambda_i}{\partial \ln p_i} = \theta_i \left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i>0} + (1-\theta_i)\left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i=0}, \quad (10)$$

where $$\left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i>0} = -\gamma_{i,i}\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2\right] \quad (11a)$$

and $$\left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i=0} = -\gamma_{i,i}\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2\right]. \quad (11b)$$

Substituting equations (9)-(11) into equation (1) and after some manipulations, we obtain the following expression for the own-price elasticity:

$$\varepsilon_{i,i} = -1 + \frac{\gamma_{i,i}\varphi_i}{W_i}\left\{\frac{1}{\varphi_i} - \theta_i\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2\right] - (1-\theta_i)\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2\right]\right\}. \quad (12)$$

Here $\phi_i(\cdot)$, $\Phi_i(\cdot)$ and $\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}$ are evaluated at the mean value of $\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}$, and W_i is evaluated at its own mean value. Standard error of $\varepsilon_{i,i}$ is derived by the “delta method.” Comparing equations (4) and (12), it can be seen that the two-step estimation corrects the bias in the elasticity estimate by the term

$$\varphi_i\left\{\frac{1}{\varphi_i} - \theta_i\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2\right] - (1-\theta_i)\left[\boldsymbol{\omega}_{\mathbf{i}}\boldsymbol{\Gamma}_{\mathbf{i}}\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2\right]\right\}.$$

Since estimation of the elasticity defined in equation (12) is based on the all sample households (including those for which $W_i = 0$), the equation can be interpreted as the unconditional elasticity. For conditional elasticity (that we do not estimate), the second stage regressions include only those households for which $W_i = 1$.

Cross-price elasticity

Cross-price elasticity is defined as the percentage change in quantity demanded of commodity *i* for one percentage change in price of commodity *j* ($i \neq j$) and is defined as:

$$\varepsilon_{i,j} = \frac{\partial \ln q_i}{\partial \ln p_j} = \frac{\partial W_i}{\partial \ln p_j}\frac{1}{W_i}, \qquad (13)$$

where

$$\frac{\partial W_i}{\partial \ln p_j} = \gamma_{i,j} + \varphi_i \frac{\partial \lambda_i}{\partial \ln p_j}. \qquad (14)$$

Similar to equations (10)-(11), we have

$$\frac{\partial \lambda_i}{\partial \ln p_j} = \theta_i \left.\frac{\partial \lambda_i}{\partial \ln p_j}\right|_{W_i>0} + (1-\theta_i)\left.\frac{\partial \lambda_i}{\partial \ln p_j}\right|_{W_i=0}, \qquad (15)$$

where $\left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i>0} = -\gamma_{i,j}\left[\boldsymbol{\omega}_\mathbf{i}\boldsymbol{\Gamma}_\mathbf{i}\frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2\right]$ (16a)

and $\left.\frac{\partial \lambda_i}{\partial \ln p_i}\right|_{W_i=0} = -\gamma_{i,j}\left[\boldsymbol{\omega}_\mathbf{i}\boldsymbol{\Gamma}_\mathbf{i}\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2\right].$ (16b)

Substituting equations (14)-(15) into equation (13), we obtain the cross-price elasticity as:

$$\varepsilon_{i,i} = \frac{\gamma_{i,j}\varphi_i}{W_i}\left\{\frac{1}{\varphi_i} - \theta_i\left[\boldsymbol{\omega}_\mathbf{i}\boldsymbol{\Gamma}_\mathbf{i}\frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2\right] - (1-\theta_i)\left[\boldsymbol{\omega}_\mathbf{i}\boldsymbol{\Gamma}_\mathbf{i}\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2\right]\right\}. \qquad (17)$$

If Heckman correction were not made in the first-stage, then $\frac{\partial W_i}{\partial \ln p_j} = \gamma_{i,j}$, and the (biased) cross-price elasticity would be given by

$$\varepsilon_{i,j} = \frac{\gamma_{i,j}}{W_i}. \qquad (18)$$

Expenditure elasticity

Expenditure elasticity is defined at the beginning and is given by:

$$e_{i,M} = \frac{\partial \ln q_i}{\partial \ln X} = 1 + \frac{\partial W_i}{\partial \ln X}\frac{1}{W_i}, \qquad (19)$$

where

$$\frac{\partial W_i}{\partial \ln X} = \beta_i + \varphi_i \frac{\partial \lambda_i}{\partial \ln X}, \qquad (20)$$

$$\left.\frac{\partial \lambda_i}{\partial \ln X}\right|_{W_i>0} = \beta_i \left[\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i} \frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2 \right], \text{ and} \qquad (21a)$$

$$\left.\frac{\partial \lambda_i}{\partial \ln X}\right|_{W_i=0} = \beta_i \left[\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i} \frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2 \right]. \qquad (21b)$$

Combining equations (19)-(21), the expenditure elasticity is written as

$$e_{i,M} = 1 + \frac{\beta_i \varphi_i}{W_i}\left\{ \frac{1}{\varphi_i} - \theta_i \left[\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i} \frac{\phi_i(\cdot)}{\Phi_i(\cdot)} + \left(\frac{\phi_i(\cdot)}{\Phi_i(\cdot)}\right)^2 \right] - (1-\theta_i)\left[\boldsymbol{\omega}_\mathbf{i} \boldsymbol{\Gamma}_\mathbf{i} \frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)} - \left(\frac{\phi_i(\cdot)}{1-\Phi_i(\cdot)}\right)^2 \right] \right\}. \qquad (22)$$

Hicksian cross-price elasticity

The (own and cross) price elasticities discussed above are also termed as Marshallian price elasticities, which are derived by holding income constant. In contrast, the Hicksian demand elasticity holds utility constant. Okrent and Alston (2011) shows that the Hicksian $\varepsilon^*_{i,j}$ and Marshallian price elasticities are related as:

$$\varepsilon^*_{i,j} = \varepsilon_{i,j} + e_{i,M} W_j \qquad (23)$$

where $\varepsilon_{i,j}$, $e_{i,M}$ and W_j have been defined earlier. Given that the relationship is linear, the Hicksian elasticity is straightforward to calculate from $\varepsilon_{i,j}$ and $e_{i,M}$. Expenditure share of good *j* needed to make this derivation is obtained from the HES database.

Estimation and Elasticity Derivation

We estimate equations (5) and (8) in a system of 16 equations, employing both the parametric and semi-parametric methods. Note that because each food category has its own inverse-Mills ratio, right-hand sides of the equations within the system are not exactly same, so that 16 equations can be estimated jointly without running into the singularity problem. When the inverse-Mills ratios are removed from the equations (i.e., when the frequent zero observation problem is ignored), then as standard applied practice, one of the equations in the system needs to be deleted given the singularity problem.

We apply equation (12) to 15 food categories to retrieve their elasticity estimates, including those of milk, dairy products, bread, rice, beef and veal, mutton and lamb, pork, other meat, poultry, fresh fruit, fresh vegetables, preserved fruit, preserved vegetables, sugar and jam, and margarine. We do not compute the elasticity of the "other food" category as it is an aggregate of all remaining categories.

C.2 Semi-Nonparametric Approach

Although the two-step Heckman procedure provides an elegant solution to the censoring problem, the estimator is derived under the assumption that the disturbance in the censoring equation follows a normal distribution (more specifically, the censoring equation and the demand equation for each commodity follow a bivariate normal distribution). This assumption may be untenable in micro data. In this robustness check, we relax the normality assumption by employing a two-step semi-nonparametric approach. The key difference is in the estimation of the first step parameters. This approach employs a semi-nonparametric model introduced by Gallant and Nychka (1987) instead of a probit model. The basic idea is to approximate the unknown densities by Hermite polynomial expansions and then employ the approximations to derive a pseudo maximum likelihood estimator for the model parameters. The estimators are $\sqrt{n}$ consistent provided that the order of polynomial increases with the sample size. The advantage of the Gallant and Nychka estimator is that it generates consistent estimates without relying on distributional assumptions, and the efficiency loss it causes is small (De Luca 2008). We choose a polynomial of order four following De Luca's Monte-Carlo simulation.

References

Deaton, A and J Muellbauer. 1980. "An Almost Ideal Demand System." *The American Economic Review*, 70(3), pp. 312-26.

De Luca, G. 2008.“SNP and SML Estimation of Univariate and Bivariate Binary-Choice Models.”*The Stata Journal*, 8(2), pp. 190–20.

Gallant, AR and DW Nychka. 1987.“Semi-nonparametric Maximum Likelihood Estimation.” *Econometrica*, 55(2), pp. 363–390.

Okrent, AM., and JM. Alston. 2011. Demand for Food in the United States. A Review of Literature, Evaluation of Previous Estimates, and Presentation of New Estimates of Demand. Giannini Foundation Monograph No 48. April.

APPENDIX D

Table D1 Marshallian Own-Price and Expenditure Elasticities for All Australian Households (Semi-Nonparametric Method)

Food Category	Own-Price Elasticity	Expenditure Elasticity
Milk	-0.149	0.525***
	(-1.03)	(37.38)
Dairy products	-0.92***	1.088***
	(-3.28)	(58.72)
Bread	-0.91***	0.375***
	(-10.17)	(16.33)
Rice	-12.91***	1.357***
	(-12.30)	(28.02)
Beef and veal	-1.69***	2.03***
	(-12.33)	(38.20)
Mutton and lamb	-5.88***	1.59***
	(-35.33)	(72.93)
Pork	-2.97***	1.56***
	(-6.35)	(41.58)
Other meat	-0.94***	1.12***
	(-4.37)	(23.27)
Poultry	-1.39***	1.28***
	(-4.70)	(25.87)
Fresh fruit	-1.30***	0.48***
	(-12.60)	(15.48)
Fresh vegetable	-0.757***	0.522***
	(-8.37)	(10.65)
Preserved fruit	-0.953**	1.72***
	(-2.01)	(12.79)
Preserved vegetables	-1.36***	0.93***
	(-5.27)	(15.12)
Sugar and jam	-0.442	0.378***
	(-0.94)	(4.06)
Margarine	-1.60***	0.566***
	(-7.75)	(9.50)

Notes: ***, **, and * refer to statistical significance at 1%, 5% and 10% levels, respectively. Figures in parentheses refer to the z-statistics.

Table D2 Hicksian Cross-Price HicksianElasticities for All Australian Households (Semi-Nonparametric Method)

Food Category	Milk	Dairy products	Bread	Rice	Beef and veal	Mutton & lamb	Pork	Other meat	Poultry	Fresh fruit	Fresh vegetables	Preserved fruit	Preserved vegetables	Sugar and jam	Margarine
Milk		0.37** (2.43)	0.20** (2.36)	-2.15*** (-3.84)	0.13 (0.97)	-0.35* (-1.95)	0.00 (0.00)	-0.11 (-0.48)	0.66*** (3.35)	-1.08*** (-7.76)	-0.47*** (-4.36)	-1.50*** (-3.78)	0.03 (0.10)	-0.55* (-1.73)	-0.42 (-1.39)
Dairy products	0.33*** (3.89)		-0.10* (-1.67)	1.66** (2.12)	0.08 (0.81)	1.00*** (6.87)	0.81* (1.86)	-0.08 (-0.34)	-0.65*** (-3.07)	-0.21* (-1.81)	-0.09 (-1.00)	0.03 (0.06)	-0.47 (-1.31)	-0.09 (-0.19)	0.31 (0.87)
Bread	0.45*** (5.16)	0.05 (0.45)		0.78* (1.84)	0.05 (0.45)	-0.79*** (-5.52)	-0.23 (-0.77)	0.43** (2.57)	-0.04 (-0.23)	-0.89*** (-7.96)	-0.42*** (-5.10)	-0.06 (-0.24)	0.55*** (2.67)	-0.41* (-1.84)	-0.18 (-0.87)
Rice	0.35*** (8.51)	0.30*** (2.86)	-0.04 (-1.45)		0.17*** (3.59)	0.45*** (6.50)	0.57*** (2.61)	0.27** (2.28)	0.32*** (3.06)	-0.22*** (-3.98)	-0.03 (-0.78)	0.24 (0.86)	0.41** (2.28)	1.37*** (5.31)	0.48*** (2.65)
Beef and veal	0.28*** (3.94)	0.08 (0.81)	-0.01 (-0.15)	-0.04 (-0.11)		0.56*** (4.46)	0.58** (2.46)	0.15 (1.10)	0.41*** (3.22)	0.14 (1.43)	0.06 (0.79)	-0.07 (-0.33)	-0.27 (-1.58)	0.16 (0.89)	0.14 (0.83)
Mutton and lamb	0.09* (1.69)	0.57*** (7.63)	-0.29*** (-7.29)	1.34*** (5.01)	0.41*** (6.19)		1.25*** (6.87)	0.04 (0.36)	0.42*** (4.31)	0.40*** (5.72)	0.01 (0.28)	0.73*** (4.24)	0.02 (0.17)	0.75*** (5.40)	0.38*** (2.86)
Pork	0.18*** (2.95)	0.29** (2.40)	-0.11*** (-2.58)	0.95** (2.07)	0.31*** (4.69)	0.73*** (7.360		-0.07 (-0.45)	0.24* (1.77)	-0.21*** (-2.77)	-0.03 (-0.53)	0.38 (1.25)	-0.37* (-1.71)	-0.04 (-0.16)	0.33 (1.55)
Other meat	0.12** (2.05)	0.04 (0.32)	0.00 (0.11)	1.09** (2.52)	0.21*** (3.01)	0.13 (1.27)	0.01 (0.04)		-0.11 (-0.80)	-0.24*** (-3.01)	-0.14** (-2.31)	0.29 (1.00)	0.14 (0.68)	0.18 (0.75)	-0.05 (-0.26)
Poultry	0.45*** (4.87)	-0.56*** (-3.07)	-0.13* (1.82)	1.37** (2.01)	0.36*** (3.23)	0.56*** (3.49)	0.44 (1.06)	-0.37 (-1.57)		0.03 (0.23)	0.07 (0.73)	0.25 (0.56)	-0.50 (-1.57)	-0.56 (-1.48)	0.43 (1.33)
Fresh fruit	-0.25*** (-4.59)	0.05 (0.64)	-0.43*** (-9.94)	0.24 (0.80)	0.32*** (4.59)	0.93*** (9.57)	0.16 (0.81)	-0.02 (-0.13)	0.27** (2.53)		-0.29*** (-5.26)	-0.17 (-0.86)	0.29* (1.94)	-0.15 (-0.86)	-0.47*** (-3.13)
Fresh vegetable	-0.12* (-1.78)	0.07 (0.73)	-0.34*** (-6.71)	0.77** (2.12)	0.20** (2.48)	0.28** (2.51)	0.36 (1.51)	-0.07 (-0.47)	0.29** (2.21)	-0.46*** (-5.34)		0.86*** (3.65)	0.04 (0.23)	-0.03 (-0.16)	-0.25 (-1.38)
Preserved fruit	0.03 (0.68)	0.11 (1.00)	-0.06* (-1.68)	0.36 (0.82)	0.20*** (3.94)	0.43*** (5.99)	0.42* (1.83)	0.11 (0.92)	0.21* (1.88)	-0.29*** (-5.04)	0.07 (1.49)		-0.08 (-0.38)	0.46 (1.52)	-0.10 (-0.53)
Preserved vegetables	0.13*** (2.87)	-0.07 (-0.68)	-0.05* (-1.68)	1.05*** (2.71)	0.05 (1.06)	0.11 (1.52)	-0.22 (-0.99)	0.08 (0.66)	-0.08 (-0.71)	-0.14** (-2.33)	-0.12*** (-2.74)	-0.01 (-0.03)		0.20 (0.86)	0.41** (2.29)
Sugar and jam	-0.03 (-0.66)	-0.02 (-0.16)	-0.27*** (-9.21)	2.36*** (5.44)	0.08** (1.99)	0.35*** (5.67)	0.04 (0.18)	0.01 (0.12)	-0.13 (-1.31)	-0.36*** (-6.61)	-0.20*** (-5.26)	0.51 (1.60)	0.08 (0.44)		-0.02 (0.13)
Margarine	0.01 (0.14)	0.09 (0.94)	-0.22*** (-2.63)	0.90*** (2.84)	0.11 (1.17)	0.21** (2.40)	0.37** (1.95)	-0.08 (-0.75)	0.15 (1.38)	-0.45*** (-7.23)	-0.23*** (-3.59)	-0.08 (-0.39)	0.27* (1.82)	-0.01 (-0.06)	

Notes:
1. Off-diagonal elements are cross-price elasticities;
2. Row headings refer to the price of the respective product, and column headings to the quantity demanded of the respective product;
3. ***, **, and * refer to statistical significance at 1%, 5% and 10% levels, respectively;
4. Figures in parentheses refer to the z-statistic.