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Disaggregated econometric estimation of consumer demand response by alcoholic beverage types*

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The paper presents estimates of price elasticities of demand for 12 disaggregated alcoholic beverages in Australia: premium beer, full strength beer, low alcohol beer and mid-strength beer; red bottled wine, white bottled wine, sparkling wine, cask wine; dark and light ready-to-drink (RTD); and dark and light spirits. These disaggregated categories correspond closely to the commodities of interest to public policymakers with respect to taxation and health policies. The system of demand equations is estimated with Nielsen's data using a semiflexible Almost Ideal Demand System model in order to impose negative semi-definiteness on the demand parameters. Results indicate elastic own-price elasticities for virtually all commodities. Cross-price elasticities suggest that beverages most linked with negative externalities, namely full strength beer, dark RTD and dark spirits, may need to be taxed jointly. Any proposed tax increase to cask wine may also result in consumers shifting demand to more undesirable beverages. The elasticity estimates are used to illustrate the effect of a hypothetical change towards taxation equalisation based on alcohol content. These elasticities offer crucially needed inputs for analysing any tax change policies.

Key words: alcohol, demand system, elasticities, semi-flexible Almost Ideal Demand System, tax.

1. Introduction

Alcohol consumption is an enjoyable and inseparable part of the Australian lifestyle, deeply ingrained in the sociocultural and economic structure of the society. However, the cost of adverse effects of alcohol abuse is huge. Risky alcohol consumption has resulted in significant numbers of hospital episodes and deaths (Chikritzhs *et al.* 2003), and alcohol abuse is also a major contributor to road accidents, violence, crimes, unemployment and suicides.

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According to Collins and Lapsley (2008), the annual cost of alcohol-related problems to Australia in 2004–2005 was $15.3 billion, including costs via workplace productivity loss, road accidents, crime and health. Latest statistics show that the consumption of alcohol at harmful levels is increasing. According to data from the Australian National Drug Strategy Household Survey, in 2010, nearly 31 per cent of the population binged at least once a year, with one out of five of them bingeing frequently at least 3 days a week. Adding to the concern is evidence of a binge epidemic among the young and an increasing popularity of premixed ready-to-drink (RTD, or 'alcopop') spirits, especially among young women (Ramful and Zhao 2008).

Alcohol policies aimed at addressing harmful and excessive drinking have long been in the forefront of the national agenda of the Australian Government. A range of policy tools have been introduced over the years including regulations limiting place and time to sell alcohol, restrictions on underage drinking, enforcement of drink driving laws, restrictions on advertising, anti-alcohol campaigns and the highly contentious alcohol pricing and taxation policy. As an important policy tool, alcohol taxes have been debated on various fronts (Zhao and Wittwer 2007; Clarke 2008; Anderson 2010a; Freebairn 2010; Srivastava and Zhao 2010). It is argued that much of the alcohol-related cost is a negative external cost that is not included in consumers' private decision-making for consumption, and an alcohol tax is a mechanism to correct this market failure. The total alcohol tax revenue was estimated at around $7 billion in 2008–2009, which is less than half of the Collins and Lapsley's estimate for the cost of alcohol harm (VAADA 2010) even though not all of this estimated cost relates to negative externalities. However, it is the details of any proposed changes to the alcohol taxation system that spark the most discussion.

The proposed tax increase for the RTDs in 2008 by the Labor government reopened the 'can of worms' of the long-standing issue of the 'anomalies' of alcohol tax in Australia and caused intense responses from grape growers, beer, wine and spirit producers, health professionals and welfare bodies (Zhao and Wittwer 2007). Australia has a very complex alcohol tax system, with beer and spirits being taxed by alcohol content with differentiated volumetric excise (VT) rates according to alcohol strength while wine is levied an ad valorem wine equalisation tax (WET) based on wholesale value. According to an update to Zhao and Wittwer (2007) based on 2007/2008 data, on volumetric alcohol basis, cask wine (CW) pays effectively $3/LAL (per litre of alcohol), bottled wine $14–$33/LAL, beers $19–$31/LAL, RTDs $41–$43/LAL and straight spirit $66/LAL. On *ad valorem* basis as a percentage of wholesale pretax price, wine pays 29 per cent, beer 76 per cent and spirit 171 per cent (Anderson 2010b). The spirit industry has long pushed for the 'equal alcohol, equal tax' argument while the wine industry lobbies for lower tax rates on the basis of its contribution to the vitality and employment of the Australian agricultural industry and externalities such as tourism. However, there has been widespread support for a comprehensive review of alcohol taxation by differentiated products. In 2009, a major review of the Australian taxation system undertaken by the Federal Department of Treasury called for an urgent introduction of a volumetric tax (VT) on wine products given the anomalous nature of the WET (Henry *et al.* 2010) and for the restructuring of taxes for certain forms of alcoholic beverages most open to excessive consumption. Both policy changes were specially targeted towards cheap CW, which pays the lowest effective tax on LAL basis. Alcohol tax reform was also high on the agenda of the 2011 Tax Summit with important lobbyists such as the Australian Medical Association (AMA) and the National Alliance for Action Against Alcohol (NAAA)[1] advocating the urgent need for alcohol tax reforms.

An important requirement for developing an effective alcohol tax policy is empirical evidence of consumer price responsiveness by differentiated alcohol types. For instance, whilst an increase in 'alcopops' tax is aimed at shifting consumers to nonalcoholic drinks, how much will demand be shifted from premixed RTDs to straight spirits as a consequence, thus encouraging potentially even riskier drinking behaviour when young people are less informed about the quantity of alcohol consumed when mixing drinks themselves? What would happen to the market equilibrium prices and consumptions of all beverages, such as CW and RTDs, if a revenue neutral across-the-board flat VT rate is to be in place as suggested by the Henry tax review? These issues may be addressed by exploring available data sources for estimating demand elasticities so that any proposed alcohol tax policies can be designed based on sound empirical knowledge (Collins and Lapsley 2008, Parliament of Australia 2008). Availability of consumption and price data by differentiated beverage types and the need for an econometric model that is consistent with economic theory and accommodates specific data features are two main challenges.

A large body of economic literature internationally that has examined alcohol consumption over the last few decades has generally found evidence of a decline in alcohol consumption in response to price and demand restriction policies (Chaloupka 1993; Pacula and Chaloupka 2001; Chaloupka *et al.* 2002; Cook and Moore 2002). However, the effectiveness of any tax policy hinges primarily on individuals' responsiveness to changes in the relative prices of different alcoholic products. From an extensive review of the economic literature on the relationship between price and the demand for three beverages, Leung and Phelps (1993) concluded that the demand for beer was significantly price inelastic while those for wine and spirits were elastic. Similar evidence was found from an earlier survey by Ornstein and Hanssens (1985), but no reliable estimates were obtained for wine price elasticity. In

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[1] The NAAA is a newly established national coalition of more than 50 major health and community organisations from across Australia such as VicHealth, Cancer Council Victoria, Heart Foundation Victoria and Turning Point Alcohol and Drug Centre, with the goal of reducing alcohol-related harm. It considers alcohol pricing and taxation as one of the three key priority areas (NAAA 2011).

contrast, some studies have found all three types of alcoholic beverages to be price inelastic (Clements and Selvanathan 1987; Heien and Pompelli 1989; Nelson 1997), of which some have used Australian data (Clements 1983; Clements and Selvanathan 1991; Selvanathan 1991). Fogarty (2006) and Gallet (2007) shed light on this disparate and conflicting literature by showing that most of the variations in the own-price elasticity of demand estimates for alcohol could be related to demand specifications, data issues, estimation methods, the level of alcohol consumption and the ethanol share in the beverages. The results on cross-price responses have been equally conflicting in the literature. As a result, there is mixed evidence on the economic relationships across the three types of alcoholic drinks.

Existing estimates for alcohol demand elasticities in Australia are few, outdated and lack the level of disaggregation for the purpose of analysing any alcohol tax policy changes that involve detailed types of alcoholic drinks. The study by Clements and Johnson (1983) was the first to use Australian data to analyse separately the demand for beer, wine and spirits. Selvanathan and Selvanathan (2005) provided another set of demand elasticity estimates for beer, wine and spirits, using aggregated consumption data up to 1998 and a conditional Rotterdam demand model with a Preference Independence assumption. Penm (1988), on the other hand, examined the effect of packaging on the consumption of beer. He found differential price responses across bottled beer, canned beer and bulk beer, with canned beer being the most price sensitive. However, more disaggregated demand analyses are needed to study the differentiated implications. For instance, the tax increase on ‘alcopops’ in 2008 was aimed at shifting consumers to nonalcoholic drinks which can be potentially harmful in their own right if they are sugar-sweetened. However, there have also been concerns about demands shifting from premixed RTDs to straight spirits. The dearth of estimates of price elasticities and the importance of ongoing data collection and analysis have time and again been underlined in alcohol policy discussions (Collins and Lapsley 2008; NDRI 2008; Parliament of Australia 2008; VicHealth 2008; Henry *et al.* 2010; VAADA 2010). When Doran *et al.* (2013) estimated impacts of alternative Australian alcohol taxation structures on consumption, public health and government revenues, they used price elasticities estimated from UK data to simulate the policy changes, which they recognised as an important limitation of their study.

The aim of this study is to estimate a flexible Almost Ideal Demand System (AIDS) model proposed by Moschini (1998) for 12 alcoholic beverage types, allowing for consumer within-group substitution across different alcoholic drinks. We use data obtained from AC Nielson Australia for state-level monthly consumption for 14 alcoholic beverage types between 2004 and 2010. We pay special attention to the econometric modelling strategies including the imposition of restrictions required by demand theory, especially concavity conditions following Moschini (1998), and corrections for seasonality and serial correlation. Conditional on total real alcohol consumption being exogenous, own and cross-price and income elasticities, together with their standard errors, are estimated. These conditional demand elasticities are then combined with recent published estimates of first-stage alcohol demand elasticities to calculate unconditional Marshallian demand elasticities, which allow for the possibility of substitution with nonalcoholic goods. To illustrate the use of the estimated elasticities, we consider an example of a hypothetical tax change scenario towards a more equalised taxation based on alcohol content and simulate the effects of this change on the demand for individual beverages. Comprehensive analyses and discussion of practical tax reform policy proposals are beyond the scope of the current paper, but the elasticity estimates presented in this study offer the crucially needed parameters for any such analyses.

2. Econometric framework

The AIDS of Deaton and Muellbauer (1980) is one of the most widely used demand system models. The AIDS model is defined for n goods as follows:

$$W_i(\mu; z) = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{y}{P}\right); \quad i = 1, \ldots, n \tag{1}$$

where W_i is a function representing budget share of commodity i, $p = (p_1, \ldots, p_n)'$ is the vector of prices, y is total expenditure, $z = (p_1, \ldots, p_n, y)$ represents the exogenous variables and μ represents the parameters.

P is the translog price index defined as follows:

$$\ln P = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j. \tag{2}$$

The regularity properties of demand theory can be summarised by the following regularity properties of the underlying cost function: positivity, monotonicity, homogeneity and concavity. In terms of the corresponding Marshallian demands, monotonicity implies non-negativity of demands; homogeneity implies adding-up and homogeneity of degree zero in prices and expenditure; and concavity implies that the Slutsky matrix is negative semi-definite. Continuous differentiability alone of the cost function implies that the Slutsky matrix is symmetric. The restrictions of adding-up, homogeneity and symmetry can be imposed by the following equality restrictions on parameters (Deaton and Muellbauer1980):

$$\begin{aligned} \text{Adding-up:} &\quad \sum_{i=1}^{n} \alpha_i = 1 \quad \sum_{i=1}^{n} \gamma_{ij} = 0 \quad \sum_{i=1}^{n} \beta_i = 0; \\ \text{Homogeneity:} &\quad \sum_{j=1}^{n} \gamma_{ij} = 0, \text{ for } i = 1, \ldots, n; \text{ and} \\ \text{Symmetry:} &\quad \gamma_{ij} = \gamma_{ji}, \text{ for all } i \neq j. \end{aligned}$$

While the theoretical properties of adding-up, homogeneity and symmetry can be imposed by parameter restrictions, the properties of non-negativity of demand and negative semi-definiteness of the Slutsky matrix cannot be imposed globally by simple parameter restrictions. The negativity conditions are satisfied if the matrix of (scaled) Slutsky substitution terms, S_{ij}, defined as

$$S_{ij} = \gamma_{ij} + \beta_i \beta_j \ln\left(\frac{y}{P}\right) - \delta_{ij} W_i + W_i W_j, \tag{3}$$

is negative semi-definite, where δ_{ij} is the Kronecker delta such that $\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ if $i \neq j$ and the share functions W_i are given by (1). Many empirical applications of the AIDS violate this curvature property (Moschini 1998), resulting in an estimated Slutsky matrix that is not necessarily negative semi-definite.

Building on the concept of semiflexible functional form in Diewert and Wales (1987, 1988), Moschini (1998) proposes a semi-flexible AIDS that not only maintains the curvature property in the AIDS at a point but also reduces the risk of losing degrees of freedom with increasing number of goods, an inherent problem in standard flexible demand systems.[2] Assuming that concavity is maintained at the point where $P = y = 1$ (i.e. when $p_i = 1$ for all i and setting $\alpha_0 = 0$), the data can be scaled appropriately so that the desired concavity property can be imposed at any point. We choose the sample geometric mean in this application. At this data point, the Slutsky substitution matrix is a function only of parameters and can be written as follows:

$$\theta_{ij} = \gamma_{ij} + \alpha_i \alpha_j - \delta_{ij} \alpha_i. \tag{4}$$

Concavity at this point is satisfied if the matrix $\Theta \equiv [\theta_{ij}]$ is negative semi-definite. A necessary and sufficient condition for the matrix Θ to be negative semi-definite is that the upper $(n-1) \times (n-1)$ submatrix of Θ be set equal to $-\mathrm{T}'\mathrm{T}$; where T is an $(n-1) \times (n-1)$ upper triangular matrix such that $\tau_{ij} = 0$ for $i > j$. The T matrix has the following structure:

$$\mathrm{T} = \begin{bmatrix} \tau_{11} & \tau_{12} & \tau_{13} & \cdots & \tau_{1n-1} \\ 0 & \tau_{22} & \tau_{23} & \cdots & \tau_{2n-1} \\ 0 & 0 & \tau_{13} & \cdots & \tau_{1n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & \tau_{n-1n-1} \end{bmatrix}. \tag{5}$$

Our approach to imposing negative semi-definiteness on the AIDS model at the geometric means follows Moschini's (1998) approach. The approach

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[2] Note that in flexible models such as the AIDS, the number of parameters to be estimated increases quadratically as the dimension of the demand system increases. This is circumvented by restricting the rank of the $(n-1)$ substitution matrix for a n-good demand system to any rank K where $1 < K < (n-1)$.

involves expressing not only the parameters in terms of the τ_{ij}'s, but also expressing the model as a function of price indexes which are, in turn, functions of the τ_{ij}'s. The advantage of this approach, as discussed by Moschini (1998), is that it simplifies estimation through simple deletion of price indexes as the rank of the Slutsky substitution matrix is reduced.

Reparameterising γ_{ij} firstly in terms of θ_{ij} and α from Equation (4) and subsequently in terms of τ_{ij} from Equation (5) allows us to write the AIDS model as follows:

$$W_i = \alpha_i + \alpha_i \ln\left(\frac{p_i}{P^{\alpha}}\right) - \sum_{s=1}^{i} \tau_{si} \ln P_s^{\tau} + \beta_i \ln\left(\frac{y}{P}\right), \quad i = 1,\ldots,n-1 \tag{6}$$

where P_s^{τ} is an aggregation function, homogeneous of degree zero in prices, given by the following:

$$\ln P_s^{\tau} = \sum_{j=s}^{n-1} \tau_{sj} \ln\left(\frac{p_j}{p_n}\right), \quad s = 1,\ldots,n-1; \tag{7}$$

P^{α} is a price function, homogeneous of degree one, given as follows:

$$\ln P^{\alpha} = \sum_{i=1}^{n} \alpha_i \ln p_i; \tag{8}$$

and the translog price index is written as follows:

$$\ln P = \ln P^{\alpha} + \frac{1}{2}(P^{\alpha})^2 + \frac{1}{2}\sum_{i=1}^{n} \alpha_i (\ln p_i)^2 - \frac{1}{2}\sum_{s=1}^{n-1} (\ln P_s^{\tau})^2. \tag{9}$$

Equation (6) results in a locally concave AIDs model. However, the estimation of this model can present convergence issues if the estimation of the unrestricted AIDS model (Eqn 1) violates local concavity. This can potentially result in a substitution matrix of less than full rank. Thus, if concavity is violated when estimating an unrestricted AIDS model, estimating a model with substitution matrix of rank $K < (n - 1)$ can be useful to achieve convergence. Along with maintaining curvature properties, this semi-flexible AIDS model has the added advantage of reducing the number of parameters to be estimated. A detailed illustration of the use of a semi-flexible model can be found in Diewert and Wales (1988). Essentially, by setting $\tau_{ij} = 0$ for all $i > K$, we can estimate a restricted model of rank $K < (n - 1)$. According to Diewert and Wales (1987), the rule of thumb for setting the rank of the restricted model is that K should not exceed the number of negative eigenvalues of the unrestricted model. Moschini (1998) discusses the implications for substitutability of these restrictions on the Slutsky matrix.

The presence of serial correlation is a common feature in time series data. While serial correlation will not affect the unbiasedness or consistency of the estimators, it does affect their efficiency. We therefore estimate the system of demand Equation (6) with a first-order autoregressive scheme, which greatly complicates the model specification. However, a simple way of illustrating the estimation procedure is provided as follows. Adding an error term to the right-hand side component of (6) results in the following:

$$w_{it} = W_i(\mu, z_t) + u_{it}, \quad i = 1, 2, \ldots, n-1;\ t = 2, \ldots, T \tag{10}$$

where w_{it} is the observed share for commodity i at time t, z_t is the vector of the corresponding exogenous variables at time t and $u_t = [u_{it}]$ is a vector of error terms. To allow for serial correlation, a first-order autoregressive scheme is specified as follows:

$$u_{it} = \rho u_{i,t-1} + e_{it}, \quad i = 1, 2, \ldots, n-1;\ t = 2, \ldots, T \tag{11}$$

where ρ is the autocorrelation coefficient, and e_t is a vector of independently and identically distributed error terms with $E[e_t] = 0$ and $E\left[e_t e_t'\right] = \Omega$. Transforming the dependent variable to $w_{it} - \rho w_{it-1}$ results in the following:

$$w_{it} = \rho w_{it-1} + W(\mu, z_t) - \rho W(\mu, z_{t-1}) + e_{it}, \quad i = 1, 2, \ldots, n-1;\ t = 2, \ldots, T. \tag{12}$$

This results in a system of equations with a first-order autoregressive scheme but with an additional parameter ρ, which is the same across all equations because of the adding-up restriction (Berndt and Savin 1975). Assuming e_{it} follow a multivariate normal distribution, we estimate the system of $n - 1$ nonlinear equations by iterated feasible generalised nonlinear least squares (FGNLS). As noted by Kmenta and Gilbert (1970) and Poi (2008), for the AIDS class of models, iterated feasible generalised least squares is equivalent to maximum likelihood estimation.

The nonlinear form of the AIDS model prevents the direct interpretation of its coefficients as elasticities. However, the signs of these coefficients still give an indication of the response of the dependent variable to a change in its determinants. For instance, the coefficients of the price variables (γ_{ij}) represent the change in expenditure share of commodity i in response to a proportionate change in prices, everything else held constant. Coefficients β_i represent the change in the ith expenditure share for a proportional change in real expenditure.[3] The demand elasticities are as follows:[4]

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[3] Total expenditure allocated to the group of n alcohol commodities, deflated by price index P.

[4] Uncompensated price elasticities take account of total effect of price changes. However, compensated elasticities compensate for the effects of changes in real income which result from price changes.

Expenditure elasticities:

$$\eta_i = 1 + \frac{\beta_i}{W_i};$$

Marshallian or uncompensated elasticities:

$$\varepsilon_{ij} = -\delta_{ij} + \frac{\gamma_{ij} + \beta_i(\alpha_j + \sum_k \gamma_{jk} \ln p_k)}{W_i};$$

Hicksian or compensated elasticities:

$$\varepsilon^*_{ij} = \varepsilon_{ij} + W_j \eta_i$$

where W_i represents the function in (1). Evaluation at the estimated parameter values and at a particular value of exogenous variables generates estimated elasticities.

3. Data

Data in this study are obtained from AC Nielsen, Australia. Information is collected using the ScanTrack Liquor service that tracks value and volume of sales for off-premise consumption of liquor from supermarkets, grocery/convenience stores and liquor chains.[5] Monthly values and volume of sales of 14 alcoholic beverage types for the period January 2004 through August 2010 at state level[6] are used in this study resulting in 400 observations for each series. These include four beer types (premium, full strength, low alcohol and mid-strength); five wine types (red bottled, white bottled, fortified, sparkling, and cask); three RTD types (dark, light, cider/cooler); and two spirits types (dark and light). Note that the consumption data do not include on-premise consumption, which potentially accounts for a significant component of alcohol consumption.

Table 1 presents the market shares of these alcoholic beverages based on value of sales. Looking at the four broad types of alcoholic products, beer has the largest market share of 42.7 per cent, which is almost double the size of its immediate competitor wine (22.6 per cent; Column 3). Due to its increasing popularity, the budget share of RTD is not far from that of wine (18.7 per cent) while spirits has the lowest share of 16 per cent. Column 4 presents the budget shares of the 14 alcohol types within each broad category of products. Within beer, full strength beer dominates the market with a high budget share

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[5] The only included on-premise component results from consumption at integrated hotels, that is, hotels that have bottle shops and bars.

[6] Note that ACT and NT are rolled into NSW and SA, respectively. Liquor data are not audited for TAS. We thus have five data points in terms of states.

Table 1 Budget shares of alcohol off-premise expenditure

	% Alcohol	Budget share by broad groups %	Within-group share %	Budget share by alcohol type %
Beer	4.3	42.7		
Premium beer	5.0		16.5	7.1
Full strength beer	4.7		62.4	26.8
Low alcohol beer	2.6		11.0	4.8
Mid-strength beer	3.4		10.1	4.3
			100.0	
Wine		22.6		
Red bottle wine	12.6		28.5	6.5
White bottle wine	12.6		33.8	7.6
Fortified wine			2.0	0.5
Sparkling wine			16.8	3.8
Cask wine	12.6		19.0	4.3
			100.0	
RTD	5.2	18.7		
Dark RTD/cider			73.4	13.5
Light RTD/cider			24.0	4.4
Cider/cooler			2.5	0.5
			100.0	
Spirits	36.0	16.0		
Dark spirits			68.9	11.1
Light spirits			31.1	5.0
			100.0	
		100.0		*100.0*

of 62.4 per cent. Within the broad wine type, bottled wine largely dominates the market, with a slightly larger share for white wine (33.8 per cent) relative to red wine (25.8 per cent). Within both RTD and spirits, dark liquor budget shares exceed those of light liquor. Finally, column 5 presents budget shares of the 14 alcohol types out of total expenditure. Full strength beer dominates the market with a high share of 26.8 per cent followed by dark RTD (13.5 per cent) and dark spirits (11.1 per cent).

As noted earlier, studies have traditionally split alcohol into three broad types of beverage: beer, wine and spirits. Here, we conduct the analysis on 12 alcohol types, grouping fortified wine and cider/cooler with sparkling wine and light RTD, respectively, due to their small expenditure shares. Implicit prices per litre of beverage are then constructed by dividing value of sales measured in dollars by respective volume of sales measured in litres of beverage. Per capita expenditure is derived using the states and territories population estimates obtained from the Australian Bureau of Statistics (ABS 2012). Before estimation, prices and per capita income are converted into logs and then normalised by subtracting their respective arithmetic mean, which is equivalent to dividing the original series by the respective geometric mean. Given the high frequency of our data, seasonality can potentially affect our results. We thus allow for seasonal intercept shifts in the demand system using a set of monthly dummy variables with their coefficients satisfying adding-up conditions.

4. Results

We start by estimating the unrestricted AIDS, which shows that at the mean point, the Slutsky matrix does not satisfy the curvature property. In particular, we find that four eigenvalues are positive and seven are negative. We thus estimate a semi-flexible model of order $K = 7$. In other words, for $i > K$, we set $\tau_{ij} = 0$.

Estimates of the constant terms, α_i's, and budget coefficients, β_j's, and the τ_{ij}'s from the 11 equations are reported in Table 2. Of the 11 budget coefficients that are estimated, six are statistically significant at the 5 per cent level and one more at the 10 per cent level. Of the 56 τ_{ij}'s, 28 are significant at the 5 per cent level and five more at the 10 per cent level. In Table 3, we present our estimated conditional budget and compensated price elasticities calculated at the mean.[7]

The positive signs on the expenditure elasticities indicate that all 12 alcohol types are normal goods. Our estimates of own-price elasticity for the beer types are in the range 1.0–5.4, higher than those of the wine types which ranged between 1.2 and 3.0, RTD types which ranged between 1.2 and 1.9 and spirits types, 1.3–1.6. Among the 12 alcohol types, premium beer and mid-strength beer have the highest own-price elasticities of 5.4 and 3.4, respectively. As expected, the magnitudes of these elasticity estimates are in general higher than previous estimates such as Clements and Johnson (1983) and Selvanathan and Selvanathan (2005), which have more aggregated product types and thus smaller scope for substitution.

Looking at the cross-price elasticities in Table 3, we start with the beverages that are most frequently associated with binge drinking and negative alcohol-related behaviours, such as verbal and physical abuse and creating public disturbance under the influence of alcohol, according to Srivastava and Zhao (2010) and Yang *et al.* (2014), namely regular strength beer including full strength and premium regular beer (FSB and PRB), dark RTD (DR) and dark spirits (DS). Both FSB and PRB are shown to be close substitutes to each other and with DR, DS and MSB (mid-strength beer). FSB, which has the highest budget share, is also shown to be a close substitute for CW. DR and DS are closest substitutes with each other, and both with PRB. DR is a close substitute with FSB, and DS is also a substitute for LR and LS. Next we look at CW, which is the beverage that is to have higher tax in most proposed tax changes. We show that CW is a closest substitute for FSB, followed by DR and WBW (white bottled wine). Overall,

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[7] More model estimation results including γ_{ij}, θ_{ij} and conditional uncompensated (Marshallian) elasticities are available on request from the corresponding author and will be published in a longer version working paper at Monash University.

Table 2 Estimated coefficients and standard errors for semiflexible Almost Ideal Demand System

αi	0.291	0.072	0.000	0.129	0.046	0.094	0.040	0.080	0.130	0.017	0.092
	(0.137)**	(0.137)	(0.000)	(0.066)*	(0.013)**	(0.037)**	(0.006)**	(0.047)*	(0.035)**	(0.008)**	(0.038)**
βi	0.036	−0.001	0.007	0.007	−0.018	0.012	0.022	−0.016	−0.046	−0.003	−0.007
	(0.006)**	(0.012)	(0.002)**	(0.005)	(0.007)**	(0.006)*	(0.005)**	(0.004)**	(0.008)**	(0.004)	(0.007)
$\tau 1i$	−0.571	0.148	0.001	0.074	0.049	0.057	0.034	0.020	0.058	0.025	0.075
	(0.047)**	(0.033)**	(0.001)*	(0.027)**	(0.012)**	(0.016)**	(0.012)**	(0.022)	(0.019)**	(0.009)**	(0.023)**
$\tau 2i$	–	0.320	0.002	−0.206	0.009	−0.021	−0.041	−0.137	−0.062	0.018	0.109
	–	(0.053)**	(0.001)	(0.050)**	(0.031)	(0.038)	(0.025)*	(0.042)**	(0.044)	(0.022)	(0.046)**
$\tau 3i$	–	–	−0.001	0.026	−0.038	0.054	−0.044	0.039	−0.025	−0.042	0.141
	–	–	(0.001)*	(0.036)	(0.032)	(0.054)	(0.025)*	(0.062)	(0.025)	(0.027)	(0.065)**
$\tau 4i$	–	–	–	0.316	−0.032	−0.060	0.003	−0.130	−0.099	0.002	0.015
	–	–	–	(0.061)**	(0.026)	(0.039)	(0.017)	(0.050)**	(0.042)**	(0.018)	(0.042)
$\tau 5i$	–	–	–	–	−0.132	0.097	−0.052	0.060	0.055	0.097	−0.152
	–	–	–	–	(0.039)**	(0.033)**	(0.026)**	(0.047)	(0.044)	(0.028)**	(0.062)**
$\tau 6i$	–	–	–	–	–	0.245	−0.034	−0.132	−0.115	0.014	0.013
	–	–	–	–	–	(0.046)**	(0.018)*	(0.041)**	(0.038)**	(0.022)	(0.059)
$\tau 7i$	–	–	–	–	–	–	−0.003	0.173	−0.314	0.005	0.099
	–	–	–	–	–	–	(0.015)	(0.052)**	(0.032)**	(0.018)	(0.045)**

Standard errors are given in parentheses; *, ** , *** denote significance at 10%, 5% and 1% respectively.

Table 3 Estimated conditional compensated (Hicksian) price and expenditure elasticities and standard errors

	Compensated own and cross-price elasticities												Expenditure elasticity
	PRB	FSB	LAB	MSB	RBW	WBW	SW	CW	DR	LR	DS	LS	
PRB	**−5.257**	1.383	0.037	0.621	0.436	0.501	0.301	0.194	0.580	0.246	0.685	0.274	1.476
	(0.718)**	(0.278)**	(0.007)**	(0.212)**	(0.105)**	(0.135)**	(0.111)**	(0.169)**	(0.165)**	(0.078)**	(0.196)**	(0.082)**	(0.082)**
FSB	0.398	**−1.215**	0.024	0.272	0.025	0.065	0.073	0.200	0.180	0.020	−0.064	0.023	0.997
	(0.080)**	**(0.155)****	(0.001)**	(0.063)**	(0.036)	(0.043)	(0.033)**	(0.048)**	(0.055)**	(0.028)	(0.055)	(0.036)	(0.046)**
LAB	0.104	0.235	**−0.974**	0.070	0.059	0.072	0.041	0.052	0.136	0.052	0.109	0.043	1.246
	(0.019)**	(0.009)**	**(0.000)****	(0.010)**	(0.003)**	(0.005)**	(0.002)**	(0.007)**	(0.004)**	(0.002)**	(0.006)**	(0.002)**	(0.078)**
MSB	0.767	1.168	0.031	**−3.374**	0.218	0.222	−0.136	0.215	0.382	0.094	0.254	0.159	1.109
	(0.262)**	(0.269)**	(0.004)**	**(0.850)****	(0.099)**	(0.173)	(0.098)	(0.208)	(0.228)*	(0.102)	(0.210)	(0.112)	(0.082)**
RBW	0.511	0.102	0.025	0.207	**−1.283**	0.232	−0.109	0.128	0.150	0.208	−0.182	0.010	0.724
	(0.124)**	(0.145)	(0.001)**	(0.094)**	**(0.191)****	(0.085)**	(0.059)*	(0.086)	(0.093)	(0.058)**	(0.107)*	(0.055)	(0.107)**
WBW	0.526	0.239	0.027	0.189	0.209	**−2.045**	0.227	0.219	0.326	−0.104	0.151	0.036	1.163
	(0.142)**	(0.156)	(0.002)**	(0.147)	(0.076)**	**(0.441)****	(0.063)**	(0.117)*	(0.122)**	(0.052)**	(0.135)	(0.058)	(0.086)**
SW	0.538	0.452	0.026	−0.197	−0.166	0.386	**−1.163**	−0.076	−0.036	0.140	0.133	−0.036	1.525
	(0.198)**	(0.207)**	(0.001)**	(0.143)	(0.090)*	(0.106)**	**(0.109)****	(0.118)	(0.126)	(0.078)*	(0.147)	(0.071)	(0.112)**
CW	0.334	1.198	0.032	0.299	0.188	0.358	−0.073	**−2.977**	0.465	0.037	0.194	−0.055	0.628
	(0.290)	(0.285)**	(0.004)**	(0.289)	(0.125)	(0.191)*	(0.113)	**(0.968)****	(0.231)**	(0.134)	(0.277)	(0.151)	(0.086)**
DR	0.318	0.343	0.026	0.170	0.070	0.170	−0.011	0.148	**−1.831**	0.031	0.466	0.099	0.665
	(0.090)**	(0.105)**	(0.001)**	(0.101)*	(0.044)	(0.064)**	(0.039)	(0.074)**	**(0.223)****	(0.044)	(0.081)**	(0.044)**	(0.058)**
LR	0.331	0.092	0.025	0.102	0.239	−0.133	0.105	0.029	0.076	**−1.164**	0.399	−0.100	0.951
	(0.105)**	(0.133)	(0.001)**	(0.111)	(0.066)**	(0.066)**	(0.059)*	(0.105)	(0.107)	**(0.102)****	(0.143)**	(0.086)	(0.067)**
DS	0.459	−0.150	0.026	0.138	−0.104	0.096	0.050	0.076	0.569	0.199	**−1.519**	0.160	0.938
	(0.131)**	(0.128)	(0.001)**	(0.114)	(0.061)*	(0.086)	(0.055)	(0.108)	(0.098)**	(0.071)**	**(0.254)****	(0.080)**	(0.066)**
LS	0.415	0.120	0.023	0.195	0.013	0.052	−0.031	−0.048	0.272	−0.113	0.362	**−1.260**	1.155
	(0.125)**	(0.187)	(0.001)**	(0.137)	(0.071)	(0.084)	(0.060)	(0.133)	(0.121)**	(0.097)	(0.182)**	**(0.187)****	(0.073)**

PRB, Premium beer; FSB, Full strength beer; LAB, Low alcohol beer; MSB, Mid-strength beer; RBW, Red bottled wine; WBW, White bottled wine; SW, Sparkling wine; CW, Cask wine; DR, Dark RTD; LR, Light RTD; DS, Dark spirits; LS, Light spirits; RTD, ready-to-drink.
Standard errors are given in parentheses; *, ** , *** denote significance at 10%, 5% and 1% respectively.

these results seem to show that any tax policy aimed at the beverages most associated with negative externalities may need to target these troubled beverages jointly. As well, any tax change to increase price of CW may result in consumers shifting demand for CW to another beverage that is more associated with negative drinking behaviours.

We next look at the bottled wines, which are shown to have lower association with self-reported negative behaviours. Both RBW and WBW are close substitutes for PRB. In addition, RBW is more substitutable with WBW, LR and MSB, whilst WBW more with DR, SW, CW and RBW. On the other hand, LR, LS and SW, perceived as female drinks, are shown to be close substitutes for both PRB and DS. SW is also closely substitutable for FSB, WBW and LR. Finally, we also find some pairs of beverages that are complementary goods with statistical significance: RBW with DS, RBW with SW and WBW with LR.

5. An illustration of simulating tax policies using demand inter-relationships

There has been considerable discussion and debate in Australia about the appropriate mix of taxes for alcoholic beverages. Economists and various industry bodies have suggested a wide range of alcohol tax reform proposals. These include a flat rate VT across all beverages based on alcohol content or simply replacing the current *ad valorem* WET with a revenue neutral VT of all wine products. Health concerns also motivate recommendations to change taxes in favour of wine and beer compared to spirits and RTD beverages. There are a myriad of policies one could analyse and such analyses would, of necessity, require the complete set of demand elasticities such as those estimated in this study. The purpose of this section is to illustrate the importance of the system of demand elasticities through evaluation of the effect of a change in the tax system that would move wine towards equalisation of taxation based on alcohol content.

In order to calculate the total effects of changes in alcohol taxes, we need unconditional price elasticities that allow for substitution both within alcohol group and outside with nonalcoholic goods. We assume a two-stage budgeting demand system framework and augment our conditional elasticities with published elasticity estimates at first-stage allocation between total alcohol and all other goods, and additional data from the ABS. Carpentier and Guyomard (2001) have developed formulas to estimate unconditional elasticities that approximately satisfy the requirements for two-stage budgeting. The formulas used to compute unconditional elasticities are as follows:

$$\begin{aligned}
\varepsilon_{ij}^{u*} &= \varepsilon_{ij}^{*} + W_j \varepsilon_{GG}^{*} \eta_i \eta_j \\
\eta_i^{u} &= \eta_i \eta_G \\
\varepsilon_{ij}^{u} &= \varepsilon_{ij}^{u*} - W_j^{u} \eta_i^{u}
\end{aligned}$$

where ε_{ij}^{u*} are unconditional compensated (Hicksian) price elasticities, ε_{ij}^{*} are within-group conditional compensated price elasticities (from Table 3), W_j is the expenditure share of alcohol type j in total alcohol expenditures, ε^*_{GG} is the compensated own-price elasticity of demand for aggregated alcoholic beverages, η_i is the conditional expenditure elasticity for alcohol type i (from Table 3), η_G is the first-stage expenditure elasticity for aggregated alcohol, ε^u_{ij} are unconditional uncompensated (Marshallian) price elasticities, W^u_j is the expenditure share of alcohol type j in total consumer expenditure, and η^u_i is the unconditional expenditure elasticity of good i. We use an estimate of $\varepsilon^*_{GG} = -0.715$ and $\eta_G = 1.113$ from Selvanathan and Selvanathan (2005). The value for W_G (expenditure share of alcohol in total expenditures) used is 0.019, derived from the National Accounts for 2005 (ABS 2005). Finally, W^u_j is approximated by W_jW_G using average expenditure shares from Table 1. The matrix of unconditional uncompensated elasticities is shown in Table 4, which are used in the tax simulation below.

In the tax illustration, we assume a stylised scenario where taxes on all wines are increased 10 per cent from their current ad valorem levels, and beer and spirits taxes are decreased proportionately (in equivalent ad valorem levels) to keep tax revenue neutral. Taxes on RTD beverages are not assumed to change in light of the April 2008 controversial increases by the Australian government (The Age 2008). To model the economic effects of this tax change scheme, it is useful to place the model in matrix form. Let $d\ln Q$ denote the $n \times 1$ vector of relative changes in quantities of the different alcoholic beverages consumed, $d\ln P = d\ln P^* + \hat{S}d\ln T$ the vector of relative changes in retail prices of the alcoholic beverages, $d\ln P^*$ the vector of relative changes in retail price net of the equivalent ad valorem tax changes (both alcohol and GST), $\hat{S}$ the $n \times n$ diagonal matrix of taxes as proportion of retail prices, and $d\ln T$ the vector of relative tax changes.[8]

The relative change in quantities demanded from the tax scheme is as follows:

$$d\ln Q = Ed\ln P = E\left(d\ln P^* + \hat{S}d\ln T\right) \tag{13}$$

where E is the $n \times n$ matrix of unconditional price elasticities of demand given in Table 4. If we assume, for sake of simplicity, that there is complete pass-through of the taxes to consumers, then $d\ln P^* = 0$, and

$$d\ln Q = E\hat{S}d\ln T. \tag{14}$$

Finally, if the tax scheme is revenue neutral, then the relative change in tax revenue, $d\ln TR = (y/(TR))\left(\sum_{i=1}^n w_is_id\ln T_i + \sum_{i=1}^n w_is_id\ln q_i\right)$ implies that

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[8] The price relationship is based on the basic price relationship between price with and price without taxes, $P_i = P^*_i(1+t_i)$ where t_i is the ad valorem tax rate (James and Alston 2002). Totally differentiating this expression yields $d\ln P_i = d\ln P^*_i + \left(\frac{p^*_iq_i}{p_iq_i}\right)d\ln\left(p^*_it_i\right) = d\ln P^*_i + s_id\ln T_i$ where $d\ln T_i = d\ln\left(p^*_it_i\right)$ represents the relative change in equivalent *ad valorem* tax rate.

Table 4 Estimated unconditional uncompensated (Marshallian) price and expenditure elasticities and standard errors

	Uncompensated own and cross-price elasticities												Expenditure elasticity
	PRB	FSB	LAB	MSB	RBW	WBW	SW	CW	DR	LR	DS	LS	
PRB	−**5.370**	1.093	−0.028	0.569	0.384	0.405	0.230	0.164	0.481	0.195	0.572	0.211	1.643
FSB	0.322	−**1.411**	−0.020	0.237	−0.010	0.000	0.025	0.180	0.113	−0.014	−0.141	−0.019	1.110
LAB	0.009	−0.010	−**1.029**	0.026	0.015	−0.009	−0.019	0.027	0.052	0.009	0.013	−0.010	1.387
MSB	0.682	0.950	−0.018	−**3.413**	0.179	0.150	−0.189	0.193	0.308	0.056	0.169	0.112	1.234
RBW	0.456	−0.040	−0.007	0.182	−**1.308**	0.185	−0.144	0.113	0.101	0.183	−0.238	−0.021	0.806
WBW	0.437	0.010	−0.024	0.148	0.168	−**2.120**	0.171	0.195	0.248	−0.144	0.062	−0.013	1.294
SW	0.421	0.152	−0.041	−0.250	−0.219	0.287	−**1.236**	−0.107	−0.138	0.088	0.016	−0.101	1.697
CW	0.286	1.074	0.005	0.277	0.166	0.317	−0.103	−**2.990**	0.423	0.015	0.146	−0.082	0.699
DR	0.267	0.212	−0.003	0.147	0.047	0.127	−0.043	0.135	−**1.876**	0.008	0.415	0.071	0.740
LR	0.258	−0.095	−0.017	0.069	0.200	−0.195	0.060	0.010	0.012	−**1.197**	0.326	−0.140	1.058
DS	0.387	−0.335	−0.015	0.105	−0.137	0.035	0.005	0.057	0.506	0.167	−**1.591**	0.120	1.044
LS	0.327	−0.107	−0.028	0.155	−0.027	−0.023	−0.086	−0.071	0.198	−0.153	0.273	−**1.309**	1.286

PRB, Premium beer; FSB, Full strength beer; LAB, Low alcohol beer; MSB, Mid-strength beer; RBW, Red bottled wine; WBW, White bottled wine; SW, Sparkling wine; CW, Cask wine; DR, Dark RTD; LR, Light RTD; DS, Dark spirits; LS, Light spirits; RTD, ready-to-drink.

$$\sum_{i=1}^{n} w_i s_i d\ln T_i = -\sum_{i=1}^{n} w_i s_i d\ln q_i \tag{15}$$

when $d\ln TR = 0$.

Table 5 shows the effects on changes in quantities demanded from this tax change. Of all the wine types, CW declines the most because it is the most own-price elastic. Demand for all beer types and dark and light spirits increase when taxes on these alcoholic beverages are decreased uniformly by 2.9 per cent in order to keep total tax revenue constant. The largest increases in consumption occur where demands are more elastic: PRB, DS, MSB and FSB. While the tax is not changed on either of the RTD beverages, we find DR consumption declines by about 0.9 per cent and LR consumption declines by about 0.3 per cent. This reflects the fact that the RTD beverages are closer substitutes with spirits, especially dark spirits. While total change in alcohol consumption from the tax scheme is negligible (only about a 0.1 per cent change), the alcohol content of alcohol consumed declines by 47 per cent caused mainly by the large shift from wine to beer.

To highlight the importance of accounting for cross-price elasticities, the last column of Table 5 shows only the effect from a tax change on own-price changes. Although the changes in quantity demanded are the same (excepting LR and DR where taxes do not change), the total effects taking account of cross-price effects are orders of magnitude smaller than the direct effects alone. For example, the total change in quantity demanded of PRB is 4.7 per cent while the direct effect from only a change in price of PRB is over 15 per cent.

6. Conclusion

This paper presents estimates of price elasticities of demand for 12 disaggregated alcoholic beverages in Australia. The beverages include four types of beer: premium beer, full strength, low alcohol and mid-strength; four types of wine: red bottled wine, white bottled wine, sparkling wine, CW; two RTD alcoholic beverages: dark and light; and two types of spirits: dark and light. These disaggregated categories correspond closely to the commodities of interest to public policymakers regarding taxation and health policies. Data were obtained from AC Nielsen, Australia, and cover the time period January 2004 through August 2010. The system of demand functions was estimated using the semi-flexible AIDS model of Moschini (1998) in order to impose negative semi-definiteness on the parameters. The error terms were also corrected for first-order autocorrelation following the methodology of Berndt and Savin (1975).

The results provide elastic own-price elasticities for virtually all the commodities. Individual beer types overall appear more elastic than wine, followed by spirits and RTD commodities. We also find some interesting cross-price relationships. Broadly speaking, beverages that are most

Table 5 Effects of 10% increase in equivalent *ad valorem* taxes of wine on quantities consumed of 12 different alcoholic beverages – tax revenue held constant

Alcoholic beverage	Tax as proportion of retail price	Percentage change in equivalent *ad valorem* tax	Percentage change in quantity demanded	Percentage change in quantity demanded (direct effect)
PRB	0.33	−2.85	4.70	15.57
FSB	0.43	−2.85	1.88	4.09
LAB	0.24	−2.85	0.72	2.98
MSB	0.36	−2.85	2.03	9.90
RBW	0.25	10	−3.01	−13.08
WBW	0.25	10	−4.64	−21.20
SW	0.25	10	−3.24	−12.36
CW	0.20	10	−7.19	−29.90
DR	0.34	0	−0.93	0
LR	0.35	0	−0.34	0
DS	0.61	−2.85	2.42	4.61
LS	0.61	−2.85	1.03	3.80

PRB, Premium beer; FSB, Full strength beer; LAB, Low alcohol beer; MSB, Mid-strength beer; RBW, Red bottled wine; WBW, White bottled wine; SW, Sparkling wine; CW, Cask wine; DR, Dark RTD; LR, Light RTD; DS, Dark spirits; LS, Light spirits; RTD, ready-to-drink.Source: Tax shares from Zhao and Wittwer (2007).

frequently associated with binge drinking and negative externalities as shown from individual level data evidence (Srivastava and Zhao 2010; Yang *et al.* 2014), namely regular strength beer, dark RTD and dark spirits, are also shown to be close substitutes to one another. CW, the controversial beverage at the centre of much tax discussion, is also shown to be substitutable by many of the beverages most linked to negative behaviours. These suggest that any tax policy aimed at the beverages that are most associated with negative externalities may need to tax these beverages as a group. As well any proposed tax change to increase price of CW may also result in consumers shifting demand to other beverages that are more associated with undesirable drinking behaviours. We also find some interesting complementarity across some drinks.

To illustrate the importance of a matrix of price elasticity of demand satisfying all the restrictions of consumer behaviour, we have used the elasticities to estimate the effect of a change in the current tax system that would move wine towards taxation equalisation based on alcohol content. A matrix of unconditional elasticities is derived using a two-stage budgeting assumption and published aggregated elasticities, allowing for substitution between alcohol and non-alcohol goods. In particular, using the elasticities, we assumed a 10 per cent increase in taxes on wine from their current ad valorem levels and a commensurate decrease in taxes on beer and spirits in order to keep tax revenue equal. Demand for each wine type decreases with the largest decrease in percentage terms occurring for CW. Demand for all beer and dark and light spirits increase with the largest increases occurring among the different beer types. The policy simulation shows the importance of having a set of demand elasticities because the mix of consumption of alcoholic beverages will change in different ways depending upon the type of taxation policy implemented. A significant finding is that, although there is only a small scope in changing total alcohol consumption, alcohol content would decline by 47 per cent because of substitution of beer for wine and little change in spirits consumption. Also, the policy simulation shows the importance of having a set of demand elasticities because the mix of consumption of alcoholic beverages will change dramatically when cross-price effects are accounted for in the tax analysis.

Discussion of the impacts of a range of proposed alcohol tax reform policies relies crucially on empirical knowledge of consumer price responsiveness across differentiated beverages. This requires the information of a set of consumer demand elasticities by disaggregated beverage types that are estimated using reliable disaggregated data and credible econometric models that are consistent with economic theory and data features. The conditional and unconditional elasticities presented in this paper offer a valuable input into the analyses of impacts of any proposed tax change policies. The tax example considered is only one of many taxation schemes authorities could undertake. Thorough examination of alternative tax change proposals and their impacts using the estimated elasticities presented here will be an important exercise but is beyond the scope of the current paper.

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