

THE DEMAND FOR VICE
Inter-Commodity Interactions with Uncertainty*

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Abstract

This paper analyses consumption patterns of vice -- marijuana, tobacco and alcohol. To deal with imperfect marijuana data, we exploit the interdependencies in the consumption of the three drugs identified in prior research, and introduce a Monte Carlo simulation procedure to formally account for the inherent uncertainty in marijuana-related data and parameters. To illustrate the application of the framework, we use Australian data to simulate the impact on the consumption of vice of a reduction in the price of marijuana; changes in pre-existing taxes on tobacco and alcohol; legalisation of marijuana, which is then subject to taxation; and a tax tradeoff involving the introduction of a revenue-neutral tax on marijuana that is offset by reduced alcohol taxation. The revenue-maximising tax rate for marijuana of about 50% is estimated to yield additional revenue of about 15% of the pre-existing proceeds from vice taxation. The role of uncertainty surrounding marijuana is highlighted by providing the entire probability distributions of all endogenous variables in a consistent multivariate framework.

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1. INTRODUCTION

This paper deals with the determinants of consumption of a good that, officially at least, does not exist -- marijuana. Despite the denial of its existence by officialdom, estimates indicate that the consumption of marijuana is quite substantial in many countries. In Australia, for instance, more than one in three people say they have tried marijuana, and Clements and Daryal (2005) estimate that its sales are something like twice those of wine. More generally, illicit drug use is part of the underground economy and a number of studies using a variety of approaches have investigated the order of magnitude of this sector (see, e. g., Bajada, 1999). The widespread use of marijuana, its unique tax-free status, the current interest in its decriminalisation/legalisation and the size of the underground economy all make research on the economics of marijuana consumption a worthwhile endeavor.

Empirical studies show that marijuana is closely related in consumption to at least two other goods, tobacco and alcohol.¹ As in many instances marijuana is mixed with tobacco and then smoked, there is a presumption that these goods are complements. Furthermore, as marijuana and alcoholic beverages contain intoxicating properties that are similar in the minds of many consumers, they both tend to serve the same want, and it is reasonable to suppose that they are substitutes. These considerations imply that the consumption of the three goods, which we dub the demand for vice, needs to be modeled jointly as an interrelated system of demand equations. Such interrelations imply cross-commodity impacts of any policy changes, so that changes in one drug market are likely to have spillover effects in related markets. For example, what would be the likely impacts on the markets for tobacco and alcohol, as well as the revenue from taxing these products, if there were further decriminalisation of marijuana? What is the potential tax revenue from marijuana were it legalised? And how would changes in taxation and regulation arrangements for alcohol and tobacco impact on marijuana consumption?

Answers to these questions depend crucially on unofficial estimates of the price and quantity data for marijuana, as well as a consistent set of own- and cross-price elasticities characterising the interrelationships in consumption of vice. The problem in constructing such a demand system is that hard data on marijuana consumption are just not available; even the data on alcohol and

¹ See, for example, Cameron and Williams (2001), Clements and Daryal (2005), Saffer and Chaloupka (1995), and Zhao and Harris (2004).

tobacco consumption are not perfect as, due to the typically high excise taxes that these goods bear, there are substantial incentives to underreport, or not report at all, to avoid the tax net.² This is an extreme example of the situation faced in modeling exercises such as equilibrium displacement modeling (EDM) (see, e.g., Zhao et al., 2000) and computable general equilibrium (CGE) modeling (see, e.g., Dixon and Rimmer, 2002), where a large number of base market values and preference elasticities need to be specified.

Even if CGE modelers do not have the required number of high-quality econometric estimates to draw upon for the basis of their elasticities, they typically do have substantial information on consumption and prices to derive base market values. As mentioned above, such is not the case for marijuana, and we have to rely on unofficial data that are surely subject to more than the usual questions about their quality. In this paper, we introduce a simulation procedure in the context of a demand system for vice -- marijuana, tobacco and alcohol -- to formally account for the inherent uncertainty in the marijuana-related data and demand elasticities. We use separability theory as a basis for organising the fragmentary information that is available on marijuana consumption, and then combine that with econometric estimates and data pertaining to tobacco and alcohol. We then use stochastic simulations as a way to formally recognise the substantial uncertainties inherent in all aspects of the consumption of marijuana, as well as those associated with tobacco and alcohol. Zhao et al. (2000) and Griffiths and Zhao (2000) have used a similar approach in the context of sensitivity analysis for an EDM of the Australian wool industry. We extend that approach by simulating the implied distributions of demand elasticities through quantification of uncertainty in fundamental preference parameters within a complete demand specification, and by also allowing for uncertainty in marijuana-related data. These procedures may be of general interest, and have applications in EDM and CGE modeling and other areas of applied economics. To illustrate the approach, we simulate the cross-commodity impacts of some hypothetical price and tax changes.

This paper is structured as follows. The next section specifies a demand system for vice using the analytical framework of the differential approach to consumption economics; this approach highlights the links between preferences and observable consumption behaviour within a general setting. Section 3 introduces a set of baseline budget shares using Australia data and

² The situation in Russia provides an illuminating example. The Economist (September 13, 2003, p. 66) describes it as follows: "The figures prove what everyone knows: Russians drink like mad. In 2001, alcohol overdoses killed 139 people in England and Wales, but more than 40,000 Russians, in a population less than three times the size. But other official figures indicate quite the opposite: the average Briton consumed the equivalent of 8.4 litres of pure alcohol in 2001, the average Russian swallowed a mere 8.1 litres. Why the discrepancy? A mix of understated production by Russian distillers and the Russian taste for industrial alcohol or toxic moonshine could be one explanation."

fundamental consumer preference parameters for the demand system, from which Frisch, Slutsky and Marshallian price elasticities and income elasticities are derived. Section 4 introduces uncertainty by specifying subjective probability distributions for the basic preference parameters, allowing for varying degrees of preference structure and deriving the implied probability distributions through Monte Carlo simulation for the demand elasticities. To illustrate the approach, in Section 5 we simulate the impacts on the consumption of vice and tax revenue of a reduction in the price of marijuana, possibly resulting from productivity enhancement in its cultivation and/or lighter regulation, and changes in tobacco and alcohol taxation. We also simulate a scenario of legalising and taxing marijuana, deriving the revenue-maximising marijuana tax and providing results on a tax-neutrality tradeoff between marijuana and alcohol taxes. Throughout the analysis the role of uncertainty surrounding preference interactions within vice, as well as the uncertainties regarding data pertaining to the consumption of marijuana, is highlighted by providing the whole probability distributions of all endogenous variables in a consistent multivariate framework. Section 6 contains concluding comments.

2. A DEMAND SYSTEM FOR VICE

This section sets out the analytical framework for the analysis of demand for vice within a complete demand system of four goods of marijuana, tobacco, alcohol and ‘other’. We use Theil’s (1980) differential approach to consumption theory due to its generality and elegant simplicity, as well as its transparent link between the structure of preferences and the nature of the demand equations.

Let p_i be the price of good i ($i = 1, \dots, n$) and q_i the corresponding quantity demanded. Then $M = \sum_{i=1}^n p_i q_i$ is total expenditure on the n goods (“income” for short) and $w_i = p_i q_i / M$ is the share of income devoted to good i , also known as the budget share of i . Furthermore, let $d(\log Q) = \sum_{i=1}^n w_i d(\log q_i)$ be the Divisia volume index representing relative change in the consumer’s real income. It follows from the budget constraint that $d(\log Q) = d(\log M) - \sum_{i=1}^n w_i d(\log p_i)$, so that the change in real income is the change in money income deflated by the Divisia price index $\sum_{i=1}^n w_i d(\log p_i)$. Under standard assumptions, we can express the demand equation for good i in differential form (Theil, 1980) as

$$(2.1) \quad w_i d(\log q_i) = \theta_i d(\log Q) + \sum_{j=1}^n v_{ij} [d(\log p_j) - d(\log P')].$$

In equation (2.1), the parameter $\theta_i = \partial(p_i q_i) / \partial M$ is the marginal share of good i , which answers the question “if income rises by one dollar what proportion of this increase is spent on good i ?”. It follows from the budget constraint that $\sum_{i=1}^n \theta_i = 1$. The term $v_{ij} = (\lambda p_i p_j / M) u^{ij}$ is the $(i, j)^{\text{th}}$ Frisch price coefficient, where u^{ij} is the $(i, j)^{\text{th}}$ element of \mathbf{U}^{-1} with $\mathbf{U} = \partial^2 u / \partial \mathbf{q} \partial \mathbf{q}'$ being the Hessian of the utility function $u(\mathbf{q})$ and $\mathbf{q} = [q_i]$, the quantity vector. Finally, $d(\log P') = \sum_{i=1}^n \theta_i d(\log p_i)$ is the Frisch price index, which uses as weights marginal shares, rather than budget shares as in the Divisia price index. If we divide both sides of equation (2.1) by w_i , we find that $\eta_i = \theta_i / w_i$ is the income elasticity of demand for good i , while $\eta_{ij}^* = v_{ij} / w_i$ is the $(i, j)^{\text{th}}$ Frisch price elasticity, which measures the effect of a Frisch-deflated (or *relative*) price change in the j^{th} good on the consumption of the i^{th} good holding real income constant.

Define $\mathbf{v} = [v_{ij}]$ as the matrix of Frisch coefficients. For a budget-constrained utility maximum, \mathbf{v} is negative definite. Another property of \mathbf{v} is that its row sums are proportional to the corresponding marginal shares,

$$(2.2) \quad \sum_{j=1}^n v_{ij} = \phi \theta_i, \quad i = 1, \dots, n.$$

The proportionality factor $\phi = \left(\frac{\partial \log \lambda}{\partial \log M} \right)^{-1} < 0$ is the reciprocal of the income elasticity of the marginal utility of income, known as the “income flexibility” for short, where λ is the marginal utility of income. It can also be shown that $d(\log \lambda) = (1/\phi) d(\log Q) - d(\log P')$. Using this relationship and (2.2), the Frisch demand equation (2.1) can alternatively be written in terms of the marginal utility of income as

$$w_i d(\log q_i) = \theta_i \phi d(\log \lambda) + \sum_{j=1}^n v_{ij} d(\log p_j) = \sum_{j=1}^n v_{ij} [d(\log p_j) - d(\log \lambda)],$$

where the last step follows from (2.2). It can be seen from the above that the Frisch price elasticity $\eta_{ij}^* = v_{ij} / w_i$ is also interpreted as the effect of a change in the price of good j on the consumption of good i *holding the marginal utility of income constant*. Following Houthakker (1960), goods i and j are called *specific* substitutes or complements according to the sign of the Frisch price elasticity η_{ij}^* .

As demand equation (2.1) is formulated in terms of deflated prices, the substitution term of that equation contains the j^{th} price twice, once explicitly and once within the Frisch price index. We use equation (2.2) to combine these by rewriting (2.1) as

$$(2.3) \quad w_i d(\log q_i) = \theta_i d(\log Q) + \sum_{j=1}^n \pi_{ij} d(\log p_j),$$

where $\pi_{ij} = v_{ij} - \phi \theta_i \theta_j$ is the $(i, j)^{\text{th}}$ Slutsky price coefficient. The symmetry and homogeneity conditions imply that $\pi_{ij} = \pi_{ji}$ and $\sum_{j=1}^n \pi_{ij} = 0$. The Slutsky coefficient, and the corresponding elasticity $\eta_{ij} = \pi_{ij} / w_i$, deal with the impact on the consumption of good i of a change in the price of j on account of the *total* substitution effect, *real income remaining unchanged*. Goods are called *Slutsky* (or *Hicksian*) substitutes or complements according to the sign of the Slutsky price elasticity. Finally, if alternatively we hold money income constant, the Marshallian price effects can be shown by substituting $d(\log Q) = d(\log M) - \sum_{i=1}^n w_i d(\log p_i)$ in (2.3) to obtain

$$w_i d(\log q_i) = \theta_i d(\log M) + \sum_{j=1}^n \gamma_{ij} d(\log p_j),$$

where $\gamma_{ij} = \pi_{ij} - \theta_i w_j$ is the Marshallian price coefficient. The corresponding Marshallian (or uncompensated) elasticity, $\eta'_{ij} = \eta_{ij} - \eta_i w_j$, gives the percentage change in the consumption of i following a one-percent change in the price of j , *holding money income constant*.

As the Frisch price coefficients deal with the specific substitution effects that directly relate to the interaction of goods in the utility function, these coefficients offer a convenient way to introduce prior notions of the likely structure of preferences. An example is the case of preference independence (PI) whereby goods do not interact with each other, such that utility is additive in the n goods, $u(q_1, \dots, q_n) = \sum_{i=1}^n u_i(q_i)$, with $u_i(q_i)$ a sub-utility function that depends only on the consumption of good i . In this case, $\partial u / \partial q_i = du_i / dq_i$, so all second-order cross derivatives vanish and both the Hessian \mathbf{U} and its inverse \mathbf{U}^{-1} are diagonal. PI thus implies that all Frisch price coefficients v_{ij} for $i \neq j$ are zero and from equation (2.2), $v_{ii} = \phi \theta_i$. Accordingly, under PI, demand equation (2.1) simplifies to

$$w_i d(\log q_i) = \theta_i d(\log Q) + \phi \theta_i [d(\log p_i) - d(\log P)],$$

so that all cross-price Frisch elasticities, $\eta_{ij}^* = v_{ij} / w_i$ for $i \neq j$, are zero. Further implications of PI are that (i) Frisch own-price elasticities are proportional to the corresponding income elasticities; and (ii) inferior goods are ruled out. These implications of PI are restrictive and clearly the hypothesis will not hold in all circumstances.

3. SPECIFICATION OF BASELINE DATA AND DEMAND PARAMETERS

In this section, we proceed to specify a set of baseline budget shares and fundamental consumer preference parameters for the demand system specified in the previous section. Income and price elasticities are then derived so that the model can be used to simulate the effects of any exogenous changes on interrelated vice markets in an internally-consistent manner.

Budget Shares, Income Elasticities, Marginal Shares and Income Flexibility

Column 2 of Table 1 gives the baseline budget shares of the four goods based on household expenditures in Australia in the late 1990's. The total household expenditure and expenditures on tobacco and alcohol are based on the Australian Household Expenditure Surveys. The marijuana quantity data are estimated from information on frequency of consumption based on a large-scale national representative survey together with assumptions regarding intensity of use, while the marijuana price data are based on information supplied by the Australian Bureau of Criminal Intelligence (see Clements et al., 2005, for details). These data are subject to more than the usual degree of uncertainty, a feature that will be taken into account in the analysis in the next section.

Column 3 of Table 1 specifies that the income elasticity of marijuana is 1.2, making it a modest luxury; that of tobacco is 0.4, a necessity; and alcohol is 1.0, a borderline case. The basis for the choice of these values is as follows. As there are few, if any, reliable published estimates of η_i for marijuana, there is clearly not much to go on other than the similarities between this good and alcohol. Accordingly, there is some presumption that consumers regard the luxuriousness of these two goods to be similar. As discussed below, we use $\eta_i = 1$ for alcohol, but we have a mild preference to regard marijuana as having a slightly higher η_i . It must be emphasised, however, that due to the absence of hard evidence, we cannot have too much confidence in the precision of this estimate. In contrast to marijuana, there have been a large number of studies published on tobacco demand; for reviews of the literature, see Cameron (1998) and Chaloupka and Warner (2000). A recent meta-analysis of 86 different studies of tobacco consumption by Gallet and List (2003) reports a mean income elasticity of 0.42 and a standard deviation of 0.43. We thus set $\eta_i = 0.4$ for tobacco, and keep in mind the uncertainties.

The good "alcohol" comprises beer, wine and spirits as a group. Prior studies almost invariably find the income elasticity for beer to be less than one, and not infrequently of the order of 0.5, making this beverage a necessity. As wine and spirits are more luxurious than beer, estimates

of their η_i tend to be substantially above one.³ With these considerations in mind, we shall use a budget-share-weighted average to estimate the income elasticity for alcohol, with the income elasticity for beer being 0.5 and 1.5 for both wine and spirits. Based on data from the Australian Household Expenditure Surveys, we use 0.50, 0.25 and 0.25 for the shares for beer, wine and spirits, respectively, to obtain the income elasticity for alcohol as a whole of 1, which agrees well with direct estimates of this elasticity obtained for Australia by Clements and Johnson (1983) and Clements and Selvanathan (1991).⁴ On this basis, we set the η_i for the aggregated good alcohol equal to 1. Finally, the η_i for the remaining good “other” can be obtained using Engel aggregation $\sum_{i=1}^4 w_i \eta_i = 1$, which implies its income elasticity is 1.0087. The marginal shares of the four commodities are computed as $\theta_i = w_i \eta_i$, and these values are given in column 4 of Table 1.

The final coefficient to be considered is the elasticity of the marginal utility of income, which, in reciprocal form, is the income flexibility ϕ . The value of the income flexibility ϕ is specified as -0.5, which is based on the following prior findings. Selvanathan (1993) uses time-series data to estimate a differential demand system for each of 15 OECD countries. For Australia, the ϕ -estimate is -0.46, with asymptotic standard error (ASE) 0.08 (Selvanathan, 1993, p. 189). When the data are pooled over the 15 countries, the estimate of ϕ is -0.45, with ASE 0.02 (Selvanathan, 1993, p. 198). Using a related approach, Selvanathan (1993, Sec. 6.4) obtains 322 estimates of ϕ , one for each year in the sample period for each of 18 OECD countries; the weighted mean of these estimates is very similar to those above at -0.46 (ASE = 0.03). Two other cross-country estimates of ϕ are also relevant. Using the data for 30 countries, Theil (1987, Sec. 2.8) obtains an estimate of ϕ of -0.53 (0.04). Chen (1999, p. 171) estimates a demand system for 42 countries and obtains an estimate of ϕ of -0.42 (0.05), when there are intercepts in his differential demand equations, which play the role of residual trends in consumption, and -0.29 (0.05) when there are no such intercepts. The final element of support for using $\phi = -0.5$ is the earlier, but still influential, survey by Brown and Deaton (1972, p. 1206) who review previous findings and

³ For a brief review of prior studies, see Clements and Selvanathan (1991). More recently, Selvanathan and Selvanathan (2005, p. 232, 237) use time-series data for 10 countries to estimate conditional income elasticities for the three alcoholic beverages. Averaging over countries, they obtain 0.75 for beer, 1.1 for wine and 1.42 for spirits, or using a somewhat different approach 0.75, 0.98 and 1.39 (in the same order). In view of sampling variability, these values are unlikely to be significantly different to those described in the text.

⁴ For details, see Clements et al. (2005). It should also be noted that a unity income elasticity for alcohol agrees with the evidence of Selvanathan and Selvanathan (2005, p. 195) who estimate this elasticity for 40 countries with time-series data. The average of these 40 estimates is 1.04. Using a somewhat different approach, the mean of another 40 estimates is 0.96 (Selvanathan and Selvanathan, 2005, p. 207).

conclude that “there would seem to be fair agreement on the use of a value for ϕ around minus one half”. Taken as a whole, it thus seems not unreasonable to use a ϕ -value of -0.5 .

Vice Interactions and Price Elasticities

Prior empirical evidence clearly indicates that marijuana, tobacco and alcohol are closely related in consumption. Using unit record data from a large-scale Australian survey (National Drug Household Survey, NDSHS, 2001), Zhao and Harris (2004) report significant correlation in individuals’ participation across the three goods. While micro-level demand studies often suffer from a lack of continuous consumption quantity data and individual level prices, overall, the available studies in Australia seem to point to a complementary relationship between marijuana and tobacco, and substitutability between marijuana and alcohol. Using the NDSHS data between 1988 and 1995, Cameron and Williams (2001) find that tobacco is a complement for marijuana, and marijuana is a substitute for alcohol. Using a trivariate approach and the NDSHS data between 1995 and 2001, Zhao and Harris (2004) find a similar pattern, although the substitutability relationship between marijuana and alcohol is insignificant. One other Australian study is also worth mentioning. Clements and Daryal (2005) use aggregate time-series data on marijuana consumption derived from the micro information from the NDSHS on individuals’ consumption frequencies, together with published data on the consumption of three alcohol beverages of beer, wine and spirits. Making a rough adjustment to hold income constant, they analyse the correlations between the consumption of the four goods, and find some evidence indicating that marijuana is a substitute for each of the three alcoholic beverages.⁵

Four other studies deal with the interrelationship in consumption of tobacco and alcohol using UK or US data (Goel and Morey, 1995, Jones, 1989, Decker and Schwartz, 2000, and Duffy, 1991). The results are mixed in relation to the sign of the cross-price effect. In a review of the US literature on the interactions within vice, Cameron and Williams (2001) point out that US studies do not typically use marijuana prices due to their unavailability, and instead use proxies such as whether or not a state has decriminalised the use of marijuana. Cameron and Williams note that on the basis of two prior US studies (Chaloupka et al., 1999, and Farrelly et al., 1999), the evidence can probably be interpreted as saying that marijuana and tobacco are complements. Another finding

⁵ Clements and Daryal (2005) also estimate a differential demand model for marijuana, beer, wine and spirits, with preference independence imposed (to keep things manageable). As this rules out complementarity, their estimates are not able to shed any light on the issue of substitutes versus complements.

to emerge from their survey is that the US evidence regarding the relationship between marijuana and alcohol is mixed, with some studies finding them to be substitutes and others complements.⁶

While not completely clear cut, prior findings regarding vice interactions can be summarised as follows. Marijuana and tobacco are in all probability complements. While there is no consensus regarding the interactions involving alcohol, there seems to be more evidence suggesting it to be a substitute for marijuana and tobacco. In what follows, we model demand interactions across drugs via the pattern of the Frisch price coefficients v_{ij} . To organise the discussion, we start with the restrictive case of preference independence and then move to a more flexible structure that allows for specific substitutability/complementarity relationships. These preference structures are then translated into sets of price elasticities that are consistent with prior evidence summarised above.

First-Pass on the Price Elasticities: Preference Independence

As a starting point, we shall assume that the four goods are preference independent (PI) in the consumer's utility function so that $v_{ij} = 0$ ($i \neq j$) and there is no specific substitution across goods. Using the data in Table 1, Table 2 presents the Frisch, Slutsky and Marshallian price elasticities under PI. Several comments can be made. First, for each element of vice the three versions of the own-price elasticities are quite similar, as can be seen by the following:

	Frisch η_{ii}^*	Slutsky η_{ii}	Marshallian η'_{ii}
Marijuana	-.60	-.59	-.61
Tobacco	-.20	-.20	-.21
Alcohol	-.50	-.48	-.52

Second, due to the substantial income effect, the three values of the own-price elasticity for other ($\eta_{44}^* = -0.50$, $\eta_{44} = -0.04$ and $\eta'_{44} = -0.96$) differ considerably. Third, the cross-price elasticities involving vice are all quite small, which is due to (i) the assumption of preference independence and (ii) the small budget shares of these goods. Finally, under PI, all four goods are Slutsky substitutes and Marshallian complements.

⁶ For an extended discussion of the prior literature, see Clements et al. (2005).

Second-Pass Price Elasticities: Preference Dependence

Under preference independence, the 4×4 matrix of price coefficients \mathbf{v} has the following structure:

$$\begin{array}{l}
 \text{Marijuana} \\
 \text{Tobacco} \\
 \text{Alcohol} \\
 \text{Other}
 \end{array}
 \begin{array}{ccccc}
 & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row sum} \\
 \left[\begin{array}{cccc}
 \phi\theta_1 & 0 & 0 & 0 \\
 0 & \phi\theta_2 & 0 & 0 \\
 0 & 0 & \phi\theta_3 & 0 \\
 0 & 0 & 0 & \phi\theta_4
 \end{array} \right] & \phi\theta_1 & \phi\theta_2 & \phi\theta_3 & \phi\theta_4 \quad .
 \end{array}$$

We now generalise this structure by allowing marijuana and tobacco to be specific complements, so that v_{12} becomes negative. We thus now specify $v_{12} = \alpha < 0$, but additionally in view of the symmetry of \mathbf{v} and the row-sum constraints (2.2), the values of many of the other previously nonzero elements of the matrix must change. In what follows, we discuss in turn each of the four rows of \mathbf{v} .

The Marijuana Row: The elements of the first row of \mathbf{v} , v_{11} , v_{12} , v_{13} , v_{14} , refer to the responsiveness of marijuana consumption to changes in the four relative prices. Under (i) PI and (ii) the proposed new preference dependence (PD) structure, this row takes the form:

$$\begin{array}{l}
 \text{PI} \\
 \text{PD}
 \end{array}
 \begin{array}{ccccc}
 & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row sum} \\
 \left[\begin{array}{cccc}
 \phi\theta_1 & 0 & 0 & 0 \\
 \phi\theta_1 & \alpha & -\alpha & 0
 \end{array} \right] & \phi\theta_1 & \phi\theta_1 & \phi\theta_1 & \phi\theta_1 \quad .
 \end{array}$$

For PD, we have enforced the row-sum constraint by setting $v_{13} = -\alpha$ and leaving v_{11} and v_{14} unchanged. This means that marijuana and alcohol are specified to be specific substitutes, while marijuana and other continue to be independent, which is reasonable considering the aggregated nature of the fourth good.

The Tobacco Row: Under the two specifications, the second row of \mathbf{v} takes the following form:

$$\begin{array}{l}
 \text{PI} \\
 \text{PD}
 \end{array}
 \begin{array}{ccccc}
 & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row sum} \\
 \left[\begin{array}{cccc}
 0 & \phi\theta_2 & 0 & 0 \\
 \alpha & \phi\theta_2 & -\alpha & 0
 \end{array} \right] & \phi\theta_2 & \phi\theta_2 & \phi\theta_2 & \phi\theta_2 \quad .
 \end{array}$$

As \mathbf{v} is a symmetric matrix, $v_{21} = v_{12}$, which implies that under PD $v_{21} = \alpha$. In other words, if marijuana and tobacco are specific substitutes, so also are tobacco and marijuana. We use the same approach as above in dealing with the row-sum constraint by setting $v_{13} = -\alpha$, so that tobacco and alcohol are specific substitutes. As again we have no strong priors, we take tobacco and other to be independent.

The Alcohol Row: The third row of \mathbf{v} is

$$\begin{array}{rccccc} & & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row} \\ & & & & & & \text{sum} \\ \text{PI} & [& 0 & 0 & \phi\theta_3 & 0] & \phi\theta_3 \\ \text{PD} & [& -\alpha & -\alpha & \phi\theta_3 + 2\alpha & 0] & \phi\theta_3 \quad . \end{array}$$

Under PD, the elements v_{31} and v_{32} are both equal to $-\alpha$ due to symmetry. As before, we take alcohol and other to be independent, so that $v_{34} = 0$. The constraint on the sum of the elements in the alcohol row under PD then implies that $v_{33} = \phi\theta_3 + 2\alpha$.

The Other Row: Finally, the fourth row of \mathbf{v} is

$$\begin{array}{rccccc} & & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row} \\ & & & & & & \text{sum} \\ \text{PI} & [& 0 & 0 & 0 & \phi\theta_4] & \phi\theta_4 \\ \text{PD} & [& 0 & 0 & 0 & \phi\theta_4] & \phi\theta_4 \quad . \end{array}$$

By symmetry, the first three elements of this row are determined by the last elements in each of the first three rows. Accordingly, these elements are all zero under PI and PD, so that the row for other is the same under the two specifications.

Combining together the above four rows, the new \mathbf{v} matrix is

$$(3.1) \quad \begin{array}{rccccc} & & \text{M} & \text{T} & \text{A} & \text{O} & \text{Row} \\ & & & & & & \text{sum} \\ \text{Marijuana} & & \phi\theta_1 & \alpha & -\alpha & 0 & \phi\theta_1 \\ \text{Tobacco} & & \alpha & \phi\theta_2 & -\alpha & 0 & \phi\theta_2 \\ \text{Alcohol} & & -\alpha & -\alpha & \phi\theta_3 + 2\alpha & 0 & \phi\theta_3 \\ \text{Other} & & 0 & 0 & 0 & \phi\theta_4 & \phi\theta_4 \quad . \end{array}$$

This matrix is symmetric and satisfies the row-sum constraints, as required. What value should the negative parameter α take? A rise in the tobacco price reduces consumption of tobacco and as marijuana and tobacco are complements, it also reduces marijuana consumption. Similarly, a rise in marijuana prices causes the consumption of both marijuana and tobacco to fall. As the parameter α represents the degree of complementarity between marijuana and tobacco, it would seem not

unreasonable for α to be the higher (in absolute value), the higher is the own-price responsiveness of both marijuana and tobacco, as measured by $\phi\theta_1$ and $\phi\theta_2$. One way to implement this idea is to take α to be some proportion of the mean of $\phi\theta_1$ and $\phi\theta_2$, so that if we use the geometric mean, we have

$$(3.2) \quad \alpha = \rho |\phi| \sqrt{\theta_1 \theta_2}, \quad -1 < \rho < 0.$$

Writing v^{ij} for the $(i, j)^{\text{th}}$ element of \mathbf{v}^{-1} , it can be shown that $-\rho \approx v^{12} / \sqrt{v^{11} v^{22}}$, so that ρ is approximately the correlation measuring the degree of complementarity between marijuana and tobacco (see Clements et al., 2005, for further details).

As it is difficult to have a strong prior idea of the precise degree of complementarity, and since $-1 < \rho < 0$, we shall focus on the case in which $\rho = -0.5$, a value mid-way between the two extremes. Using the data given in Table 1, Table 3 contains the price elasticities corresponding to $\rho = -0.5$, and as can be seen, the cross elasticities involving vice are now larger in absolute value than those of Table 2. Next, in Figure 1 we explore the implication of differing values of ρ for the three versions of the elasticity of demand for marijuana with respect to the price of tobacco. The Frisch elasticity takes the form $\eta_{12}^* = v_{12} / w_1 = \rho |\phi| \sqrt{\theta_1 \theta_2} / w_1$. If we invert the scales on both the vertical and horizontal axes, the plot of this elasticity against ρ is a ray coming out of the origin, as can be seen from Figure 1. The corresponding Slutsky elasticity is $\eta_{12} = \eta_{12}^* - \phi \theta_1 \theta_2 / w_1$, the plot of which is parallel to Frisch, with vertical intercept equal to the general substitution effect $-\phi \theta_1 \theta_2 / w_1 = 0.5 \times 0.024 \times 0.008 / 0.02 = 0.0048$, which is very small. Finally, the Marshallian elasticity is $\eta'_{12} = \eta_{12} - \eta_1 w_2$, which differs from Slutsky by the income effect of the price change, $-\eta_1 w_2 = -1.2 \times 0.02 = -0.024$, and is thus the “top” curve in the figure. The main message from the figure is that the three cross elasticities all increase in absolute value with ρ , but only about half as fast.⁷

⁷ For an analysis of the impact of ρ on the other price elasticities, see Clements et al. (2005).

4. STOCHASTIC VICE: PROBABILITY DISTRIBUTIONS FOR DEMAND ELASTICITIES

The above price elasticities are consistent with what is known about the demand for vice. As that knowledge is highly imperfect, in this section we introduce a simulation approach to formally quantify the uncertainty regarding the structure of preferences. The approach involves describing uncertainty with subjective probability distributions of the budget shares and the demand parameters, based on the available prior information such as economic theory, published econometric estimates, and our subjective judgment. The implied probability distributions for the elasticities, which are non-linear functions of the budget shares and parameters, are then obtained through Monte Carlo simulation. These uncertainties in both the data and preference parameters can then be translated to probability statements regarding the own- and cross-industry impacts in policy analysis. An advantage of the approach is that inequality constraints required by economic theory or subjective beliefs can be imposed easily through simulation.⁸

The basic ingredients for the simulation are the four budget and marginal shares (w_i and θ_i), the income flexibility (ϕ) and the correlation ρ . Each of these follows a truncated normal distribution with the mode (which is equivalent to the mean before truncation) given by the base values specified in Section 3 and a specified standard deviation. Regarding the budget shares, for marijuana the mean of the distribution is 2% and we shall take the 95% confidence interval to be 1-3%, which, on the basis of normality, implies a standard deviation of 0.5% and coefficient of variation of $0.5/2=25\%$. Furthermore, we restrict the range of this share by a truncation of the normal distribution such that $0 < w_i < 1$. This information is contained in the first row of Table 4. For tobacco and alcohol, as consumption of these products is legal, it is reasonable to suppose that there is less uncertainty about their budget shares and we take their coefficients of variation to be 12.5%, one half that of marijuana, as indicated in rows 2 and 3 of column 4 in Table 4. We also restrict these shares to the (0, 1) interval. As $\sum_{i=1}^4 w_i = 1$, all the information on the distribution of the budget share of the fourth good, other, can be derived from those pertaining to the first three, and is recorded in row 4 of Table 4.

Due to the “unobservable” nature of the marginal shares, it is not unreasonable to suppose their values are more uncertain than those of the budget shares. The coefficient of variation of θ_i

⁸ Subjective probability distributions and the simulation techniques described above are typically used in modern Bayesian analysis (see, for example, Geweke, 1999). For examples of a similar approach in the context of equilibrium displacement models, see Griffiths and Zhao (2000) and Zhao et al. (2000).

for marijuana is taken to be 50%, while that for tobacco and alcohol is taken to be 25%. Here again we employ the rule that marijuana is twice as uncertain as the other two goods. Each θ_i is also constrained to lie between zero and one, and the four shares have a unit sum. The most likely value for ϕ is -0.5, its CV is specified to be 25% and is restricted to be negative. As there is considerable more uncertainty regarding the value of ρ , we take its coefficient of variation to be 50%, while its mode is -0.5 and its value is restricted to the interval $(-1, 0)$. The above information is recorded in rows 5-10 of Table 4. Finally, the Frisch matrix \mathbf{v} is restricted to be negative definite, and the distributions for its elements are derived from the above, as indicated in the bottom part of Table 4.

To simulate the uncertainty of the data and parameters, we draw 5,000 independent sets of repeated realisations from the eight distributions specified above. These eight comprise three for w_i (the fourth is determined by $\sum_{i=1}^4 w_i = 1$), three for θ_i (the fourth is again given by $\sum_{i=1}^4 \theta_i = 1$), one for ϕ and one for ρ . If any of the constraints of Table 4 are violated, the draw is discarded. The procedure is repeated until there are 5,000 sets of draws that satisfy all the constraints. We then estimate the implied subjective probability distributions for all elasticities using frequency distributions. For example, in Figure 2, the estimated probability density functions are plotted for the four Marshallian price elasticities for marijuana, as well as the income elasticity for this good. As can be seen, these distributions display varying degrees of asymmetry. The estimated means, standard deviations, and the 95% probability intervals for all elasticities are given in Table 5. In all cases, the dispersion is larger for the marijuana rows, reflecting the greater uncertainties associated with this product.

5. SIMULATING POLICY CHANGES

We consider three examples in this section to illustrate the application of our approach to policy issues. As this analysis is intended to be illustrative, we abstract from the supply side by assuming infinitely elastic supply schedules, so that all price and tax changes are fully passed onto consumers. Table 6 gives the basic information on pre-existing taxation and consumption in Australia that will be used subsequently. As can be seen, tax accounts for about 54% of the consumer price for tobacco and 41% for alcohol.

A Fall in the Marijuana Price

Suppose marijuana prices were to fall by 10% due to productivity enhancement and/or a reduced policing effort.⁹ When money income remains unchanged, the change in consumption of good i as a result of a change in the price of good j is given by

$$(5.1) \quad d(\log q_i) = \eta'_{ij} d(\log p_j),$$

where η'_{ij} is the (i, j) th Marshallian price elasticity.¹⁰ To implement this for a 10% fall in marijuana price, we set $j = 1$ and $d(\log p_1) = -0.1$ to estimate the changes in consumption of marijuana, alcohol and tobacco ($i = 1, 2$ and 3). Allowing for the uncertainty involved in η'_{ij} , we use the previous 5,000 simulated values of this elasticity to generate 5,000 values of $d(\log q_i)$. In the column 2 of Panel A in Table 7, we present the means, standard deviations and the 95% probability intervals for the relative quantity changes for the three goods. As indicated by the 95% probability intervals, there is considerable uncertainty in these quantity changes.

What happens to revenue from taxation as a result of the fall in the price of marijuana? Although there is no direct effect as marijuana escapes the tax net, there are indirect effects on tobacco and alcohol taxes. Because marijuana and tobacco are complements, the fall in the price of marijuana stimulates tobacco consumption and thus raises its tax revenue. Offsetting this is the reduced tax revenue from alcohol, the consumption of which falls as it is a substitute for marijuana. Assuming both prices and tax rates are unchanged for the two legal goods, the relative changes in tax revenue are equal to the relative changes in quantity, or $d(\log R_i) = d(\log q_i)$, where R_i denotes the tax revenue for good i ($i = 2, 3$). Results for the relative tax revenue changes are given in column 2 of Panel B of Table 7. Using the base tax revenues given in Table 6 and the Australian population of 15 million (aged 14 years and over), these translate into an average annual tax revenue change of \$87 million for tobacco and $-\$43$ million for alcohol, resulting in a net tax increase of \$44 million. The means, standard deviations and 95% probability intervals for these revenue changes are given in column 2 of Panel C of Table 7. Accounting for all uncertainty involved in both data and elasticities, the 95% probability interval for the change in total tax revenue is \$7 to \$105 million, which is obviously rather wide and reflects the genuine uncertainty surrounding marijuana.

⁹ Over the 1990s, the relative price of marijuana fell in Australia by about 40% (Clements, 2004).

¹⁰ The same analysis could also be carried out using Slutsky price elasticities assuming real income constant. However, it is probably more realistic to assume money income constant for the policy scenarios considered in this section.

An Increase in Tobacco and Alcohol Taxes

Next, consider the effect of a 10-percentage-point increase in the taxes on tobacco and alcohol, which, for simplicity, we take to be *ad valorem* taxes. For tobacco (alcohol), the tax of 54% (41%) of consumer prices implies a tax of 119% (69%) of pre-tax prices, so that a 10-percentage-point increase in the latter rate brings it to 129% (79%). This increase amounts to a 4.6% (5.9%) relative change in the retail price of tobacco (alcohol).¹¹ Using equation (5.1) with $d(\log p_2) = 0.046$ and $d(\log p_3) = 0.059$ separately, we can estimate the resulting relative changes in the quantities demanded for all three goods. Again accounting for the uncertainty in the data and demand elasticities involved, we use the 5,000 sets of elasticities to compute 5,000 sets of relative quantity changes. The means, standard deviations, as well as 95% probability intervals are presented in columns 3 and 4 of Panel A in Table 7. For example, the 10-percentage-point rise in the alcohol tax rate is estimated to decrease alcohol consumption by 4.1% on average, but to increase marijuana and tobacco consumption by 0.91% and 0.93%, respectively.

The change in taxation revenue from good i is $d(\log R_i) = d(\log t'_i) + d(\log q_i)$, where t'_i is the tax as a proportion of the pre-tax price. For the 10-percentage-point increase in the tobacco tax rate, we have $d(\log t'_2) = dt'_2/t'_2 \approx 0.1/1.19$, so that $d(\log R_2) = 0.1/1.19 + \eta'_{22}(0.046)$ is the direct revenue change, and $d(\log R_3) = \eta'_{32}(0.046)$ is the indirect effect on account of the impact of the higher tobacco price on drinking. Similarly, for the 10-percentage-point rise in the alcohol tax rate, $d(\log R_2) = \eta'_{23}(0.059)$ and $d(\log R_3) = 0.1/0.69 + \eta'_{33}(0.059)$. The means, standard deviations and the 95% probability intervals for the annual tax revenue changes (in relative and dollar terms) are given in columns 3 and 4 of Panels B and C of Table 7. For example, the increase in the alcohol tax causes the annual alcohol tax revenue to increase by \$551 million on average, and tobacco tax revenue increases by around \$45 million, resulting on average a total annual tax increase of \$596 million. The 95% probability interval for this total increase is \$458–\$693 million, which is moderately wide but still not huge.

As the base tax rates for tobacco and alcohol differ, the 10-percentage-point increase implies a differential change in the tax rates. The two tax increases can be put on a more equal footing by

¹¹ Let p_i , p'_i , q_i , t_i , and t'_i be the retail price, pre-tax price, quantity consumed, tax as a proportion of the retail price, and tax as a proportion of the pre-tax price for good i , respectively. The two sets of prices are linked according to $p_i = (1 + t'_i)p'_i$, so that $d(\log p_i) = dt'_i/(1 + t'_i)$. Thus with $dt'_i = 0.1$, $t'_2 = 1.19$ and $t'_3 = 0.69$ and for simplicity holding retail margins and GST unchanged, the relative change in the retail price of tobacco is $0.1/(1+1.19) = 0.046$, while that for alcohol is $0.1/(1+0.69) = 0.059$.

increasing each of the rates by 10%, and columns 5-6 of Table 7 contain the results. The major difference from before is that now the mean increase in total taxation revenue from tobacco is approximately the same as that for alcohol at about 4%, as can be seen from row 6 of columns 5 and 6.

Taxing Marijuana – The Revenue-Maximising Rate and a Tax Tradeoff

Suppose marijuana were legalised and its consumption taxed. The legalisation of marijuana itself could shift its supply and demand curves and lead to a reshuffling of the vice budget; for an analysis of these issues, see Clements and Daryal (2005) and Clements et al. (2005). But to keep things as simple as possible, we shall ignore these “legalisation effects” on production and consumption and focus on the opportunities to tax marijuana and its implications. We commence with an investigation of the likely revenue available from taxing marijuana, and then proceed to consider the implications of redistributing the additional revenue to vice consumers in the form of lower alcohol taxes. Again, it is to be emphasised that the analysis is only illustrative of the capabilities of the approach.

We consider two situations denoted by $\tau = 0$ and $\tau = 1$ for before and after the change in taxation arrangements. Total tax revenue in period τ is given by $R^{(\tau)} = \sum_{i=1}^3 R_i^{(\tau)}$, where $R_i^{(\tau)} = t_i^{(\tau)} p_i' q_i^{(\tau)}$ is tax revenue from good i in τ , $t_i^{(\tau)}$ is the tax rate on i in τ , p_i' its pre-tax price (assumed to be constant throughout), and $q_i^{(\tau)}$ is the corresponding quantity. A Marshallian demand system in relative change form is given by $d(\log q_i) = \sum_{j=1}^3 \eta_{ij}' d(\log p_j)$, and this can be used to estimate the effects of any exogenous tax changes via the resulting price changes $d(\log p_j) = (t_j^{(1)} - t_j^{(0)}) / (1 + t_j^{(0)})$ under the assumption of infinitely elastic supply.¹² It follows that consumption of good i after the tax changes can be expressed as

$$(5.2) \quad q_i^{(1)} = q_i^{(0)} \exp \left[\sum_{j=1}^3 \eta_{ij}' \left(\frac{t_j^{(1)} - t_j^{(0)}}{1 + t_j^{(0)}} \right) \right] .$$

As marijuana is initially untaxed, $t_1^{(0)} = 0$, and we impose a tax on it at rate $t_1^{(1)}$, while holding the pre-existing rates on tobacco and alcohol constant, so that $t_j^{(1)} = t_j^{(0)}$, $j = 2, 3$. Equation (5.2) then defines the new quantities consumed, and we use various values of the marijuana tax rate

¹² The basis for the last equation is the definition of the consumer price of good j , $p_j = (1 + t_j') p_j'$, so that $d(\log p_j) = dt_j' / (1 + t_j')$. We then interpret dt_j' as $t_j^{(1)} - t_j^{(0)}$ and $1 + t_j'$ as $1 + t_j^{(0)}$.

to evaluate tax revenue with the 5,000 sets of the elasticities. As can be seen from Table 8, the tax yields a nontrivial amount of revenue; for example, a 30% rate yields a mean of about \$85 per capita p. a. on average, which represents additional revenue of about one quarter of the pre-existing revenue from tobacco. But as tobacco is a complement for marijuana, increasing the tax on the latter causes tobacco revenue to fall, as shown by column 3 of Table 8. The 30% marijuana tax causes proceeds from tobacco to fall from \$324 to \$302 on average, a reduction of about 7%. Substitutability with alcohol causes alcohol revenue to rise with the marijuana tax, but as can be seen from column 4 of Table 8, this rise is quite modest at about 3% for a 30% marijuana tax. The net effect of these changes on total receipts from vice taxation is given in column 5, which for a 30% marijuana tax rises from \$684 to a mean of \$759, or about 11%.¹³ There are two noticeable patterns in the dispersion of revenue. Relative to mean revenue, the standard deviations all rise with the marijuana tax rate, and the marijuana standard deviations are all substantially larger than those of tobacco and alcohol. This reflects the greater uncertainty of the impacts of a tax regime that is more distant from the pre-existing one, as well as the greater uncertainty of the underlying data and parameters pertaining to marijuana. Figure 3 plots mean revenue against the marijuana tax rate and as it has a (gentle) inverted U-shape, it could be described as a type of “Laffer curve”. As can be seen, the revenue-maximising tax rate is in the vicinity of 50%.¹⁴ As shown in Table 8, at this revenue-maximising rate, marijuana generates around \$102 per capita on average, which represents an increment of about 15% of existing tax revenue from tobacco and alcohol. Panel B of Figure 3 illustrates the underlying uncertainty of the tax revenues by presenting a type of “fan chart” (Britton

¹³ The issue of estimating possible revenues from taxing marijuana in a legalised environment has been considered previously in several other studies (Bates, 2004, Caputo and Ostrom, 1994, Easton, 2004, Miron, 2005, and Schwer et al., 2002). In what seems to be the most widely-cited paper in this area, Caputo and Ostrom (1994) estimate that for the US it would be possible to raise \$US3-5 billion from marijuana taxation in 1991. This estimate is based on conservative assumptions regarding the continued existence after legalisation of a black market that avoided the tax. For comparison, in the same year tax revenue from tobacco and alcohol combined was \$22b (roughly evenly split between tobacco and alcohol). Using the mid-point of the above range of \$4b, the marijuana tax would thus represent an addition of about 18% to revenue from vice taxation. As shown in the sixth row of column 2 of our Table 8 (corresponding to a marijuana tax of 50%), we estimate that the maximum revenue from taxing marijuana in Australia is about \$A102 per capita, or about $102/684 \approx 15\%$ of pre-existing revenue from vice. Accordingly, our estimates seem to be in broad agreement with those of Caputo and Ostrom (1994). In a more recent US study, Miron (2005) estimates that marijuana could generate about \$US2b p.a. if taxed at the same rate as other goods, or \$6b if taxed at a rate comparable to that on tobacco and alcohol. Miron argues that these figures are similar to the earlier revenue estimates of Caputo and Ostrom (1994).

¹⁴ Revenue from marijuana is $R_1^{(1)} = t_1^{(1)} p_1' q_1^{(0)} \exp(\eta_{11}' t_1^{(1)})$, so that the first-order condition for a maximum is $\partial R_1^{(1)} / \partial t_1^{(1)} = (1 + \eta_{11}' t_1^{(1)}) p_1' q_1^{(0)} \exp(\eta_{11}' t_1^{(1)}) = 0$. Accordingly, the revenue-maximising tax is $t_1^{(1)*} = -1 / \eta_{11}'$. The corresponding tax as a proportion of the consumer price is $t_1^{(1)*} = t_1^{(1)*} / (1 + t_1^{(1)*}) = 1 / (1 - \eta_{11}')$. Using the mean elasticity of $\eta_{11}' = -0.67$, gives $t_1^{(1)*} = 0.6$. In view of the approximation involved in using means (ignoring Jensen’s inequality), this value is in reasonable agreement with the revenue-maximising rate of Figure 3.

et al., 1998, Wallis, 1999) in which the darker colours denote values that have a higher probability of occurrence. This shows clearly how revenue uncertainty increases with the marijuana tax rate.

Next, we analyse the implications of the additional revenue by considering an offsetting reduction in alcohol taxes that serves to keep constant total tax collections from vice. That is, we shall keep tobacco taxes unchanged and consider a revenue-neutral reduction in alcohol taxes associated with the new tax on marijuana, so that the marijuana tax dividend is given to drinkers in the form of lower taxes. Our problem is to specify the marijuana tax rate at some fixed value, say $t_1^{(1)} = \hat{t}_1'$, and to solve for the revenue-neutral reduction in alcohol taxes. More formally, the problem is to find the new tax on alcohol, $t_3^{(1)}$, that satisfies the following conditions:

- (i) $t_1^{(0)} = 0$ [Marijuana is initially tax free],
- (ii) $t_1^{(1)} = \hat{t}_1'$ [Marijuana is now taxed at rate \hat{t}_1'],
- (iii) $t_2^{(1)} = t_2^{(0)}$ [Tobacco continues to be taxed at the same rate], and
- (iv) $R^{(1)} = R^{(0)}$ [Total tax revenue is unchanged] .

Details of the numerical solution to the above problem are contained in Clements et al. (2005). Panel A of Figure 4 gives this tradeoff by averaging over the 5,000 trials as before. As can be seen, the tradeoff is negatively-sloped for marijuana tax rates of up to the revenue-maximising rate of about 50%, but since the curve tends to get flatter as the marijuana tax increases, the tradeoff worsens as we move down the curve. This is due to two reasons. (1) Because the higher marijuana tax causes its consumption (the tax base) to be lower, a further increase in the rate generates a smaller increment to revenue, allowing only a smaller reduction of alcohol taxes. (2) As it is a substitute for marijuana, alcohol consumption rises with a higher marijuana tax, so that the reduction in the alcohol tax rate required to just absorb the additional revenue from marijuana is smaller, which contributes to the flattening out of the curve.¹⁵ When the marijuana tax exceeds the revenue-maximising rate, the tradeoff becomes positively sloped. The slope of the tradeoff is given in Panel B of Figure 4. This reveals that for a marijuana tax of 20% for example, the tradeoff is approximately 1:2, so that a two-percentage-point increase in the marijuana tax is associated with almost a one-percentage-point reduction in the alcohol tax. This reflects primarily the differences in

¹⁵ It is to be noted that along the tradeoff not only does consumption of alcohol and marijuana change, but so also does that of tobacco. As tobacco and marijuana are complements, an increase in the marijuana tax lowers tobacco consumption and taxation revenue from this good; and because tobacco and alcohol are substitutes, a lowering of the alcohol tax also leads to reduced revenue from tobacco. Accordingly, as we move down the tradeoff, for a marijuana tax of less than 50%, revenue from taxing tobacco falls unambiguously. By construction, along the tradeoff these changes in revenue from tobacco are “neutralised” by offsetting changes in the alcohol tax which serve to keep overall taxation revenue constant.

the tax bases of the two goods, and to a lesser extent, differences in their price elasticities. But as the marijuana tax increases from 20% to, say, 30%, the slope of the curve (in absolute value) falls, from 0.46 to 0.41.

As the tradeoff of Figure 4 is the mean over the 5,000 trials, it represents the centre-of-gravity effects. But to understand the underlying uncertainty of these effects, we need to examine other aspects of the simulation results, such as the frequencies given in Figure 5. These show that the nature of the tradeoff is reasonably well defined for low rates of marijuana taxation, but uncertainty increases with the tax rate. This, of course, is to be expected as increased marijuana taxation involves a move away from its current tax-free status to something that has not been previously observed. Finally, we consider the distribution of the alcohol tax conditional on the marijuana tax by analysing cross sections of the “vice mountain” of Figure 5. The left-hand side of Panel A of Figure 6 presents the conditional distribution when marijuana is taxed at 10%. As can be seen, the mean alcohol tax is about 35%, while the standard deviation of the 5,000 trials is 1 percentage point. As the marijuana tax is increased to 20 and 30%, the mean alcohol tax falls to 30 and 26%, respectively, and the standard deviation rises to 1.6 and 2.7 percentage points, as shown in Panels B and C of the figure. The increased dispersion of the distribution clearly reflects the greater uncertainty of the alcohol tax as we move further away from the status quo of not taxing marijuana. This phenomenon is also reflected in the conditional distributions of the slope of the tradeoff, given on the right-hand side of Figure 6.

6. CONCLUDING COMMENTS

This paper has considered the generic problem of how to analyse the demand for a product for which there is limited information available in the form of hard data and its price responsiveness. We introduced procedures that (i) draw on the interactions in consumption of the product with others, and (ii) organise whatever information there is available in the form of subjective probability distributions. We applied these procedures to the demand for marijuana, a product for which there exists no official data, and only fragmentary evidence on its price responsiveness, mainly based on survey information. But as marijuana consumption is known to be related to tobacco and alcohol usage, we were able to exploit some of this prior knowledge by using a system-wide demand model that considers all three goods simultaneously. To organise this knowledge efficiently, we started with a differential demand system that has strong links with the structure of the consumer’s preferences, and then proceeded to derive the associated price

elasticities. As the utility-based parameters of the demand system are random, reflecting the uncertainty regarding their true values, the price elasticities have probability distributions, which we obtained via Monte Carlo simulations. In other situations where little data are available, our procedures could also be useful. For example, they could be used to analyse the determinants of the consumption of other illicit goods, new goods, or goods that have been substantially “reconfigured”.

To illustrate some applications of the approach, we used Australian data to carry out several price/tax simulations. For example, we considered the hypothetical legalisation of the consumption of marijuana, which was then subject to taxation. The tax has the effect of inhibiting marijuana usage, stimulating drinking (as alcoholic beverages are a substitute for marijuana) and reducing the smoking of tobacco (a complement for marijuana). The net effect is for revenue from vice taxation to increase with the marijuana tax up until the rate hits about 50% of consumer prices (or about 100% of producer prices). We estimate that the maximum revenue attainable from taxing marijuana is equivalent to about 15% of pre-existing revenue from tobacco and alcohol. Next, we analysed the reduction in alcohol taxes if the marijuana tax dividend were used in a revenue-neutral tax tradeoff. For modest rates of marijuana taxation, this resulted in a rough rule of one-half; for each percentage-point increase in the marijuana tax, alcohol taxation could be reduced by about one-half of a percentage point. For higher marijuana tax rates, as marijuana consumption falls and drinking increases, the tradeoff worsens and successive increases in the marijuana tax allow only smaller and smaller reductions in alcohol taxes. The attractive feature of our approach is that it provides the whole distribution of the alcohol tax corresponding to each rate of marijuana taxation. The dispersion of this distribution, which reflects the underlying uncertainty concerning data and parameters, increases as we move away from the status quo whereby marijuana escapes the tax net, and subject it to successively higher rates of taxation.

REFERENCES

- Bajada, C. (1999). "Estimates of the Underground Economy for Australia." Economic Record 75: 369-84.
- Bates, S. W. (2004). "The Economic Implications of Marijuana Legalisation in Alaska." Report for Alaskans for Rights and Revenues, Fairbanks, Alaska.
- Britton, E., P. Fisher and J. Whitley (1998). "The Inflation Report Projection: Understanding the Fan Chart." Bank of England Quarterly Bulletin 38: 30-37.
- Brown, A., and A. Deaton (1972). "Surveys in Applied Economics: Models of Consumer Behaviour." Economic Journal 82: 1145-1236.
- Cameron, S. (1998). "Estimation of the Demand for Cigarettes: A Review of the Literature." Economic Issues 3: 51-70.
- Cameron, L., and J. Williams (2001). "Cannabis, Alcohol and Cigarettes: Substitutes or Complements?" Economic Record 77: 19-34.
- Caputo, M. R., and B. J. Ostrom (1994). "Potential Tax Revenue from a Regulated Marijuana Market: A Meaningful Revenue Source." American Journal of Economics and Sociology 53: 475-90.
- Chaloupka, F. J., R. Pacula, M. Farrelly, L. Johnston, P. O'Malley and J. Bray (1999). "Do Higher Cigarette Prices Encourage Youth to Use Marijuana?" NBER Working Paper 6939.
- Chaloupka, F. J. and K. E. Warner (2000). "The Economics of Smoking." In A. J. Culyer and J. P. Newhouse (eds) Handbook of Health Economics. Volume 1. Amsterdam: Elsevier. Pp. 1539-1627.
- Chen, D. L. (1999). World Consumption Economics. Singapore: World Scientific.
- Clements, K. W. (2004). "Three Facts About Marijuana Prices." Australian Journal of Agricultural and Resource Economics. 48: 271-300.
- Clements, K. W., and M. Daryal (2005). "The Economics of Marijuana Consumption." Chapter 10 in S. Selvanathan and E. A. Selvanathan (eds) The Demand for Alcohol, Tobacco and Marijuana: International Evidence. Aldershot: Ashgate. Pp. 243-67.
- Clements, K. W., and L. W. Johnson (1983). "The Demand for Beer, Wine and Spirits: A System-Wide Analysis." Journal of Business 56: 273-304.
- Clements, K.W., Y. Lan and X.Y. Zhao (2005). "The Demand for Vice: Inter-Commodity Interactions with Uncertainty." Discussion Paper No 05.30, Economics Program, The University of Western Australia.
- Clements, K. W., and S. Selvanathan (1991). "The Economic Determinants of Alcohol Consumption." Australian Journal of Agricultural Economics 35: 209-31.
- Decker, S. L., and A. E. Schwartz (2000). "Cigarettes and Alcohol: Substitutes or Complements?" NBER Working Paper 7535.
- Dixon, P. B., and M. T. Rimmer (2002). Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH. Amsterdam: North Holland.
- Duffy, M. (1991). "Advertising and the Consumption of Tobacco and Alcoholic Drink: A System-Wide Analysis." Scottish Journal of Political Economy 38: 369-85.
- Easton, S. T. (2004). "Marijuana Growth in British Columbia." Public Policy Sources, Fraser Institute Occasional Paper.
- Farrelly, M., J. Bray, G. Zarkin, B. Wendling and R. Pacula (1999). "The Effects of Prices and Policies on the Demand for Marijuana: Evidence from the National Household Surveys on Drug Abuse." NBER Working Paper 6940.
- Gallet, C. A., and J. A. List (2003). "Cigarette Demand: A Meta-Analysis of Elasticities." Health Economics 12: 821-35.

- Geweke, J. (1999). "Using Simulation Methods for Bayesian Econometric Models: Inference, Development and Communication." Econometric Reviews 18: 1-126.
- Goel, R. K., and M. J. Morey (1995). "The Interdependence of Cigarette and Liquor Demand." Southern Economic Journal 62: 451-59.
- Griffiths, W., and X. Zhao (2000). "A Unified Approach to Sensitivity Analysis in Equilibrium Displacement Models: Comment." American Journal of Agricultural Economics 82: 236-40.
- Jones, A. M. (1989). "A Systems Approach to the Demand for Alcohol and Tobacco." Bulletin of Economic Research 41:85-105.
- Miron, J. A. (2005). "The Budgetary Implications of Marijuana Prohibition." Paper available at <http://www.prohibitioncosts.org/mironreport.html>
- National Drug Strategy Household Survey (2001). Computer Files of Unit Record Data, National Drug Strategy Household Surveys, 1998 and 2001. Canberra: Social Science Data Archives, The Australian National University.
- Saffer, H., and F. Chaloupka (1995). "The Demand for Illicit Drugs." NBER Working Paper No. 5238.
- Schwer, R.K., M. Riddell and J. Henderson (2002). "Fiscal Impact of Question 9: Potential State-Revenue Implications." Centre for Business and Economic Research, University of Nevada, Las Vegas.
- Selvanathan, S. (1993). A System-Wide Analysis of International Consumption Patterns. Boston: Kluwer.
- Selvanathan, S., and E. A. Selvanathan (2005). The Demand for Alcohol, Tobacco and Marijuana: International Evidence. Aldershot: Ashgate.
- Theil, H. (1980). The System-Wide Approach to Microeconomics. Chicago: The University of Chicago Press.
- Theil, H. (1987). "Evidence from International Consumption Comparisons" Chapter 2 in H. Theil and K. W. Clements Applied Demand Analysis: Results from System-Wide Approaches. Cambridge, Mass.: Ballinger. Pp. 37-100.
- Wallis, K. (1999). "Asymmetric Density Forecasts of Inflation and the Bank of England's Fan Chart." National Institute Economic Review 167: 106-12.
- Zhao, X., W. Griffiths, G. Griffith and J. Mullen (2000). "Probability Distributions for Economic Surplus Changes: The Case of Technical Change in the Australian Wool Industry." Australian Journal of Agricultural and Resource Economics 44: 83-106.
- Zhao, X., and M. Harris (2004). "Demand for Marijuana, Alcohol and Tobacco: Participation, Levels of Consumption, and Cross-Equation Correlations." Economic Record 80: 394-410.

TABLE 1

BASELINE DATA FOR VICE DEMAND

Commodity	Budget share $w_i \times 100$	Income elasticity η_i	Marginal share $\theta_i \times 100$
(1)	(2)	(3)	(4)
Marijuana	2.0	1.2	2.4
Tobacco	2.0	0.4	0.8
Alcohol	4.0	1.0	4.0
Other	92.0	1.0087	92.8
Total	100.0		100.0
Income flexibility		$\phi = -.5$	

FIGURE 1

PRICE ELASTICITIES OF DEMAND FOR MARIJUANA WITH RESPECT TO THE PRICE OF TOBACCO AND THE DEGREE OF COMPLEMENTARITY

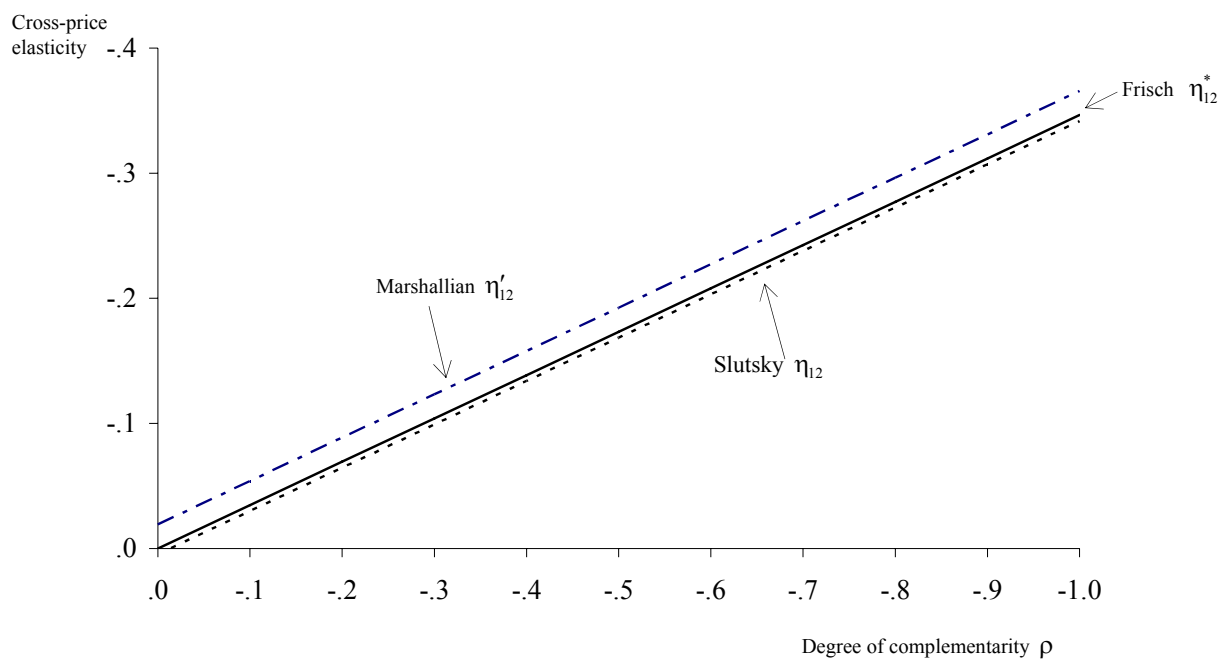


TABLE 2

FIRST SPECIFICATION OF BASELINE PRICE RESPONSIVENESS OF DEMAND: $\rho = 0$ (Preference Independence)

Good	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other
A. <u>Price Coefficients \mathbf{v} ($\times 10^2$)</u>					B. <u>Inverse of Price Coefficients \mathbf{v}^{-1} ($\times 10^{-1}$)</u>				C. <u>Frisch Price Elasticities [η_{ij}^*]</u>			
Marijuana	-1.20	0	0	0	-8.33	0	0	0	-.60	0	0	0
Tobacco	0	-.40	0	0	0	-.25	0	0	0	-.20	0	0
Alcohol	0	0	-2.00	0	0	0	-.5	0	0	0	-.50	0
Other	0	0	0	-46.40	0	0	0	-.22	0	0	0	-.50
D. <u>Slutsky Coefficients [π_{ij}] ($\times 10^2$)</u>					E. <u>Slutsky Price Elasticities [η_{ij}]</u>				F. <u>Marshallian Price Elasticities [η'_{ij}]</u>			
Marijuana	-1.17	.01	.05	1.11	-.586	.005	.024	.557	-.610	-.019	-.024	-.547
Tobacco	.01	-.40	.02	.37	.005	-.198	.008	.186	-.003	-.206	-.008	-.182
Alcohol	.05	.02	-1.92	1.86	.012	.004	-.480	.464	-.008	-.016	-.520	-.456
Other	1.11	.37	1.86	-3.34	.012	.004	.020	-.036	-.008	-.016	-.020	-.964

TABLE 3

SECOND SPECIFICATION OF BASELINE PRICE RESPONSIVENESS OF DEMAND: $\rho = -.5$ (Preference Dependence)

Good	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other
A. <u>Price Coefficients \mathbf{v} ($\times 10^2$)</u>					B. <u>Inverse of Price Coefficients \mathbf{v}^{-1} ($\times 10^{-1}$)</u>				C. <u>Frisch Price Elasticities [η_{ij}^*]</u>			
Marijuana	-1.20	-.35	.35	0	-11.12	9.45	-.22	0	-.60	-.17	.17	0
Tobacco	-.35	-.40	.35	0	9.45	-36.16	-3.44	0	-.17	-.20	.17	0
Alcohol	.35	.35	-2.69	0	-.22	-3.44	-4.18	0	.09	.09	-.67	0
Other	0	0	0	-46.40	0	0	0	-.22	0	0	0	-.50
D. <u>Slutsky Coefficients [π_{ij}] ($\times 10^2$)</u>					E. <u>Slutsky Price Elasticities [η_{ij}]</u>				F. <u>Marshallian Price Elasticities [η'_{ij}]</u>			
Marijuana	-1.17	-.34	.39	1.11	-.586	-.168	.197	.557	-.610	-.192	.149	-.547
Tobacco	-.34	-.40	.36	.37	-.168	-.198	.181	.186	-.176	-.206	.165	-.182
Alcohol	.39	.36	-2.61	1.86	.099	.091	-.653	.464	-.079	.071	-.693	-.456
Other	1.11	.37	1.86	-3.34	.012	.004	.020	-.036	-.008	-.016	-.020	-.964

TABLE 4

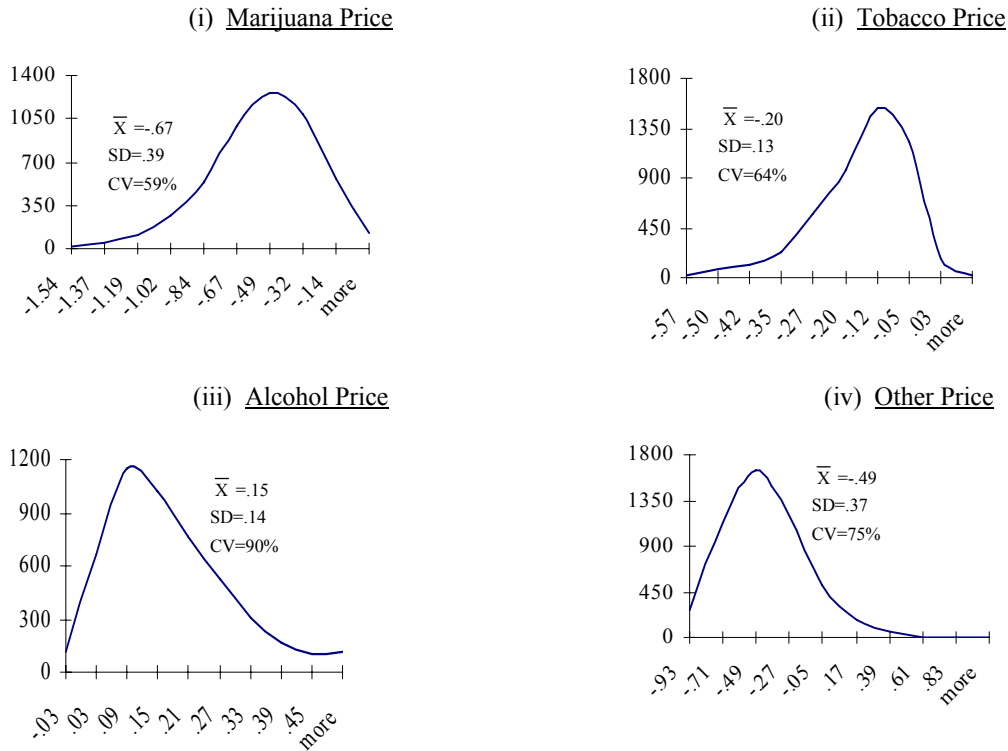
STOCHASTIC SPECIFICATION OF DATA AND DEMAND COEFFICIENTS

Variable/ parameter (1)	Mean (2)	Standard Deviation (3)	Coefficient of Variation (4)	95% Probability Interval (5)	Constraint (6)
<u>Budget shares w_i</u>					
1. Marijuana	.02	.005	.25	(.0114, .0283)	$0 < w_1 < 1$
2. Tobacco	.02	.0025	.125	(.0157, .0242)	$0 < w_2 < 1$
3. Alcohol	.04	.005	.125	(.0316, .0483)	$0 < w_3 < 1$
4. Other	.92	.0075	.008	(.9075, .9333)	$0 < w_4 < 1,$ $w_4 = 1 - \sum_{i=1}^3 w_i$
Sum	1.00				
<u>Income flexibility</u>					
5. ϕ	-.5	.125	.25	(-.7384, -.2501)	$\phi < 0$
<u>Correlation coefficient</u>					
6. ρ	-.5	.25	.50	(-0.9150, -.0843)	$-1 < \rho < 0$
<u>Marginal shares θ_i</u>					
7. Marijuana	.024	.012	.50	(.0038, .0482)	$\theta_1 > 0$
8. Tobacco	.008	.002	.25	(.00413, .01197)	$\theta_2 > 0$
9. Alcohol	.04	.01	.25	(.0205, .0590)	$\theta_3 > 0$
10. Other	.928	.016	.017	(.8969, .9565)	$\theta_4 > 0,$ $\theta_4 = 1 - \sum_{i=1}^3 \theta_i$
Sum	1.00				
<u>Frisch price coefficient matrix \mathbf{V}</u>					
$\begin{bmatrix} \phi\theta_1 & \alpha & -\alpha & 0 \\ \alpha & \phi\theta_2 & -\alpha & 0 \\ -\alpha & -\alpha & \phi\theta_3 + 2\alpha & 0 \\ 0 & 0 & 0 & \phi\theta_4 \end{bmatrix}$					\mathbf{V} negative definite

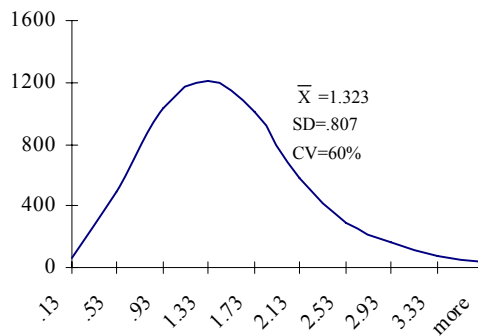
Note: The summary statistics refer to the analytical results for the non-truncated normal distributions.

FIGURE 2
SIMULATED DEMAND ELASTICITIES FOR MARIJUANA

A. MARSHALLIAN PRICE ELASTICITIES



B. INCOME ELASTICITY



Note: Panel A contains the distributions of the price elasticity of demand for marijuana with respect to the price of marijuana [graph (i)], tobacco [graph (ii)], alcohol [graph (iii)] and other [graph (iv)].

TABLE 5

SUMMARY OF DEMAND ELASTICITIES

Good	Price			
	Marijuana	Tobacco	Alcohol	Other
A. Frisch Price Elasticities [η_{ij}^*]				
Marijuana	-0.66 (.41) [-1.71, -.09]	-.18 (.13) [-.49, -.01]	.18 (.13) [.01, .49]	0 (0) [0, 0]
Tobacco	-.17 (.10) [-.42, -.01]	-.20 (.08) [-.38, -.08]	.17 (.10) [.01, .42]	0 (0) [0, 0]
Alcohol	.08 (.05) [.01, .21]	.08 (.05) [.01, .21]	-.68 (.25) [-1.25, -.27]	0 (0) [0, 0]
Other	0 (0) [0, 0]	0 (0) [0, 0]	0 (0) [0, 0]	-.50 (.13) [-.75, -.26]
B. Slutsky Price Elasticities [η_{ij}]				
Marijuana	-.641 (.393) [-1.633, -.089]	-.171 (.125) [-.478, -.012]	.203 (.140) [.024, .548]	.609 (.373) [.084, 1.552]
Tobacco	-.162 (.102) [-.408, -.012]	-.201 (.077) [-.377, -.077]	.175 (.106) [.020, .431]	.188 (.072) [.072, .355]
Alcohol	.096 (.057) [.013, .233]	.088 (.053) [.010, .213]	-.654 (.240) [-1.204, -.266]	.470 (.176) [.190, .875]
Other	.012 (.006) [.002, .027]	.004 (.001) [.002, .007]	.020 (.007) [.008, .035]	-.037 (.012) [-.062, -.017]
C. Marshallian Price Elasticities [η'_{ij}]				
Marijuana	-.665 (.390) [-1.651, -.115]	-.195 (.125) [-.502, -.035]	.155 (.140) [-.024, .502]	-.495 (.371) [-1.020, .438]
Tobacco	-.170 (.102) [-.415, -.019]	-.209 (.077) [-.385, -.086]	.159 (.106) [.004, .415]	-.180 (.072) [-.295, -.014]
Alcohol	.076 (.057) [-.009, .212]	.068 (.053) [-.010, .193]	-.694 (.238) [-1.243, -.308]	-.450 (.175) [-.729, -.049]
Other	-.008 (.008) [-.023, .009]	-.016 (.003) [-.022, -.010]	-.020 (.009) [-.036, -.002]	-.964 (.014) [-.993, -.940]
D. Income Elasticities [η_i]				
	1.323 (.807) [.193, 3.120]	.405 (.115) [.202, .653]	1.018 (.292) [.502, 1.613]	1.008 (.019) [.972, 1.044]

Note: The first entry in each cell is the mean over the 5,000 trials. The second entry, given on the right in parentheses, is the associated standard deviation. The range below the mean and standard deviation is the 95% probability interval.

TABLE 6

TAXATION AND CONSUMPTION OF VICE

Variable (1)	Marijuana (2)	Tobacco (3)	Alcohol (4)	Total (5)
1. Consumption expenditure (Dollars per capita)	372	597	879	1,848
2. Tax rate (% of consumer price)	0	54.3	41.0	-
3. Tax revenue (Dollars per capita)	0	324	360	684

Notes:

1. Consumption expenditure is for 1998, from Clements et al. (2005, Panel A of Table A2).
2. The tax rate for tobacco is derived from excise and customs revenue published by the Australian Institute of Health and Welfare in *Statistics on Drug Use in Australia 2002*, Tables 2.5 and 2.6, as well as consumption data from the Australian Bureau of Statistics Cat. No. 5206.0
3. The tax rate for alcohol is derived from Selvanathan and Selvanathan (2005) as follows. In their Table 11.12 (page 319), the Selvanathans report for Australia the following taxes (as percentages of consumer prices): Beer 43%, wine 23% and spirits 55%. The corresponding conditional budget shares ($\times 100$), from Clements et al. (2005, Panel B of Table A1), are 55, 23 and 22 (in the same order). Thus a budget-share weighted average tax rate for alcohol as a whole is $.55 \times 43 + .23 \times 23 + .22 \times 55 = 41\%$, as reported in row 2 of column 4 above.
4. Tax revenue is the product of the corresponding tax rate and consumption expenditure.
5. Population, used to convert to per capita, refers to those aged 14 years and over.

TABLE 7
SIMULATIONS OF VICE CONSUMPTION AND TAXATION REVENUE

Endogenous variable	Exogenous change					
	10% fall in marijuana prices	10-percentage-point increase in the tax rate		10% increase in the tax rate		
		Tobacco	Alcohol	Tobacco	Alcohol	
		$100 \times \Delta t'_2 = 10$ $100 \times \frac{\Delta t'_2}{t'_2} = 8.4$	$100 \times \Delta t'_3 = 10$ $100 \times \frac{\Delta t'_3}{t'_3} = 14.4$	$100 \times \Delta t'_2 = 11.9$ $100 \times \frac{\Delta t'_2}{t'_2} = 10$	$100 \times \Delta t'_3 = 7.0$ $100 \times \frac{\Delta t'_3}{t'_3} = 10$	
(1)	(2)	(3)	(4)	(5)	(6)	
A. Quantity consumed (Logarithmic changes $\times 100$)						
1. Marijuana	7.01 (-4.11) [1.20, 17.39]	-0.89 (0.57) [-2.30, -.16]	0.91 (0.82) [-.14, 2.95]	-1.06 (0.68) [-2.73, -.19]	0.64 (0.57) [-.10, 2.07]	
2. Tobacco	1.79 (1.08) [.20, 4.37]	-0.95 (0.35) [-1.76, -.39]	0.93 (0.62) [.02, 2.44]	-1.14 (0.42) [-2.09, -.47]	0.65 (0.43) [.02, 1.71]	
3. Alcohol	-0.8 (0.6) [-2.24, .09]	0.31 (0.24) [-.04, .88]	-4.08 (1.4) [-7.31, -1.81]	0.37 (0.29) [-.05, 1.05]	-2.86 (0.98) [-5.12, -1.27]	
B. Taxation revenue (Logarithmic changes $\times 100$)						
4. Tobacco	1.79 (1.08) [.20, 4.37]	7.46 (0.35) [6.65, 8.02]	0.93 (0.62) [.02, 2.44]	8.87 (0.42) [7.91, 9.54]	0.65 (0.43) [.02, 1.71]	
5. Alcohol	-0.8 (0.6) [-2.24, .09]	0.31 (0.24) [-.04, .88]	10.2 (1.4) [6.98, 12.48]	0.37 (0.29) [-.05, 1.05]	7.14 (0.98) [4.88, 8.73]	
6. Total	0.41 (0.24) [.07, 1.01]	3.67 (0.16) [3.31, 3.93]	5.85 (0.6) [4.48, 6.79]	4.36 (0.19) [3.93, 4.68]	4.09 (0.42) [3.14, 4.76]	
C. Taxation revenue (\$m)						
7. Tobacco	87 (52) [10, 212]	362 (17) [323, 390]	45 (30) [1, 119]	431 (20) [385, 464]	32 (21) [1, 83]	
8. Alcohol	-43 (32) [-121, 5]	17 (13) [-2, 48]	551 (76) [377, 674]	20 (16) [-3, 57]	386 (53) [264, 472]	
9. Total	44 (26) [7, 105]	379 (16) [342, 406]	596 (61) [458, 693]	451 (19) [406, 483]	417 (43) [442, 462]	

Note: The first entry in each cell is the mean over the 5,000 trials. The second entry, given on the right in parentheses, is the associated standard deviation. The range below the mean and standard deviation is the 95% probability interval.

TABLE 8

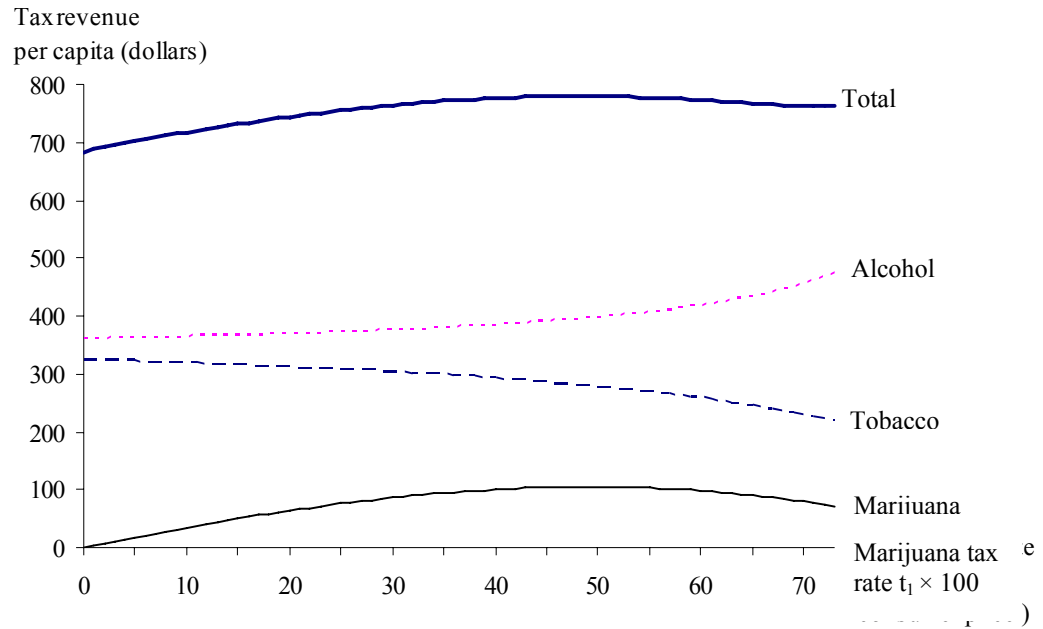
REVENUE FROM TAXING MARIJUANA

Marijuana tax rate $t_1 \times 100$	Tax revenue (dollars per capita)			
	Marijuana	Tobacco	Alcohol	Total vice
(1)	(2)	(3)	(4)	(5)
0	0 -	324 -	360 -	684 -
10	35 (1) [31, 37]	318 (4) [310, 323]	363 (2) [360 369]	716 (2) [710, 720]
20	63 (6) [49, 72]	311 (8) [292, 323]	367 (5) [360, 380]	741 (7) [724, 753]
30	85 (13) [55, 106]	302 (13) [271, 322]	372 (9) [359, 395]	759 (15) [725, 783]
40	98 (22) [50, 138]	290 (19) [246, 320]	(379) (15) [358, 415]	768 (24) [715, 811]
50	102 (33) [36, 166]	275 (27) [214, 318]	390 (23) [357, 446]	767 (34) [699, 833]
60	94 (44) [19, 188]	254 (37) [174, 315]	405 (36) [356, 495]	754 (43) [680, 846]
70	75 (51) [6, 199]	224 (49) [123, 310]	434 (62) [353, 591]	733 (48) [662, 850]

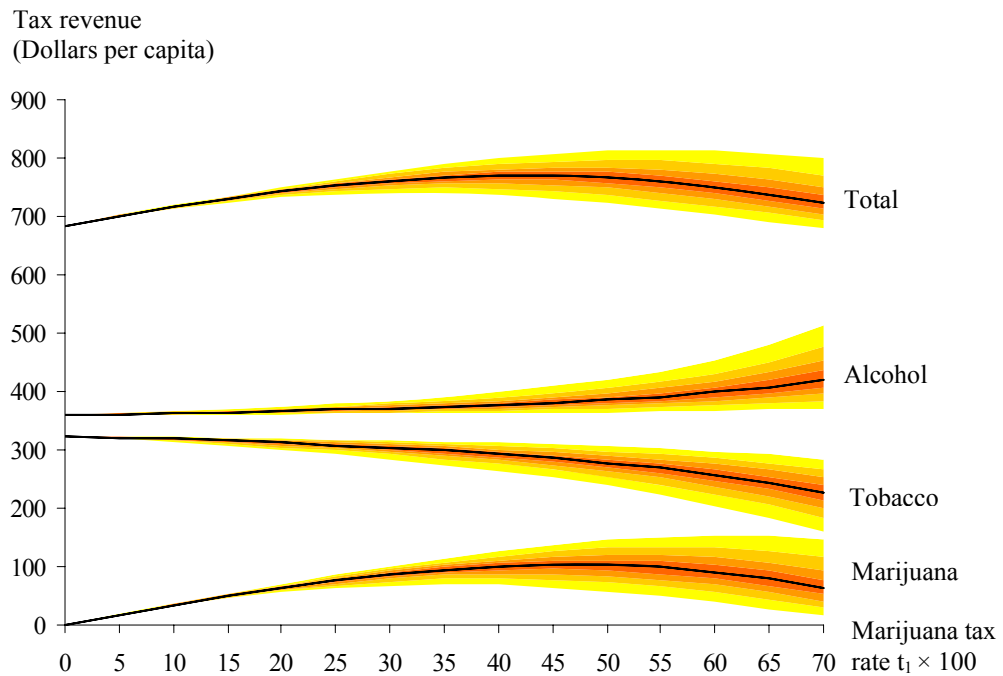
Note: The first entry in each cell is the mean over the 5,000 trials. The second entry, given on the right in parentheses, is the associated standard deviation. The range below the mean and standard deviation is the 95% probability interval.

FIGURE 3
THE MARIJUANA LAFFER CURVE

A. Taxation Revenues



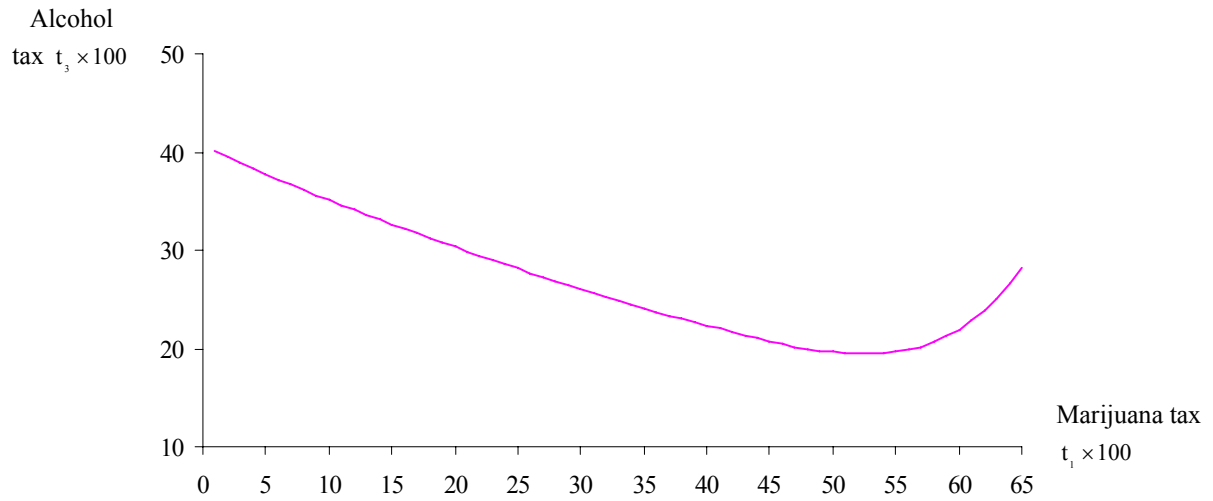
B. The Uncertainty of Taxation Revenues



Note: Panel A plots the means over the 5,000 trials. In Panel B, the boundaries of the fan chart are the 10, 20, ..., 90 percentiles of the distribution of tax revenues from the simulation, so that the solid lines are the medians, instead of the means as in Panel A.

FIGURE 4
THE ALCOHOL-MARIJUANA TAX TRADEOFF
(Means over 5,000 trials)

A. The Tradeoff



B. The Slope of the Tradeoff

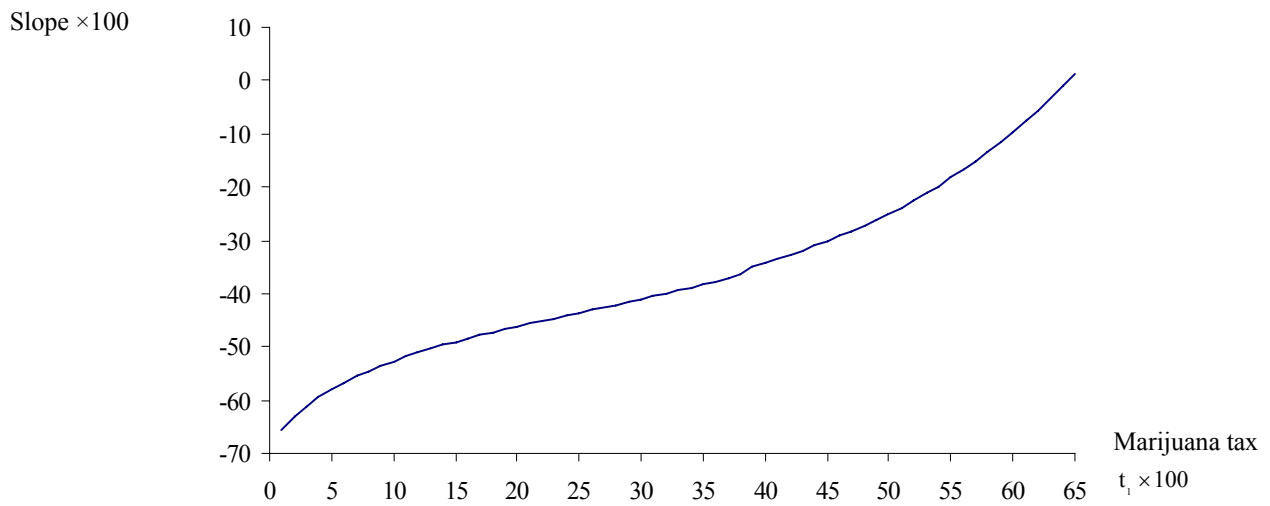
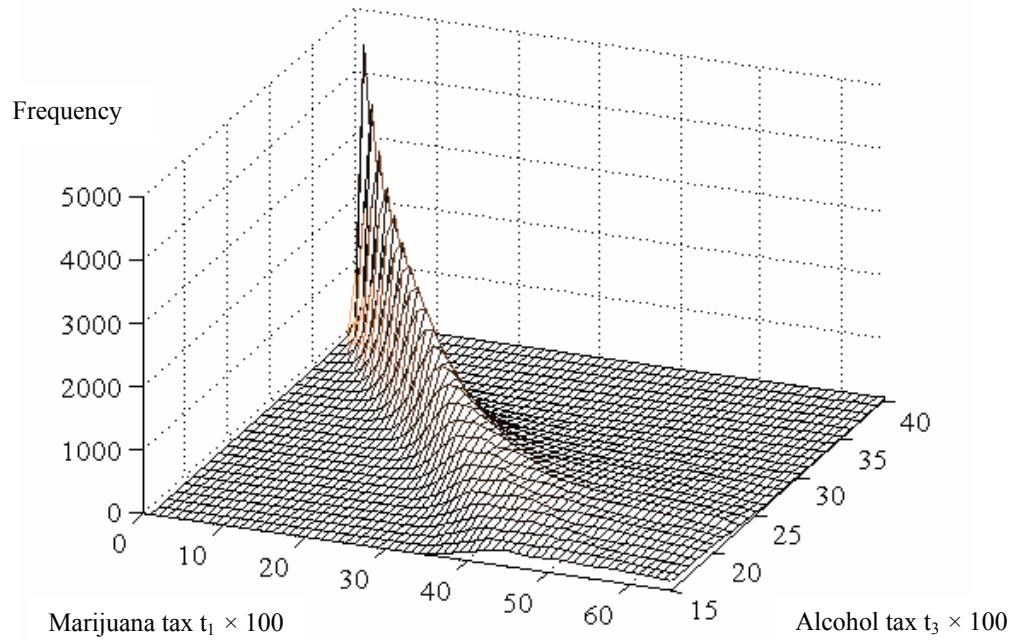


FIGURE 5
THE UNCERTAINTY OF THE TRADEOFF

A. The Tradeoff



B. The Slope of the Tradeoff

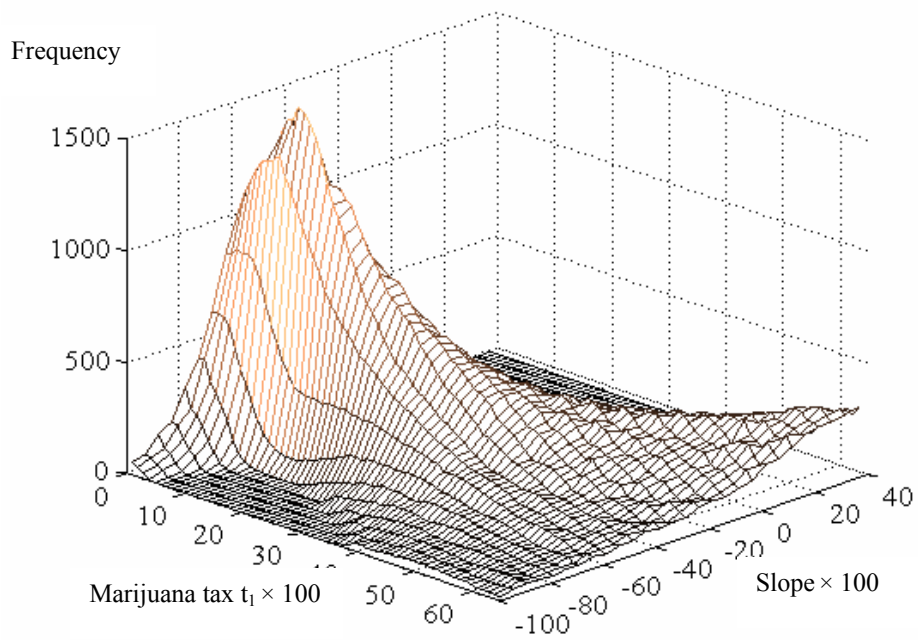


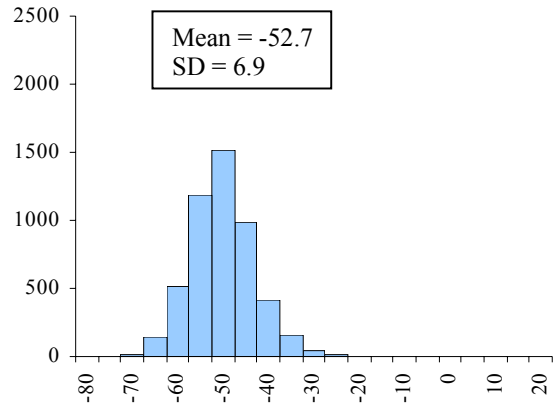
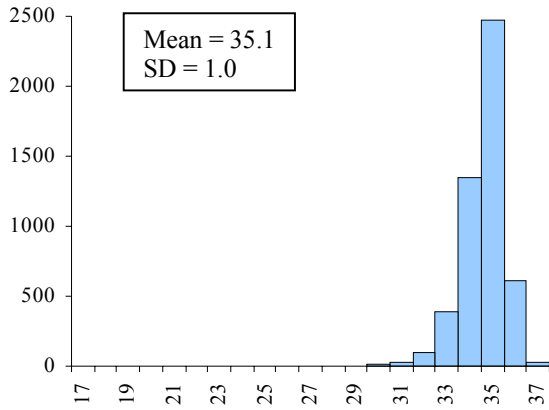
FIGURE 6

CONDITIONAL DISTRIBUTION OF ALCOHOL TAX AND SLOPE OF TRADEOFF

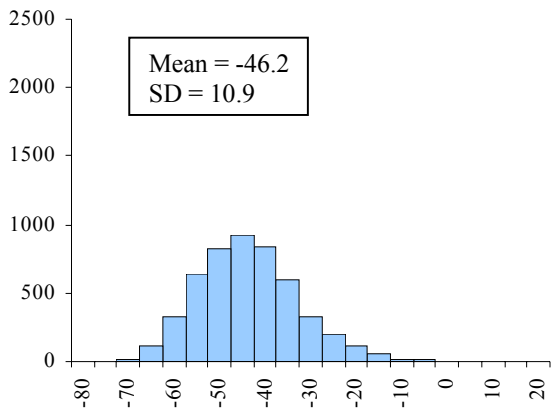
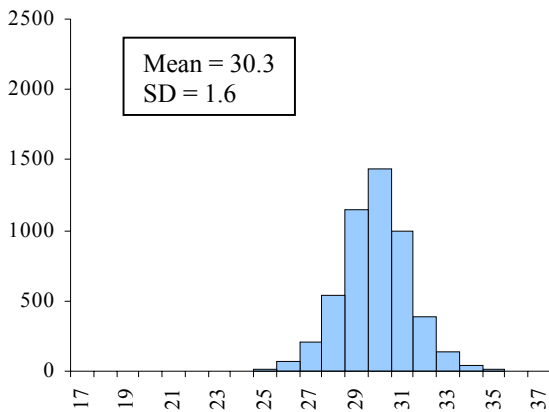
Alcohol tax rate $\times 100$

Slope of tradeoff $\times 100$

A. Marijuana tax rate $\times 100 = 10\%$



B. Marijuana tax rate $\times 100 = 20\%$



C. Marijuana tax rate $\times 100 = 30\%$

