

**THE DEMAND FOR VICE
Inter-Commodity Interactions with Uncertainty***

by

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Abstract

This paper introduces a simulation procedure in the context of a demand system for vice -- marijuana, tobacco and alcohol -- to formally account for the inherent uncertainty in marijuana-related data and parameters. This entails using existing econometric estimates pertaining to the consumption of alcohol and tobacco, and the much more limited information on marijuana. As an illustrative application of the framework, we 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 of about 50 percent is estimated to yield additional revenue of about 15 percent of the pre-existing proceeds from vice taxation. The role of uncertainty surrounding preference interactions within vice, as well as the uncertainties regarding marijuana data, is highlighted by providing the whole distribution of each endogenous variable.

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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. A recent paper by Bajada (1999) that uses the currency demand approach concludes that the value of the Australian underground economy is about 15 percent of measured GDP. 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.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. Accordingly, marijuana consumption could be expected to be negatively related to the price of tobacco, and positively related to alcohol prices. Symmetry of the substitution effects means that the consumption of alcohol and tobacco will respond in a similar manner to variations in marijuana prices. 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. These links of marijuana consumption to tobacco and alcohol would also imply cross-commodity impacts of any policy changes, so that changes in one drug market are likely to have impacts on 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 beer, wine, spirits and tobacco impact on marijuana consumption?

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

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 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). If there are n consumer goods, a CGE model then requires numerical values of n income elasticities and n^2 own- and cross-price elasticities, which for $n = 100$, not an atypical value for a contemporary CGE model, implies that more than 10,000 individual elasticities are required. As it is impossible to obtain econometric estimates of such a large number of parameters, CGE models almost invariably employ separability theory to reduce the number of unknowns to manageable proportions.³

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 quantities of data on consumption patterns and prices. 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 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) 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

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."

³ An example of a prominent CGE model that employs this approach is MONASH (Dixon and Rimmer, 2002, Sec. 17.4).

demand elasticities through the quantification of the 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 equilibrium displacement and CGE modeling, and other areas of applied economics. As an illustrative application of the framework, we simulate the cross-commodity impacts of price and tax changes.

This paper is structured as follows. The next section sets out 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 deals with the application of this approach to the demand for vice. Section 4 introduces the uncertainty involved in cross-commodity demand relationships for vice 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 price elasticities. To illustrate the approach, in Section 5 we simulate the impact on the consumption of vice of a reduction in the price of marijuana (possibly resulting from productivity enhancement in its cultivation and/or lighter regulation), and changes in the taxes on tobacco and alcohol. We also derive the revenue-maximising marijuana tax, and provide results on the tradeoff between marijuana and alcohol taxes, whereby the tax proceeds from marijuana are redistributed to drinkers in the form of lower 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 distribution of each endogenous variable. Section 6 contains concluding comments.

2. DEMAND EQUATIONS

This section sets out the analytical framework that is applied subsequently to the demand for vice. We use Theil's (1980) differential approach to consumption theory due to its generality and elegant simplicity, and because it makes transparent the 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 of the 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 a price index, which is a budget-share weighted average of the n price changes. Under general conditions, we can express the demand equation for good i in differential form as

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

where $\theta_i = \partial(p_i q_i) / \partial M$ is the marginal share of good i ; v_{ij} is the $(i, j)^{\text{th}}$ Frisch price coefficient; and $d(\log P') = \sum_{i=1}^n \theta_i d(\log p_i)$ is the Frisch price index, which uses as weights marginal shares. 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 holds constant the marginal utility of income. The marginal share θ_i in equation (2.1) 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 $\sum_{i=1}^n \theta_i = 1$.

Let the utility function be $u(q_1, \dots, q_n) = u(\mathbf{q})$, where $\mathbf{q} = [q_i]$ is the consumption vector, and $\mathbf{U} = \partial^2 u / \partial \mathbf{q} \partial \mathbf{q}'$ be the Hessian matrix. A sufficient condition for a budget-constrained utility maximum is for \mathbf{U} to be negative definite. The Frisch coefficient v_{ij} in equation (2.1) is defined as $(\lambda p_i p_j / M) u^{ij}$, where $\lambda > 0$ is the marginal utility of income and u^{ij} is the $(i, j)^{\text{th}}$ element of the inverse of the Hessian \mathbf{U}^{-1} . If we write $\mathbf{v} = [v_{ij}]$ for the matrix of Frisch coefficients and \mathbf{P} for the diagonal matrix with p_1, \dots, p_n on the main diagonal, we then have

$$(2.2) \quad \mathbf{v} = (\lambda / M) \mathbf{P} \mathbf{U}^{-1} \mathbf{P}.$$

As $\lambda, M > 0$, \mathbf{P} is a symmetric positive definite matrix and \mathbf{U}^{-1} is symmetric negative definite, we can conclude that \mathbf{v} is also symmetric negative definite. Inverting both sides of equation (2.2), we obtain

$$(2.3) \quad \mathbf{v}^{-1} = (M / \lambda) \mathbf{P}^{-1} \mathbf{U} \mathbf{P}^{-1},$$

or $v^{ij} = (M/\lambda) \partial^2 u / \partial(p_i q_i) \partial(p_j q_j)$, where v^{ij} is the $(i, j)^{\text{th}}$ element of v^{-1} . As $\partial u / \partial(p_i q_i)$ is the marginal utility of a dollar spent on i , $\partial^2 u / \partial(p_i q_i) \partial(p_j q_j)$ is interpreted as the change in this marginal utility when spending on j increases by one dollar. Accordingly, equation (2.3) shows that the Frisch coefficient matrix v is inversely proportional to the Hessian matrix of the utility function in expenditure terms. The final property of v is that its row sums are proportional to the corresponding marginal shares,

$$(2.4) \quad \sum_{j=1}^n v_{ij} = \phi \theta_i, \quad i = 1, \dots, n.$$

The proportionality factor $\phi < 0$ is the reciprocal of the income elasticity of the marginal utility of income, known as the “income flexibility” for short.

The substitution term of equation (2.1) contains the j^{th} price twice, once explicitly and once within the Frisch price index. We use equation (2.4) to combine these by writing the substitution term as $\sum_j v_{ij} [d(\log p_j) - \sum_k \theta_k d(\log p_k)] = \sum_j \pi_{ij} d(\log p_j)$, where $\pi_{ij} = v_{ij} - \phi \theta_i \theta_j$ is the $(i, j)^{\text{th}}$ Slutsky price coefficient. This 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. If alternatively we hold money income constant, the Marshallian (or uncompensated) price 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 .

Next, we consider the implications for the demand equations of the case whereby tastes are such that utility is additive in the n goods, $u(q_1, \dots, q_n) = \sum_{i=1}^n u_i(q_i)$, where $u_i(q_i)$ is a sub-utility function that depends only on the consumption of good i . In this case, $\partial u / \partial q_i = d u_i / d q_i$, all second-order cross derivatives vanish and the Hessian U , and its inverse U^{-1} , are both diagonal matrices. Due to the absence of utility interactions among goods, this specification of tastes is known as a preference independence (PI). PI means that all the price coefficients v_{ij} for $i \neq j$ are zero and from equation (2.4), $v_{ii} = \phi \theta_i$, $i = 1, \dots, n$. 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, η_{ij}^* 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. Below we shall use PI as a starting point for constructing our elasticities.⁴

3. APPLICATION TO VICE

This section proceeds to derive income and price elasticities of demand for marijuana, tobacco and alcohol, which we dub “vice”, as well as for a residual category all other goods, which we call “other”, so that $n = 4$ goods.

Budget Shares, Income Elasticities, Marginal Shares and the Income Flexibility

Column 2 of Table 1 gives the budget shares of the four goods. On the basis of data presented in Appendix 1, these values are not too far away from the observed shares in Australia in the 1990s. As discussed in Appendix 1, the underlying marijuana quantity data are estimated from a frequency of consumption survey together with assumptions regarding intensity of use. The marijuana price data are based on information supplied by the Australian Bureau of Criminal Intelligence. These data are subject to more than the usual degree of uncertainty, a feature that will be taken into account in the analysis below. 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 marginal shares of the first three commodities are computed as $\theta_i = w_i \times \eta_i$, and these values are given as the first three elements of column 4 of Table 1. The marginal share for other is defined residually as $\theta_4 = 1 - \sum_{i=1}^3 \theta_i$. The value of the income flexibility ϕ is specified as -0.5.

The basis for the above values of the income elasticities 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

⁴ For more details of the material of this section, see Clements (1987).

η_i . While marijuana is reported to be consumed by a variety of types of people, it is reasonable to suppose that young adults, university students and baby boomers are well represented.⁵ As these socioeconomic groups tend to be affluent, we set the income elasticity of marijuana at slightly above unity at 1.2. 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, although there is no compelling reason to expect it to be a biased one way or the other. 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 0.42.⁶ However, there is still considerable dispersion among the underlying elasticities as the standard deviation is quite large at 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. To analyse the income elasticity of the group, write total expenditure on alcohol as $M_A = \sum_{i=1}^3 p_i q_i$, where p_i , q_i are the price and the quantity demanded of beverage i ($i = 1, 2, 3$, for beer, wine and spirits). Let $w'_i = p_i q_i / M_A$ be the conditional budget share of beverage i . The change in total expenditure can then be decomposed into price and quantity indexes, $d(\log M_A) = d(\log P_A) + d(\log Q_A)$, where $d(\log P_A) = \sum_{i=1}^3 w'_i d(\log p_i)$ and $d(\log Q_A) = \sum_{i=1}^3 w'_i d(\log q_i)$. Accordingly, the natural way to measure the consumption of alcohol as a whole is via the Divisia volume index $d(\log Q_A)$. The income elasticity of demand for alcohol is then $d(\log Q_A) / d(\log M) = \sum_i w'_i \eta_i^A$, where $\eta_i^A = \partial(\log q_i) / \partial(\log M)$ is the income elasticity of beverage i , M being income. Prior studies almost invariably find η_i^A 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^A tend to be substantially above one.⁷ As in the case of tobacco, there is considerable uncertainty surrounding the precise numerical values of the alcohol elasticities. With these

⁵ For an analysis of university students’ marijuana consumption, see Daryal (2002).

⁶ The median of the short-run income elasticities is 0.28, while that of the long-run elasticities is 0.39.

⁷ 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.

considerations in mind, we shall use $\eta_i^A = 0.5$ for beer and 1.5 for both wine and spirits. The data given in Appendix 3 for Australia reveal that over the 1990s beer absorbs about one half of total expenditure on alcohol, with the remainder split roughly evenly between wine and spirits, so that $w_i' \approx 0.5$ for beer, and 0.25 for both wine and spirits. Using these values yields the income elasticity for alcohol as a whole of $\sum_{i=1}^3 w_i' \eta_i^A = 1$, which agrees well with direct estimates of this elasticity obtained for Australia by Clements and Johnson (1983) and Clements and Selvanathan (1991).⁸ On this basis, we set the η_i for alcohol as a whole equal to 1. However, that even in the case of alcohol it is appropriate to acknowledge the considerable uncertainty regarding the value of its income elasticity.

The final income elasticity to be considered is that of the marginal utility of income, which, in reciprocal form, is the income flexibility ϕ . Specifying that $\phi = -0.5$ 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 ICP data for 30 countries from Kravis et al. (1982), Theil (1987, Sec. 2.8) obtains a ϕ -estimate 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 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 .⁹

⁸ A unity income elasticity for alcohol also agrees with the evidence in 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).

⁹ It should be noted that treating the income flexibility as a constant parameter is at variance with Frisch’s (1959) famous conjecture that ϕ should increase in absolute value as the consumer becomes more affluent. However, most tests of the Frisch conjecture tend to reject it; see, e.g., Clements and Theil (1996), Selvanathan (1993, Secs. 4.8 and

Vice Interactions

Prior empirical evidence clearly indicates that marijuana, tobacco and alcohol are closely related in consumption. Using unit record data from the Australian National Drug Strategy Household Surveys (NDSHS) involving over 40,000 individuals, Zhao and Harris (2004) report sample statistics given in Table 2 that demonstrate this relationship. As can be seen from the unconditional proportions of column 2, 14 percent of respondents say that they consume marijuana, 24 percent consume tobacco and 84 percent consume alcohol. However, from the conditional proportions of column 3, as many as 56 percent of marijuana users also smoke tobacco; as this is more than twice the corresponding unconditional percentage of 24 percent, this points to marijuana and tobacco being used by the same consumers simultaneously, or the two goods being complementary in consumption.¹⁰ This would also seem to be supported by the symmetrical comparison: among users of tobacco, 34 percent also use marijuana, much larger than the proportion of the whole population who use marijuana, 14 percent. The unconditional and conditional relative frequencies in the last row of Table 2 are closer together, so there seems to be less evidence of complementarity when alcohol is involved.

A more formal way to measure the interactions between goods in consumption is via the cross-price effects. However, econometric estimates of these effects for the three drugs tend to be inconclusive. Demand studies using unit record survey data are often hindered by the unavailability of individual-level price data. In addition, consumption data from drug surveys are almost always in the form of answers to discrete choices, which means that none of the microeconomic demand studies involving these drugs can use a demand system that incorporates symmetry of the

6.5), Theil (1975/76, Sec. 15.4), Theil (1987, Sec. 2.13) and Theil and Brooks (1970/71). On the other hand, evidence supporting Frisch has been reported by DeJanvry et al. (1972) and Lluch et al. (1977). Note also that according to Frisch (1959, p. 189) a ϕ -value of -0.5 would pertain to the “middle income bracket, ‘the median part’ of the population”, which is perhaps not unreasonable.

¹⁰ The idea of using information on consumption patterns in this manner to identify substitutes and complements can be clarified as follows. Suppose we hold constant prices and total expenditure on vice, and some shock hits the market that results in a reshuffling of the consumption basket, causing some elements to increase and others to decrease. The source of such a shock could be the release of new findings on the health effects of vice consumption, a police crackdown on illicit drugs, legalisation, etc. If this shock leads to a rise in the consumption of good i that is accompanied by a simultaneous fall in that of good j , what can be said about the relationship between these two goods? As additional consumption of one is offset by reduced consumption of the other they are competitive, so that both goods satisfy the same basic want of the consumer and it would be reasonable to describe the two goods as being substitutes. Conversely, goods that are positively correlated are complements in consumption. As in order to keep total expenditure unchanged, additional spending on one good has to be offset by reduced spending on others, it follows that on average at least all goods are substitutes. This notion of substitutability goes back to Allen and Bowley (1935) and is based the co-movement of quantities, while the more conventional approach employs the sign of the effect on consumption of good i of a change in the j^{th} price. As income is not held constant in Table 2, the above argument has to be qualified as the co-movement between marijuana and tobacco could also possibly reflect a common income effect.

substitution effects. Such a study could find that the coefficient on the price of drug B in the demand equation for drug A was negative, implying that the two are complements; but the same study could also find from the equation for drug B that the same two drugs are substitutes. When this approach is adopted, there is no internal consistency of choice and the interpretation of the estimated price responses can be problematic. Overall, though, the available micro-level 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.¹¹

Another study by Harris et al. (forthcoming) investigates alcohol consumption for different types of drinkers using a flexible model. While there is some indication of a complementary relationship between alcohol participation and marijuana, the response of frequent drinkers to the marijuana price is insignificant. Williams and Mahmoudi (2004) also find marijuana and alcohol to be complements for people who admit to using both drugs at the same time. 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 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.

One other Australian study is 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, beer, wine and spirits. Making a rough adjustment to hold income constant, they

¹¹ But to complicate matters somewhat, in the context of alcohol consumption, Williams and Mahmoudi (2004) and Harris et al. (forthcoming) find some evidence of marijuana and alcohol being complements.

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.¹²

Four other studies deal with the interrelationship in consumption of tobacco and alcohol. First, Goel and Morey (1995) analyse the demand for tobacco and spirits with panel data for the states of the US. They find that as the cross-price elasticities are positive, these two goods are substitutes in consumption. But as these authors exclude from their study the other two alcoholic beverages, beer and wine, this can only be treated as weak evidence regarding the relationship between tobacco and alcohol. Second, in a study of vice computation in the UK, Jones (1989) uses aggregate time-series data to estimate a demand system for tobacco, beer, wine, spirits, cider, and all other goods. The cross-price elasticities between tobacco consumption and the four alcoholic beverages are all negative, indicating complementarity. However, only one of the four elasticities is highly significant (tobacco-spirits) and Jones (1989, p. 99) concludes “although the estimated cross-price elasticities should not be treated with too much confidence, they do provide evidence of complementarity between the two activities”. Third, Duffy (1991) analyses the joint determinants of the demand for beer, wine, spirits and tobacco in the UK. Conditional on the consumption of this group of products remaining unchanged, he finds both substitutability and complementarity between alcoholic beverages on the one hand, and tobacco on the other, but none of these effects is significantly different from zero (Duffy, 1991, p. 376). But for the unconditional demand equations, when group consumption is allowed to vary, and the restrictions of homogeneity and symmetry are imposed, he finds substitutability in each of the three pairwise cases (Duffy, p. 378). However, while the t-values increase in going from the conditional to unconditional demand equations, the effects are still not highly significant. In the fourth study, Decker and Schwartz (2000) use individual data from the US and find that higher alcohol prices discourage smoking, while higher cigarette prices increase drinking. Thus, the two goods cannot be classified as either substitutes or complements in an unambiguous manner, a problem that highlights the difficulties in studying consumption of related goods within a single-equation framework.

While not completely clear cut, prior findings regarding vice interactions can probably be summarised as follows. Marijuana and tobacco are in all probability complements, while there is no consensus regarding the interactions within vice involving alcohol. In what follows, we analyse the interactions between the consumption of the three drugs via the specification of the Frisch price

¹² Clements and Daryal (2005) also estimate the Rotterdam 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.

coefficients v_{ij} , which are fundamental behavioural parameters directly related to the consumer's utility function. To organise the discussion, we start with the restrictive structure of preference independence and then move to a more flexible structure that allows for specific substitutability/complementarity. These preference structures are 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 in the consumer's utility function. Using the data of Table 1, Table 3 presents the results and 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, the three versions of the cross-price elasticities pertaining to the effects of the price of other on the consumption of vice are quite different:

	Frisch η_{i4}^*	Slutsky η_{i4}	Marshallian η'_{i4}
Marijuana	0	.56	-.55
Tobacco	0	.19	-.18
Alcohol	0	.46	-.46

The above Frisch elasticities are zero by the assumption of PI. The Slutsky counterparts reflect the operation of the general substitution effect; the positive signs indicate substitutability, which is implied by preference independence. The three Marshallian elasticities are all negative, indicating complementarity due to the size of the income effect.

Second-Pass Price Elasticities

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

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

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 (2.4), 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:

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

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. The decision to leave the value of v_{11} unchanged at $\phi\theta_1$, while not the only possibility, is justified on the basis of simplicity and in view of subsequent developments, this turns out to be a convenient approach. As the $(i, j)^{\text{th}}$ Frisch elasticity is $\eta_{ij}^* = v_{ij} / w_i$, the specification that $v_{12} = -v_{13}$ implies that $\eta_{12}^* = -\eta_{13}^*$, so that if the relative prices of tobacco and alcohol both rise by the same proportionate amount, there are exactly offsetting effects as the consumption of marijuana remains unchanged. The justification for marijuana and other to remain independent is that as we have no strong priors about their interaction, this is a “neutral” specification.

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

	M	T	A	O	Row sum
PI	[0	$\phi\theta_2$	0	0]	$\phi\theta_2$
PD	[α	$\phi\theta_2$	$-\alpha$	0]	$\phi\theta_2$

As $v_{ij} = v_{ji}$, under PD $v_{21} = \alpha$ since $v_{12} = \alpha$. 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

	M	T	A	O	Row sum
PI	[0	0	$\phi\theta_3$	0]	$\phi\theta_3$
PD	[$-\alpha$	$-\alpha$	$\phi\theta_3 + 2\alpha$	0]	$\phi\theta_3$

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

	M	T	A	O	Row sum
PI	[0	0	0	$\phi\theta_4$]	$\phi\theta_4$
PD	[0	0	0	$\phi\theta_4$]	$\phi\theta_4$

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 zeros under PI and PD, so that this row takes exactly the same form under the two specifications.

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

	M	T	A	O	Row sum
Marijuana					
Tobacco					
Alcohol					
Other					

(3.1)

$$\begin{bmatrix} \phi\theta_1 & \alpha & -\alpha & 0 \\ \alpha & \phi\theta_2 & -\alpha & 0 \\ -\alpha & -\alpha & \phi\theta_3 + 2\alpha & 0 \\ 0 & 0 & 0 & \phi\theta_4 \end{bmatrix} \begin{matrix} \phi\theta_1 \\ \phi\theta_2 \\ \phi\theta_3 \\ \phi\theta_4 \end{matrix}$$

What value should the negative parameter α take? A rise in the relative price of tobacco reduces consumption of that good and, as marijuana and tobacco are specified as complements, marijuana consumption also falls. 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 specify α as some proportion of the mean of $\phi\theta_1$ and $\phi\theta_2$. If we use the geometric mean, so that

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

then we can interpret the proportionality factor ρ as a type of correlation coefficient.

According to equation (2.3), \mathbf{v}^{-1} is proportional to the inverse of the Hessian matrix of the utility function in expenditure terms. Thus, to analyse the implications of matrix (3.1) for the structure of the utility function, we need its inverse. While this inverse is available, its form is complex. Some insights are available, however, if we follow Barten (1964) and use an approximation to the inverse. We can express $\mathbf{v} = [v_{ij}]$ as $\mathbf{v} = -\mathbf{D}(\mathbf{I} + \mathbf{\Gamma})\mathbf{D}$, where $\mathbf{D} = \text{diag}[-v_{ii}^{1/2}]$, and $\mathbf{\Gamma} = [\gamma_{ij}]$ is a symmetric 4×4 matrix with diagonal elements zero. This means that the $(i, j)^{\text{th}}$ off-diagonal element of \mathbf{v} takes the form $v_{ij} = \gamma_{ij} \sqrt{v_{ii} v_{jj}}$. Thus as $v_{12} = \alpha$, in view of equation (3.2), we find that $\gamma_{12} = \rho$. If the elements of $\mathbf{\Gamma}$ are not “too large”, then

$$(3.3) \quad \mathbf{v}^{-1} \approx -\mathbf{D}^{-1}(\mathbf{I} - \mathbf{\Gamma})\mathbf{D}^{-1}.$$

Thus $v^{ii} \approx 1/v_{ii}$ and $v^{12} \approx -\rho/|\phi| \sqrt{\theta_1 \theta_2} > 0$. As $v^{12} \propto \partial^2 u / \partial(p_1 q_1) \partial(p_2 q_2)$, we see that additional spending on tobacco raises the marginal utility of expenditure on marijuana. Note also that $v^{12} \approx -\rho \sqrt{v^{11} v^{22}} \approx -\rho / \sqrt{v_{11} v_{22}}$. Accordingly, $-\rho \approx v^{12} / \sqrt{v^{11} v^{22}}$ is now interpreted as a type of correlation coefficient for the relevant elements of \mathbf{v}^{-1} , so its value determines the degree

of complementarity between marijuana and tobacco where complementarity is understood to refer here to the interaction in the utility function.

The value of the parameter ρ determines the degree of complementarity between marijuana and tobacco. As it is difficult to have strong prior ideas of the precise degree of this 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 same basic data given in Table 1, Table 4 contains the results for $\rho = -0.5$. In Panel B, the second element of the first row, v^{12} , equals 94.5. The corresponding diagonal elements of \mathbf{v}^{-1} are $v^{11} = -111.2$ and $v^{22} = -361.6$, which, if we ignore the signs, have a geometric mean of about 200. Accordingly, the ratio of v^{12} to this geometric mean is about 0.5, which is the absolute value of ρ . This result is reassuring about the adequacy of approximation (3.3). The value of v^{13} is -2.2 , which is much smaller in absolute value than v^{12} , implying that the marginal utility of marijuana expenditure is less sensitive to variations in alcohol spending than it is to tobacco spending. From Panels C, E and F, the three versions of the own-price elasticities for vice are

	Frisch η_{ii}^*	Slutsky η_{ii}	Marshallian η'_{ii}
Marijuana	-.60	-.59	-.61
Tobacco	-.20	-.20	-.21
Alcohol	-.67	-.65	-.69

For a given product, the three elasticities are quite similar, as before with preference independence. Comparing these to the corresponding values of Table 3, which are based on preference independence ($\rho = 0$), we see that the results are identical for marijuana and tobacco; for alcohol, however, when $\rho = -0.5$ the own-price elasticities are now somewhat larger (in absolute value).

Next, in Figure 1 we explore the implication of differing values of ρ for the key elasticities. Consider first the three versions of the elasticity of demand for marijuana with respect to the price of tobacco -- Frisch, Slutsky and Marshallian. Frisch 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 Panel A of 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 Panel A. The main message of Panel A is that the three cross elasticities all increase in absolute value with ρ , but only about half as fast. Panel B of Figure 1 contains a similar analysis of the dependence on the value of ρ of the three elasticities of demand for marijuana with respect to the price of alcohol. With the minor exception of the Marshallian elasticity for small values of ρ , these cross elasticities are always positive (here the vertical scale is not inverted), indicating substitutability, and also increase with $|\rho|$. Panel C gives the plots of the three own-price elasticities of demand for alcohol, and shows that their absolute values also increase with $|\rho|$.

4. STOCHASTIC VICE

In the previous section, we derived several sets of price elasticities for a demand system for vice by allowing for varying degrees of consumer preference structures, as summarised in matrix (3.1). A key parameter of that matrix is α , and we explored the implications of different values of this parameter by undertaking some limited sensitivity analysis. In this section, we extend this analysis by introducing a simulation approach to formally quantify uncertainty regarding the structure of preferences, and the implied uncertainty in values of the demand elasticities. The approach involves describing our uncertainty with subjective probability distributions of market data (the w_i) and the basic preference parameters (the θ_i and v_{ij}), based on all available prior information such as economic theory, published econometric estimates, and our subjective judgment. The implied probability distributions for the elasticities, which are usually non-linear functions of the basic parameters, are then obtained through Monte Carlo simulation. The uncertainty regarding the demand elasticities can further be translated to probability statements regarding own- and cross-industry impacts in any policy analysis. An advantage of the approach is that any inequality constraints required by economic theory or subjective beliefs can be imposed easily through simulation. Subjective probability distributions and the simulation techniques

described above are typically used in modern Bayesian analysis (see, for example, Geweke, 1999).¹³

The basic ingredients for the simulation are the four budget and marginal shares, the income flexibility and the correlation coefficient ρ . We shall assume that each of these variables/parameters follows a truncated normal distribution with the mean given by the relevant entry of Table 1 and a specified standard deviation. Regarding the budget shares, for marijuana the mean of the distribution is 2 percent and we shall take the 95 percent confidence interval to be 1-3 percent, which, on the basis of normality, implies a standard deviation of 0.5 percent, and a coefficient of variation of $0.5 / 2 = 25$ percent. Furthermore, we restrict the range of this share such that $0 < w_1 < 1$. This information is contained in the first row of Table 5. 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. We thus specify their coefficients of variation to be 12.5 percent, one half that of marijuana, as indicated in rows 2 and 3 of column 5 in Table 5. 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 budget share of the fourth good, other, can be derived from that pertaining to the first three, and is recorded in row 4 of Table 5.

The means of the distributions of θ_i and ϕ are as specified in Table 1, while it is assumed additionally that the correlation coefficient ρ has mean of -0.5 . Regarding the standard deviations of these parameters, consider first the marginal shares θ_i . Due to their “unobservable” nature, we shall assume that there is twice as much uncertainty with respect to their values relative to that of the corresponding budget shares. Thus, the coefficient of variation of θ_i for marijuana is specified as $2 \times 25 = 50$ percent, as indicated in column 5 and row 7 of Table 5. A similar principle applies to the other three marginal shares. Each θ_i is also constrained to lie between zero and one, and the four shares have a unit sum. In our discussion in the previous section of prior estimates of ϕ , it emerged that there was a certain “consensus” that the value of this parameter was of the order of -0.5 . Accordingly, the coefficient of variation of ϕ is specified to be 25 percent, and its value is restricted to be negative. In comparison with ϕ , as there is considerable more uncertainty regarding the value of ρ , we shall take its coefficient of variation to be 50 percent,

¹³ For examples of a similar approach in the context of equilibrium displacement models, see Griffiths and Zhao (2000) and Zhao et al. (2000).

while its range is restricted to be $[-1, 0]$. This information is summarised in rows 5-10 of Table 5. Finally, as indicated by the last part of Table 5, the values of all the parameters are restricted such that the matrix \mathbf{v} is negative defined. For each trial, we draw from eight univariate normal distributions with means and standard deviations as specified above. These eight comprise three for the w_i (the fourth is determined by the constraint $\sum_{i=1}^4 w_i = 1$), three for θ_i (the fourth is again determined by $\sum_{i=1}^4 \theta_i = 1$), one for ϕ and one for ρ . If any of the constraints of column 6 of Table 5 are violated, the trial is discarded. The procedure is then repeated until there are 5,000 realisations of each of the elements in the first ten rows of Table 5 and of \mathbf{v} that satisfy all the constraints. We then use these values to calculate 5,000 values of the Frisch, Slutsky and Marshallian elasticity matrices.

The left-hand part of Table 6 summarises the results of the simulation by first providing for each of three types of price elasticities the means over the 5,000 trials and the associated standard deviations. A comparison of the means of this part of the table with the corresponding elements of Table 4 reveals that they are quite close to their non-stochastic counterparts, which is reassuring. For tobacco, alcohol and other, the standard deviations of the own-price elasticities are all less than one half of the corresponding means; for marijuana, these standard deviations are relatively larger, which reflects the greater uncertainty surrounding this good. Regarding the cross-price elasticities, in those cases when the elasticity is random the standard deviations are all less than the corresponding means, and the standard deviations in the non-marijuana rows are relatively smaller. Finally, the left-hand part of Panel D of Table 6 gives the means and standard deviations of the income elasticities of the four goods. These are also in agreement with the Table 1 values, and the standard deviations of the non-marijuana elasticities are relatively smaller than those for marijuana.

The above simulation takes the budget shares and the parameters to be all random. In principle at least, the true values of the budget shares are directly observable. While there are issues associated with sampling procedures, and incentives for producers and consumers to systematically underreport (especially for marijuana, but also for tobacco and alcohol), these are just practical problems that could be resolved with sufficient resources and ingenuity. The parameters of the demand equations, ϕ , ρ and θ_i , are in a completely different category as their true values are inherently unobservable, no matter how much high-quality data we have. The best we can do is to obtain econometric estimates of these parameters. But as even if we had perfect data, these estimates are subject to estimation error due to random factors associated with

model uncertainty, it is plausible to suppose that relative to the budget shares, there is more uncertainty with respect to the values of the parameters. The recognition of this distinction between variables and parameters was the basis of the above approach of specifying the coefficients of variation of the w_i as being one half those of the corresponding θ_i . To pursue this idea further, we redo the previous simulation experiment with budget shares taken to be nonrandom. A further reason for treating the w_i as fixed is that their reciprocals appear in the expressions for the elasticities. When w_i is random there is some probability that in a certain trial it will take a very small value, causing the corresponding elasticity to “explode”. Accordingly, fixing w_i avoids the problem.¹⁴ Thus in the second experiment, the values of the w_i are held fixed in each trial at those given in rows 1-4 of column 2 of Table 5, while the parameters are drawn from univariate normal distributions with the same means and standard deviations as before. The results are summarised in the right-hand part of Table 6 and, as can be seen, the means are close to those of the previous experiment, while in nearly all cases the standard deviations are lower, as is to be expected. The standard deviations of the price elasticities in the marijuana rows fall on average by about 25 percent, while the reduction in the other rows is of the order of 10 percent.

Figures 2 and 3 give the frequency distributions for each price elasticity from the two experiments. To facilitate understanding, these figures are presented in a commodity \times commodity format, like the matrices of Table 6. Thus, for example, the frequency in the top right-hand corner of Panel A of Figure 2, in the marijuana “row” and “column”, refers to the Frisch own-price elasticity of demand for marijuana when everything is taken to be random. The frequencies are all unimodal, but many exhibit substantial asymmetry. A case can be made that in Figure 2 the degree of asymmetry is greater (smaller) in the marijuana (other) rows. As the elasticities all involve the reciprocals of the budget shares, this result could possibly reflect the relatively high (low) standard deviation of the marijuana (other) share. This interpretation would seem to be supported by the distributions presented in Figure 3, where the budget shares are not random, as here the contrast between marijuana and the other three goods is not quite so stark. Figure 4 contains the corresponding distributions for the income elasticities. As these elasticities are the ratios of marginal shares θ_i to the corresponding budget shares w_i , in Panel B of this figure, where the θ_i are normal and w_i fixed, the distributions are all normal by construction.

¹⁴ A related issue is that ratios of normal variables do not possess finite moments. See, e.g., Bewley and Fiebig (1990) and Zellner (1978).

As a final way to “visualise” our approach, we consider the demand curve for marijuana. From Table A2 of the Appendix, per capita expenditure on marijuana in 1998 was \$372, while consumption was 0.7873 ounces per capita (Clements and Daryal, 2005a), so that the implicit price is $372/0.7872 = \$473$ per ounce. These price-quantity values are represented by the point A in Figure 5, and we take this point as lying on the demand curve. The other points on the demand curve can be derived as follows. We return to the differential demand equation (2.1) for $i = 1$ (for marijuana), divide both sides by w_1 , hold real income and all non-marijuana prices constant to yield $d(\log q_1) = \eta_{11} d(\log p_1)$, where $\eta_{11} = (v_{11} - \phi\theta_1\theta_1)/w_1$ is the Slutsky own-price elasticity of demand for marijuana. Denote the observed price and quantity by a second “0” subscript, so that $p_{10} = 473$, $q_{10} = 0.7872$, and unobserved “new” values by p_{1*} and q_{1*} . Accordingly, $\log(q_{1*}/q_{10}) = \eta_{11} \log(p_{1*}/p_{10})$, so that $q_{1*} = q_{10} \exp[\eta_{11} \log(p_{1*}/p_{10})]$. As this equation expresses the new quantity in terms of the new price p_{1*} , the other points on the demand curve are obtained by varying p_{1*} . To allow for uncertainty in the parameters and data, for each value of p_{1*} we use the 5,000 values of the elasticity η_{11} described above, where everything is random, and the results are presented in Figure 6.¹⁵ This shows that the precision of the demand curve decreases substantially as we move away from the observed price-quantity configuration. This can be seen even more clearly in the associated distributions of consumption conditional on the price, which are given in Figure 7. As can be seen from Panel B, when the price is \$500, which is close to that prevailing in 1998, the consumption distribution is fairly compact around the mean of 0.76 oz, and the standard deviation is 0.02 oz. But when the price rises to \$800, 60 percent above the status quo, the distribution moves to the left, with mean consumption falling to 0.57, while its dispersion increases substantially, as indicated by the standard deviation of 0.11.¹⁶

5. ILLUSTRATIVE APPLICATIONS

To illustrate the application of our approach, in this section we use it to consider the impact of a reduction in marijuana prices and changes in taxation arrangements pertaining to vice. As this

¹⁵ Figure 5 is derived by plotting for each value of p_{1*} the mean over the 5,000 trials of the corresponding quantity demanded q_{1*} .

¹⁶ As a check, we use the means given in Panels B and C of this figure to derive a price elasticity of $\log(.57/.76)/\log(800/500) \approx -.29/.47 \approx -0.6$. This value agrees with the relevant elasticity given in Table 6.

analysis is only illustrative, we abstract from the supply side by assuming infinitely elastic supply schedules, so that all price and tax changes are passed onto consumers in their entirety; see Appendix 2 for a discussion of the issues involved. Table 7 gives the basic information on pre-existing taxation and consumption that will be used subsequently. As can be seen, tax accounts for about 54 percent of the consumer price for tobacco and 41 percent for alcohol.

Changes in Marijuana Prices and Taxation of Tobacco and Alcohol

Suppose marijuana prices were to fall by 10 percent because of productivity enhancement in the production of marijuana and/or a reduced policing effort in enforcing pre-existing laws prohibiting its consumption.¹⁷ The change in consumption of good i as a result of a change in the price of good j is

$$(5.1) \quad d(\log q_i) = \eta_{ij} d(\log p_j),$$

where $\eta_{ij} = \partial(\log q_i) / \partial(\log p_j)$ is one version of the $(i, j)^{\text{th}}$ price elasticity. To implement equation (5.1) for marijuana, alcohol and tobacco ($i = 1, 2, 3$), we set $j = 1$, so that $d(\log p_j) = d(\log p_1) = \log(1-0.1)$, representing a 10 percent fall in the price of marijuana, and interpret the price elasticity as the Slutsky version. We then use in equation (5.1) the previous 5,000 simulated values of η_{ii} , which yields 5,000 values of $d(\log q_i)$. The first three elements of column 2 of Table 8 give the mean and standard deviation of consumption for each good. Mean consumption for each good is simply the mean of the elasticity, from the left-hand part of Panel B of Table 6, times $\log 0.9$.

What happens to revenue from taxation as a result of the fall in the price of marijuana? As marijuana escapes the tax net, there is no direct effect, but there are indirect effects due to its interactions in consumption with tobacco and alcohol, which are taxed. Because marijuana and tobacco are complements, the fall in the price of marijuana stimulates tobacco consumption, which raises tax revenue. Offsetting this is the reduced tax revenue from alcohol, the consumption of which falls as it is a substitute for marijuana. The impact on taxation total revenue from vice then depends on the relative magnitudes of these two effects. To analyse these effects in detail, let p'_i be the producer (or pre-tax) price of good i , p_i be the corresponding consumer (or post-tax) price and t'_i be the tax rate expressed as a proportion of p'_i , so that $p_i = (1 + t'_i)p'_i$. Taxation revenue

¹⁷ Over the 1990s, the relative price of marijuana fell in Australia by about 40 percent (Clements, 2004).

from i is then $R_i = t'_i p'_i q_i = t_i p_i q_i$, where $t_i = t'_i / (1 + t'_i)$ is the tax rate as a proportion of the consumer price. The change in tax revenue is then $d(\log R_i) = d(\log t_i) + d(\log p_i) + d(\log q_i)$, or

$$(5.2) \quad d(\log R_i) = d(\log t'_i) + d(\log p'_i) + d(\log q_i).$$

Total tax revenue from vice is $R = R_2 + R_3$, or in change form

$$(5.3) \quad d(\log R) = \gamma d(\log R_2) + (1 - \gamma) d(\log R_3),$$

where $\gamma = R_2 / R$ is the share of tobacco in total tax revenue.

When marijuana prices fall by 10 percent, then with everything else unchanged, it follows from equation (5.2) that $d(\log R_i) = d(\log q_i)$ for $i = 2, 3$, so that revenue is proportional to consumption. Accordingly, the elements in rows 4 and 5 of column 2 of Table 8, which give $d(\log R_i)$, are identical to those in rows 2 and 3 of the same column. Equation (5.3) gives the change in total revenue as a weighted average of the changes in revenue from tobacco and alcohol. To implement this equation, we use for the share of tobacco in total revenue $\gamma = 0.47$, which follows from row 3 of Table 7. Row 6 of column 2 of Table 8 reveals that averaging over the 5,000 trials, total revenue increases by 0.3 percent as a result of the 10 percent reduction in marijuana prices.

In the above simulation we used the Slutsky elasticities, which amount to holding real income constant. Alternatively, we could hold money income constant and allow real income to rise with the fall in marijuana prices, and redo the simulations with the Marshallian elasticities. The elements of row 7-12 of column 2 of Table 8 give the results with the Marshallian elasticities and, as can be seen, these are fairly similar to the previous set of results. The choice of which set of elasticities to use depends on the nature of the exogenous change: If it is something that just reshuffles the pre-existing resources of the economy, as would be the case following a change in taxation arrangements, then since there would be no first-order income effects of such a change, it is appropriate to use the Slutsky elasticities. Alternatively, a productivity improvement raises real incomes and the Marshallian elasticities should be used. However, the differences in the results are fairly modest in this case. As the same is true in the subsequent simulations, in what follows we shall concentrate on the results with the Slutsky elasticities.¹⁸

¹⁸ The detailed results for the Marshallian case are given in Panel II of Table 8.

Next, consider the effects of increasing taxation of tobacco and alcohol. For tobacco, the tax rate of 54 percent of consumer prices implies a tax of 119 percent of pre-tax prices, so that if we increase it by 10 percentage points to 129 percent, t'_2 then increases by 8.4 percent. As $p_i = (1 + t'_i)p'_i$, the change in the consumer price is

$$(5.4) \quad d(\log p_i) = \frac{dt'_i}{(1 + t'_i)}.$$

To apply this equation for $i = 2$ (tobacco), we use $dt'_2 = 0.1$ and $t'_2 = 1.19$. We then substitute the right-hand side of equation (5.4) for $d(\log p_i)$ in equation (5.1), use the 5,000 elasticities, and compute the means and standard deviations of consumption, as before. The results are given in the first three entries of column 3 of Table 8.

What happens to tax revenue following this tax increase? When the producer price p'_i is held constant, equation (5.2) implies the change in revenue from i is

$$(5.5) \quad d(\log R_i) = \frac{dt'_i}{t'_i} + d(\log q_i),$$

with $d(\log q_i) = \eta_{ii} d(\log p_i) = \eta_{ii} dt'_i / (1 + t'_i)$, which follows from equations (5.1) and (5.4). We implement equation (5.5) for tobacco, by setting $dt'_2 = 0.1$ and $t'_2 = 1.19$, as before. The change in alcohol tax revenue following the increase in tobacco taxes is $d(\log R_3) = \eta_{32} dt'_2 / (1 + t'_2)$, from equations (5.1), (5.2) and (5.4), while the evolution of total taxes is given by equation (5.3). Rows 4-6 of column 3 of Table 8 give the results of the increase in the tobacco tax obtained by applying the same procedure as that used above. As can be seen, total taxes increase by about 3.7 percent, with a standard deviation of 0.16 percent.

Column 4 of Table 8 gives the results of increasing alcohol taxes by 10 percentage points. As the pre-existing tax rate is $t_3 \times 100 = 41$ percent or $t'_3 \times 100 = 70$ percent, such an increase translates to a 14 percent rise. To put the point another way, when both tax rates rise by 10 percentage points, equation (5.4) implies that consumer prices of tobacco increase by about $10/2.19 = 4.6$ percent, while those of alcohol increase by $10/1.70 = 5.9$ percent. It is thus not surprising that the results pertaining to alcohol in column 4, for the alcohol tax increase, are substantially larger than those pertaining to tobacco of column 3, which refer to the tobacco tax increase. We can put the two tax increases on a more equal footing by increasing each of the rates

by 10 percent, and the results are contained in columns 5 and 6 of Table 8. Now the increase in total revenue is approximately equal in the two cases at about 4 percent, as can be seen from row 6 of columns 5 and 6.

In the previous section, we argued that there was some merit in treating the budget shares as fixed in each trial. We can apply this approach to the present simulations, and columns 7 to 11 of Table 8 contain the results. An element-by-element comparison shows that the mean for each case is approximately the same whether or not the budget share is random. As is to be expected however, the standard deviations fall when the budget shares are fixed, especially those in the two rows involving marijuana.

Taxing Marijuana

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 Appendix 2. 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 need to consider two situations, before and after the change in taxation arrangements, to be denoted by the superscript $\tau = 0$ and $\tau = 1$, respectively. To keep the notation as clear as possible, the τ superscript will be placed in parentheses, so that $R_i^{(\tau)}$ is the revenue from taxing good i in situation (or period) τ , $\tau = 0, 1$. If $t_i^{(\tau)}$ 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 demand, then $R_i^{(\tau)} = t_i^{(\tau)} p_i' q_i^{(\tau)}$, and total revenue is $R^{(\tau)} = \sum_{i=1}^3 R_i^{(\tau)}$. It follows from $d(\log q_i) = \sum_{j=1}^3 \eta_{ij} d(\log p_j)$ and $d(\log p_j) = (t_j^{(1)} - t_j^{(0)}) / (1 + t_j^{(0)})$ that consumption of good i after the tax change can be expressed as

$$(5.6) \quad q_i^{(1)} = q_i^{(0)} \exp \left[\sum_{j=1}^3 \eta_{ij} \left(\frac{t_j^{(1)} - t_j^{(0)}}{1 + t_j^{(0)}} \right) \right] .$$

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 (5.6) then defines the new base, and we use various values of the marijuana tax rate to evaluate revenue with the 5,000 values of the elasticity, in exactly the same manner as before. Table 9 gives the results for revenue in the form of means over the 5,000 trials. As can be seen, the tax yields a nontrivial amount of revenue; for example, a 30 percent rate yields about \$86 per capita p. a., 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 9: The 30 percent marijuana tax causes proceeds from tobacco to fall from \$324 to \$303, a reduction of about 6 percent. Substitutability with alcohol causes alcohol revenue to rise with the marijuana tax, but as can be seen from column 4 of Table 9, this rise is quite modest at about 4 percent for a 30 percent marijuana tax. The net effect of these changes on total receipts from vice taxation is given in column 5, which for a 30 percent marijuana tax rises from \$684 to \$764, or about 12 percent.¹⁹ There are two noticeable patterns in the revenue standard errors. 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 8 plots 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 percent.²⁰ Panel B of Figure 8 illustrates the

¹⁹ 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 percent to revenue from vice taxation. As shown in the sixth element of column 2 of our Table 9, we estimate that the maximum revenue from taxing marijuana in Australia is about \$A105 per capita, or about $105/684 \approx 15$ percent 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).

²⁰ Revenue from marijuana is $R_1^{(1)} = t_1^{(1)} p_1' q_1^{(1)} \exp(\eta_1 t_1^{(1)})$, so that the first-order condition for a maximum is $\partial R_1^{(1)} / \partial t_1^{(1)} = (1 + \eta_1 t_1^{(1)}) p_1' q_1^{(1)} \exp(\eta_1 t_1^{(1)}) = 0$. Accordingly, the revenue-maximizing tax is $t_1^{(1)*} = 1 / \eta_1$. The corresponding tax

underlying uncertainty of the tax revenues by presenting a type of “fan chart” (Britton 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 some of 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 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 t_1^{*}]
- (iii) $t_2^{(1)} = t_2^{(0)}$ [Tobacco continues to be taxed at the same rate]
- (iv) $R^{(1)} = R^{(0)}$ [Total tax revenue is unchanged].

Details of the numerical solution to this problem are contained in Appendix 3. Panel A of Figure 9 gives this tradeoff by averaging over the 5,000 trials as before. As can be seen, the tradeoff is negatively-sloped, 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; and this smaller amount of additional revenue is then redistributed in the form of a smaller reduction of alcohol taxes, resulting in the flattening out of the tradeoff. When the marijuana tax exceeds the revenue-maximising rate, the slope of the tradeoff switches to positive (but this cannot be easily seen from Figure 9). (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.²¹ The slope of the tradeoff (again averaged over the 5,000 trials) is

as a proportion of the consumer price is $t_1^{(0)*} = t_1^{(0)}/(1+t_1^{(0)}) = 1/(1-\eta_{ii})$. Using the mean elasticity of $\eta_{ii} = -0.64$, $t_1^{(0)*} = 0.6$. In view of the approximation involved in using means (ignoring Jensen’s inequality), this value seems in reasonable agreement with the revenue-maximising rate of Figure 8.

²¹ 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

given in Panel B of Figure 9. This reveals that for rates of taxation of marijuana of 20 percent 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 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 percent to, say, 30 percent, the slope of the curve falls (in absolute value), from 0.47 to 0.42.

As the tradeoff of Figure 9 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 10. 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. Note from Panel B of Figure 10 there is a hint that high rates of taxation cause the slope to become positive, as the revenue-maximising rate is exceeded. Finally, we consider the distribution of the alcohol tax conditional on the marijuana tax by analysing cross sections of the “vice mountain” of Figure 10. The left-hand side of Panel A of Figure 11 presents the conditional distribution when marijuana is taxed at 10 percent. As can be seen, the mean alcohol tax is about 35 percent, while the standard deviation of the 5,000 trials is 1 percentage points. As the marijuana tax is increased to 20 and 30 percent, the mean alcohol tax falls to 30 and 26 percent, respectively, and the standard deviation rises to 1.5 and 2.6 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 distribution of the slope of the tradeoff, given on the right-hand side of Figure 11.

6. CONCLUDING COMMENTS

This paper has considered the generic problem of how to analyse the demand for a product for which there is little information available in the form of hard data and its price responsiveness. To deal this problem, we introduced procedures that (i) draw on the interactions in consumption

alcohol tax also leads to reduced revenue from tobacco. Accordingly, as we move down the tradeoff, 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.

between the products 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 available, 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 derived 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 carried 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). However, the net effect is for revenue from vice taxation to increase with the marijuana tax up until the rate hits about 50 percent of consumer prices (or about 100 percent of producer prices). We estimate that the maximum revenue attainable from taxing marijuana is equivalent to about 15 percent of pre-existing revenue from vice. Next, we analysed by how much alcohol taxes could be reduced 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, has the reasonable property that it increases as we move away from the status quo whereby marijuana escapes the tax net, and subject it to successively higher rates of taxation.

APPENDIX 1

THE DATA

Table A1 provides Australian data on the expenditure on the three alcoholic beverages -- beer, wine and spirits -- as well as total alcohol. As can be seen from Panel B, in the late 1990s beer absorbs slightly more than one half of total spending on alcohol, while the remainder is split roughly equally between wine and spirits. Table A2 gives the corresponding data for marijuana and tobacco, and compares this with alcohol and total consumption expenditure. The quantity data for marijuana is estimated on the basis of the Australian National Drug Strategy Household Survey (various issues), together with some plausible assumptions that link intensity of use to frequency of use; see Clements and Daryal (2005) for details. Although all care was taken in preparing these estimates, and they are not inconsistent with independent estimates, it must be acknowledged that they are likely to be subject to a substantial margin of error. The marijuana prices have been described by Clements (2004) as follows:

The data on Australian marijuana prices were generously supplied by Mark Hazell of the Australian Bureau of Criminal Intelligence. These prices were collected by law enforcement agencies in the various states and territories during undercover buys. In general, the data are quarterly and refer to the period 1990-1999, for each state and territory. The different types of marijuana identified separately are leaf, heads, hydroponics, skunk, hash resin and hash oil. However, we focus on only the prices of "leaf" and "heads", as these products are the most popular. The data are described by Australian Bureau of Criminal Intelligence (1996) who discuss some difficulties with them regarding different recording practices used by the various agencies and missing observations. While it is unlikely that these data constitute a random sample, a common problem when studying the prices of almost any illicit good, it is not clear that they would be biased either upwards or downwards. In any event, they are the only data available.

The prices are usually recorded in the form of ranges and the basic data are listed in Clements and Daryal (2001). The data are "consolidated" by: (i) Using the mid-point of each price range; (ii) converting all gram prices to ounces by multiplying by 28; and (iii) annualising the data by averaging the quarterly or semi-annual observations. Annualising has the effect of reducing the considerable noise in the quarterly/semi-annual data. Plotting the data revealed several outliers which probably reflect some of the above-mentioned recording problems. Observations are treated as outliers if they are either less than one-half of the mean for the corresponding state, or greater than twice the mean. This rule led to five outlying observations which are omitted and replaced with the relevant means, based on the remaining observations.

For a listing of the price data, after consolidation and editing, see Clements (2004).

The last column of Panel B of Table A2 presents the budget share of vice -- the sum of marijuana, tobacco and alcohol -- and, interestingly, this has declined noticeably over the decade of the 1990s. This share was 13.4 percent in 1988 and fell by more than 5 percentage points to end up

at 7.8 percent in 1998. A large part of this fall is accounted for by the decline in the share of tobacco, which fell by almost 4 percentage points.

APPENDIX 2

NOTES ON LEGALISATION, TAXES AND MARIJUANA PRICES

In the text, we considered the scenario of legalising the consumption and production of marijuana and then subjecting it to varying degrees of taxation. We supposed that this would lead to the consumer price of marijuana increasing by the full amount of the tax, implying that (i) legalisation without taxation would have the effect of leaving the price unchanged and (ii) all of the tax is borne by consumers.²² While this approach has the merit of simplicity, it is not the only possibility, and in this appendix we explore the issues involved.

Following Miron (2005), we can analyse the change in the price resulting from legalisation by reference to the relative shifts of the marijuana demand and supply curves. According to the “forbidden fruit” hypothesis, legalisation makes marijuana less attractive and shifts the demand curve down and to the left, as in panel A of Figure 12. Evidence on this hypothesis from the experience with decriminalisation (which could be thought of as a weak form of legalisation) in (predominantly) the states of the US is mixed: Studies using data pertaining to the whole population (Cameron and Williams, 2001, Model, 1993, Saffer and Chaloupka, 1995, 1998) find a significant increase in marijuana consumption due to decriminalisation.²³ By contrast, three other studies involving youths only (Johnston et al., 1981, Pacula, 1997, Theis and Register, 1993) find that decriminalisation has no significant impact. Evidently, as the general population consume less marijuana than do the young, their consumption is more sensitive to changes in its legal status. On the basis of a survey of university students, Daryal (2002) finds that on average consumption would increase modestly with legalisation.

Regarding the supply curve, Miron (1998, 2005) argues on a priori grounds that legalisation could shift it either up or down, as shown in panel B of Figure 12. With legalisation, producers would no longer be forced to incur costs associated with concealing their activities to avoid prosecution, causing the supply curve to shift down and to the right. On the other hand however, legalisation would also mean that producers would have to pay taxes and charges, and comply with all regulations that legitimate businesses are subject to. Additionally, marijuana producers would possibly have to incur advertising expenses if the product were legalised. These effects would cause the supply curve to shift up and to the left.

²² There is also the possibility of some combination of a rise in the pre-tax price with legalisation, coupled with just the right amount of the tax (less than 100 percent) being borne by consumers, leading to the same result. As this would seem to be an unlikely possibility, we do not consider it further.

²³ It is to be noted, however, Cameron and Williams (2001) find the increase in consumption to be only temporary.

The net effect of these shifts in the demand and supply curves on prices is ambiguous as is illustrated in panel C of Figure 12 for the simplified case in which the demand curve remains unchanged. This ambiguity can only be resolved with empirical evidence. While such evidence is not easy to obtain, Miron (2005) argues that on the basis of a comparison of marijuana prices in the US, where restrictions are stronger, and Australian and The Netherlands, where they are weaker, the net effect on prices likely to be quite small. Another piece of evidence that points in the same direction is Miron's (2003) finding on the basis of an extremely detailed and careful analysis that markups from "farmgate" to consumers of heroin and cocaine are substantially smaller than previously thought; in fact, he finds these markups to be not massively larger than those of legal goods such as chocolate, coffee and tea. On the basis of other evidence, Miron (2003, p. 529) estimates "that the black market price of cocaine is 2-4 times the price that would obtain in a legal market, and of heroin 6-19 times. In contrast, prior research has suggested that cocaine sells at 10 to 40 times its legal price and heroin at hundreds of times its legal price." The smaller markups could be taken to imply that as the illicit nature of these drugs per se has only a limited (or a more limited than previously thought) impact on prices, the price effects of legalisation would likewise be limited.²⁴ Consistent with this line of thinking is research which shows that increased enforcement of drug laws does not seem to result in higher prices (DiNardo, 1993, Weatherburn and Lind, 1997, Yuan and Caulkins, 1998).

The response of the consumer price to the imposition of the tax relates to the incidence of the tax. The economic incidence of a tax is independent of its legal incidence (in the sense of who writes the cheque for the tax), and in a partial equilibrium framework it is shared between producers and consumers, depending on the value of the price elasticity of supply relative to the price elasticity of demand. In the special case in which supply is infinitely elastic, producers escape all the burden of the tax, and consumers pay 100 percent in the form of higher prices; that is, in this situation the tax is completely passed onto consumers. Although it is difficult to argue convincingly that this accurately describes the supply side of the marijuana market, the ease with which it can be cultivated with hydroponic techniques, the ready availability of the required technology, and the lack of specialised inputs -- remembering that we are considering a legalised regime -- all point in the direction of the elasticity of supply being high. Accordingly, the assumption that all of the tax is borne by consumers may not be too bad as a first approximation;

²⁴ Miron (1999) provides another piece of evidence with his study of the impact of prohibition on alcohol consumption in the United States during 1920-33. Using the death rate from liver cirrhosis as a proxy for alcohol consumption, he finds that prohibition "exerted a modest and possibly even positive effect on consumption." This could be because prices fell for reasons given above. But there are other possibilities including a highly inelastic demand for alcohol and/or prohibition giving alcohol the status of a "forbidden fruit" (Miron, 1999).

but of course to the extent to which the elasticity is less than infinite, some of the tax would be absorbed by producers and our results would overstate its impact on consumers.

APPENDIX 3

NUMERICAL ASPECTS OF THE MARIJUANA-ALCOHOL TAX TRADEOFF

This appendix sets out the details of the numerical analysis regarding the tradeoff between marijuana and alcohol taxes. With the introduction of the marijuana tax at the rate of $t_1^{(1)}$, our objective is to obtain the new alcohol tax rate $t_3^{(1)}$ that keeps the total tax revenue from vice constant.

The tax base of good i under the new tax regime, $q_i^{(1)}$, is given by equation (5.6). We can express tax revenue from marijuana in terms of producer prices as $R_i^{(1)} = t_i^{(1)} p_i' q_i^{(1)}$. As we possess the base-period consumption of tobacco and alcohol and assume that their prices do not change, it is convenient to express tax revenues from these two goods in terms of consumer prices. We then set the total tax revenue from vice under the new regime, $R^{(1)}$, equal to the previous total tax revenue, $R^{(0)}$, i.e.,

$$(A1) \left\{ \begin{aligned} R^{(1)} &= \sum_{i=1}^3 R_i^{(1)} = t_1^{(1)} p_1' q_1^{(0)} \exp\left(\sum_{j=1}^3 \eta_{1j} \frac{t_j^{(1)} - t_j^{(0)}}{1 + t_j^{(0)}}\right) + t_2^{(1)} p_2 q_2^{(0)} \exp\left(\sum_{j=1}^3 \eta_{2j} \frac{t_j^{(1)} - t_j^{(0)}}{1 + t_j^{(0)}}\right) \\ &+ t_3^{(1)} p_3 q_3^{(0)} \exp\left(\sum_{j=1}^3 \eta_{3j} \frac{t_j^{(1)} - t_j^{(0)}}{1 + t_j^{(0)}}\right) = R^{(0)}. \end{aligned} \right.$$

The constant tobacco tax rate, $t_2^{(1)} = t_2^{(0)}$, makes the second term in the summation of each of the exponential functions disappear. This also leads to $t_2^{(1)} = t_2^{(0)} = 0.543$ (from Table 7). We also obtain $R^{(0)} = 684$ from Table 7 and the following base-period consumption expenditures: $p_1' q_1^{(0)} = 372$, $p_2 q_2^{(0)} = 597$, $p_3 q_3^{(0)} = 879$. Substituting $t_3^{(1)} = t_3^{(1)} / (1 + t_3^{(1)})$ into equation (A1), we see that revenue is a function of only two unknown variables $t_1^{(1)}$ and $t_3^{(1)}$. Thus if we define the function $g = R^{(1)} - R^{(0)}$, the alcohol-marijuana tax tradeoff takes the form $g = g(t_1^{(1)}, t_3^{(1)}; \theta) = 0$, where θ refers to the remaining known variables from Table 7 and the elasticities. To be explicit,

$$(A2) \left\{ \begin{aligned} g &= t_1^{(1)} \times 372 \times \exp\left(\eta_{11} t_1^{(1)} + \eta_{13} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}}\right) + .543 \times 597 \times \exp\left(\eta_{21} t_1^{(1)} + \eta_{23} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}}\right) \\ &+ \frac{t_3^{(1)}}{1 + t_3^{(1)}} \times 879 \times \exp\left(\eta_{31} t_1^{(1)} + \eta_{33} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}}\right) - 684 = 0. \end{aligned} \right.$$

We specify the value of $t_1^{(1)}$ in equation (A2) and increase it progressively from 0, 0.001, 0.002, For each value of $t_1^{(1)}$ and each set of η_{ii} , we solve for $t_3^{(1)}$ in $g = g(t_1^{(1)}, t_3^{(1)}; \theta) = 0$. As $g(\bullet) = 0$ is nonlinear in $t_3^{(1)}$, its solution requires numerical methods. We use a grid search to find the value of $t_3^{(1)}$ that satisfies $|g| < 0.1$. Using approximation $\exp(x) \approx 1 + x$ for small x , new consumption of good i can be expressed as

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

Instead of using equation (5.6), we substitute the above equation into the revenue expression (A1), so that the approximation to $g = g(\bullet)$, call it $g' = g'(\bullet)$, is now quadratic in $t_3^{(1)}$:

$$\begin{aligned} g' = t_1^{(1)} p_1' q_1^{(0)} \left(1 + \eta_{11} t_1^{(1)} + \eta_{13} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}} \right) + t_2^{(1)} p_2' q_2^{(0)} \left(1 + \eta_{21} t_1^{(1)} + \eta_{23} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}} \right) \\ + \frac{t_3^{(1)}}{1 + t_3^{(1)}} p_3' q_3^{(0)} \left(1 + \eta_{31} t_1^{(1)} + \eta_{33} \frac{t_3^{(1)} - t_3^{(0)}}{1 + t_3^{(0)}} \right). \end{aligned}$$

There are two real roots for the equation $g'(\bullet) = 0$ when $t_1^{(1)}$ is in the range of 0 and 0.61, which corresponds to the marijuana tax in terms of consumer prices $t_1^{(1)}$ being in the range of 0 and 0.38. We thus use the root that lies between 0 and 1 as the initial guess of $t_3^{(1)}$ and then use a grid search to locate the solution of $g(\bullet) = 0$. This procedure converges fairly quickly. For a given value of $t_1^{(1)} \leq 0.38$, we use the 5,000 simulated values of η_{ii} described in the text to obtain 5,000 values of $t_3^{(1)}$. In particular, we record the mean of $t_3^{(1)}$ corresponding to $t_1^{(1)} = 0.38$ as $\tilde{t}_3^{(1)}$. When $t_1^{(1)} > 0.38$, as $g'(\bullet) = 0$ has no real roots, we use $\tilde{t}_3^{(1)}$ as the initial value in a grid search. This procedure also converges reasonably quickly to the solution of original equation $g(\bullet) = 0$.

Finally, we convert the tax rate as a proportion of the consumer price using $t_3^{(1)} = t_3^{(1)} / (1 + t_3^{(1)})$.

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TABLE 1
BASIC 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		$\phi = -.5$	

TABLE 2
RELATIVE FREQUENCIES OF VICE CONSUMPTION IN AUSTRALIA
(Percentages)

Good	Unconditional	Conditional on consumption of		
		Marijuana	Tobacco	Alcohol
(1)	(2)	(3)	(4)	(5)
Marijuana	14.2	1	33.8	16.5
Tobacco	23.7	56.3	1	25.9
Alcohol	83.9	96.5	90.7	1

Source: Zhao and Harris (2004, p. 397).

TABLE 3
FIRST SPECIFICATION OF PRICE RESPONSIVENESS OF DEMAND: $\rho = 0$

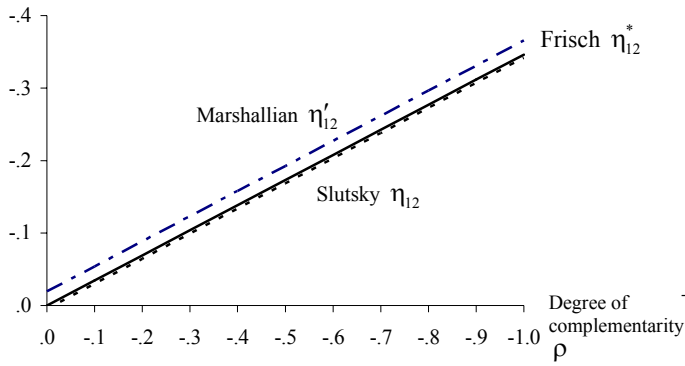
Good	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other
	A. Price Coefficients $\mathbf{v} (\times 10^2)$				B. Inverse of Price Coefficients $\mathbf{v}^{-1} (\times 10^{-1})$				C. Frisch Price Elasticities $[\eta_{ij}^*]$			
Marijuana	-1.20	0	0	0	-8.33	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. Slutsky Coefficients $[\pi_{ij}] (\times 10^2)$				E. Slutsky Price Elasticities $[\eta_{ij}]$				F. Marshallian Price Elasticities $[\eta'_{ij}]$			
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 4
SECOND SPECIFICATION OF PRICE RESPONSIVENESS OF DEMAND: $\rho = -.5$

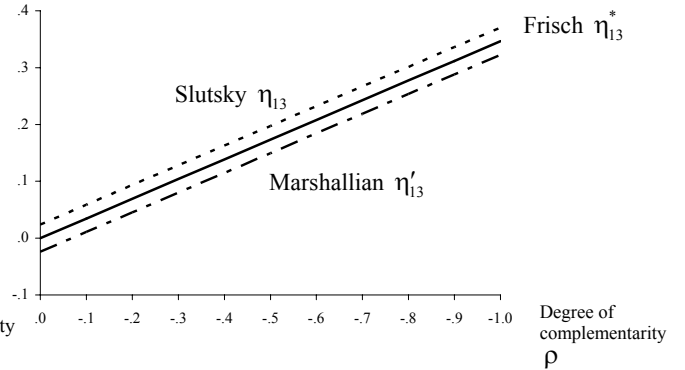
Good	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other
	A. Price Coefficients $\mathbf{v} (\times 10^2)$				B. Inverse of Price Coefficients $\mathbf{v}^{-1} (\times 10^{-1})$				C. Frisch Price Elasticities $[\eta_{ij}^*]$			
Marijuana	-1.20	-.35	.35	0	-11.12	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. Slutsky Coefficients $[\pi_{ij}] (\times 10^2)$				E. Slutsky Price Elasticities $[\eta_{ij}]$				F. Marshallian Price Elasticities $[\eta'_{ij}]$			
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

FIGURE 1
 PRICE ELASTICITIES OF DEMAND AND
 THE DEGREE OF COMPLEMENTARITY

A. Marijuana with respect to the Price of Tobacco



B. Marijuana with respect to the Price of Alcohol



C. Own-Price Elasticities of Demand For Alcohol

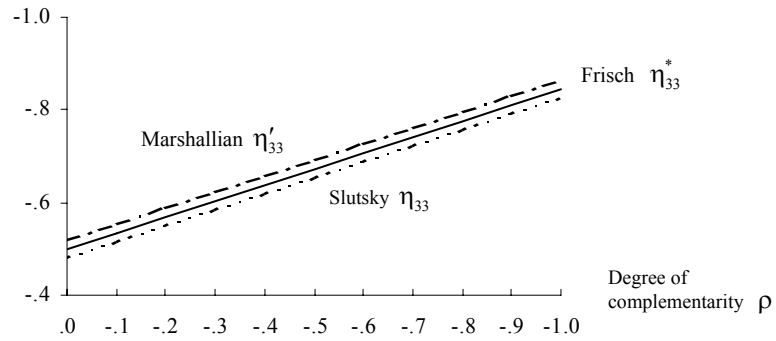


TABLE 5
DATA FOR STOCHASTIC VICE

Variable/ parameter (1)	Mean (2)	Range (3)	Implied standard deviation (4)	Coefficient of variation (5)	Constraint (6)
<u>Budget shares w_i</u>					
1. Marijuana	.02	(.01, .03)	.005	.25	$0 < w_1 < 1$
2. Tobacco	.02	(.015, .025)	.0025	.125	$0 < w_2 < 1$
3. Alcohol	.04	(.03, .05)	.005	.125	$0 < w_3 < 1$
4. Other	.92	(.905, .935)	.0075	.008	$0 < w_4 < 1, w_4 = 1 - \sum_{i=1}^3 w_i$
Sum	<u>1.00</u>				
<u>Income flexibility</u>					
5. ϕ	-.5	(-.75, -.25)	.125	.25	$\phi < 0$
<u>Correlation coefficient</u>					
6. ρ	-.5	(-1.00, .00)	.25	.50	$-1 < \rho < 0$
<u>Marginal shares θ_i</u>					
7. Marijuana	.024	(.000, .048)	.012	.50	$\theta_1 > 0$
8. Tobacco	.008	(.004, .012)	.002	.25	$\theta_2 > 0$
9. Alcohol	.04	(.02, .06)	.01	.25	$\theta_3 > 0$
10. Other	.928	(.896, .96)	.016	.017	$\theta_4 > 0, \theta_4 = 1 - \sum_{i=1}^3 \theta_i$
Sum	<u>1.00</u>				
<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 range for each variable given in column 3 is the approximate 95 percent confidence interval based on normality.

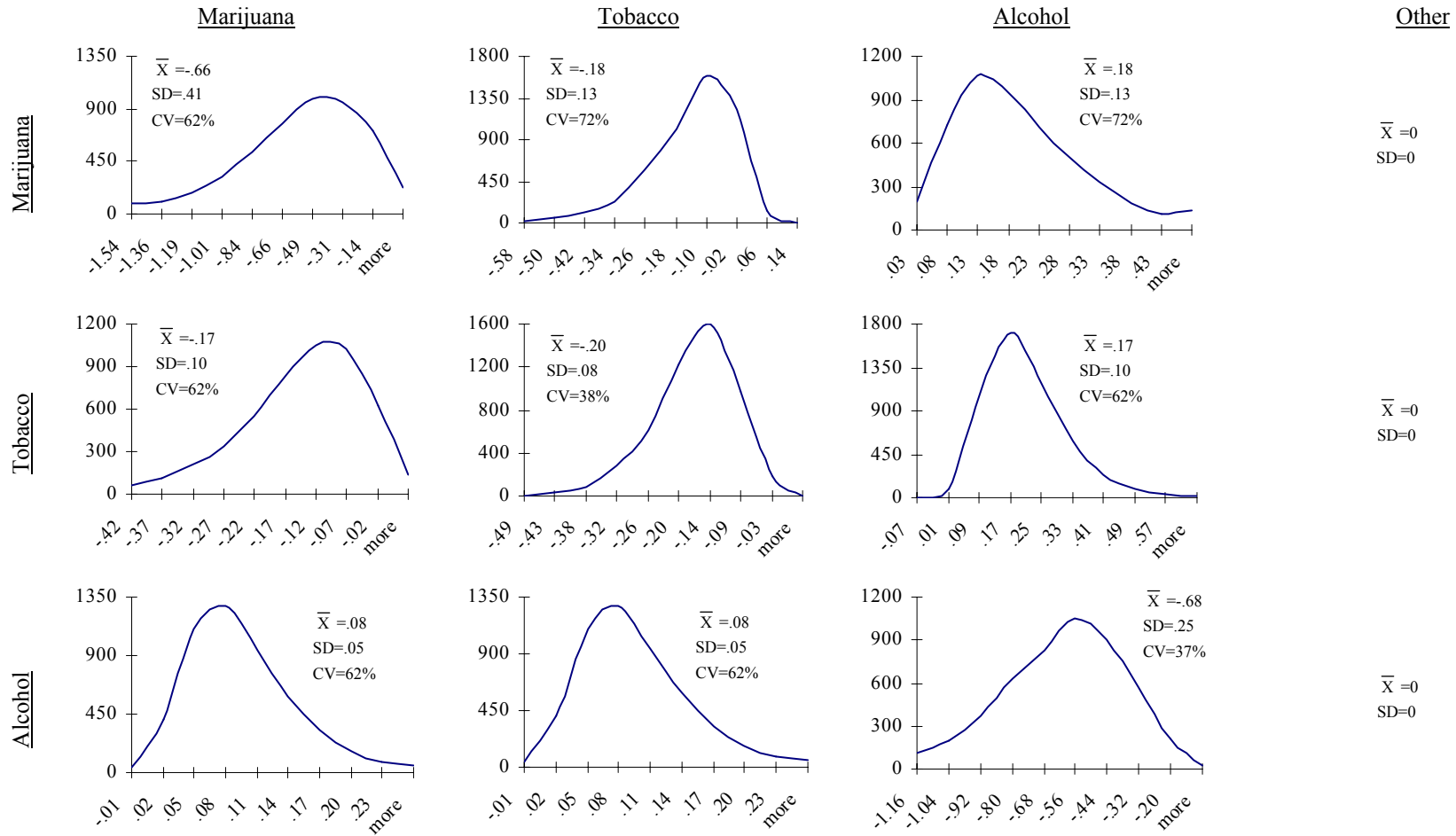
TABLE 6
SUMMARY OF SIMULATION RESULTS

Good	Everything random				Budget shares nonrandom			
	Marijuana	Tobacco	Alcohol	Other	Marijuana	Tobacco	Alcohol	Other
<u>A. Frisch Price Elasticities [η_{ij}^*]</u>								
Marijuana	-.66 (.41)	-.18 (.13)	.18 (.13)	0 (0)	-.61 (.30)	-.16 (.10)	.16 (.10)	0 (0)
Tobacco	-.17 (.10)	-.20 (.08)	.17 (.10)	0 (0)	-.16 (.10)	-.20 (.07)	.16 (.10)	0 (0)
Alcohol	.08 (.05)	.08 (.05)	-.68 (.25)	0 (0)	.08 (.05)	.08 (.05)	-.67 (.23)	0 (0)
Other	0 (0)	0 (0)	0 (0)	-.50 (.13)	0 (0)	0 (0)	0 (0)	-.50 (.13)
<u>B. Slutsky Price Elasticities [η_{ij}]</u>								
Marijuana	-.641 (.393)	-.171 (.125)	.203 (.140)	.609 (.373)	-.590 (.283)	-.160 (.095)	.189 (.104)	.561 (.269)
Tobacco	-.162 (.102)	-.201 (.077)	.175 (.106)	.188 (.072)	-.160 (.095)	-.199 (.071)	.173 (.098)	.186 (.067)
Alcohol	.096 (.057)	.088 (.053)	-.654 (.240)	.470 (.176)	.095 (.052)	.086 (.049)	-.645 (.223)	.464 (.168)
Other	.012 (.006)	.004 (.001)	.020 (.007)	-.037 (.012)	.012 (.006)	.004 (.001)	.020 (.007)	-.036 (.012)
<u>C. Marshallian Price Elasticities [η'_{ij}]</u>								
Marijuana	-.665 (.390)	-.195 (.125)	.155 (.140)	-.495 (.371)	-.614 (.283)	-.184 (.095)	.141 (.104)	-.543 (.269)
Tobacco	-.170 (.102)	-.209 (.077)	.159 (.106)	-.180 (.072)	-.168 (.095)	-.207 (.071)	.157 (.098)	-.182 (.067)
Alcohol	.076 (.057)	.068 (.053)	-.694 (.238)	-.450 (.175)	.075 (.052)	.066 (.049)	-.685 (.223)	-.456 (.168)
Other	-.008 (.008)	-.016 (.003)	-.020 (.009)	-.964 (.014)	-.008 (.006)	-.016 (.001)	-.020 (.007)	-.964 (.012)
<u>D. Income Elasticities [η_i]</u>								
	1.323 (.807)	.405 (.115)	1.018 (.292)	1.008 (.019)	1.208 (.561)	.400 (.101)	1.008 (.250)	1.008 (.017)

Note: The first entry in each cell is the mean over the 5,000 trials. The second entry, given in parentheses, is the associated standard deviation.

FIGURE 2

A. SIMULATED FRISCH PRICE ELASTICITIES: EVERYTHING RANDOM

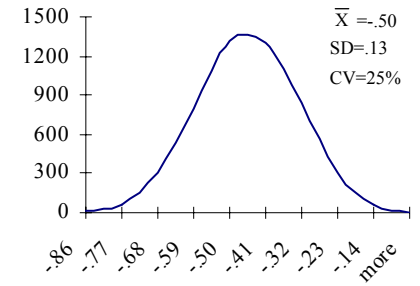


Other

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SD=0

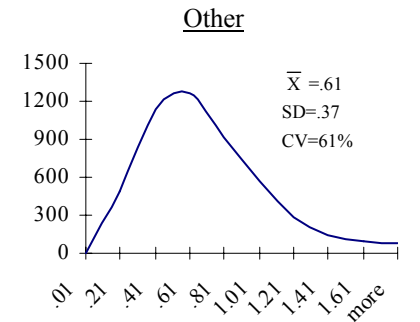
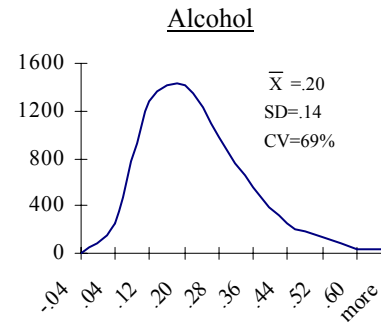
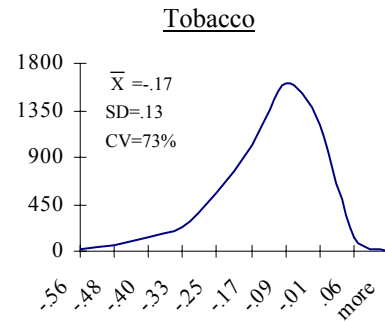
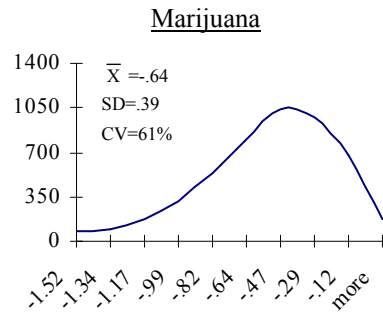
$\bar{X} = 0$
SD=0

$\bar{X} = 0$
SD=0

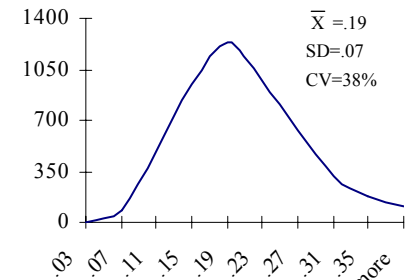
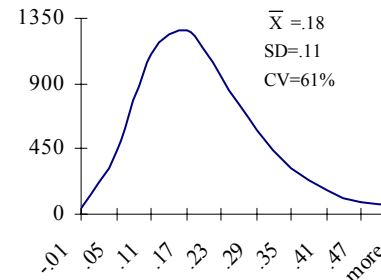
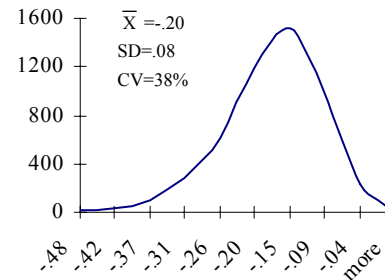
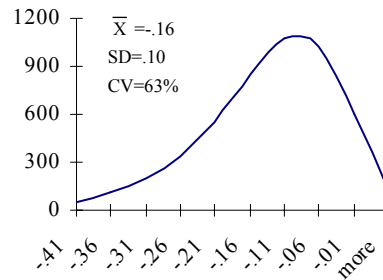


B. SIMULATED SLUTSKY PRICE ELASTICITIES: EVERYTHING RANDOM

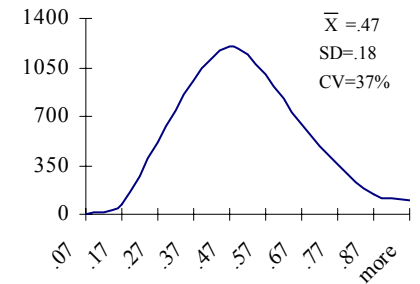
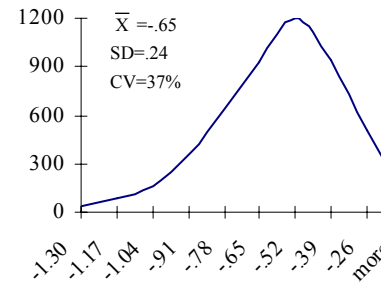
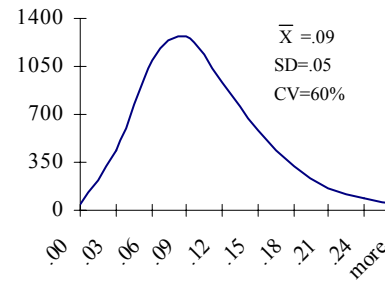
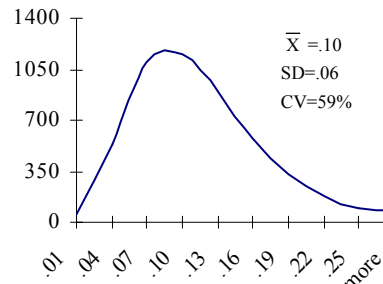
Marijuana

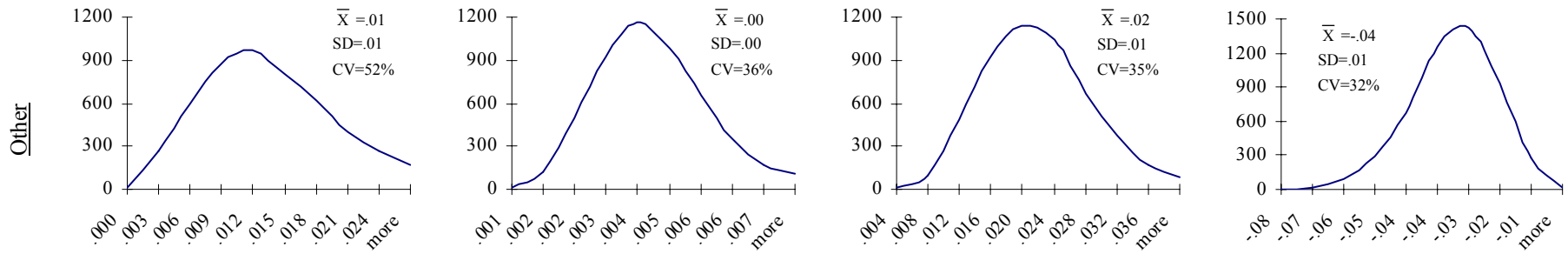


Tobacco

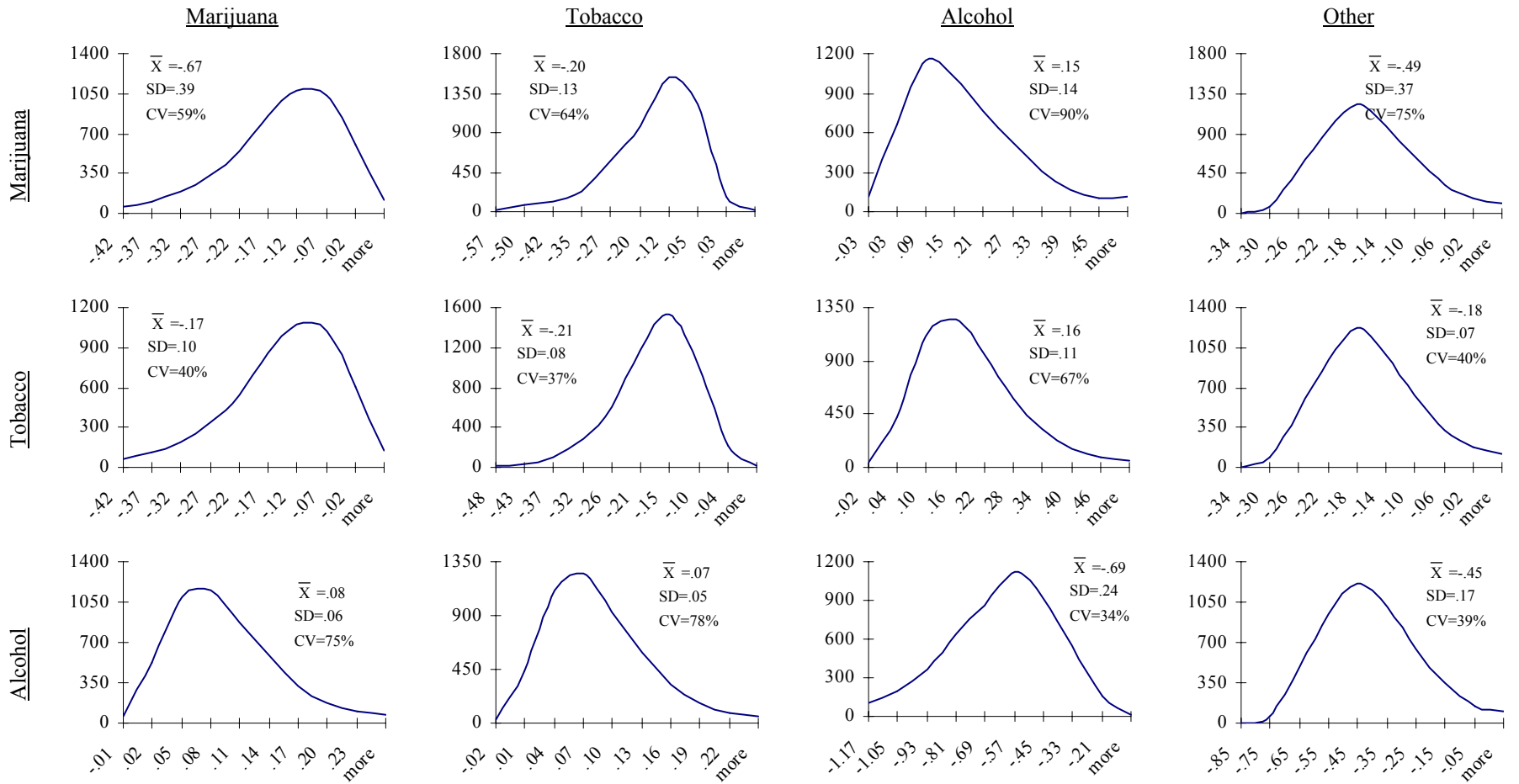


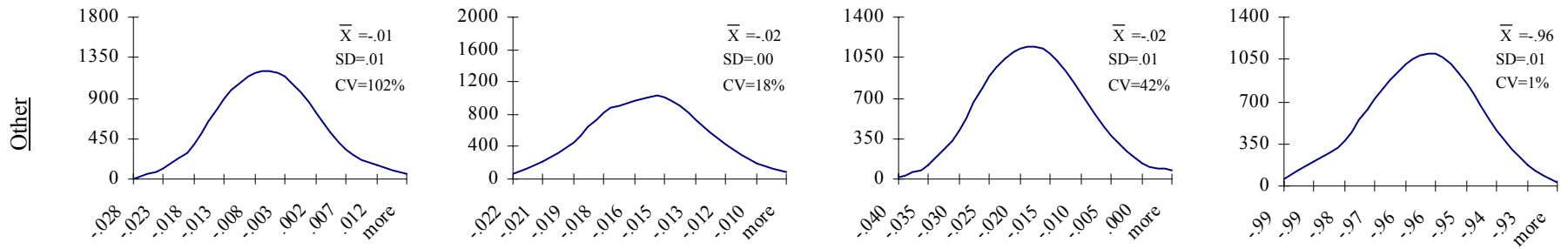
Alcohol





C. SIMULATED MARSHALLIAN PRICE ELASTICITIES: EVERYTHING RANDOM

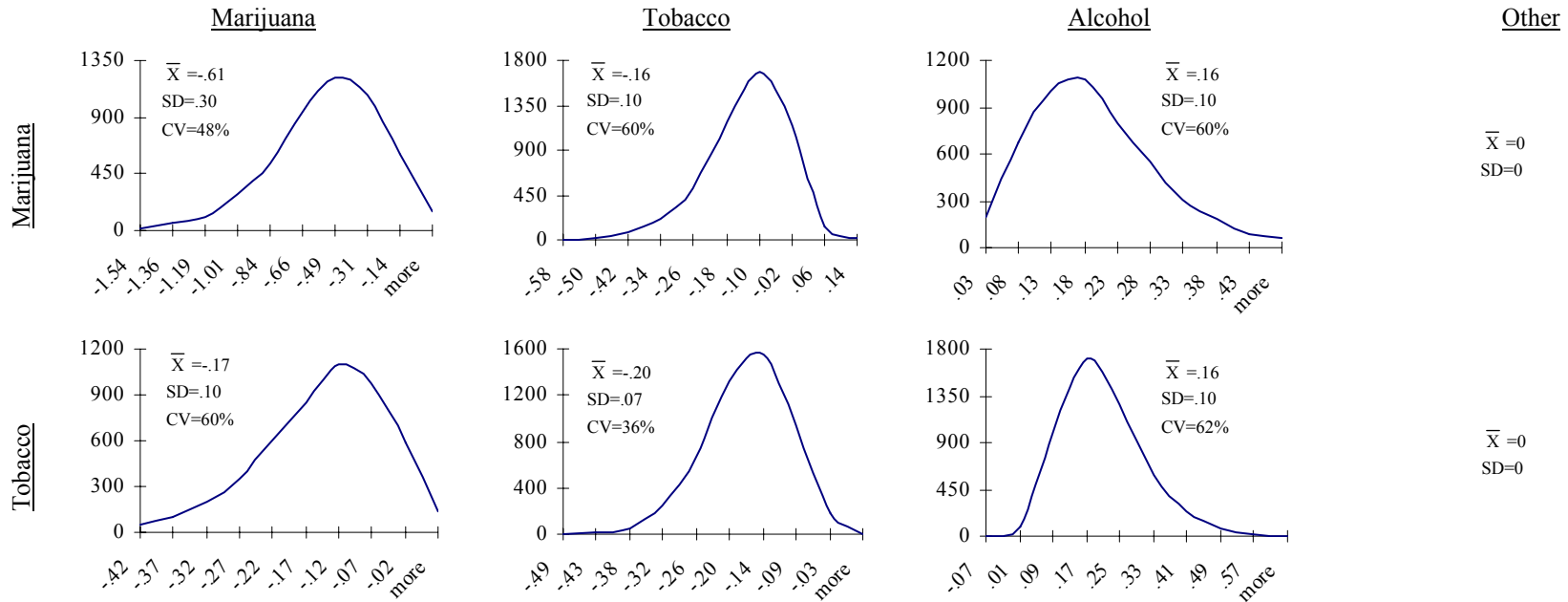


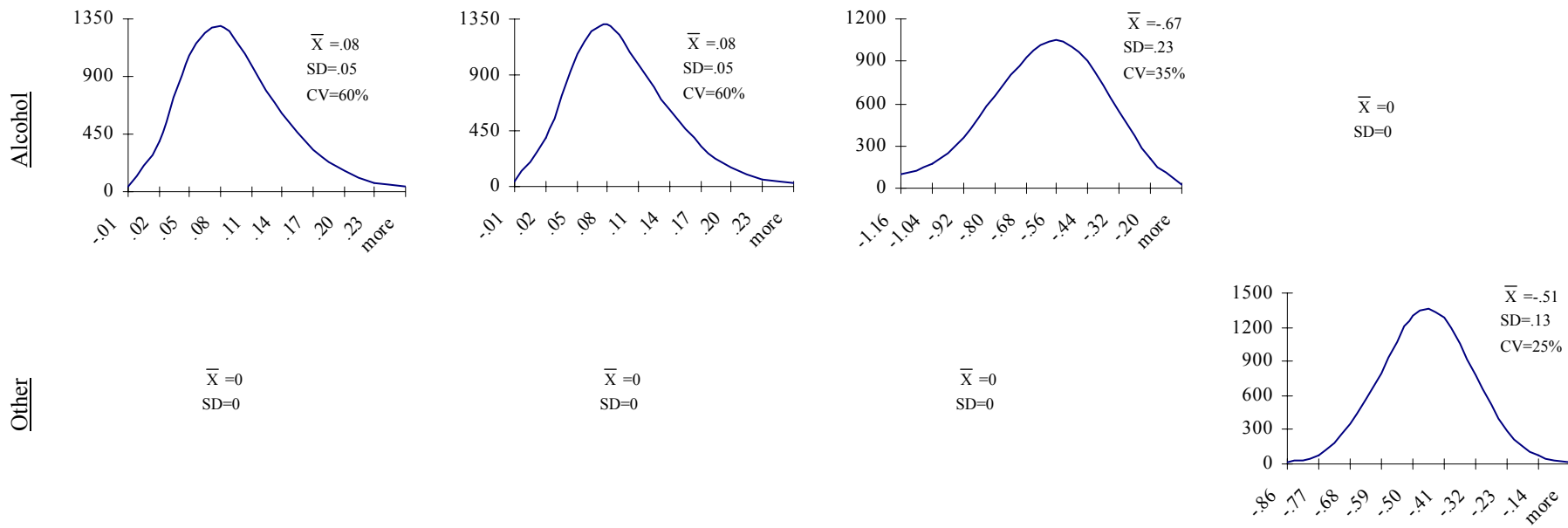


Note: The bin-length for each elasticity is chosen so that there are at least 4,900 observations within nine bins. In a few cases, long tails are truncated with approximately an equal number of observations on both sides of the mean.

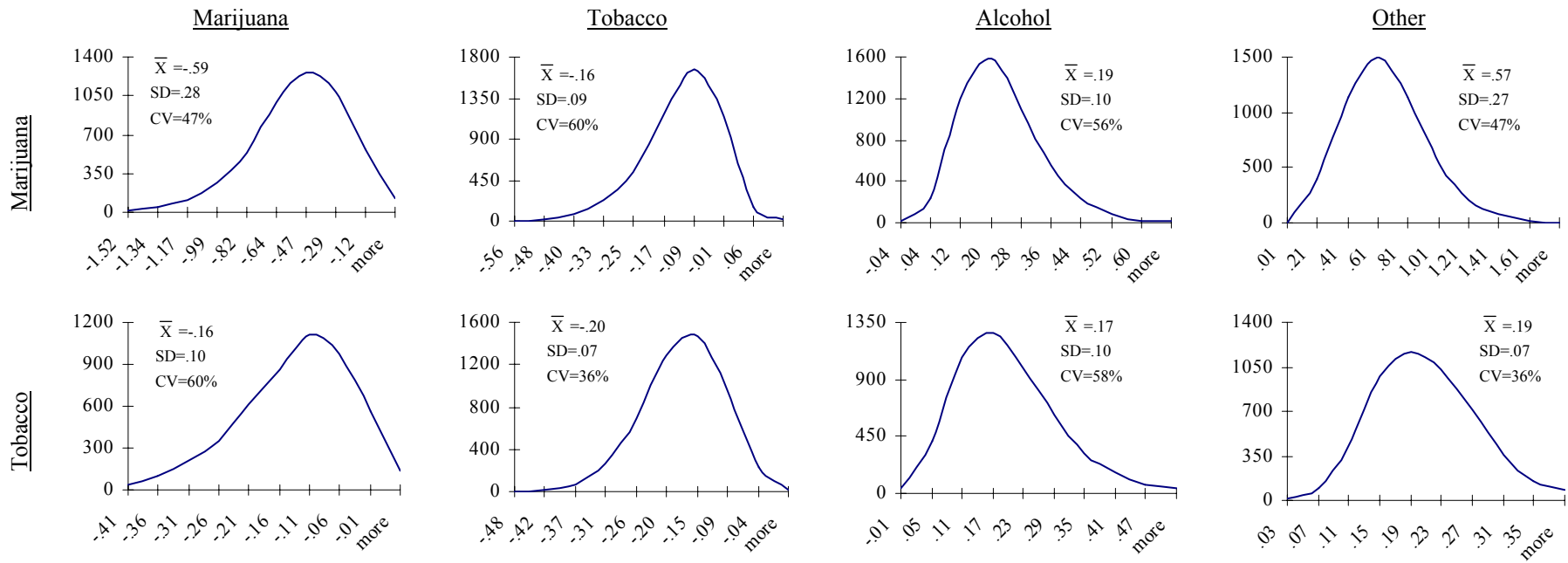
FIGURE 3

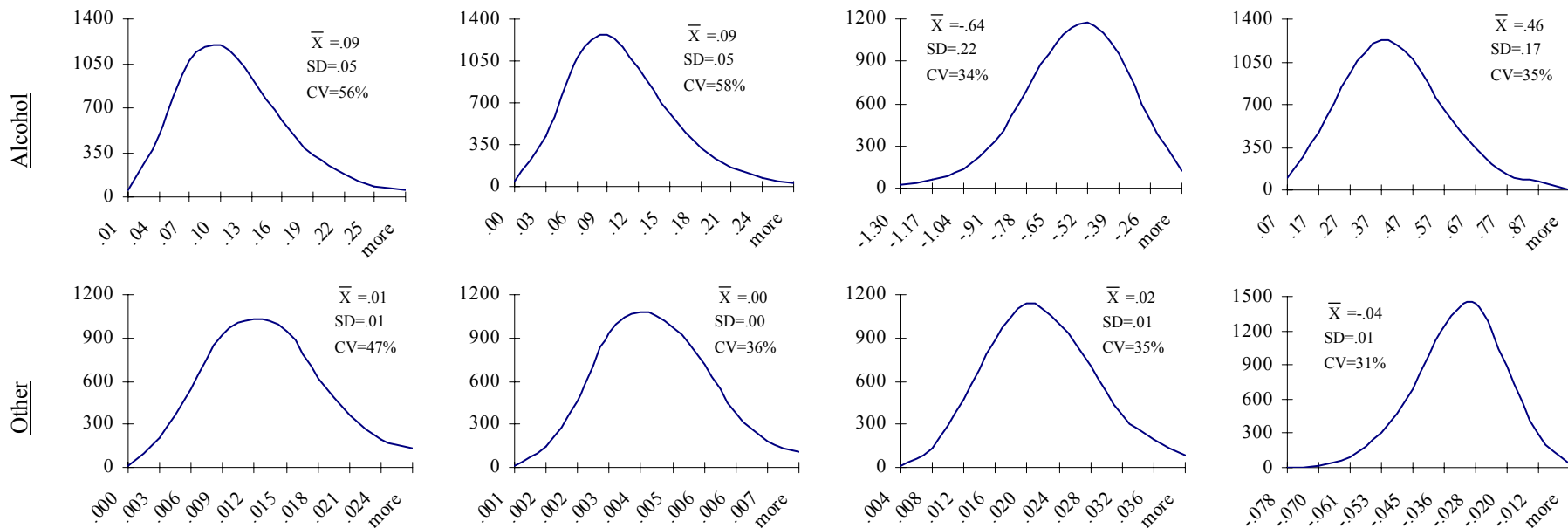
A. SIMULATED FRISCH PRICE ELASTICITIES: BUDGET SHARES NOT RANDOM



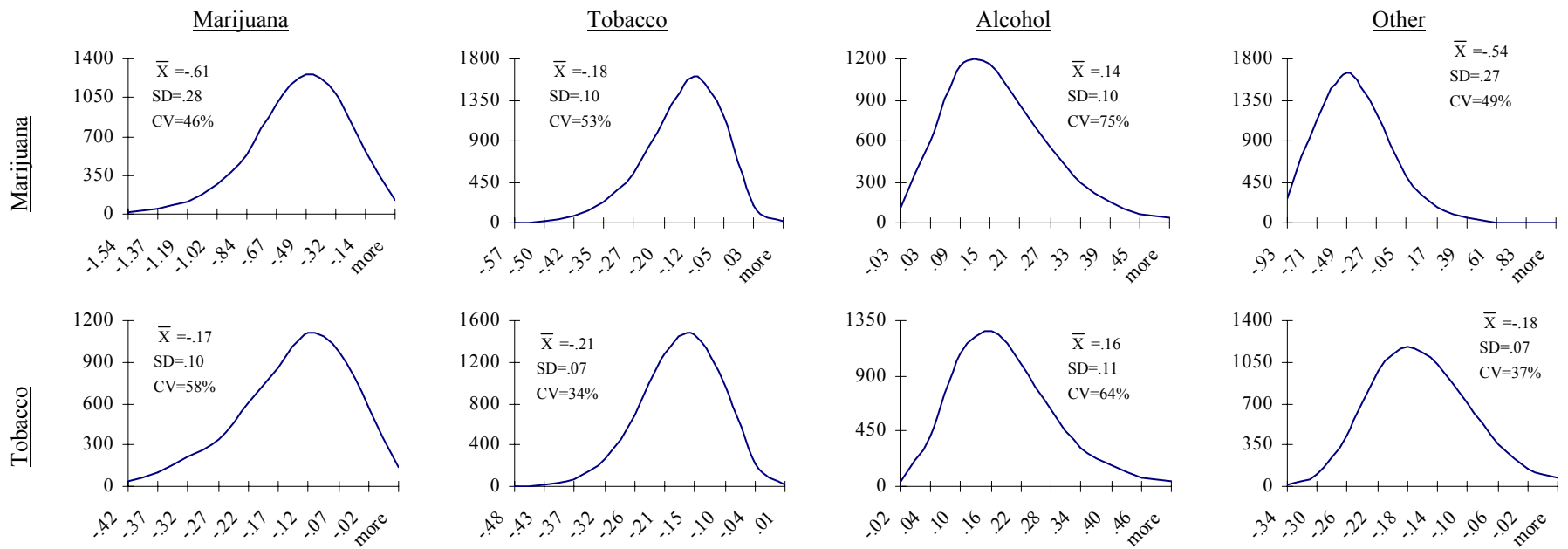


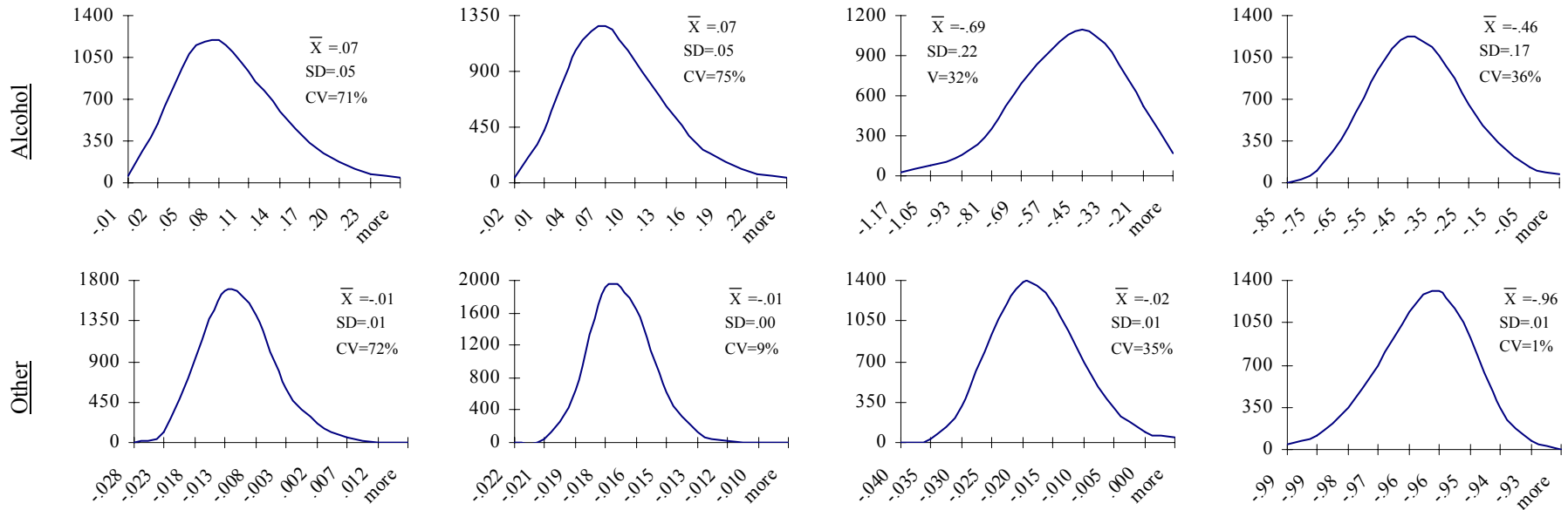
B. SIMULATED SLUTSKY PRICE ELASTICITIES: BUDGET SHARES NOT RANDOM





C. SIMULATED MARSHALLIAN PRICE ELASTICITIES: BUDGET SHARES NOT RANDOM





See notes to Figure 2

FIGURE 4
SIMULATED INCOME ELASTICITIES

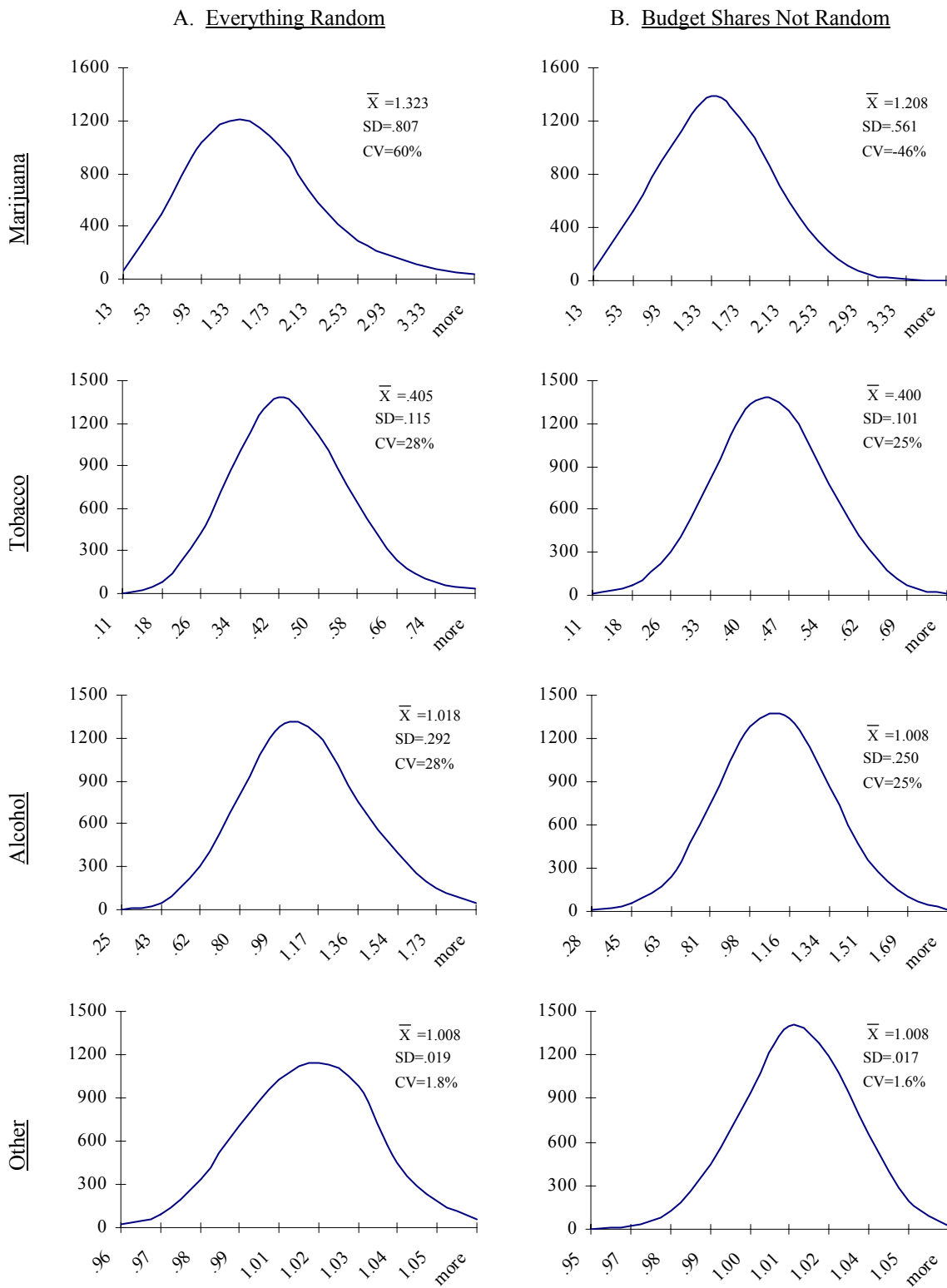


FIGURE 5
THE MARIJUANA DEMAND CURVE
(Mean over 5,000 trials)

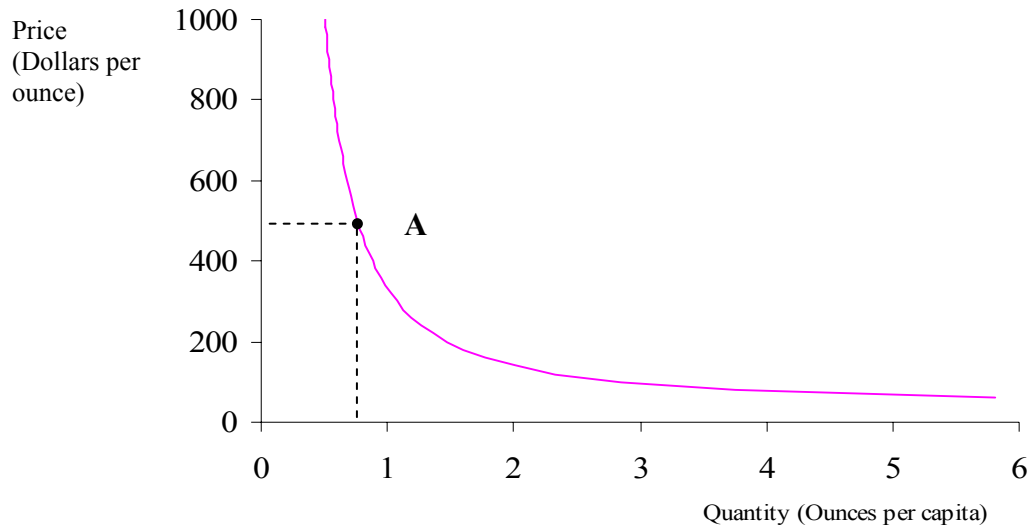


FIGURE 6
THE UNCERTAINTY OF THE DEMAND CURVE

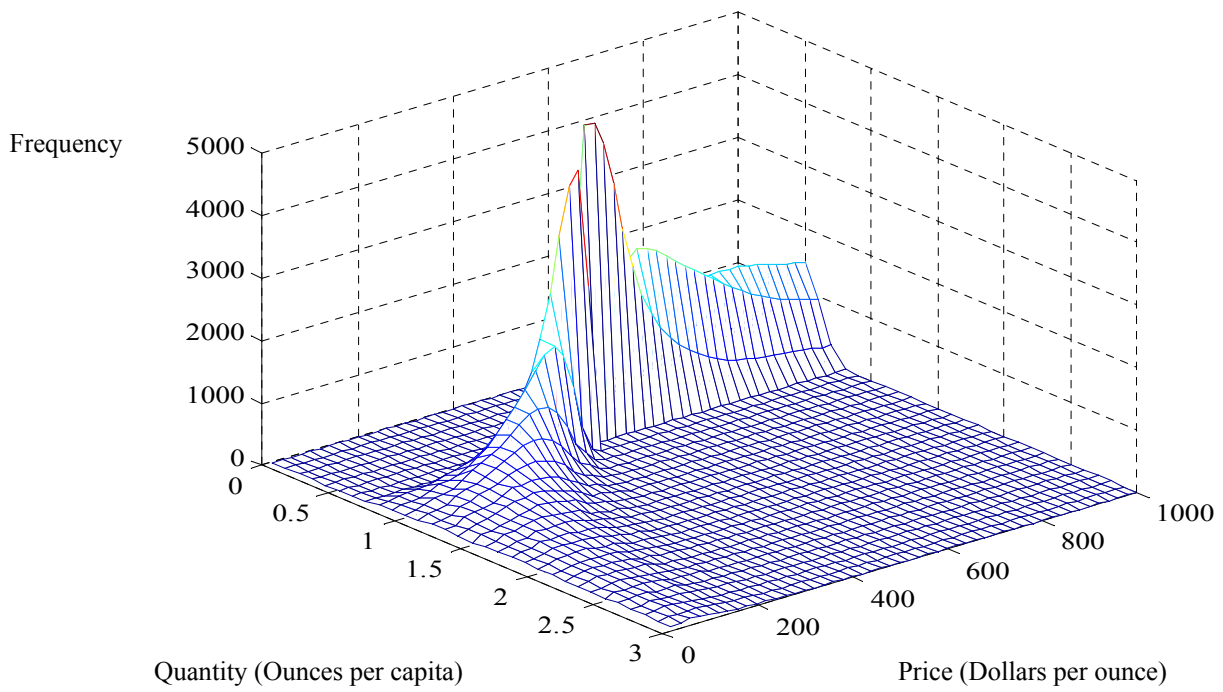
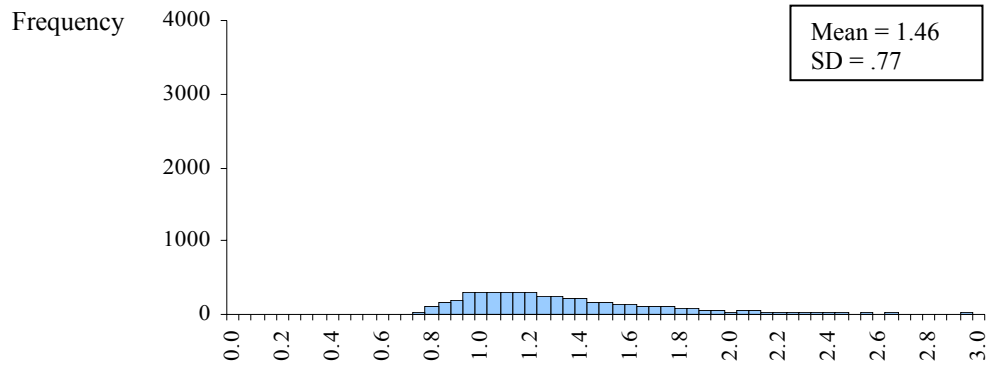
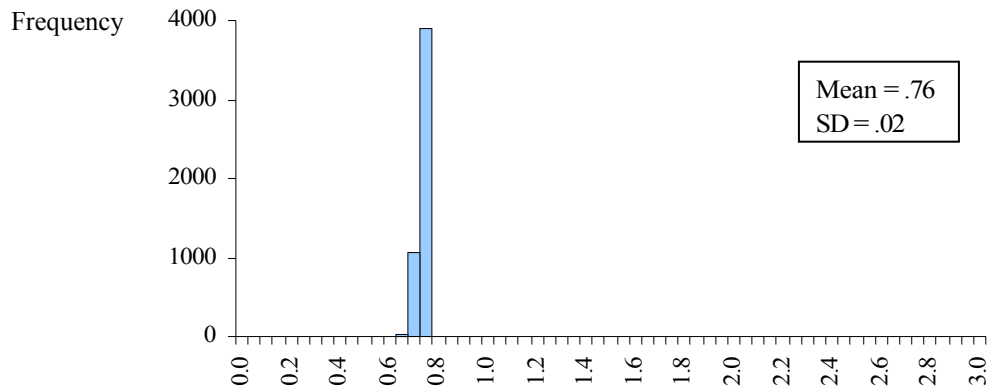


FIGURE 7
 CONDITIONAL DISTRIBUTION OF MARIJUANA CONSUMPTION
 (Ounces per capita)

A. Marijuana price = \$200



B. Marijuana price = \$500



C. Marijuana price = \$800

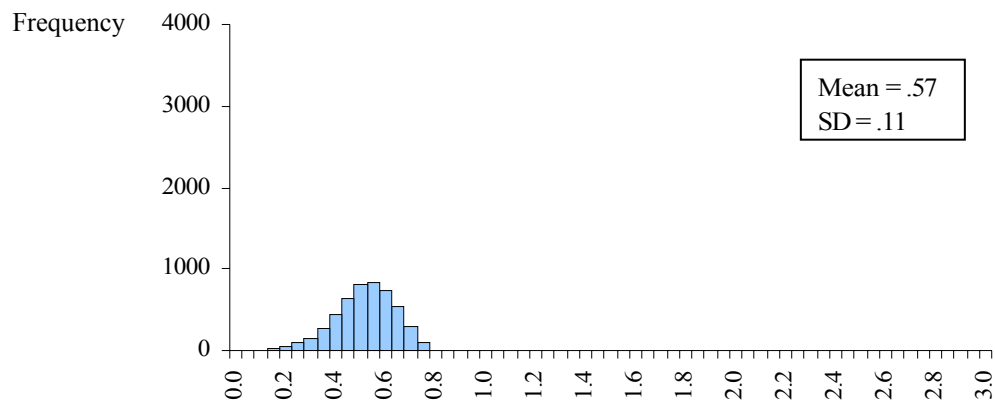


TABLE 7
TAXATION AND CONSUMPTION OF VICE

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

- Notes:
1. Consumption expenditure is from Panel A of Table A2 for 1998.
 2. The tax rate for tobacco is derived from excise and customs revenue published in the Australian Institute of Health and Welfare 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 percent, wine 23 percent and spirits 55 percent. The corresponding conditional budget shares ($\times 100$), from Panel B of Table A1 for 1998, are 55, 23 and 22 (in the same order). Thus a budget-share weighted average tax rate for alcohol as a whole is $.55 \times 43 + .23 \times 23 + .22 \times 55 = 41$ percent, 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 8
SIMULATIONS OF VICE CONSUMPTION AND TAXATION REVENUE
(Logarithmic changes $\times 100$)

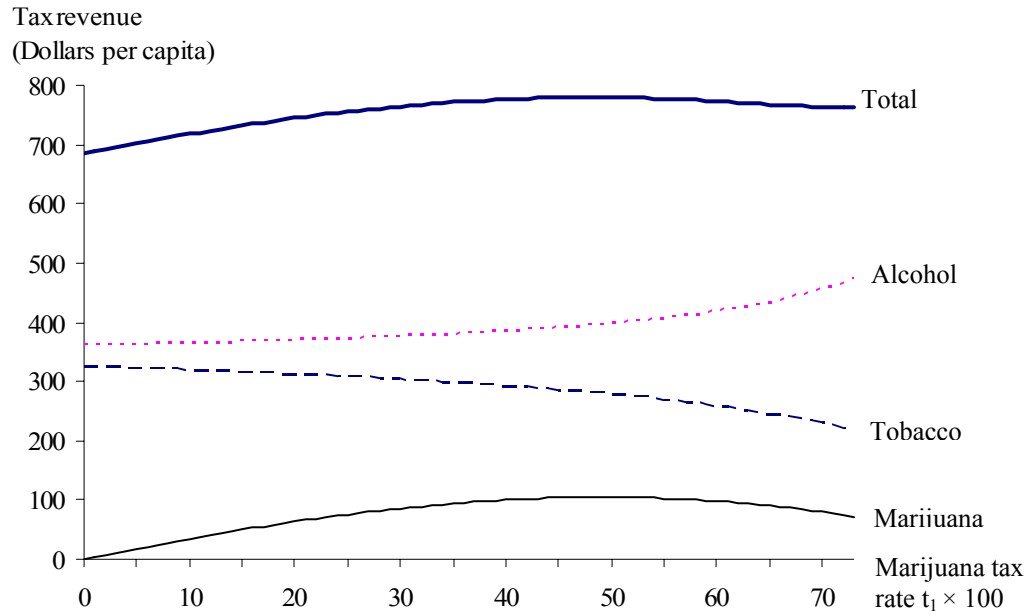
Endogenous variable	Exogenous change									
	Everything random					Budget shares not random				
	10% fall in marijuana prices	10 percentage point increase in the tax rate		10 percent increase in the tax rate		10% fall in marijuana prices	10 percentage point increase in the tax rate		10 percent increase in the tax rate	
		Tobacco $100 \times \Delta t'_2 = 10$ $100 \times \frac{\Delta t'_2}{t'_2} = 8.4$	Alcohol $100 \times \Delta t'_3 = 10$ $100 \times \frac{\Delta t'_3}{t'_3} = 14.4$	Tobacco $100 \times \Delta t'_2 = 11.9$ $100 \times \frac{\Delta t'_2}{t'_2} = 10$	Alcohol $100 \times \Delta t'_3 = 7.0$ $100 \times \frac{\Delta t'_3}{t'_3} = 10$		Tobacco $100 \times \Delta t'_2 = 10$ $100 \times \frac{\Delta t'_2}{t'_2} = 8.4$	Alcohol $100 \times \Delta t'_3 = 10$ $100 \times \frac{\Delta t'_3}{t'_3} = 14.4$	Tobacco $100 \times \Delta t'_2 = 11.9$ $100 \times \frac{\Delta t'_2}{t'_2} = 10$	Alcohol $100 \times \Delta t'_3 = 7.0$ $100 \times \frac{\Delta t'_3}{t'_3} = 10$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
I. Real Income Constant										
Quantity consumed										
1. Marijuana	6.75 (4.14)	- .78 (.57)	1.19 (.82)	-.93 (.68)	.83 (.57)	6.21 (2.95)	-.73 (.44)	1.11 (.62)	-.87 (.53)	.78 (.43)
2. Tobacco	1.70 (1.08)	-.92 (.35)	1.03 (.62)	-1.09 (.42)	.72 (.43)	1.69 (1.02)	-.91 (.33)	1.02 (.59)	-1.09 (.39)	.71 (.41)
3. Alcohol	-1.01 (.60)	.40 (.24)	-3.85 (1.41)	.48 (.29)	-2.69 (.99)	-1.00 (.56)	.40 (.23)	-3.79 (1.30)	.47 (.27)	-2.65 (.91)
Taxation Revenue										
4. Tobacco	1.70 (1.08)	7.49 (.35)	1.03 (.62)	8.92 (.42)	.72 (.43)	1.69 (1.02)	7.50 (.33)	1.02 (.59)	8.92 (.39)	.71 (.41)
5. Alcohol	-1.01 (.60)	.40 (.24)	10.44 (1.41)	.48 (.29)	7.31 (.99)	-1.00 (.56)	.40 (.23)	10.50 (1.30)	.47 (.27)	7.35 (.91)
6. Total	.26 (.24)	3.73 (.16)	6.02 (.61)	4.49 (.19)	4.21 (.42)	.27 (.19)	3.73 (.14)	6.04 (.53)	4.44 (.17)	4.23 (.37)
II. Money Income Constant										
Quantity consumed										
7. Marijuana	7.01 (4.11)	-.89 (.57)	.91 (.82)	-1.06 (.68)	.64 (.57)	6.47 (2.95)	-.84 (.44)	.83 (.62)	-1.00 (.53)	.58 (.43)
8. Tobacco	1.79 (1.08)	-.95 (.35)	.93 (.62)	-1.14 (.42)	.65 (.43)	1.77 (1.02)	-.95 (.33)	.93 (.59)	-1.13 (.39)	.65 (.41)
9. Alcohol	-.80 (.60)	.31 (.24)	-4.08 (1.40)	.37 (.29)	-2.86 (.98)	-.79 (.56)	.30 (.23)	-4.02 (1.30)	.36 (.27)	-2.82 (.91)
Taxation Revenue										
10. Tobacco	1.79 (1.08)	7.46 (.35)	.93 (.62)	8.87 (.42)	.65 (.43)	1.77 (1.02)	7.46 (.33)	.93 (.59)	8.88 (.39)	.65 (.41)
11. Alcohol	-.80 (.60)	.31 (.24)	10.20 (1.40)	.37 (.29)	7.14 (.98)	-.79 (.56)	.30 (.23)	10.26 (1.30)	.36 (.27)	7.18 (.91)
12. Total	.41 (.24)	3.67 (.16)	5.85 (.60)	4.36 (.19)	4.09 (.42)	.42 (.19)	3.67 (.14)	5.87 (.53)	4.36 (.17)	4.11 (.37)

TABLE 9
REVENUE FROM TAXING MARIJUANA

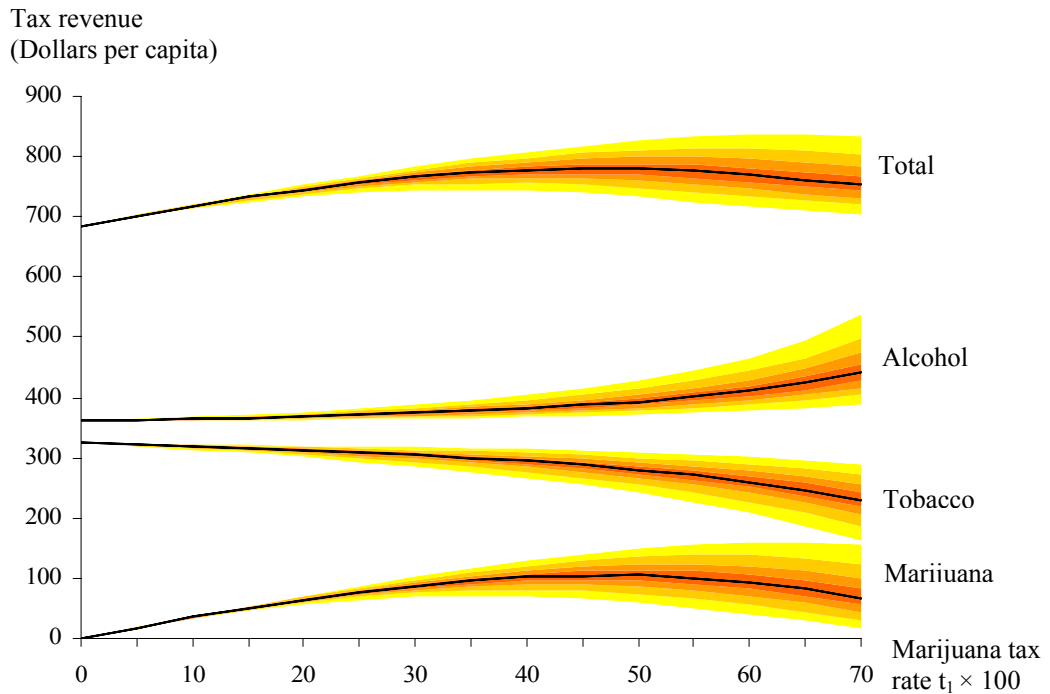
Marijuana tax rate $t_1 \times 100$	Tax revenue (dollars per capita)			
	Marijuana	Tobacco	Alcohol	Total vice
(1)	(2)	(3)	(4)	(5)
0	0 -	324 -	360 -	684 -
10	35 (1)	318 (4)	364 (2)	717 (3)
20	64 (6)	311 (8)	369 (5)	744 (8)
30	86 (13)	303 (13)	376 (9)	764 (15)
40	100 (23)	292 (19)	385 (15)	776 (25)
50	105 (34)	277 (27)	397 (23)	779 (36)
60	98 (46)	257 (37)	418 (37)	773 (46)
70	79 (54)	228 (50)	455 (65)	763 (52)

Note: The elements in the table are the means over the 5,000 trials and the corresponding standard deviations are in parentheses.

Figure 8
 THE MARIJUANA LAFFER CURVE
 A. Taxation Revenues



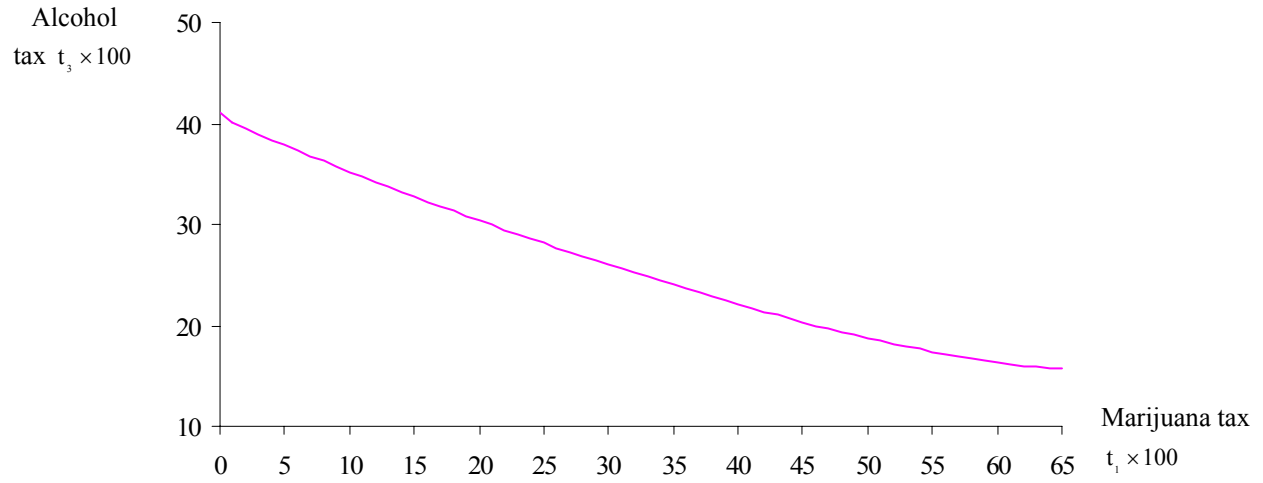
B. The Uncertainty of Taxation Revenues



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 9
THE ALCOHOL-MARIJUANA TAX TRADEOFF
(Means over 5,000 trials)

A. The Tradeoff



B. The Slope of the Tradeoff

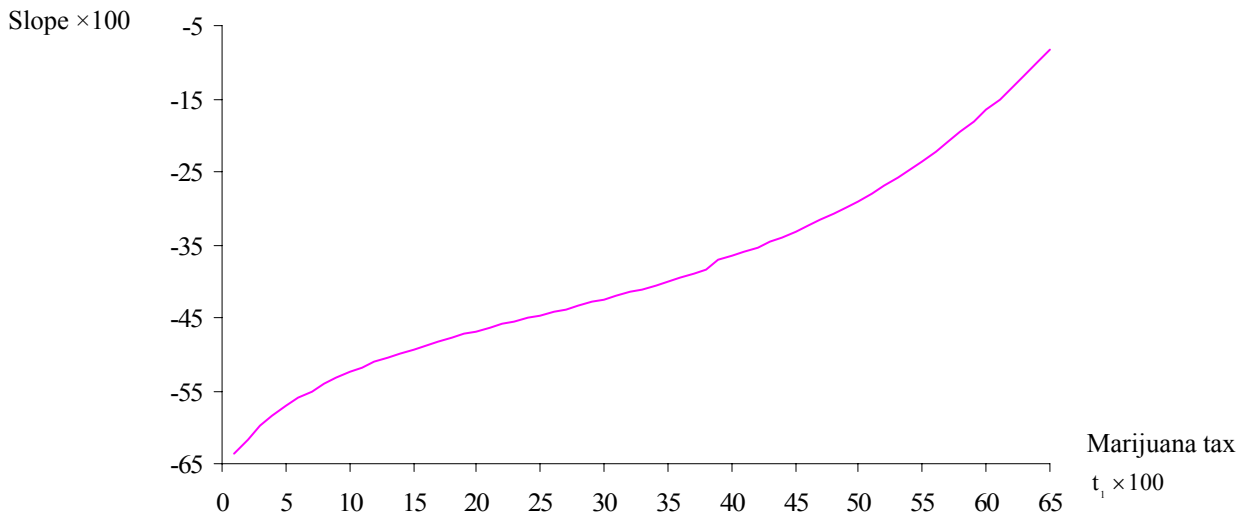
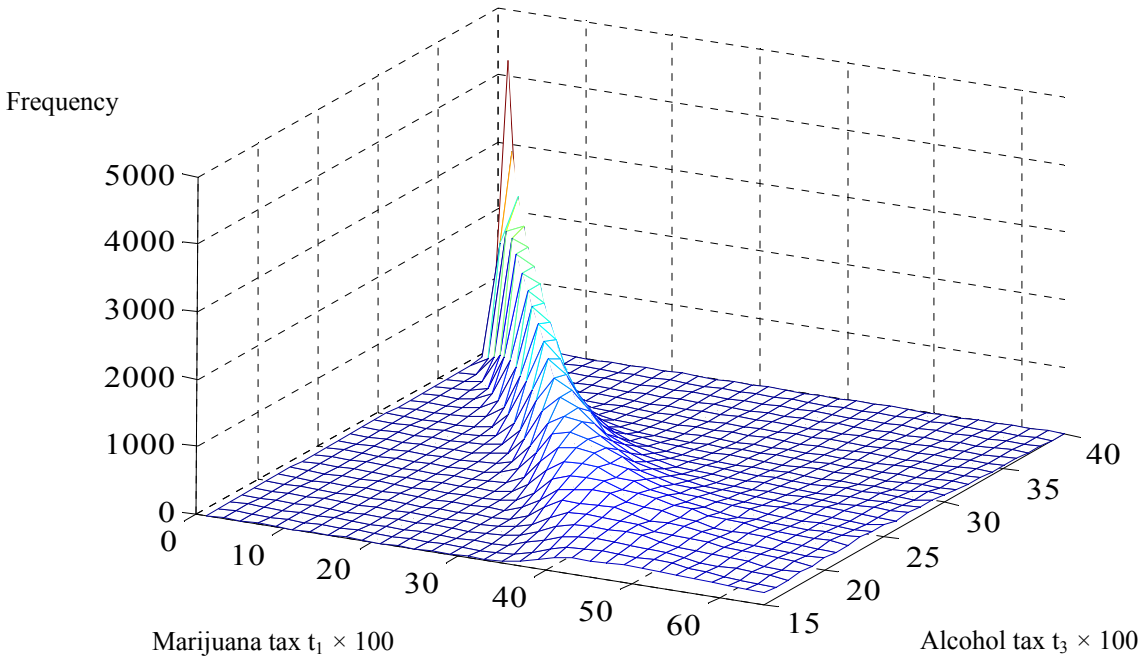


FIGURE 10
THE UNCERTAINTY OF THE TRADEOFF

A. The Tradeoff



B. The Slope of the Tradeoff

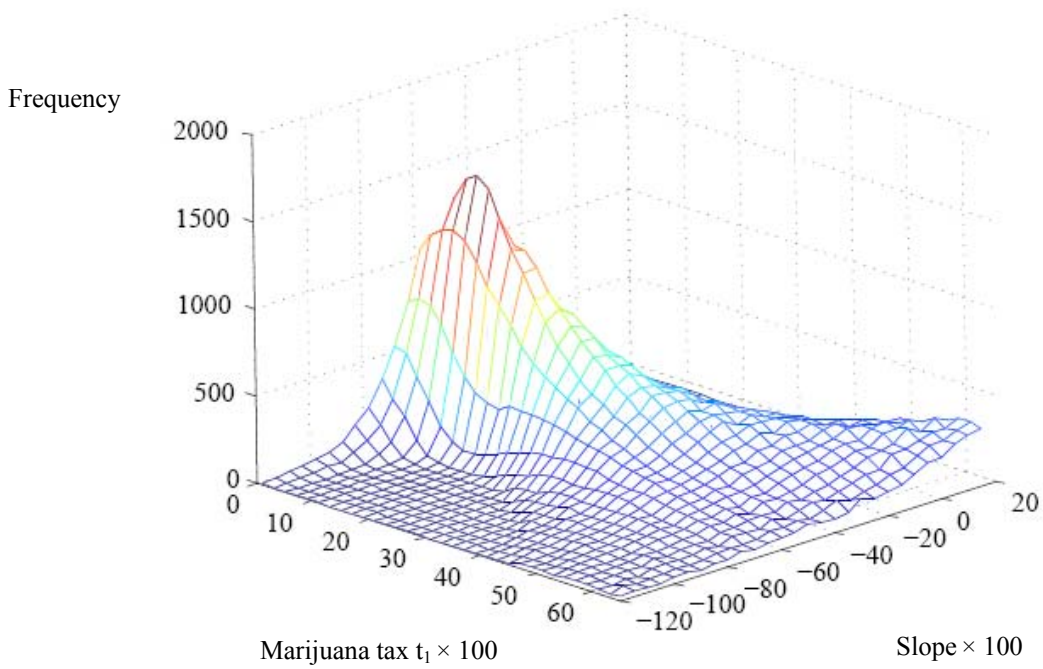


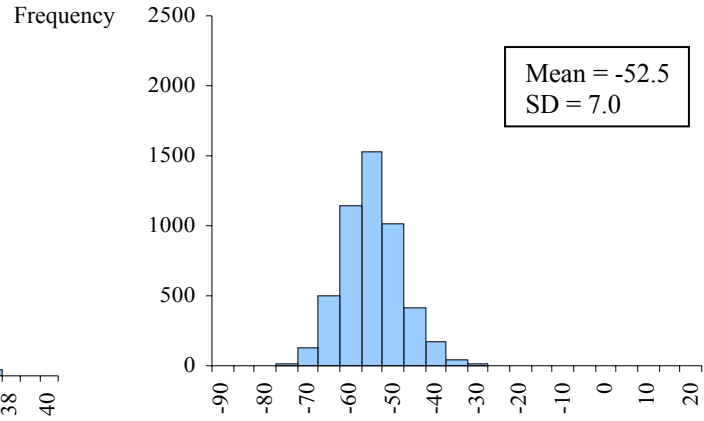
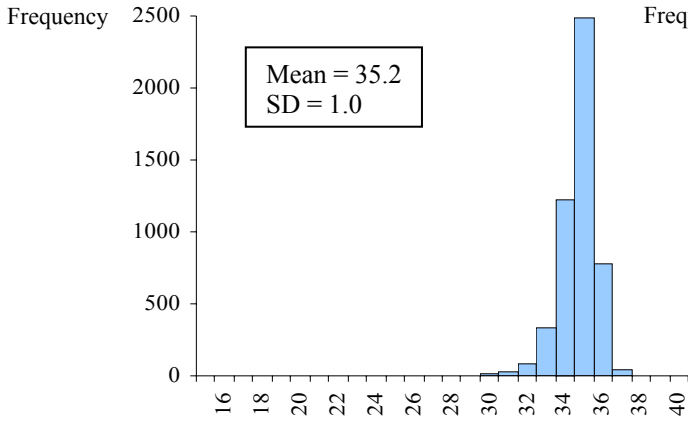
FIGURE 11

CONDITIONAL DISTRIBUTION OF ALCOHOL TAX AND SLOPE OF TRADEOFF

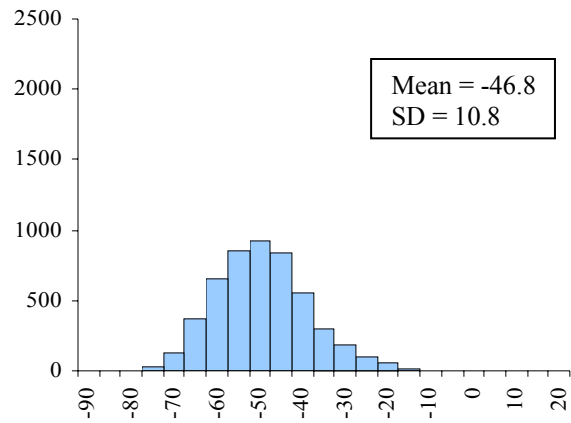
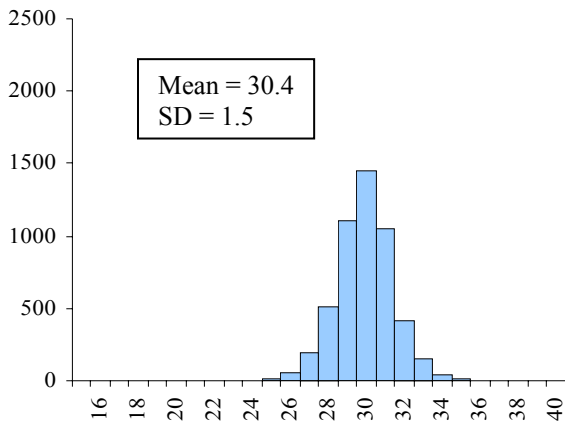
Alcohol tax rate \times 100

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%

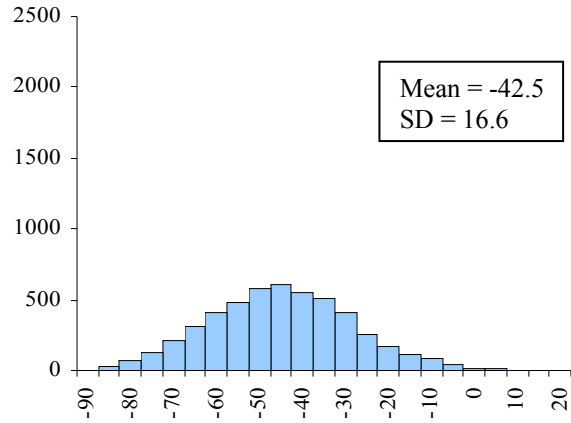
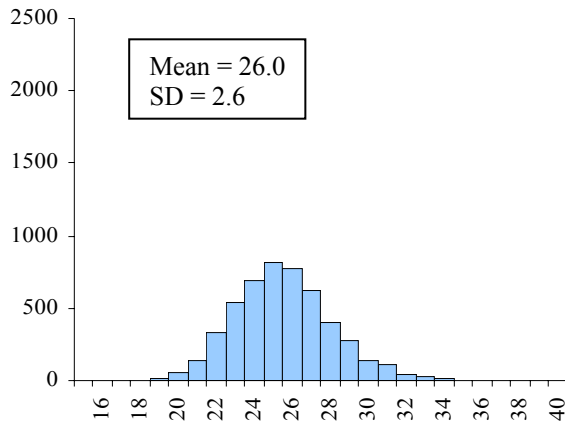


TABLE A1
ALCOHOL EXPENDITURE AND BUDGET SHARES

Year (1)	Beer (2)	Wine (3)	Spirits (4)	Alcohol (5) = (2)+(3)+(4)
<u>A. Expenditures</u> (Dollars per capita)				
1988	422	146	134	703
1989	442	147	145	734
1990	464	143	148	755
1991	451	154	149	754
1992	444	153	158	755
1993	451	162	190	804
1994	459	168	183	810
1995	475	175	198	848
1996	485	185	194	863
1997	486	199	210	895
1998	485	203	190	879
<u>B. Conditional Budget Shares</u> (Percentages)				
1988	60	21	19	
1989	60	20	20	
1990	61	19	20	
1991	60	20	20	
1992	59	20	21	
1993	56	20	24	
1994	57	21	23	
1995	56	21	23	
1996	56	21	22	
1997	54	22	23	
1998	55	23	22	

Note: In Panel A, “per capita” expenditure refers to expenditure divided by the number of Australians aged 14 years and over.

Source: E. A. Selvanathan (2003) provided per capita expenditures defined for the total population, which we then converted to a 14-year-and-over basis, using population data from ABS Catalogue No. 3201.

TABLE A2
VICE EXPENDITURE AND TOTAL CONSUMPTION

Year (1)	Marijuana (2)	Tobacco (3)	Alcohol (4)	Total Consumption (5)
<u>A. Expenditures</u> (Dollars per capita)				
1988	392	916	703	15,005
1989	417	900	734	16,407
1990	442	873	755	17,068
1991	453	819	754	17,870
1992	349	755	755	18,437
1993	316	692	804	19,005
1994	338	636	810	20,178
1995	329	605	848	21,244
1996	360	597	863	21,802
1997	370	597	895	22,769
1998	372	597	879	23,592
<u>B. Unconditional Budget Shares for Vice</u> (Percentages)				
1988	2.6	6.1	4.7	13.4
1989	2.5	5.5	4.5	12.5
1990	2.6	5.1	4.4	12.1
1991	2.5	4.6	4.2	11.3
1992	1.9	4.1	4.1	10.1
1993	1.7	3.6	4.2	9.5
1994	1.7	3.2	4.0	8.8
1995	1.5	2.8	4.0	8.4
1996	1.7	2.7	4.0	8.4
1997	1.6	2.6	3.9	8.2
1998	1.6	2.5	3.7	7.8

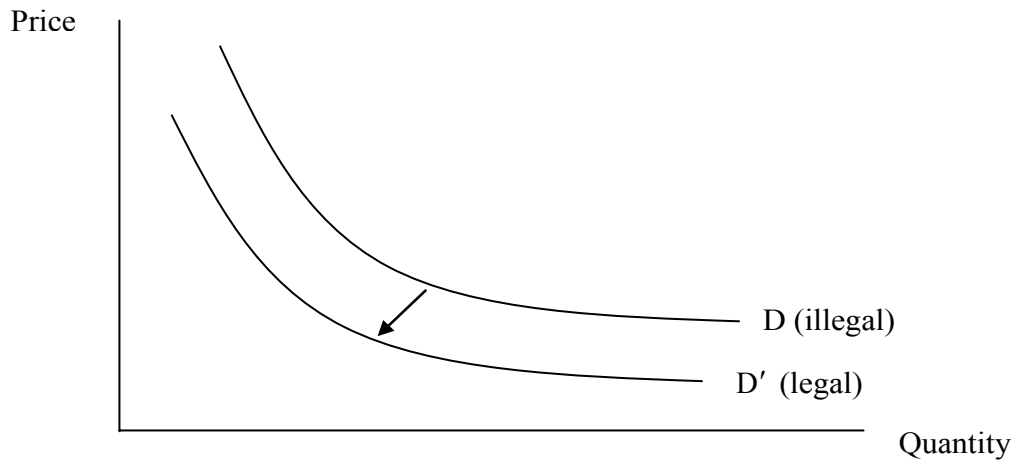
Note: In Panel A, the total population aged 14 years and over is used to compute per capita expenditures.

- Sources:
1. Marijuana expenditure in Panel A of column 2 is the product of the price per unit and the quantity consumed. The price data are from Clements (2004) and the quantity from Clements and Daryal (2005). As the marijuana prices for the year 1988 and 1989 are not available, we compute them by backwards extrapolation by using the average annual log change of marijuana prices for the period 1990-98.
 2. Panel A, column 3 is computed as total tobacco expenditure (ABS Cat. No. 5206.0) divided by population aged 14 and over (ABS Cat. No. 3201).
 3. Panel A, column 4 is from Table A1, column 5.
 4. Panel A, column 5 is conventionally-defined total consumption expenditure, from Selvanathan (2003), plus marijuana expenditure. The unconditional budget shares in Panel B use in their denominators this broader measure of total consumption.

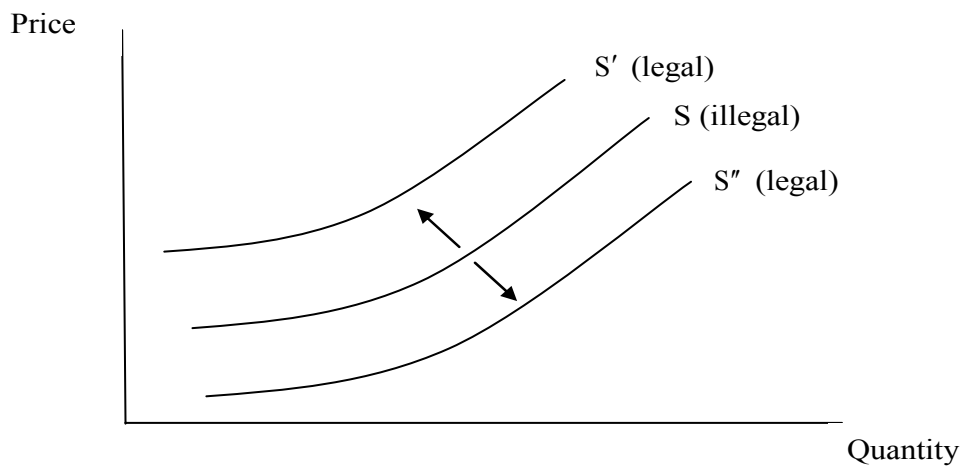
FIGURE 12

LEGALISING MARIJUANA

A. The Forbidden Fruit Hypothesis



B. Which Way Does the Supply Curve Shift?



C. Prices May Increase or Decrease

