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PRICING AND PACKAGING: THE CASE OF MARIJUANA

by

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Abstract

In many markets unit prices decline as the quantity purchased rises, a phenomenon which can be considered to be part of the economics of packaging. For example, in Australia marijuana costs as much as 80 percent less if purchased in the form of ounces rather than grams. This paper reviews the economic foundations of quantity discounts and proposes new ways of measuring and analysing them. These ideas are implemented with the prices of marijuana, a product that is shown to be priced in a manner not too different to that used for groceries and other illicit drugs. In broad terms, the results support the following pricing rule: *The unit price falls by 2.5 percent when the product size increases by 10 percent.*

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1. INTRODUCTION

Over the 1990s in Australia, the average price of a gram of marijuana was about \$A35, while an ounce cost \$449. As there are 28 grams in an ounce, this means that the per ounce cost of a gram was 28 × 35 = \$980, or more than twice the cost when marijuana was purchased in the form of an ounce. Put another way, there is a substantial discount for purchasing marijuana in bulk, or a premium for smaller purchases. This paper deals with the measurement and understanding of these sorts of quantity discount.

One explanation for the phenomena of quantity discounts is the role of risk. Suppose a dealer has, say, ten ounces of marijuana to sell and is faced with the alternative of making either ten individual sales of one ounce each, or 280 gram sales. The latter marketing strategy could possible run the risk of greater exposure of the illicit drug operation. If the dealer has contact with a larger number of people, this could possibly increase the risk of apprehension, increasing the expected value of a penalty from the justice system. More generally, as the activities of larger dealers could possibly be more hidden from the law, they do not have to spend so much investing in "security". On the other hand, dealers on the street may have to either bribe police or engage in expensive security arrangements to be able to stay in business. Sjaastad (2003) argues that "[t]he gangs here in Chicago, which dominate the drug trade, maintain rather expensive organisations to keep them in motion and they face a lot of competition as there is free entry into the street business. On the other hand, the bulk dealers are likely to be part of a cartel, which has no competition." These considerations all lead to the unit cost of illicit drugs increasing as the size of the sale falls.

A completely different explanation of quantity discounts involves the value added as the product moves through the supply chain. The "conversion" of marijuana from ounce to gram lot sizes is not a costless operation, and can be thought of as analogous to the economic role played by any retailing business such as a service station which sells petrol to motorists. The economic function performed by a service station is the transformation of tanker loads of petrol into smaller lot sizes suitable for individual cars. As this activity is valued by consumers, they are willing to pay for it in the form of petrol prices at the bouser that are considerably higher than the wholesale price.

Accordingly, the quantity discount that the service station receives when it purchases petrol from the wholesaler is its retail margin that simultaneously represents consumers' valuation of the economic function it performs, as well as its value added. Thus to make 280 gram sales of marijuana, rather than ten sales of one ounce each, would be a more costly way of marketing the product, due to the time and effort associated with splitting ounces to grams, and the need to service a larger number of customers individually.

A third explanation of quantity discounts relates to pricing strategies of firms with market power. In cases where larger buyers have a more elastic demand for the product and resale can be prevented, then the discounts they receive may be a manifestation of price discrimination by a powerful supplier. For arguments along these lines, see, e.g., Mills (1996, 2002).

This paper introduces new ways of measuring and analysing quantity discounts, with an emphasis on the marijuana market. Section 2 explores in some detail alternative approaches to the problem. Section 3 discusses the discounts available for purchasing marijuana in bulk, while the concept of the "discount" is formalised in Section 4 in terms of what we call the "size" and "discount" elasticities of prices. In Section 5 we present a novel way of extracting estimates of the discount elasticity from the distribution of prices. Sections 6 and 7 deal with the econometrics of packaging, and the procedures discussed therein are implemented in Section 8 with marijuana prices. Section 9 considers pricing practices in other markets, including groceries. Concluding comments are contained in Section 10.

2. ALTERNATIVE APPROACHES TO PACKAGE PRICING

This section considers several different approaches to understanding aspects of the economics of package pricing.

Two-Part Pricing

Consider a product whose price is related to the cost of its package size and the volume of the product. Following Telser (1978, Sec. 9.4), let s denote the volume of the product in the package, so that $s^{1/3}$ is proportional to the linear dimension of the package and the square of this, $s^{2/3}$, is proportional to the area of the package surface. The cost of the contents of the package is proportional to the volume, αs, while the cost of the packaging is proportional to the area, $\beta s^{2/3}$. Suppose that as an approximation, the price of a package of size s, p, is the sum of these two costs:

$$p = \alpha s + \beta s^{2/3}. \tag{2.1}$$

The price per unit of the product is

$$p / s = \alpha + \beta s^{-1/3}. \tag{2.2}$$

This shows that unit price declines with package size, as the package cost increases less than proportionately to the volume of the product. The declining unit price result can also be expressed in terms of the elasticity of price with respect to size. If this elasticity is less than unity, then the per unit price falls. It follows from equation (2.1) that the effect on package price of an increase in size is $\partial p / \partial s = \alpha + (2\beta / 3) s^{-1/3}$. Thus price increases with size, but at a decreasing rate. Let η denote the size elasticity $\partial(\log p) / \partial(\log s) = (\partial p / \partial s) / (p / s)$. It follows from the above expression for the marginal effect and equation (2.2) for the corresponding average that the size elasticity takes the form

$$\eta = \frac{\alpha + (2\beta / 3) s^{-1/3}}{\alpha + \beta s^{-1/3}}. \tag{2.3}$$

As the numerator is clearly less than the denominator, the elasticity is less than unity.

Next, suppose there is a cost per transaction that is independent of the price and package size. This fixed cost could be associated with the processing of the sale, and/or other administrative expenses. Then, if γ is the fixed cost, equations (2.1) and (2.2) become

$$p = \gamma + \alpha s + \beta s^{2/3}, \qquad p / s = \alpha + \gamma(1/s) + \beta s^{-1/3},$$

and the size elasticity takes the form

(2.4) $$\eta = \frac{\alpha + (2\beta/3)s^{-1/3}}{\alpha + \gamma(1/s) + \beta s^{-1/3}}.$$

As there is an additional positive term in the denominator of (2.4), $\gamma(1/s)$, the value of the elasticity is now lower than before. This is because as the transaction cost is fixed, it is spread over a larger base as size increases, and the proportionate effect of size on price is now lower.

A Multi-Stage Supply Chain

Consider an individual who purchases an ounce of marijuana and then splits it into 28 gram packets to sell. What can be said about the relationship between the ounce price and the gram price? As the seller of ounces and grams may be the same person, we could consider the relationship between the two prices to be determined by an arbitrage condition, according to which the seller is indifferent between the form in which the product is sold. This issue has wider applicability than to just the market for illicit drugs, as analytically exactly the same considerations apply to packaging decisions pertaining to legal products, such as selling rice by the kilo or half kilo. As for many products wholesale transactions involve larger volumes than retail, the issue is also similar to the spread between wholesale and retail prices. We thus proceed with some generality and consider a generic step in a multi-stage supply chain.

Let p_{i-1} be the price of a good sold at step $i-1$ in the supply chain, such as the price of an ounce of marijuana sold in the form of an ounce. Then if q_{i-1} is the corresponding quantity, $p_{i-1}q_{i-1}$ is total revenue derived from step $i-1$. This revenue is to be compared to the costs of selling q_{i-1} at step $i-1$. Suppose these are made up of material costs plus processing and selling expenses; denote these costs per unit by c_{i-1}. Total cost is $c_{i-1} q_{i-1}$, and profit is

(2.5) $$p_{i-1} q_{i-1} - c_{i-1} q_{i-1}.$$

Suppose at the next stage of the marketing chain the product is processed further and then split such that the unit sold is now as a multiple $1/s_i < 1$ of that at the previous step. In terms of the units at step i, s_i is the package size at the previous step; in terms of the units at $i-1$, $1/s_i$ is the size at i. In transforming marijuana from ounces into grams at step i, $s_i = 28$. With p_i the price at this step (dollars per gram), the profit from selling the same quantity involved in (2.5), q_{i-1}, in the form of smaller units is

$$(2.6) \qquad p_i\, s_i\, q_{i-1} - c_i\, s_i\, q_{i-1},$$

where c_i is the overall per unit cost at step i.

Note that c_{i-1} and $c_i s_i$ are the costs of materials, processing and selling exactly the same volume of the product at successive steps in the supply chain. If, for example, the only cost were a constant fixed cost for each sale, then $c_i = c_{i-1}$ and $c_i\, s_i > c_{i-1}$ as $s_i > 1$. But this is an extreme case, and in all likelihood per unit cost would fall with the volume transacted, so that $c_i < c_{i-1}$. It still seems reasonable however that this cost falls less than proportionately than the quantity transacted s_i, so that the cost per gram of marijuana when sold in the form of ounces, c_{i-1}/s_i, is less than the same cost when sold in the form of grams c_i. We shall thus assume that

$$(2.7) \qquad c_i\, s_i > c_{i-1}.$$

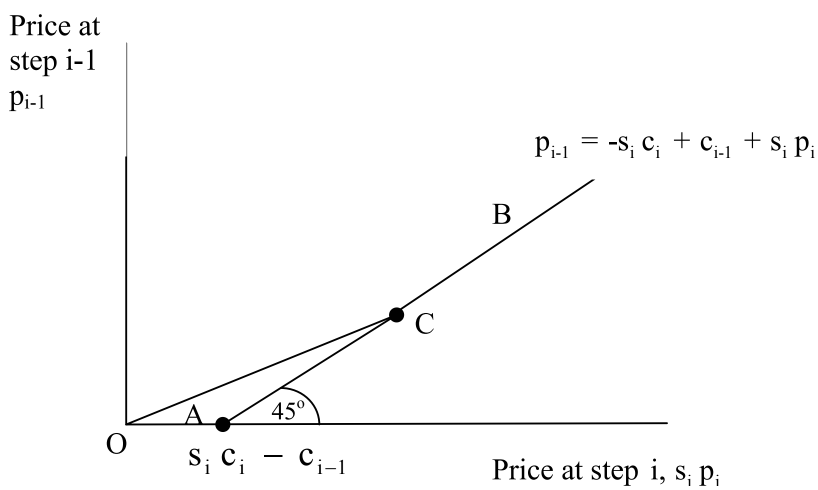
In words, the overall cost associated with one sale of an ounce of marijuana is less than that of 28 distinct sales of 1 gram each. If entrepreneurs have a choice regarding where in the supply chain they locate, arbitrage will ensure that profits at each step are equalised. Thus equating (2.5) and (2.6), we obtain

$$(2.8) \qquad p_{i-1} - c_{i-1} = s_i\left(p_i - c_i\right),$$

so that the net-of-cost price, appropriately adjusted for the differing quantities transacted, is equalised at each step in the chain: The profit from processing and selling an ounce of marijuana is equal to 28 times that of processing and selling a gram. Equation (2.8) has several interesting implications. First, we write it in the form $p_{i-1} = s_i p_i - s_i c_i + c_{i-1}$ and then in Figure 1 plot p_{i-1} against $s_i p_i$. The slope of the curve AB is 45º, while the slope of a ray from the origin to any point on the curve, such as OC, is less as long as condition (2.7) is satisfied. As the elasticity is the ratio of the slope of the curve to the slope of the ray, under (2.7) the elasticity of the price at stage i-1 in the chain with respect to the price at stage i is greater than unity. Accordingly, the volatility of prices is amplified as we move back through the supply chain. This agrees with the observation that retail prices of meat, for example, are much more stable than livestock prices. More generally, agricultural prices at the farm-gate level generally exhibit more volatility than their retail counterparts.

FIGURE 1

PRICES AT TWO STEPS IN THE SUPPLY CHAIN



A second implication of equation (2.8) can be revealed if we write it as $p_i - c_i = (1/s_i)(p_{i-1} - c_{i-1})$, or

(2.9) $$p_i = c_i + (p_{i-1} - c_{i-1})(1/s_i).$$

We see that the price is the sum of a fixed cost per transaction plus a variable cost related to the quantity in the package. Third, by successive substitution it is possible to use equation (2.9) to express the price at any step in the supply chain in terms of the characteristics of all previous steps as

$$p_i = c_i + \left(p_{i-n} - c_{i-n}\right)\prod_{k=0}^{n-1}\left(1/s_{i-k}\right), \tag{2.10}$$

where n is the number of steps in the chain before step i. Thus the price at step i comprises (i) unit costs at this step and (ii) the price of the "basic" product, net of basic costs, appropriately discounted to reflect the economic distance that the product has travelled up the supply chain, away from its basic source. Equation (2.10) thus reveals how a shock to the price at the basic level in the chain is transmitted to all higher levels. As it travels up through the chain, such a shock has a dampened impact due to the splitting of the product at each step; that is, as $\left(1/s_{i-k}\right) < 1$ for all k, $\prod_{k=0}^{n-1}\left(1/s_{i-k}\right) \ll 1$. Consider the special case where the product is divided by the same amount at each step, so that $s_i = s$. If this were to describe the operation of the marijuana supply chain, the volume transacted at successive steps would be $\ldots 28^2 \times \text{ounces}$, $28 \times \text{ounces}$, ounces, grams. In this situation, the last term on the right-hand side of equation (2.10) simplifies to $\prod_{k=0}^{n-1}\left(1/s_{i-k}\right) = \left(1/s\right)^n$.

Finally, equation (2.8) has implications for the nature of quantity discounts. Consider again the case of marijuana with processing of ounces into grams. The term p_{i-1} is then the price if we buy an ounce of marijuana in the form of an ounce, while $s_i\, p_i$ is the cost of the same quantity if purchased in the form of 28 lots of gram packages. Accordingly, $d_{i-1,i} \equiv \left(p_{i-1} - s_i\, p_i\right)/s_i\, p_i$ is the proportionate quantity discount available in the transition from step $i\text{-}1$ to i. It follows from equation (2.8) that the discount takes the form $d_{i-1,i} = c_i'\left(c_{i-1}/c_i\, s_i - 1\right)$, where $c_i' = c_i / p_i$ is the <u>proportionate</u> cost at step i. Condition (2.7) implies that $d_{i-1,i} < 0$. If we write the discount as a function of the package size, $d_{i-1,i} = f\left(s_i\right)$, then $f' < 0$ and $f'' > 0$. In words, as the package size rises, the discount increases (in absolute value), but at a decreasing rate. The relationship between the size elasticity and quantity discounts will be discussed subsequently in Section 4.

A related way of modelling the operation of the marketing chain, which does not rely on an arbitrage condition, is as follows. In the above formulation the unit cost c_i represents the costs of materials, processing and selling at step i. A component of this overall cost is the cost of the product at the previous step. We now decompose the overall cost into the cost of the product used as input, p_{i-1}/s_i, and "other" costs $\tilde{c}_i$, so that $c_i = \tilde{c}_i + p_{i-1}/s_i$. If δ_i is the markup factor at stage i, then the price is linked to costs according to:

$$p_i = \delta_i\left(\tilde{c}_i + p_{i-1}/s_i\right). \tag{2.11}$$

As δ_i and $\tilde{c}_i$ in equation (2.11) are both positive, the elasticity of p_i with respect to p_{i-1} is less than unity. This amounts to the elasticity of p_{i-1} with respect to p_i being greater than unity, the same result as before; see the discussion below equation (2.8).[1]

<u>A Log-Linear Model</u>

Caulkins and Padman (1993) propose a model which gives some further insight into the relationship between price and package size. In particular, their approach relates the size elasticity of price to some more basic features of the packaging business. This sub-section sets out this approach.

Suppose there is a log-linear relationship between price and package size, $\log p = \alpha' + \beta \log s$, where α' is an intercept and β is the size elasticity. Writing $p(s)$ for price as a function of size, we have

$$p(s) = \alpha s^{\beta}, \tag{2.12}$$

where $\alpha = \exp(\alpha')$. Suppose that initially an ounce of marijuana is purchased and that we

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[1] Equation (2.11) has on the left-hand side the price in terms of the unit transacted at step i (such as dollars per gram), while on the right is the price at the previous step in terms of the same unit (the ounce price expressed in the form of dollars per gram). Thus, (2.11) could be considered as a first-order difference equation in the price measured in a common unit. It is therefore tempting to analyse the solution to this equation and declare that the natural end to the supply chain occurs when the price hits its steady-state value of $\delta\tilde{c}/(1-\delta)$. But such an approach is misguided as the steady-state is never reached because the markup δ is presumably always greater than unity. One alternative way of proceeding would be to treat the markup as endogenously determined such that the chain ends when δ falls below unity as a result of the forces of competition.

measure size in terms of grams, so that $s = 28$ and $p(28)$ is the price of this ounce. If this ounce is then split into 28 gram packages, so that $s = 1$ now, the revenue from these 28 packages is $28 \times p(1)$, where $p(1)$ is the price of one gram. Define the ratio of this revenue to the cost of an ounce as the markup factor, $\delta = 28 \times p(1) / p(28)$, or $28 \times p(1) = \delta \times p(28)$. More generally, let $\phi > 1$ be the conversion factor that transforms the larger quantity s into a smaller one s / ϕ; in the previous example $\phi = 28$. Thus we have the following general relationship between prices of different package sizes, the markup and conversion factors:

$$(2.13) \qquad \phi \times p\left(\frac{s}{\phi}\right) = \delta \times p(s).$$

Our objective is to use equations (2.12) and (2.13) to derive an expression for the size elasticity β that involves the markup and conversion factors δ and ϕ. To do this, we use equation (2.12) in the form $p(s / \phi) = \alpha(s / \phi)^{\beta}$, so that the left-hand side of equation (2.13) becomes $\phi\alpha(s / \phi)^{\beta}$. Using equation (2.12) again, we can write the right-hand side of (2.13) as $\delta\alpha s^{\beta}$. Accordingly, equation (2.13) can be expressed as $\phi(s/\phi)^{\beta} = \delta s^{\beta}$, or $\phi^{(1-\beta)} = \delta$, which implies

$$(2.14) \qquad \beta = 1 - \frac{\log\delta}{\log\phi}.$$

Equation (2.14) shows that the size elasticity falls with the markup δ and rises with the conversion factor ϕ. If there is no markup, $\delta = 1$ and the size elasticity $\beta = 1$, so that price is just proportional to package size and there would be no quantity discount for buying in bulk. When $\delta > 1$, the unit price falls with the quantity purchased, so that discounts would apply. As the markup rises, so does the quantity discount and the (proportionate) increase in the total price resulting from a unit increase in package size is lower. In other words, the size elasticity β falls with the markup. Other things equal, the greater the conversion factor ϕ, the more the product can be "split" or "cut" and the higher is the profit from the operation. The role of the conversion factor in equation (2.14) is then to normalise by deflating the markup by the size of the conversion involved (e.g., in going from ounces to grams), thus making the size elasticity a pure number. To illustrate the workings of equation (2.14), suppose that the markup is 100 percent, so that $\delta = 2$, and we convert from ounces to grams, in which case $\phi = 28$. With these values, $\beta = 1 - \log 2 / \log 28 \approx 0.8$, so that a doubling of package size is associated with an 80 percent increase in price. Equation (2.14) is an elegant result which yields some additional understanding of the interactions between price and package size.

Pricing Strategies

A branch of the literature views the price-package relationship as part of producers' competitive strategy. Here subtle forms of price discrimination are practiced by charging different classes of consumers of a given good a different unit price. Such practises are inconsistent with competitive markets, and there must be some form of barrier (real or artificial) preventing arbitrage between the different classes of consumers.

Mills (2002, pp. 121-127) studied about 1,750 prices for 149 products sold at Sydney supermarkets. In a number of instances he found quantity surcharges, whereby unit prices increase with package size, the opposite to the more familiar case of discounts for larger quantities.[2] Overall, about 9 percent of cases represented quantity surcharges and these were concentrated in five product groups: Toothpaste for which 33 percent of cases were surcharges; canned meat (33 percent); flour (23 percent); snack foods (19 percent); and paper tissues (19 percent). To account for the observed surcharge on the largest package size of toothpaste, Mills (p. 122) argues that "… manufacturers probably believe that a significant proportion of customers will nevertheless choose that size - on grounds of convenience, or because the customers think (without checking) that there will be a quantity discount". In other words, as prices do not reflect costs, toothpaste manufacturers probably practice price discrimination. Moreover, Mills (p. 124) argues that a quantity discount can also be consistent with price discrimination if not all of the cost savings associated with a larger quantity are passed onto consumers.[3]

[2] Quantity surcharges have also been identified in several earlier studies (Cude and Walker, 1984, Gerstner and Hess, 1987, Walker and Cude 1984 and Widrick, 1979a, b), as discussed by Mills (2002, pp. 119-120).
[3] For a further analysis, see Mills (1996). We shall return to Mills' data in Section 9 below.

Others argue that in some instances, unit price differences reflect equalising price differences, rather than price discrimination. Telser (1978, p. 339), for example, discusses the case of those who buy larger quantities less frequently and pay lower unit prices:

> Assume that the retailer has two kinds of customers for some product, customers who buy large amounts for their inventory and customers who buy small amounts more frequently. When there is a large price decrease, there is a large sales increase to those who are willing to store the good. Sales to this group drop sharply after the price reduction and may subsequently return to the normal level. The behaviour of these customers impose a constraint on the retailer, since he cannot expect the same effect on his rates of sale to them for given price reductions without regard to their timing. Those who buy small amounts frequently will not buy much more at temporarily lower prices. Such buyers will have a relatively steady demand over time. Hence sellers hold larger stocks relative to the mean rate of sales for the light buyers than for the heavy buyers. The difference between the regular and the sales price represents the cost of storage to the sellers and is therefore an equalising price difference. It is most emphatically not an example of price discrimination. On the contrary, it is a price pattern consistent with a competitive market.

3. MARIJUANA PRICES

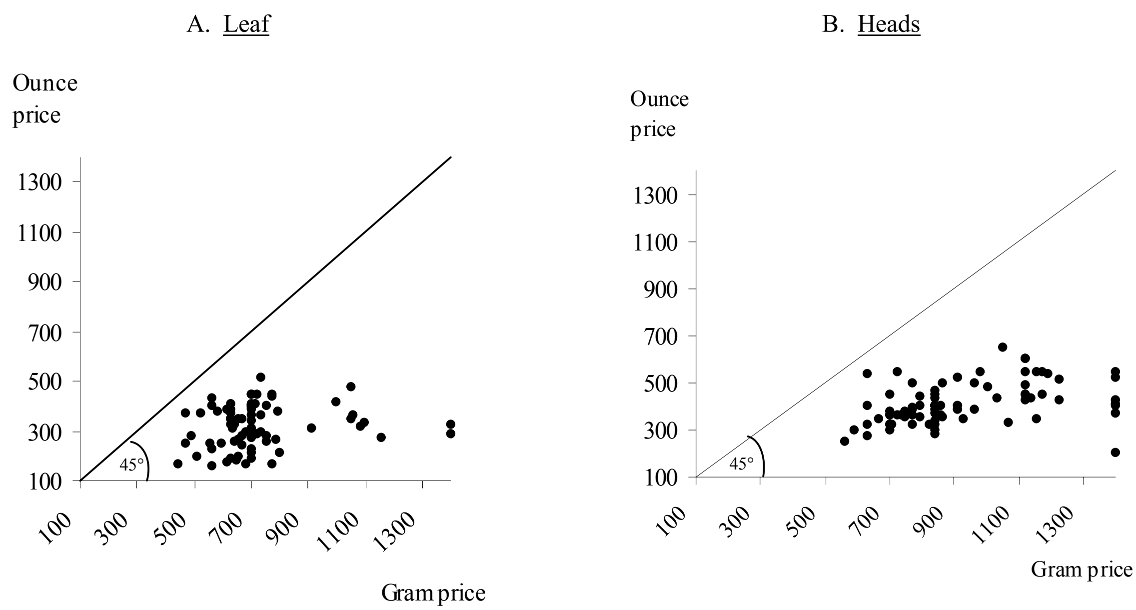
In this section we present data on marijuana prices purchased in the form of two package sizes, ounces and grams. These data were supplied by the Australian Bureau of Criminal Intelligence and refer to the period 1990-99 and the eight states and territories of Australia. For a listing of the data and further details, see the Appendix.

Figure 2 (which has the same format as Figure 1) plots the ounce price against the gram price for two broad types of marijuana, leaf and heads. As all prices are expressed in terms of dollars per ounce, they are directly comparable. As can be seen, all the observations lie below the 45° line, indicating that the unit price for ounce purchases are less than those for gram purchases. Table 1 presents the quantity discounts in logarithmic form, with the negative signs confirming the presence of discounts. Looking at the last entry in the last column for leaf (panel I of the table), we see that for Australia as a whole on average there is an 85 percent discount from buying ounces rather than grams; the corresponding mean for heads is 79 percent. While these are clearly substantial discounts, it should be kept in mind that to gain such a discount a substantially larger purchase must be made (28 times larger, to be precise).

FIGURE 2

OUNCE AND GRAM PRICES OF MARIJUANA

(Dollars per ounce)



In Figure 3 we plot the discounts for leaf (in panel A), heads (panel B) and leaf and heads combined (panel C). The two products leaf and heads are combined by weighting them according to their relative importance in consumption, guesstimated to be .3 and .7, respectively (Clements, 2002a)[4]. The combined histogram is unimodal, (at about –70 percent), somewhat less "raggard" than the other two and the mean discount is about 80 percent. Note also that all three histograms seem to have long left-hand tails, which probably reflects the high variability of the underlying data (Clements, 2002a).

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[4] In a conventional histogram, each observation is equally weighted and the vertical axis records the number of observations falling in each bin. For the weighted version, such as panel C of Figure 3, observations in each bin are sorted into the two products, weighted according to the above scheme and then the weighted number of observations is recorded on the vertical axis. Accordingly, the area of a given column of the weighted histogram is proportional to the product-weighted importance of the observations that fall within the relevant bin.

TABLE 1

DISCOUNT FOR BULK BUYING OF MARIJUANA

(100 × logarithmic ratios of ounce to gram prices)

Year	Region								Australia
	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	
					I. Leaf				
1990	-56.4	-36.0	-113.5	-134.0	-59.0	-93.4	-106.7	-42.2	-65.1
1991	-79.3	-53.7	-118.0	-151.1	-56.0	-93.4	-109.9	-68.1	-80.6
1992	-107.4	-65.7	-120.9	-72.2	-91.2	-84.7	-131.5	-58.8	-93.5
1993	-42.0	-55.3	-140.3	-118.3	-48.5	-86.1	-125.4	-86.7	-68.4
1994	-86.8	-57.2	-127.5	-88.8	-66.2	-100.3	-95.8	-63.3	-82.6
1995	-122.4	-56.0	-33.6	-82.1	-59.6	-91.6	-123.4	-107.9	-82.4
1996	-146.0	-72.8	-64.2	-97.9	-58.8	-109.7	-93.2	-54.0	-102.8
1997	-158.1	-54.2	-26.2	-90.9	-58.8	-91.4	-33.6	-46.3	-96.8
1998	-119.2	-70.5	-51.9	-62.5	-62.4	-82.3	-21.9	-47.4	-84.1
1999	-143.5	-70.9	-45.5	-79.9	-58.8	-84.7	-89.6	-44.2	-93.1
Mean	-106.1	-59.2	-84.2	-97.8	-61.9	-91.8	-93.1	-61.9	-84.9
					II. Heads				
1990	-62.4	-48.0	-122.1	-62.4	-125.3	-76.7	-55.0	-59.6	-73.3
1991	-62.4	-71.1	-119.2	-65.0	-194.6	-76.7	-91.2	-80.6	-84.0
1992	-131.7	-91.2	-85.2	-68.0	-65.7	-44.2	-105.9	-43.2	-101.2
1993	-54.6	-64.8	-86.0	-66.7	-95.8	-65.7	-99.1	-66.8	-68.7
1994	-74.2	-74.1	-118.1	-74.2	-96.9	-86.3	-70.5	-57.8	-83.0
1995	-79.4	-68.4	-96.9	-74.9	-95.5	-79.5	-119.4	-85.8	-81.8
1996	-75.6	-74.2	-66.1	-77.3	-80.7	-108.8	-90.9	-98.1	-75.4
1997	-93.4	-76.3	-15.8	-84.7	-74.2	-88.0	-60.3	-58.5	-74.0
1998	-83.1	-77.2	-27.3	-82.9	-90.4	-92.9	-67.8	-62.4	-71.1
1999	-87.0	-45.4	-67.5	-80.6	-74.2	-103.0	-66.2	-74.2	-73.5
Mean	-80.4	-69.1	-80.4	-73.7	-99.3	-82.2	-82.6	-68.7	-78.6

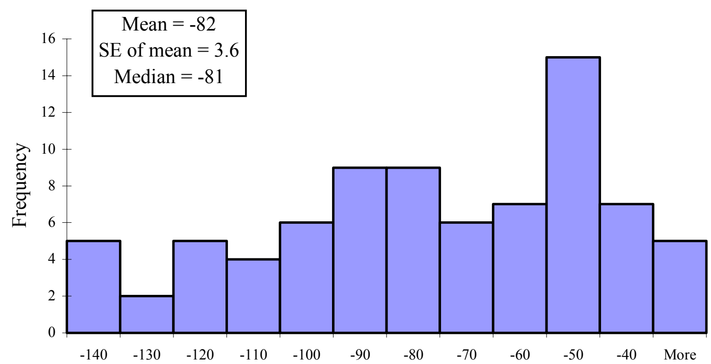
FIGURE 3

HISTOGRAMS OF DISCOUNT FOR BULK

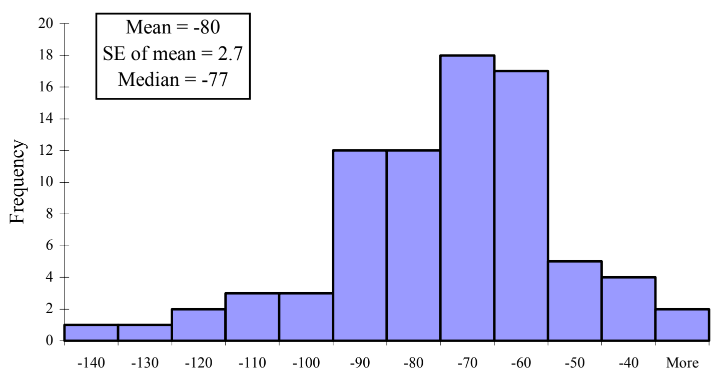
BUYING OF MARIJUANA

(100 × logarithmic ratios of ounce to gram prices)

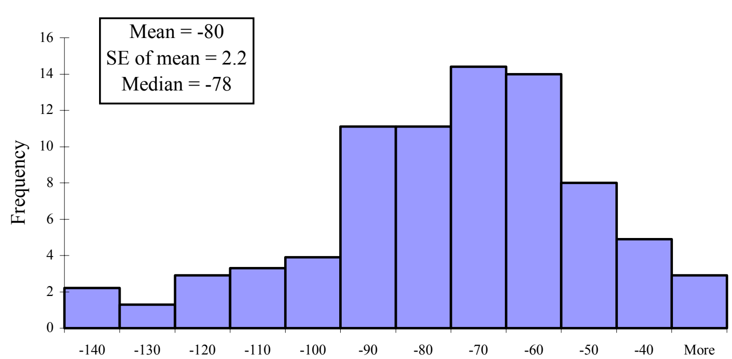
A. <u>Leaf</u>



B. <u>Heads</u>



C. <u>Leaf and Heads</u>



4. THE SIZE AND DISCOUNT ELASTICITIES

It is convenient to introduce at this juncture a slightly different notation that will be used in the remainder of the paper. Let p'_s be the price of marijuana sold in the form of a packet of size s, $s = 1$ for a gram packet and $s = 28$ for an ounce packet. It is to be noted that as the quantity units differ, the two values of p'_s are not directly comparable as p'_1 is measured in terms of dollars per gram, while p'_{28} is in dollars per ounce. Consider the following relationship between price and packet size:

$$(4.1) \qquad \log p'_s = \alpha + \beta' \log s,$$

where β' is the <u>size elasticity</u> of the price. As we have previously observed substantial quantity discounts for marijuana, the price increases less than proportionately to size, so we expect $0 < \beta' < 1$. As p'_s / s is the price per gram, this version of the price is comparable for $s = 1, 28$. We shall refer to p'_s / s as the <u>unit price</u>. To simplify the notation, write p_s for the unit price p'_s / s, and let $\beta = \beta' - 1$, which we shall call the <u>discount elasticity</u>, the percentage change in the unit price resulting from a one-percent increase in packet size. It follows from equation (4.1) that

$$(4.2) \qquad \log p_s = \alpha + \beta \log s,$$

so that the unit price falls for larger-sized purchases if $\beta < 0$, or when the size elasticity $\beta' < 1$.

Next, consider the price of ounce purchases in terms of the price of grams. There are two versions of this relative price, p'_{28} / p'_1 and p_{28} / p_1. The units of the relative price p'_{28} / p'_1 are grams per ounce, while those of p_{28} / p_1 are grams per gram, which is a pure number. We previously measured the <u>quantity discount</u> available by buying in ounces rather than grams by the logarithmic ratio $\log\left(p_{28} / p_1\right)$. In logarithmic terms, it follows from equations (4.1) and (4.2) that these relative prices can be expressed as

$$\log \frac{p'_{28}}{p'_1} = \beta' \log 28, \quad \log \frac{p_{28}}{p_1} = \beta \log 28 .$$

It then follows that the size and discount elasticities, β' and β, are related to the relative prices according to

(4.3) $$\beta' = \frac{\log \frac{p'_{28}}{p'_1}}{\log 28}, \quad \beta = \frac{\log \frac{p_{28}}{p_1}}{\log 28}.$$

In the previous section we observed that the quantity discount was of the order of 80 percent; that is, $\log(p_{28}/p_1) \approx -.80$. Using this value, together with $\log 28 \approx 3.33$, it follows from the second member of equation (4.3) that an estimate of the discount elasticity is

(4.4) $$\hat{\beta} = \frac{\log \frac{p_{28}}{p_1}}{\log 28} \approx \frac{-.80}{3.33} \approx -.25 .$$

In Section 6 we shall show that this way of estimating β has some attractions.

Recall that the quantity discount $\log(p_{28}/p_1)$ is a pure number: Marijuana is approximately 80 percent cheaper if purchased in the form of ounces rather than grams. But this percentage has embodied in it the transition from grams to ounces, which involves a factor of 28. As revealed by equation (4.3), the discount elasticity β normalises the discount by deflating it by log 28. The upshot of this is that while the quantity discount is not comparable across products involving size differences other than ounces/grams, the discount elasticity β has no such problems. Note that equation (4.4) implies an estimated size elasticity of $\hat{\beta}' = \hat{\beta} + 1 \approx .75$, so that the rate of increase of marijuana prices is only about three-quarters of the proportionate increase in package size.

5. SIZE AND THE DISTRIBUTION OF PRICES

Rather than just two sizes of the product, now consider a larger number given by the set **G**. It is then possible to consider the nature of the distribution of prices, and its relationship to package size. Let w_s be the market share of the product when sold in the form of size $s \in \mathbf{G}$, with $\sum_{s \in \mathbf{G}} w_s = 1$.

We summarise the prices and sizes by their weighted geometric means, the logarithms of which are:

(5.1) $$\log P = \sum_{s \in \mathbf{G}} w_s \log p_s, \qquad \log S = \sum_{s \in \mathbf{G}} w_s \log s.$$

The use of market shares as weights serves to give more weight to the more popular sizes, which is reasonable. The mean of the prices can also be viewed as a stochastic price index with the following interpretation (Theil, 1967, p. 136). Consider the prices $\log p_s$, $s \in \mathbf{G}$, as random variables drawn from a distribution of prices. Suppose we draw prices at random from this distribution such that each dollar of expenditure has an equal chance of being selected. Then, the market share w_s is the probability of drawing $\log p_s$, so that the expected value of the price is $\sum_{s \in \mathbf{G}} w_s \log p_s$, which is the first member of equation (5.1). A similar interpretation applies to the mean packet size $\log S$. It follows directly from equation (4.2) that the two means are related according to

(5.2) $$\log P = \alpha + \beta \log S.$$

This shows that the mean price is independent of mean size under the condition that there is no quantity discount, as then the size elasticity of prices, β', is unity and $\beta = 0$. When there are quantity discounts, $\beta < 0$ and the mean price falls as the mean size rises.

The means in (5.1) can be considered as weighted first-order moments of the price and size distributions. The corresponding second-order moments are

(5.3) $$\Pi_p = \sum_{s \in \mathbf{G}} w_s \left(\log p_s - \log P\right)^2, \quad \Pi_s = \sum_{s \in \mathbf{G}} w_s \left(\log s - \log S\right)^2.$$

These measures are non-negative, increase with the dispersion of the relevant distribution and can be referred to as the <u>price and size variances</u>. It follows from equations (4.2) and (5.2) that the deviation of the price of the product of size s from its mean, $\log p_s - \log P$, is related to the corresponding size deviation, $\log s - \log S$, viz., $\log p_s - \log P = \beta(\log s - \log S)$. Squaring both sides of this equation, multiplying by the relevant market share w_s and then summing over $s \in \mathbf{G}$, we obtain the result $\Pi_p = \beta^2 \Pi_s$, or

(5.4) $$\sqrt{\Pi_p} = |\beta| \sqrt{\Pi_s}\,.$$

In words, the standard deviation of prices is proportional to the standard deviation of sizes, with $|\beta|$ the factor of proportionality. As $|\beta|$ is expected to be a fraction, result (5.4) implies that the dispersion of prices is less than that of sizes. Only when the size elasticity is unity, $\beta = 0$ and the price distribution is degenerate; this, of course, follows from equation (4.2) with $\beta = 0$, as then each price takes the same value α. Note also that result (5.4) has an interesting symmetry property for quantity discounts and premia. If we have two values of the size elasticity $\beta' = 1 \pm k$, for $k > 0$, then the values of the discount elasticity are $\beta = \pm k$. In the case when $\beta' = 1 + k$, the price increases more than proportionately to size, there is a size premium and the "discount" elasticity is positive, $\beta = k$. As equation (5.4) involves the absolute value of β, for a given standard deviation of sizes, the dispersion of prices when $\beta = k$ is identical to that when $\beta = -k$.

To illustrate the workings of the above concepts, we use the marijuana data with two package sizes, ounces and grams. Guesstimates of the two market shares are 20 percent for grams and 80 percent for ounces (Clements, 2002a), so that $w_1 = .2$ and $w_{28} = .8$. Using the price data given in the Appendix, we compute the index defined in the first member of equation (5.1) and the results are given in Table 2 for leaf and heads. These indexes are expressed as $\exp(\log P)$, so the units are dollars per ounce. The second last entries in the last column of each of the two panels of Table 2 show that for Australia as a whole in 1999, the index of leaf prices is \$388 per ounce, while that of heads is \$468. Regarding the package size index, this is a constant equal to $\log S = w_1 \log 1 + w_{28} \log 28 = .8 \times 3.33 = 2.67$, or, in terms of grams, $S = \exp(\log S) = 14.4$. Using exactly the same approach, we compute the variance of prices defined in equation (5.3) and the results are given in Table 3 in the form of standard deviations; it can be seen from equation (5.3) that this measure of dispersion is unit free. About 74 percent of the standard deviations of the leaf prices fall in the range 20-40 percent; while for heads, about 88 percent fall in this range. As before with the first moment, the variance of size is a constant, and equal to $\sqrt{\Pi_s} = 1.33$. It follows from equation (5.4) that the ratio of $\sqrt{\Pi_p}$ to $\sqrt{\Pi_s}$ equals $|\beta|$, the absolute value of the discount elasticity. Figure 4 gives histograms of these ratios for the two products in all years and all regions (panels A and B), as well as for the two products combined (panel C).[5] As can be seen, the means (and medians) are of the order of .25, which agrees with the previous estimate of the discount elasticity given in equation (4.4).

6. ECONOMETRIC ISSUES

Equation (4.2) is a relationship between the unit price of package size s, p_s, and its size. We apply this equation at time $t\,(t = 1,\ldots,T)$ and add a disturbance term ε_{st}:

(6.1) $$\log p_{st} = \alpha + \beta \log s + \varepsilon_{st},$$

where α is the intercept and β the discount elasticity. Before implementing this equation, it is useful to explore the nature of the least-squares estimates.

Suppose we have price data on two package sizes, ounce and grams. If we measure size in terms of grams, we can then write p_{28} for the per gram price of an ounce purchase and p_1 for the gram price of a gram purchase. Let $y_{st} = \log p_{st}$, $[y_{s1},\ldots,y_{sT}]'$ be a vector of T observations on the price of package size s, s = 1, 28; $\boldsymbol{\iota}$ be a column vector of T unit

[5] As for Figure 3, the ratios for the two products are combined by weighting them according to their relative share in consumption of .3 for leaf and .7 for heads.

TABLE 2

INDEXES OF MARIJUANA PRICES

(Dollars per ounce)

Year	Region								Australia
	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	
					I. Leaf				
1990	490	551	282	275	437	332	387	449	444
1991	557	501	272	230	447	332	436	372	448
1992	449	414	239	393	270	355	245	394	377
1993	417	457	222	253	427	334	225	297	374
1994	498	442	234	344	371	298	206	454	402
1995	407	447	428	363	391	353	209	318	413
1996	435	443	398	344	394	328	241	455	418
1997	395	318	454	315	394	346	401	423	388
1998	423	418	416	283	396	354	392	495	407
1999	366	361	486	293	394	355	313	492	388
Mean	444	435	343	309	392	339	305	415	406
					II. Heads				
1990	680	715	527	680	514	379	586	522	646
1991	680	634	539	572	295	379	540	441	596
1992	488	540	460	447	414	492	525	545	491
1993	558	396	431	493	545	414	419	438	481
1994	638	426	415	464	516	386	418	617	511
1995	631	459	388	411	530	420	444	520	506
1996	640	464	454	379	477	352	465	639	517
1997	663	466	555	355	464	427	432	497	540
1998	576	453	581	325	407	391	420	510	504
1999	610	438	343	294	464	369	371	556	468
Mean	616	499	470	442	463	401	462	528	526

elements; $\mathbf{0}$ be a vector of zeros; and $\boldsymbol{\varepsilon} = [\boldsymbol{\varepsilon}_1' \vdots \boldsymbol{\varepsilon}_{28}']'$, with $\boldsymbol{\varepsilon}_s = [\varepsilon_{s1},\ldots,\varepsilon_{sT}]'$. Then as $\log 1 = 0$, we can write equation (6.1) for $s = 1, 28$ and $t = 1,\ldots,T$ in vector form as

$$\begin{bmatrix} \mathbf{y}_1 \\ \hline \mathbf{y}_{28} \end{bmatrix} = \begin{bmatrix} \boldsymbol{\iota} & \mathbf{0} \\ \hline \boldsymbol{\iota} & \log 28\,\boldsymbol{\iota} \end{bmatrix} \begin{bmatrix} \alpha \\ \hline \beta \end{bmatrix} + \begin{bmatrix} \boldsymbol{\varepsilon}_1 \\ \hline \boldsymbol{\varepsilon}_{28} \end{bmatrix},$$

TABLE 3

STANDARD DEVIATIONS OF MARIJUANA PRICES

$(\sqrt{\Pi_p} \times 100)$

Year	Region								Australia
	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	
				I. Leaf					
1990	22.6	14.4	45.4	53.6	23.6	37.4	42.7	16.9	26.1
1991	31.7	21.5	47.2	60.4	22.4	37.4	43.9	27.2	32.2
1992	43.0	26.3	48.4	28.9	36.5	33.9	52.6	23.5	37.4
1993	16.8	22.1	56.1	47.3	19.4	34.5	50.1	34.7	27.3
1994	34.7	22.9	51.0	35.5	26.5	40.1	38.3	25.3	33.1
1995	49.0	22.4	13.5	32.8	23.9	36.7	49.4	43.2	32.9
1996	58.4	29.1	25.7	39.1	23.5	43.9	37.3	21.6	41.1
1997	63.3	21.7	10.5	36.4	23.5	36.5	13.5	18.5	38.7
1998	47.7	28.2	20.8	25.0	24.9	32.9	8.8	19.0	33.7
1999	57.4	28.4	18.2	32.0	23.5	33.9	35.8	17.7	37.2
Mean	42.5	23.7	33.7	39.1	24.8	36.7	37.2	24.8	34.0
				II. Heads					
1990	25.0	19.2	48.8	25.0	50.1	30.7	22.0	23.8	29.3
1991	25.0	28.4	47.7	26.0	77.8	30.7	36.5	32.3	33.6
1992	52.7	36.5	34.1	27.2	26.3	17.7	42.3	17.3	40.5
1993	21.8	25.9	34.4	26.7	38.3	26.3	39.7	26.7	27.5
1994	29.7	29.6	47.2	29.7	38.8	34.5	28.2	23.1	33.2
1995	31.8	27.4	38.7	30.0	38.2	31.8	47.8	34.3	32.7
1996	30.2	29.7	26.4	30.9	32.3	43.5	36.4	39.2	30.2
1997	37.4	30.5	6.3	33.9	29.7	35.2	24.1	23.4	29.6
1998	33.2	30.9	10.9	33.2	36.2	37.2	27.1	25.0	28.4
1999	34.8	18.2	27.0	32.3	29.7	41.2	26.5	29.7	29.4
Mean	32.2	27.6	32.2	29.5	39.7	32.9	33.1	27.5	31.4

or using an obvious notation, $\mathbf{y} = \mathbf{X}\gamma + \boldsymbol{\varepsilon}$. It follows that

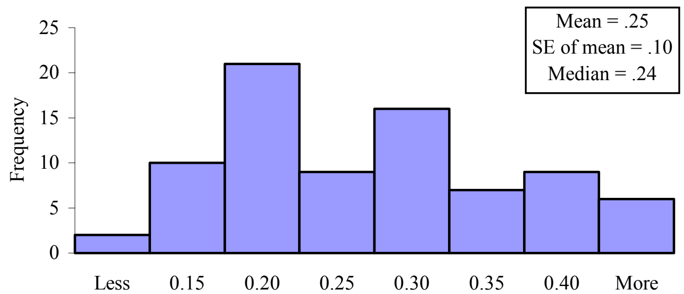
$$(6.2) \qquad \mathbf{X}'\mathbf{X} = T\log 28 \begin{bmatrix} \dfrac{2}{\log 28} & 1 \\ 1 & \log 28 \end{bmatrix}, \qquad (\mathbf{X}'\mathbf{X})^{-1} = \frac{1}{T\log 28} \begin{bmatrix} \log 28 & -1 \\ -1 & \dfrac{2}{\log 28} \end{bmatrix},$$

$$\mathbf{X}'\mathbf{y} = \begin{bmatrix} \boldsymbol{\iota}' & \boldsymbol{\iota}' \\ 0 & \log 28\,\boldsymbol{\iota}' \end{bmatrix} \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_{28} \end{bmatrix} = \begin{bmatrix} \sum_s \sum_t y_{st} \\ \log 28 \sum_t y_{28,t} \end{bmatrix}.$$

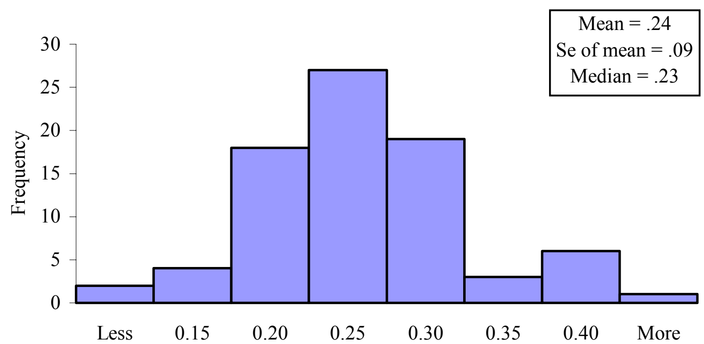
FIGURE 4

HISTOGRAMS OF RATIOS OF STANDARD DEVIATION OF PRICES TO STANDARD DEVIATION OF SIZE

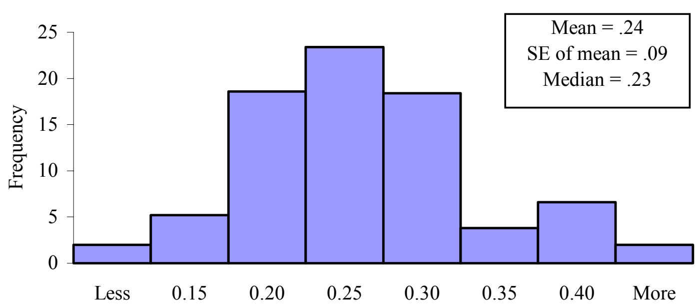
A. Leaf



B. Heads



C. Leaf and Heads



The LS estimator of the coefficient vector γ is $\left(\mathbf{X}'\mathbf{X}\right)^{-1}\mathbf{X}\mathbf{y}$. In view of the special structure of model (6.1) and using the above results, the estimator takes the form

$$\frac{1}{T\log 28}\begin{bmatrix}\log 28 & -1 \\ -1 & \dfrac{2}{\log 28}\end{bmatrix}\begin{bmatrix}\sum_s\sum_t y_{st} \\ \log 28 \sum_t y_{28,t}\end{bmatrix} = \frac{1}{T}\begin{bmatrix}\sum_s\sum_t y_{st} - \sum_t y_{28,t} \\ \dfrac{1}{\log 28}\left(-\sum_s\sum_t y_{st} + 2\sum_t y_{28,t}\right)\end{bmatrix}$$

$$= \begin{bmatrix}\bar{y}_1 \\ \dfrac{1}{\log 28}\left(-\bar{y}_1 - \bar{y}_{28} + 2\bar{y}_{28}\right)\end{bmatrix} ,$$

where $\bar{y}_s = (1/T)\Sigma_t y_{st}$ is the logarithmic mean price of package size s. As $\gamma = [\alpha \;\; \beta]'$, in terms of the parameters of equation (6.1), we have

$$\text{(6.3)} \qquad \hat{\alpha} = \bar{y}_1, \qquad \hat{\beta} = \frac{\bar{y}_{28} - \bar{y}_1}{\log 28}.$$

In words, the estimated intercept is the mean of gram prices, while the slope is the excess of the ounce price mean over the gram price mean, normalised by the difference in package size, $\log 28 - \log 1 = \log 28$.[6] It is to be noted that the above expression for the estimate of the discount elasticity is exactly the same as that of equation (4.4). The covariance matrix of the LS estimator is $\hat{\sigma}^2\left(\mathbf{X}'\mathbf{X}\right)^{-1}$, where $\hat{\sigma}^2$ is an estimate of the variance of ε_{st}, the disturbance in equation (6.1). It follows from the diagonal elements of the matrix on the far right of equation (6.2) that

$$\text{var}\left(\hat{\alpha}\right) = \frac{\hat{\sigma}^2}{T}, \qquad \text{var}\left(\hat{\beta}\right) = \frac{2\hat{\sigma}^2}{T\left(\log 28\right)^2}.$$

The dependent variable in equation (6.1) is the unit price. Why use this, rather than the total price of package $p_s' = s \times p_s$, and then estimate the size elasticity $\beta' = (1+\beta)$, according to equation (4.1)? Although either way would yield the same estimates of β' and β, it may appear preferable to use the unit price as the dependent variable because of units of

[6] Another way to establish result (6.3) is to note that as equation (6.1) will pass through the means for both grams and ounces, we have for the two package sizes $\bar{y}_1 = \hat{\alpha}$, $\bar{y}_{28} = \hat{\alpha} + \hat{\beta}\log 28$. These two equations then yield result (6.3).

measurement considerations. The units of p_s are comparable across different package sizes as they are expressed in terms of dollars per gram. By contrast, the units of p'_s differ from dollars per gram, for $s = 1$, to dollars per ounce, for $s = 28$. One could then argue that as the variance of p'_{28} would be likely to be greater than $\text{var}(p'_1)$, the disturbances could be heteroscedastic. But such an argument does not apply when we use the logarithms of the prices as then the factor converting one price to another becomes an additive constant rather than multiplicative, so that $\text{var}(\log p_s) = \text{var}(\log p'_s)$.

The price data underlying the LS estimates given in equation (6.3) are expressed in terms of dollars per gram. It would be equally acceptable, however, to use dollars per ounce as the alternative unit of measurement. How do the estimates (6.3) change if we use prices per ounce, rather than prices per gram? Intuition suggests that the estimated intercept would become the mean of prices of ounce-sized packets; and that the estimated slope would remain unchanged as this is an elasticity, which is a dimensionless concept. We now briefly investigate this issue. Recall that p_s is the price per gram when marijuana is purchased in a package of size s, $s = 1 \text{ (grams)}, 28 \text{ (ounces)}$. These prices can be expressed in terms of ounces simply by multiplying by 28. Thus using a " ˜ " to denote prices and sizes expressed in terms of ounces, we have $\tilde{p}_{s/28} = 28 \times p_s$, or $\tilde{p}_{\tilde{s}} = 28 \times p_s$, with $\tilde{s} = (1/28) \times s$ for $\tilde{s} = 1/28 \text{ (grams)}, 1 \text{ (ounces)}$. To enhance understanding of the workings of this notational scheme, it can be enumeratored as follows:

	Unit of Measurement			
	Grams		Ounces	
Package size	Size s	Price p_s	Size $\tilde{s}$	Price $\tilde{p}_{\tilde{s}}$
Gram	1	p_1	$1/28$	$\tilde{p}_{1/28}$
Ounce	28	p_{28}	1	$\tilde{p}_1$

When using ounces, equation (6.1) becomes

$$(6.1') \qquad \log \tilde{p}_{\tilde{s}t} = \tilde{\alpha} + \tilde{\beta} \log \tilde{s} + \tilde{\varepsilon}_{\tilde{s}t}, \qquad \tilde{s} = 1/28, 1; \quad t = 1,\ldots,T.$$

As $\log\tilde{s} = -\log 28$ for $\tilde{s} = 1/28$ and $\log\tilde{s} = 0$ for $\tilde{s} = 1$, proceeding as before, we have

$$\begin{bmatrix} \tilde{\mathbf{y}}_{1/28} \\ \tilde{\mathbf{y}}_1 \end{bmatrix} = \begin{bmatrix} \boldsymbol{\iota} & -\log 28\,\boldsymbol{\iota} \\ \boldsymbol{\iota} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{\alpha} \\ \boldsymbol{\beta} \end{bmatrix} + \begin{bmatrix} \tilde{\boldsymbol{\varepsilon}}_{1/28} \\ \tilde{\boldsymbol{\varepsilon}}_1 \end{bmatrix}$$

or $\tilde{\mathbf{y}} = \tilde{\mathbf{X}}\boldsymbol{\gamma} + \tilde{\varepsilon}$. Thus[7]

$$\tilde{\mathbf{X}}'\tilde{\mathbf{X}} = \mathrm{T}\ \log 28 \begin{bmatrix} \dfrac{2}{\log 28} & -1 \\ -1 & \log 28 \end{bmatrix}, \qquad \left(\tilde{\mathbf{X}}'\tilde{\mathbf{X}}\right)^{-1} = \frac{1}{\mathrm{T}\ \log 28} \begin{bmatrix} \log 28 & 1 \\ 1 & \dfrac{2}{\log 28} \end{bmatrix}$$

$$\tilde{\mathbf{X}}'\tilde{\mathbf{y}} = \begin{bmatrix} \boldsymbol{\iota}' & \boldsymbol{\iota}' \\ -\log 28\,\boldsymbol{\iota} & \mathbf{0}' \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{y}}_{1/28} \\ \tilde{\mathbf{y}}_1 \end{bmatrix} = \begin{bmatrix} \sum_{\tilde{s}}\sum_{t} \tilde{y}_{\tilde{s}t} \\ -\log 28 \sum_{t} \tilde{y}_{1/28,t} \end{bmatrix}.$$

The LS estimates now thus take the form

$$\frac{1}{\mathrm{T}\log 28} \begin{bmatrix} \log 28 & 1 \\ 1 & \dfrac{2}{\log 28} \end{bmatrix} \begin{bmatrix} \sum_{\tilde{s}}\sum_{t} \tilde{y}_{\tilde{s}t} \\ -\log 28 \sum_{t} \tilde{y}_{1/28,t} \end{bmatrix} = \frac{1}{\mathrm{T}} \begin{bmatrix} \sum_{\tilde{s}}\sum_{t} \tilde{y}_{\tilde{s}t} - \sum_{t} \tilde{y}_{1/28,t} \\ \dfrac{1}{\log 28}\left(\sum_{\tilde{s}}\sum_{t} \tilde{y}_{\tilde{s}t} - 2\sum_{t} \tilde{y}_{1/28,t}\right) \end{bmatrix}$$

$$= \begin{bmatrix} \bar{\tilde{y}}_{1/28} + \bar{\tilde{y}}_1 - \bar{\tilde{y}}_{1/28} \\ \dfrac{1}{\log 28}\left(\bar{\tilde{y}}_{1/28} + \bar{\tilde{y}}_1 - 2\bar{\tilde{y}}_{1/28}\right) \end{bmatrix}.$$

Thus the estimates of the parameters of equation (6.1′) are

$$\text{(6.3′)} \qquad \hat{\tilde{\alpha}} = \bar{\tilde{y}}_1, \qquad \hat{\tilde{\beta}} = \frac{\bar{\tilde{y}}_1 - \bar{\tilde{y}}_{1/28}}{\log 28}.$$

---

[7] Note that the relationship between the ounce and gram notation is as follows: $\tilde{\mathbf{y}} = \mathbf{y} + \log 28\,\boldsymbol{\iota}$ and $\tilde{\mathbf{X}} = \mathbf{X} + \left[\mathbf{0} \,\vdots\, -\log 28\,\boldsymbol{\iota}\right]$, where $\boldsymbol{\iota}$ is a vector of 2T unit elements and $\mathbf{0}$ is a vector of 2T zero elements.

As $\tilde{p}_{\tilde{s}} = 28 \times p_s$, with $\tilde{s} = s/28$, $\tilde{p}_{\tilde{s}} = 28 \times p_{28\tilde{s}}$. In logarithmic terms, the two sets of prices are thus related according to $\tilde{y}_{\tilde{s}} = \log 28 + y_{28\tilde{s}}$, so that $\bar{\tilde{y}}_1 = \log 28 + \bar{y}_{28}$ and $\bar{\tilde{y}}_{1/28} = \log 28 + \bar{y}_1$. It thus follows from equations (6.3) and (6.3′) that $\hat{\hat{\alpha}} = \log 28 + \bar{y}_{28}$, $\hat{\hat{\beta}} = (\bar{y}_{28} - \bar{y}_1)/\log 28 = \hat{\beta}$. This establishes that in moving from grams to ounces as the unit of measurement (i) the estimated intercept becomes the logarithmic mean of the prices of the ounce-sized packages; and (ii) the estimated size elasticity remains unchanged. The respective standard errors of $\hat{\hat{\alpha}}$ and $\hat{\hat{\beta}}$ are identical to those of $\hat{\alpha}$ and $\hat{\beta}$.

7. HEDONIC REGRESSIONS

The hedonic regression model relates the overall price of a product to its basic characteristics, and "unbungles" a package of attributes by estimating the marginal cost/valuation of each characteristic in the form of a regression coefficient. The seminal paper on this topic is Rosen (1974). Equation (6.1) can be thought of as a hedonic regression equation in which marijuana has one characteristic, package size. A recent paper by Diewert (2003) considered some unresolved issues in hedonic regressions that are relevant to the previous discussion, and the following is a simplified summary of some of his results.

Consider a cross-section application in which $p_1,\ldots, p_K$ are the prices of K types of a certain product, such as a personal computer, and $z_1,\ldots, z_K$ are the corresponding values of a single characteristic of each type, such as the amount of memory of each of the K computers. Consider further the hedonic regression:

$$f(p_k) = \alpha + g(z_k)\beta + \varepsilon_k, \quad k = 1,\ldots,K, \tag{7.1}$$

where $f(p_k)$ is either the identity or logarithmic function, so that $f(p_k) = p_k$ or $f(p_k) = \log p_k$; $g(z_k)$ is also either the identity of logarithmic function; α and β are coefficients to be estimated; and ε_k is a disturbance term with a zero mean and a constant variance. The question to be discussed is, what form should the functions $f(\ )$ and $g(\ )$ take, the identity or logarithmic? Suppose we use the logarithm of the price on the left of model (7.1) and the identity function for the characteristic. One advantage of doing this is that the coefficient β is then interpreted as the (approximate) percentage change in the price resulting from a one-unit increase in the characteristic. When we additionally use $\log z_k$ on the right, then β becomes the elasticity of the price with respect to z. Assume we have $\log p_k$ on the left of (7.1), and we wish to test the bench-mark hypothesis that the price increases proportionately with the characteristic z; in other words, that there are constant returns to scale so that the price per unit of the characteristic (p_k/z_k, the price of a computer per unit of memory) is constant. With $\log p_k$ on the left of (7.1), this test can be implemented by setting $g(z_k) = \log z_k$ and testing $\beta = 1$. This convenient property points to the use of logarithms on both sides of model (7.1).

Now consider the stochastic properties of the disturbance ε_k in equation (7.1). When $f(p_k) = p_k$ and $f(p_k) = \log p_k$, we have, respectively,

(7.2a) $$\varepsilon_k = p_k - \alpha - \beta g(z_k)$$

(7.2b) $$\varepsilon'_k = \frac{p_k}{\exp\{\alpha + \beta g(z_k)\}},$$

where $\varepsilon'_k = \exp(\varepsilon_k)$. Which disturbance is more likely to have a constant variance? As products with a high value of z_k are likely to be more expensive, and vice versa, the disturbances in equation (7.2a) would be likely to take higher values for more expensive products, and lower for cheaper ones. Consequently, these disturbances are likely to be heteroscedastic. This would possibly be less of a problem with the logarithmic formulation (or its transform, the exponential) in equation (7.2b) as this involves the ratio of the price to its mean, which is more likely to have a constant variance. That is, while more expensive products would still tend to have larger disturbances, if these errors are more or less proportional to the corresponding prices, then the variance of the ratio of the price to the conditional mean will be more or less constant. This argument also favours the use of the logarithm of the price on the left of equation (7.1).

Next, consider the implications of ensuring that the hedonic regression model is invariant to a change in the units of measurement of the characteristic z. Suppose that the function $f(\ )$ is unspecified, $g(\ )$ is logarithmic, and that the characteristic is now measured as

$z^* = z/c$ with c a positive constant. The hedonic model now takes the form $f(p_k) = \alpha^* + \beta^* \log z_k^*$, where α^* and β^* are new coefficients. Invariance requires that the prices predicted by the two models coincide, so that $\alpha + \beta \log z_k = \alpha^* + \beta^* \log z_k^*$ for all values of z. This implies that the two sets of coefficients are related according to $\beta^* = \beta$ and $\alpha^* = \alpha - \beta^* \log c$. Note in particular that invariance requires that there be an intercept in the model.

Some types of the product will typically be more economically important than others, which raises the question of weighting. If there are only three types of the product and the sales of the first are twice those of the second and third, for example, it would then seem natural for the first product, relative to the second and third, to receive twice the weight in the hedonic regression. While these issues usually involve questions about how to induce homoscedasticity in the disturbance term, Diewert (2003) emphasises the idea from index-number theory that the regression should be representative. To justify this approach, Diewert quotes Fisher (1922, p. 43):

> It has already been observed that the purpose of any index number is to strike a 'fair average' of the price movements -- or movements of other groups of magnitudes. At first a *simple* average seemed fair, just because it treated all terms alike. And, in the absence of any knowledge of the relative importance of the various commodities included in the average, the simple average *is* fair. But it was early recognized that there are enormous differences in importance. Everyone knows that pork is more important than coffee and wheat than quinine. Thus the quest for fairness led to the introduction of weighting.

Paraphrasing Diewert (2003, p. 5) slightly to accommodate our terminology and notation, he justifies weighting as follows:

> If product type k sold q_k units, then perhaps product type k should be repeated in the hedonic regression q_k times so that the regression is representative of sales that actually occurred.

Diewert argues that an equivalent way of repeating the observation on product type k q_k times is to weight the single observation by $\sqrt{q_k}$. The sense in which these two approaches are equivalent is that the LS estimators of the model with repeated observations are identical to those of the weighted model; Diewert refers to Greene (1993, pp. 277-79) for a proof. The weighted approach has the advantage that we are able to assume more plausibly that the disturbances are iid. As the disturbances of the repeated-observation approach are identical for a given type of product, they obviously cannot be independently distributed. Although the (square roots of) quantity weights are preferable to equal weights, value weights are even better. The reason is that quantity weights tend to under- (over-) represent expensive (cheap) products; the value, price × quantity, strikes a proper balance between the two dimensions of the product. Accordingly, Diewert favours weighting observations in model (7.1) by the square roots of the corresponding value of sales. This is, of course, equivalent to weighting by the square roots of the market shares as these differ from sales by a factor proportionality, the reciprocal of the square root of total sales, which drops out in the LS regression. The occurrence of the square roots of shares in regressions involving prices is familiar from the stochastic index number theory of Clements and Izan (1981, 1987) and and Selvanathan and Rao (1994).

To summarise, Diewert (2003) has a preference for logarithms to be used on both sides of the hedonic model (7.1), for an intercept to be included and for that model to be estimated by weighted LS, with weights equal to the square roots of the value of sales or, equivalently, market shares. Equation (6.1) satisfies the first two of these three *desiderata*. We now analyse the impact of weighting on this equation. Let w_{st} be the market share of marijuana sold in package size s $(s = 1, 28$ for grams and ounces) in year t, with $w_{1,t} + w_{28,t} = 1$. We multiply both sides of equation (6.1) by the square root of this share to give

$$\text{(7.3)} \qquad \sqrt{w_{st}}\, y_{st} = \alpha\sqrt{w_{st}} + \beta\sqrt{w_{st}}\log s + \sqrt{w_{st}}\,\varepsilon_{st},$$

where $y_{st} = \log p_{st}$. We write this equation for $s = 1, 28$ and $t = 1,\ldots,T$ in vector form as

$$\begin{bmatrix} \sqrt{\mathbf{W}_1}\,\mathbf{y}_1 \\ \hline \sqrt{\mathbf{W}_{28}}\,\mathbf{y}_{28} \end{bmatrix} = \left[\begin{array}{c|c} \sqrt{\mathbf{w}_1} & \mathbf{0} \\ \hline \sqrt{\mathbf{w}_{28}} & \log 28\sqrt{\mathbf{w}_{28}} \end{array}\right] \begin{bmatrix} \alpha \\ \hline \beta \end{bmatrix} + \begin{bmatrix} \sqrt{\mathbf{W}_1}\,\boldsymbol{\varepsilon}_1 \\ \hline \sqrt{\mathbf{W}_{28}}\,\boldsymbol{\varepsilon}_{28} \end{bmatrix},$$

where $\sqrt{\mathbf{W}_s} = \operatorname{diag}\left[\sqrt{\mathbf{w}_s}\right]$; $\sqrt{\mathbf{w}_s} = \left[\sqrt{w_{s1}},\ldots,\sqrt{w_{sT}}\right]'$; $\mathbf{y}_s = \left[y_{s1},\ldots,y_{sT}\right]'$; $\mathbf{0}$ is a vector of zeros; and $\boldsymbol{\varepsilon}_s = \left[\varepsilon_{s1},\ldots,\varepsilon_{sT}\right]'$. If we let $w_{s\bullet} = \sum_{t=1}^{T} w_{st}$, it then follows from the constraint $w_{1t} + w_{28,t} = 1$ that $w_{1\bullet} = T - w_{28\bullet}$. Writing the above as $\mathbf{y} = \mathbf{X}\boldsymbol{\gamma} + \boldsymbol{\varepsilon}$, we have

$$\mathbf{X}'\mathbf{X} = w_{28\bullet} \log 28 \begin{bmatrix} \dfrac{T}{w_{28\bullet} \log 28} & 1 \\ 1 & \log 28 \end{bmatrix}, \qquad (\mathbf{X}'\mathbf{X})^{-1} = \frac{1}{(T - w_{28\bullet}) \log 28} \begin{bmatrix} \log 28 & -1 \\ -1 & \dfrac{T}{w_{28\bullet} \log 28} \end{bmatrix},$$

$$\mathbf{X}'\mathbf{y} = \begin{bmatrix} \sqrt{\mathbf{w}_1'} & \sqrt{\mathbf{w}_{28}'} \\ \mathbf{0}' & \log 28 \sqrt{\mathbf{w}_{28}'} \end{bmatrix} \begin{bmatrix} \sqrt{\mathbf{W}_1}\, \mathbf{y}_1 \\ \sqrt{\mathbf{W}_{28}}\, \mathbf{y}_{28} \end{bmatrix} = \begin{bmatrix} \sum_t w_{1t}\, y_{1t} + \sum_t w_{28,t}\, y_{28,t} \\ \log 28 \sum_t w_{28,t}\, y_{28,t} \end{bmatrix} .$$

The LS estimator for the coefficient vector of $\boldsymbol{\gamma}$, $(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y}$, thus takes the form

$$\frac{1}{(T - w_{28\bullet}) \log 28} \begin{bmatrix} \log 28 & -1 \\ -1 & \dfrac{T}{w_{28\bullet} \log 28} \end{bmatrix} \begin{bmatrix} \sum_t w_{1t}\, y_{1t} + \sum_t w_{28,t}\, y_{28,t} \\ \log 28 \sum_t w_{28,t}\, y_{28,t} \end{bmatrix}$$

$$= \frac{1}{T - w_{28\bullet}} \begin{bmatrix} \sum_t w_{1t}\, y_{1t} + \sum_t w_{28,t}\, y_{28,t} - \sum_t w_{28,t}\, y_{28,t} \\ \dfrac{1}{\log 28}\left(-\sum_t w_{1t}\, y_{1t} - \sum_t w_{28,t}\, y_{28,t} + \dfrac{T}{w_{28\bullet}} \sum_t w_{28,t}\, y_{28,t} \right) \end{bmatrix}$$

$$= \begin{bmatrix} \sum_t \dfrac{w_{1t}}{T - w_{28\bullet}}\, y_{1t} \\ \dfrac{1}{\log 28}\, \dfrac{1}{T - w_{28\bullet}} \left\{ \left(\dfrac{T}{w_{28\bullet}} - 1 \right) \sum_t w_{28,t}\, y_{28,t} - \sum_t w_{1t}\, y_{1t} \right\} \end{bmatrix}$$

$$= \begin{bmatrix} \sum_t \dfrac{w_{1t}}{T - w_{28\bullet}}\, y_{1t} \\ \dfrac{1}{\log 28} \left(\sum_t \dfrac{w_{28,t}}{w_{28\bullet}}\, y_{28,t} - \sum_t \dfrac{w_{1t}}{T - w_{28\bullet}}\, y_{1t} \right) \end{bmatrix} .$$

As $\sum_t w_{1t} = T - w_{28\bullet}$ and $\sum_t w_{28,t} = w_{28\bullet}$, the terms $w_{1t}/(T - w_{28\bullet})$ and $w_{28,t}/w_{28\bullet}$ are both normalised shares, each with a unit sum. We write these as $w_{st}' = w_{st}/w_{s\bullet}$. Thus the estimates of the parameters of (7.3) are

$$\text{(7.4)} \qquad \hat{\alpha} = \overline{\overline{y}}_1, \qquad \hat{\beta} = \frac{\overline{\overline{y}}_{28} - \overline{\overline{y}}_1}{\log 28},$$

where $\overline{\overline{y}}_s = \sum_{t=1}^{T} w_{st}'\, y_{st}$ is the weighted mean of the (logarithmic) price of package size s. In words, the estimated intercept is the weighted mean of the gram prices, while the slope coefficient is the difference between the weighted means of the two prices, normalised by the difference in the package size, $\log 28 - \log 1 = \log 28$. Result (7.4) is to be compared with (6.3). As can be seen, both have exactly the same form, and the only difference is that the former involves weighted means of the price, while the means in the latter are unweighted. It should be noted that the weights in result (7.4) are with respect to time, not commodities. Accordingly, if the weights are constant over time, $w'_{st} = 1/T, \forall t, \; \bar{\bar{y}}_s = \bar{y}_s$ and (7.4) then coincides with (6.3).

8. FURTHER ESTIMATES OF THE DISCOUNT ELASTICITY FOR MARIJUANA

We return to equation (6.1) which relates the unit price of package size s at time t, p_{st}, to the package size,

$$\log p_{st} = \alpha + \beta \log s + \varepsilon_{st}, \tag{8.1}$$

where α is the intercept and β the discount elasticity; and ε_{st} is a disturbance term. Previously, we presented two types of estimates of the discount elasticity for marijuana, (i) the preliminary estimate given in equation (4.4), which is based on the centre of gravity of the discount available when purchasing in ounces rather than grams; and (ii) the estimates based on the ratios of standard deviations of prices to those of the package size, given in Figure 4. In both cases, the estimates of β are of the order of -.25. In this section, we provide a third set of estimates on the elasticity by estimating equation (8.1) with time-series data.

Before proceeding, several items need to be discussed. First, as our market shares for marijuana are constant over time, in view of the analysis in the previous section, there is no gain to be had by using these shares as weights when estimating equation (8.1). Second, an adjustment needs to be made for overall inflation during the sample period. The usual approach to this problem in the hedonic framework is to use a dummy variable for each period, which is known as the “adjacent year regression” (Girliches, 1971). We shall follow this approach. Third, as our database has a regional dimension to it, in addition to the package size and time dimensions, it would seem sensible to also control for this aspect. If we denote region r by the corresponding superscript, the pricing equation to be estimated is then

(8.2) $$\log p_{st}^{r} = \alpha + \beta \log s_{t}^{r} + \text{regional and time dummies} + \varepsilon_{st}^{r}.$$ [8]

To estimate equation (8.2), we use the data described in the Appendix for $r = 1,\ldots,8$ regions, $s = 1, 28$ package sizes and $t = 1990,\ldots,1999$. For each of the two product, leaf and heads, there are thus $8 \times 2 \times 10 = 160$ observations. Column 2 of Table 4 gives the least-squares estimates of equation (8.2) for leaf and as can be seen, the estimated discount elasticity is -.25 with a standard error of .01. The coefficients of the regional dummies are all negative, indicating that leaf is cheaper in all these regions as compared to NSW. All except one of the coefficients of the time dummies are negative, implying that leaf prices have declined over time. These regional and temporal aspects of marijuana prices in Australia have been previously identified (Clements, 2002b). Looking at column 3 of Table 4, we see that the results are similar for heads, although their prices fall faster than those of leaf. The data for leaf and heads are combined in column 4 by adding a product dummy variable. Here, the discount elasticity is again of the same order of magnitude (-.24), and the product dummy indicates that on average leaf is about 26 percent cheaper than heads. This difference in prices agrees with the information presented in Table 2, from which it can be seen that on average over the ten years the price of heads at the national level is \$526 per ounce, while that of leaf is \$406, a 23 percent difference.

In the Appendix we provide estimates of the discount elasticity β for each of the ten years individually, for each of the two products and for the two products combined. This amounts to $10 \times (2 + 1) = 30$ estimates of β, twenty of which are independent. Additionally, we present twenty-four reginal estimates of β, sixteen of wihich are

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[8] We also experimented with the following more parsimonious way of dealing with inflation and regional effects simultaneously. Define an index of marijuana prices for region r and year t as $\log P_{t}^{r} = \sum_{s=1,28} w_{s} \log p_{st}^{r}$ where $w_{1} = .2$ and $w_{28} = .8$ are the guesstimated market shares for grams and ounces (Clements, 2002a); and p_{st}^{r} is the price of package size s in year t and region r. The relative price of marijuana is then $\log\left(p_{st}^{r}/P_{t}^{r}\right)$, which can be used as the new dependent variable in the regression $\log\left(p_{st}^{r}/P_{t}^{r}\right) = \alpha + \beta \log s^{r} + \varepsilon_{st}^{r}$. The interpretation of the coefficient α is as the expected value of $\log\left(p_{st}^{r}/P_{t}^{r}\right)$ for grams ($s = 1$), and the coefficient β continues to be interpreted as the discount elasticity. This approach yields point estimates of β identical to those reported in this section.

TABLE 4

MARIJUANA PRICING EQUATIONS

$$\log p_{st}^{r} = \alpha + \beta \log s_{t}^{r} + \text{regional and time dummies}$$

(Standard errors in parentheses)

Independent variable (1)	Leaf (2)	Heads (3)	Leaf and heads (4)
Constant α	6.881 (.073)	7.221 (.062)	7.182 (.050)
Log s, β	-.246 (.010)	-.239 (.009)	-.242 (.007)
Regional dummies			
VIC	-.164 (.069)	-.257 (.059)	-.210 (.046)
QLD	-.357 (.069)	-.280 (.059)	-.319 (.046)
WA	-.391 (.069)	-.378 (.059)	-.385 (.046)
SA	-.258 (.069)	-.239 (.059)	-.248 (.046)
NT	-.308 (.069)	-.424 (.059)	-.366 (.046)
TAS	-.446 (.069)	-.285 (.059)	-.366 (.046)
ACT	-.206 (.069)	-.191 (.059)	-.199 (.046)
Time dummies			
1991	.005 (.077)	-.078 (.066)	-.037 (.051)
1992	-.114 (.077)	-.140 (.066)	-.127 (.051)
1993	-.182 (.077)	-.214 (.066)	-.198 (.051)
1994	-.116 (.077)	-.153 (.066)	-.135 (.051)
1995	-.076 (.077)	-.151 (.066)	-.113 (.051)
1996	-.023 (.077)	-.153 (.066)	-.088 (.051)
1997	-.061 (.077)	-.196 (.066)	-.128 (.051)
1998	-.038 (.077)	-.238 (.066)	-.138 (.051)
1999	-.042 (.077)	-.304 (.066)	-.173 (.051)
Leaf dummy			-.263 (.023)
R^2	.818	.854	.833
SEE	.272	.186	.205
No. of obs.	160	160	320

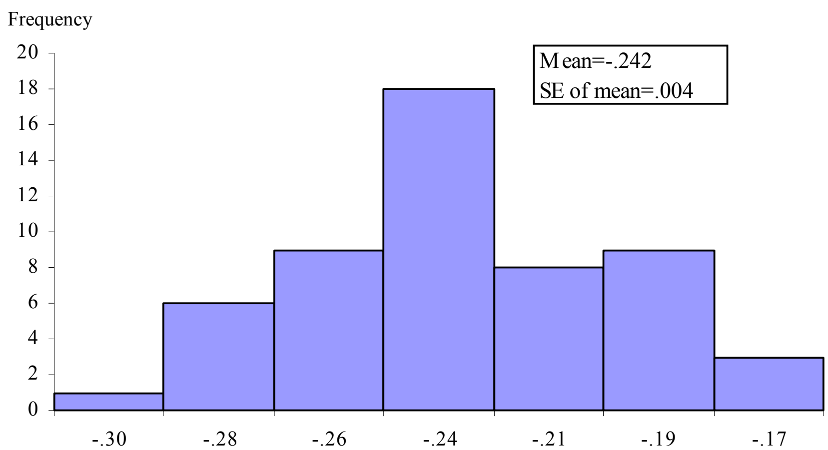
Notes: NSW is the base for the regional dummy variables, while 1990 is the base for the time dummies. In column 4, the leaf dummy variable takes the value one for leaf and zero otherwise, so the estimate of its coefficient measures the average proportionate difference between leaf and heads prices.

independent. Figure 5 presents histograms of these additional estimates; panel A deals with the entire set of $30 + 24 = 54$ estimates, while panel B deals with the $20 + 16 = 36$ independent estimates. While there is some dispersion, these histograms support the notion that the discount elasticity is of the order of -.25.

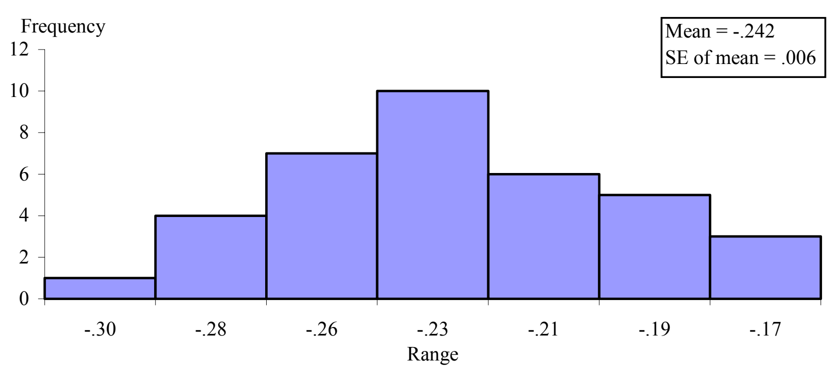
FIGURE 5

HISTOGRAMS OF DISCOUNT ELASTICITIES FOR MARIJUANA

A. Entire Set



B. Independent Subset



In Section 2, equation (2.14) relates the size elasticity to the markup factor (δ) and the conversion factor in going from a larger package size to a smaller one (ϕ). In terms of the present notation, this equation implies that the discount elasticity is related to these two factors according to $\beta = -\log\delta / \log\phi$. Thus, a value of $\beta = -.25$ and $\phi = 28$, implies a markup factor of $\delta = \exp(.25 \times \log 28) = 2.30$, or about 130 percent in transforming ounces into grams. This value seems not unreasonable.

9. EVIDENCE FROM OTHER MARKETS

Our investigations in the previous sections revealed that marijuana prices are subject to substantial quantity discounts. Using several approaches, we found that marijuana prices tend to obey the rule that the elasticity of the unit price with respect to package size is about -.25. Does this same rule apply to other markets? In this section, we examine this issue with the prices of groceries and other illicit drugs.

Mills (2002, Chap. 7) conducted a special survey of Sydney supermarkets in January 1995 to study quantity discounts. He collected prices of pre-packed goods sold in two or more package sizes, from one store of each of the five major chains and one major franchise group; where available, "discounted" or "special" prices are used. For a total of 149 products, there were 423 distinct package sizes. The 149 products were then aggregated into 29 product groups. Mills generously provided us with the basic price data for the seven product groups listed in column 1 of Table 5. These product groups were chosen on the basis that they (i) exclude those products for which Mills found quantity surcharges; (ii) are mostly undifferentiated products; and (iii) are relatively homogenous.[9]

We use the groceries data to regress the unit price on package size and a set of product dummy variables to control for any within-group heterogeneity. The results are contained in panel I of Table 5 and as can be seen, the estimated discount elasticity ranges from -.12 for rice, to -.42 for baked beans, and all are significantly different from zero. In panel II of this table the product dummies are suppressed and the only discount elasticity that changes appreciably is that for sugar (from -.15 to -.30).

Brown and Silverman (1974) analyse the pricing of heroin in a number of US cities and relate the price per unit to package size, purity and the month of purchase. In discussing the

[9] There are two exceptions to this rule: (i) "Baked beans" refer to both baked beans in tomato sauce and spaghetti in tomato sauce. (ii) "Canned vegetables" refer to cans of green beans, mushrooms, kidney and other beans, beetroot, peas and creamed corn.

TABLE 5

GROCERIES PRICING EQUATIONS

$$\log p_{si} = \alpha + \beta \log s_i + \text{product dummies}$$

(Standard errors in parentheses)

Product group	Constant	Discount elasticity	Coefficient of Product Dummies								R^2	SEE	No. of obs.
	α	β	2	3	4	5	6	7	8	9			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						I. With Product Dummies							
1. Baked beans	1.108 (.118)	-.419 (.020)	-.011 (.030)	-.118 (.030)	-.309 (.039)						.885	.096	69
2. Cheese	.933 (.098)	-.183 (.016)	-.026 (.033)	-.240 (.057)	-.018 (.033)	-.047 (.034)	-.144 (.034)	-.066 (.040)			.717	.069	78
3. Flour	4.854 (.080)	-.259 (.052)	.157 (.098)	-.336 (.156)	-.358 (.124)	-.298 (.124)	-.376 (.156)	-.313 (.156)	.279 (.156)	-.262 (.156)	.740	.192	35
4. Milk	4.716 (.018)	-.151 (.024)	.156 (.038)	.113 (.038)	.357 (.050)	.004 (.032)	.114 (.050)				.820	.066	32
5. Rice	4.964 (.018)	-.122 (.012)	.057 (.036)	-.114 (.025)	-.095 (.035)	-.318 (.036)	-.095 (.027)				.795	.075	71
6. Sugar	4.907 (.023)	-.148 (.033)	-.305 (.035)	-.154 (.035)	-.213 (.046)						.874	.073	34
7. Canned vegetables	.405 (.114)	-.308 (.019)	.441 (.044)	.246 (.045)	.047 (.044)	-.071 (.047)	.372 (.045)	.383 (.046)	-.228 (.046)		.909	.111	122

Continued on next page

TABLE 5 (continued)

GROCERIES PRICING EQUATIONS

$$\log p_{si} = \alpha + \beta \log s_i + \text{product dummies}$$

(Standard errors in parentheses)

Product group	Constant	Discount elasticity	Coefficient of Product Dummies								R^2	SEE	No. of obs.
	α	β	2	3	4	5	6	7	8	9			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						II. Without Product Dummies							
1. Baked beans	.831 (.155)	-.383 (.027)									.748	.138	69
2. Cheese	.832 (.121)	-.176 (.020)									.511	.088	78
3. Flour	4.760 (.058)	-.232 (.079)									.206	.291	35
4. Milk	4.780 (.021)	-.149 (.040)									.318	.116	32
5. Rice	4.884 (.015)	-.140 (.018)									.466	.116	71
6. Sugar	4.768 (.024)	-.296 (.048)									.540	.132	34
7. Canned vegetables	1.030 (.219)	-.388 (.037)									.481	.257	122

possible reasons for a negative relationship between the unit price and package size, Brown and Silverman (1974, p. 597) argue as follows:

> Because of both the changing nature of the risk involved and the value added to the product by the activities of middlemen, there is reason to believe that the price at which a gram of heroin can be bought is affected by the quantity…of the purchase made. A supplier may be willing to the charge less per gram when selling a larger quantity of heroin, since the number of transactions – and, presumably, the risk – are lower.

Later in the paper, Brown and Silverman (1974, p. 599) qualify the argument by adding in parentheses: "Risk is not the only factor here; quantity discounts exist for licit goods as well." This is an important qualification since not only are licit goods subject to quantity discounts, but as we have seen above the extent of these discounts, as measured by the discount elasticity β, seems to be more or less the same in both licit and illicit markets, at least to a first approximation. The results of Brown and Silverman for the discount elasticity are summarised in Table 6. As can be seen, the mean (weighted and unweighted, given in rows 42 and 43) of these elasticities is not too different to the previous values that we estimated for marijuana.

Caulkins and Padman (1993) extended the approach of Brown and Silverman and applied it to the pricing of several illicit drugs. Although they estimate the size elasticities β', these can be readily transformed into discount elasticiites via the relationship $\beta = \beta' - 1$, which are presented in Table 7. The mean of the four elasticities for marijuana is -.23, which is consistent with our results, while that of the other six drugs is -.17, which is a bit lower than most of the prior estimates. Caulkins and Padman also provide some evidence that (the absolute value of) β tends to fall modestly -- or β' rises -- as the package size increases, which could be taken as saying the markup falls with size. This result is illustrated in Figure 6 which plots the size elasticity β' against package size for methamphetamine prices. Although Caulkins and Padman imply that this is an instance in which there is a distinct upward trend in β', the majority of this "trend" is accounted for by the behaviour at the two extremes of the weight range -- weight class 1, on the one hand, and classes 11 and 12 on the other. For the other weight classes, that is, 2-10, which represent 75 percent of the total number of classes, the elasticity is much more constant at around .75 (which implies a discount elasticity of -.25). This conclusion about the constancy of β' when we omit the extremes would seem to be not inconsistent with the sampling variability of these estimates, as indicated by the one-standard error band given in Figure 6.[10]

TABLE 6

ESTIMATED DISCOUNT ELASTICITIES FOR HEROIN

(Standard errors in parentheses)

City	Elasticity	City	Elasticity
1. Albuquerque	-.22 (.03)	23. New York/ New Jersey	-.29 (.07)
2. Atlanta	-.11 (.04)	24. New York/ Long Island	-.34 (.15)
3. Baltimore	-.28 (.04)	25. New York/ Bronx	-.22 (.07)
4. Boston	-.16 (.04)	26. New York/ Brooklyn	-.15 (.03)
5. Boulder	.14 (.26)	27. New York/ Manhattan	-.17 (.02)
6. Buffalo	-.97 (.04)	28. Nashville	.04 (.09)
7. Chicago	-.22 (.03)	29. New Orleans	-.27 (.02)
8. Cleveland	-.23 (.05)	30. Philadelphia	-.40 (.08)
9. Dallas	-.29 (.04)	31. Phoenix	-.29 (.02)
10. Denver	-.41 (.04)	32. Pittsburgh	.01 (.17)
11. Detroit	-.17 (.02)	33. Portland	-.23 (.04)
12. Hartford	-.16 (.03)	34. San Antonio	-.20 (.04)
13. Honolulu	-.80 (.06)	35. San Francisco area	-.04 (.13)
14. Houston	-.41 (.03)	36. San Francisco	-.22 (.05)
15. Indianapolis	-.25 (.07)	37. Seattle	-.28 (.04)
16. Jacksonville	-.31 (.06)	38. St Louis	-.27 (.05)
17. Kansas City	-.32 (.04)	39. Tampa	-.34 (.31)
18. Los Angeles	-.15 (.02)	40. Tucson	-.43 (.03)
19. Memphis	-.42 (.06)	41. Washington D.C	-.21 (.04)
20. Miami	-.22 (.03)	42. Mean - unweighted	-.22
21. Milwaukee	-.46 (.19)	43. Mean - weighted	-.26
22. Minneapolis	1.56 (.31)		

Source: Derived from Brown and Silverman (1974, Table 2).

Note: The weights in the weighted mean in row 43 are proportional to the reciprocals of the standard errors.

[10] For related research, see Rhodes et al. (1994).

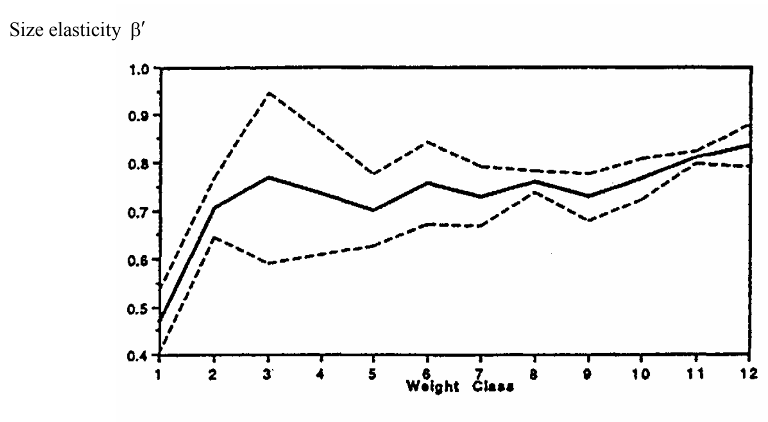
TABLE 7
ESTIMATED DISCOUNT ELASTICITIES
FOR ILLICIT DRUGS

(Standard errors in parentheses)

	Drug	Elasticity
1.	Marijuana - Imported	-.28
	- Domestic	-.24
	- Sinsmilla	-.15
	- Hashish	-.23
	- Mean	-.23
2.	Crack	-.21 (.02)
3.	Methamphetamine	-.21 (.01)
4.	Black Tar Heroin	-.10 (.01)
5.	Power Cocain	-.17 (.01)
6.	White Heroin	-.17 (.02)
7.	Brown Heroin	-.16 (.02)
8.	Mean of rows 2-7	-.17

Source: Derived from Caulkins and Padman (1993, Tables 3 and 4).

FIGURE 6
SIZE ELASTICITIES FOR METHAMPHETAMINES



Note: The solid line plots the estimated elasticity against package size, while the broken lines give ± one standard error.

Source: Caulkins and Padman (1993, Figure 3).

10. CONCLUDING COMMENTS

In many markets it is common for unit prices to decline as the quantity purchased rises, a phenomenon which can be considered to be part of the economics of packaging. This paper has reviewed the economic foundations of quantity discounts, proposed new ways of measuring and analysing them, and carried out an empirical investigation involving the prices of marijuana, as well as groceries and some other illicit drugs. The unit cost of marijuana typically involves something like an 80-percent discount when purchased in the form of ounces than grams. As it is convenient to standardise for the magnitude of the quantity difference in going from ounces to grams, we introduced the "size elasticity" β', the ratio of the percentage change in the (total) price to the corresponding change in the package (or lot) size. Another useful concept is the "discount elasticity" β, the percentage change in the unit price resulting from a one-percent change in the size, which is related to the size elasticity according to $\beta = \beta' - 1$. Quantity discounts mean that the (total) price rises less than proportionally with size, and the unit price falls, so that $\beta' < 1$ and $\beta < 0$.

For marijuana our estimates of the discount elasticity are of the order of minus one quarter, so the size elasticity is about three quarters. Table 8 provides a summary of all the discount elasticities estimated or reviewed in the paper. As can be seen, the value for marijuana of about minus one quarter is not too different from averages found in other markets which pertain to both licit and illicit goods (groceries and drugs). This points in the direction of concluding that just because a good is illegal, there is not necessarily anything special about the manner in which it is priced; in this sense, economic forces transcend the law. Accordingly, these sorts of products seem to be subject to the following pricing rule:

The price increases by 7.5 percent when the product size increases by 10 percent.

Or alternatively:

The unit price falls by 2.5 percent when the product size increases by 10 percent.

While such a rule has much appeal in terms of its elegant simplicity, it is probably a bit of an exaggeration to claim that it has universal applicability. Although as an approximation the rule seems work satisfactorily with the averages reported in Table 8, there is still considerable dispersion among the underlying elasticities, as indicated in Figure 7. Thus rather than the discount elasticity being in the class of a "natural constant", it would seem more reasonable to regard the value of -.25 as having the status of the centre of gravity of this elasticity, at least for the products considered in this paper.

Table 8

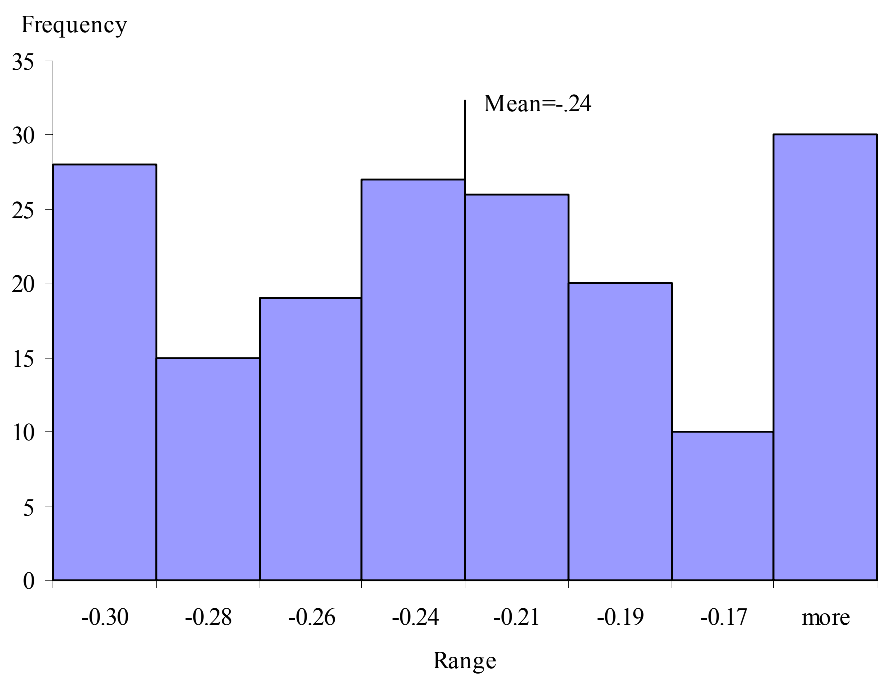
SUMMARY OF DISCOUNT ELASTICITIES

Source	Elasticity
1. Mean ratio of standard deviation of marijuana prices to that of size	-.24
2. Marijuana pricing equation	-.24
3. Groceries pricing equation	-.23
4. Heroin	-.26
5. Marijuana -- Caulkins and Padman	-.23
6. Other illicit drugs -- Caulkins and Padman	-.17

Sources: 1. Row 1 is from panel C of Figure 4 (with the sign changed).
2. Row 2 is from panel B of Figure 5.
3. Row 3 is the average of the entries in panel I, column 3 of Table 5.
4. Row 4 is from the last entry of Table 6, the weighted mean.
5. Row 5 is from the fifth entry of the last column of Table 7.
6. Row 6 is from row 8 of Table 7.

FIGURE 7

HISTOGRAM OF ALL DISCOUNT ELASTICTIES



APPENDIX

The Marijuana Data[11]

The data on Australian marijuana prices were generously supplied by Mark Halzell, of the Australian Bureau of Criminal Intelligence (ABCI). 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 only focus on the prices of "leaf" and "heads", as these products are the most popular. The data are described by ABCI (1996) who discuss some difficulties with them regarding different recording practices used by the various agencies and missing observations.

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. 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. These observations are omitted and replaced with the relevant means, based on the remaining observations. The data after consolidation and editing, for each state and territory are given in Table A1 and A2 for leaf and heads, purchased in the form of grams and ounces. The prices for Australia as a whole (given in the last column of the two tables) are population-weighted means of the regional prices.

Table 1 of the text gives the discounts available if marijuana is purchased in the form of ounces rather than grams. For the two products, the eight regions and Australia as whole, these discounts are plotted against time in Figures A1 and A2. While the discounts display considerable variability over time in some regions, most of this "washes out" at the national level and the Australian discounts are fairly stable.

Further Results

Table 4 presents estimates of equation (8.2) for all regions and all years. Tables A3 and A4 present estimates of the analogous equation on a (i) year-by-year basis and (ii) region-by-region basis. Figure 5 of the text is a histogram of these estimated discount elasticities.

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[11] The first part of this section is from Clements (2002b) which, in turn, draws on Clements and Daryal (2001).

TABLE A1

MARIJUANA PRICES: LEAF

(Dollars per ounce)

Year	Region								Australia
	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	
				Purchased in the form of a gram					
1990	770	735	700	802	700	700	910	630	748
1991	1,050	770	700	770	700	700	1,050	642	852
1992	1,060	700	630	700	560	700	700	630	797
1993	583	711	683	653	630	665	613	595	645
1994	998	698	648	700	630	665	443	753	780
1995	1,085	700	560	700	630	735	560	753	797
1996	1,400	793	665	753	630	788	508	700	950
1997	1,400	490	560	653	630	718	525	613	843
1998	1,097	735	630	467	653	683	467	723	798
1999	1,155	636	700	556	630	700	642	700	817
Mean	1060	697	648	675	639	705	642	674	803
				Purchased in the form of an ounce					
1990	438	513	225	210	388	275	313	413	390
1991	475	450	215	170	400	275	350	325	381
1992	362	363	188	340	225	300	188	350	313
1993	383	409	168	200	388	281	175	250	326
1994	419	394	181	288	325	244	170	400	341
1995	319	400	400	308	347	294	163	256	350
1996	325	383	350	283	350	263	200	408	340
1997	288	285	431	263	350	288	375	386	320
1998	333	363	375	250	350	300	375	450	344
1999	275	313	444	250	350	300	262	450	322
Mean	362	387	298	256	347	282	257	369	342

TABLE A2

MARIJUANA PRICES: HEADS

(Dollars per ounce)

Year	Region								Australia
	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	
				Purchased in the form of a grams					
1990	1,120	1,050	1,400	1,120	1,400	700	910	840	1,160
1991	1,120	1,120	1,400	962	1,400	700	1,120	840	1,167
1992	1,400	1,120	910	770	700	700	1,225	770	1,103
1993	863	665	858	840	1,173	700	927	747	834
1994	1,155	770	1,068	840	1,120	770	735	980	993
1995	1,190	793	843	749	1,138	793	1,155	1,033	974
1996	1,171	840	771	704	910	840	963	1,400	946
1997	1,400	858	630	700	840	863	700	793	977
1998	1,120	840	723	630	840	823	723	840	889
1999	1224	630	589	560	840	840	630	1006	842
Mean	1,176	869	919	788	1,036	773	909	925	989
				Purchased in the form of an ounce					
1990	600	650	413	600	400	325	525	463	558
1991	600	550	425	502	200	325	450	375	504
1992	375	450	388	390	363	450	425	500	401
1993	500	348	363	431	450	363	344	383	419
1994	550	367	328	400	425	325	363	550	433
1995	538	400	320	354	438	358	350	438	430
1996	550	400	398	325	406	283	388	525	445
1997	550	400	538	300	400	358	383	442	466
1998	488	388	550	275	340	325	367	450	437
1999	513	400	300	250	400	300	325	479	404
Mean	526	435	402	383	382	341	392	461	449

FIGURE A1

DISCOUNT FOR BULK BUYING: LEAF

(100 × logarithmic ratios of ounce to gram prices)

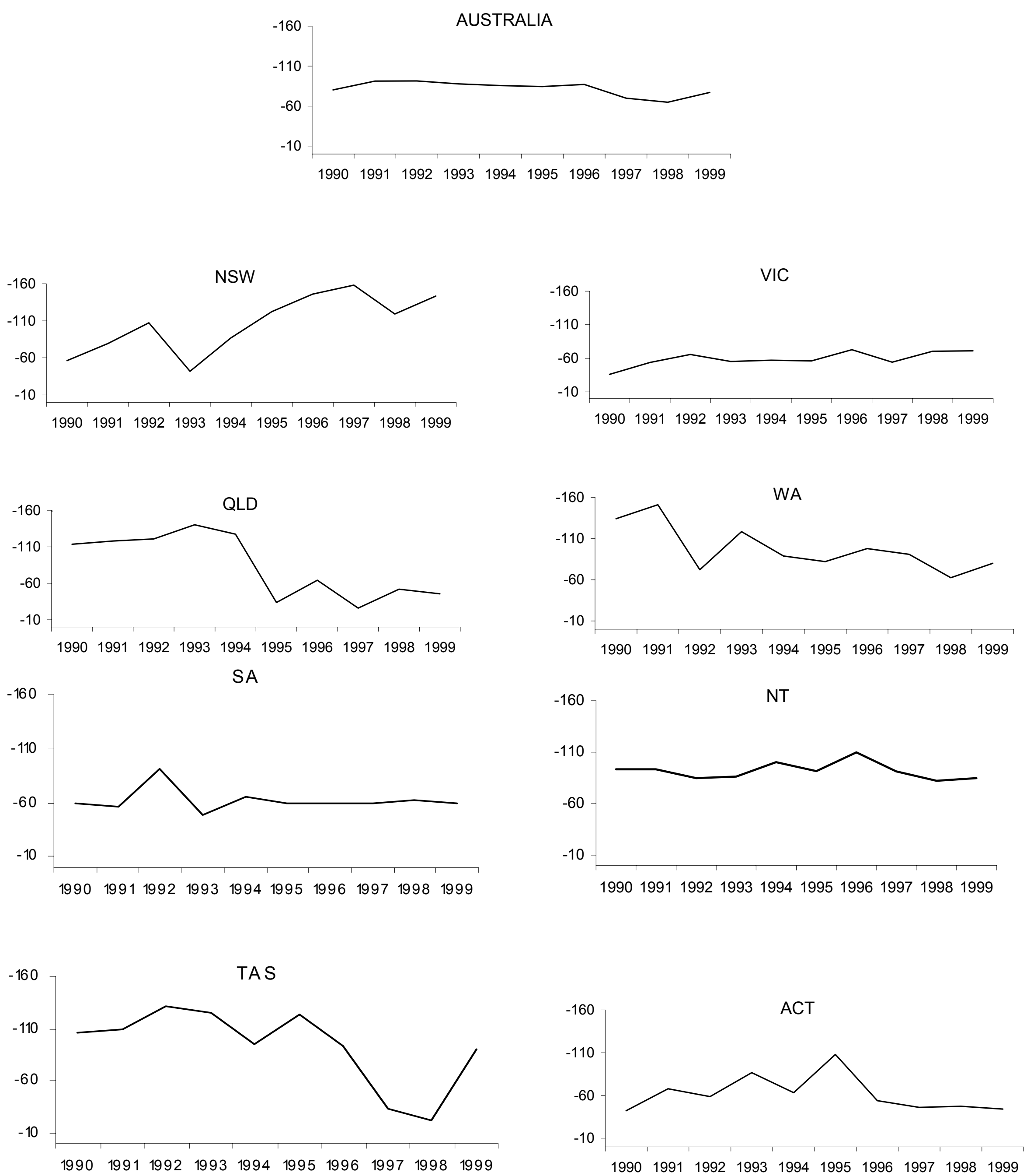

FIGURE A2

DISCOUNT FOR BULK BUYING: HEADS

(100 × logarithmic ratios of ounce to gram prices)

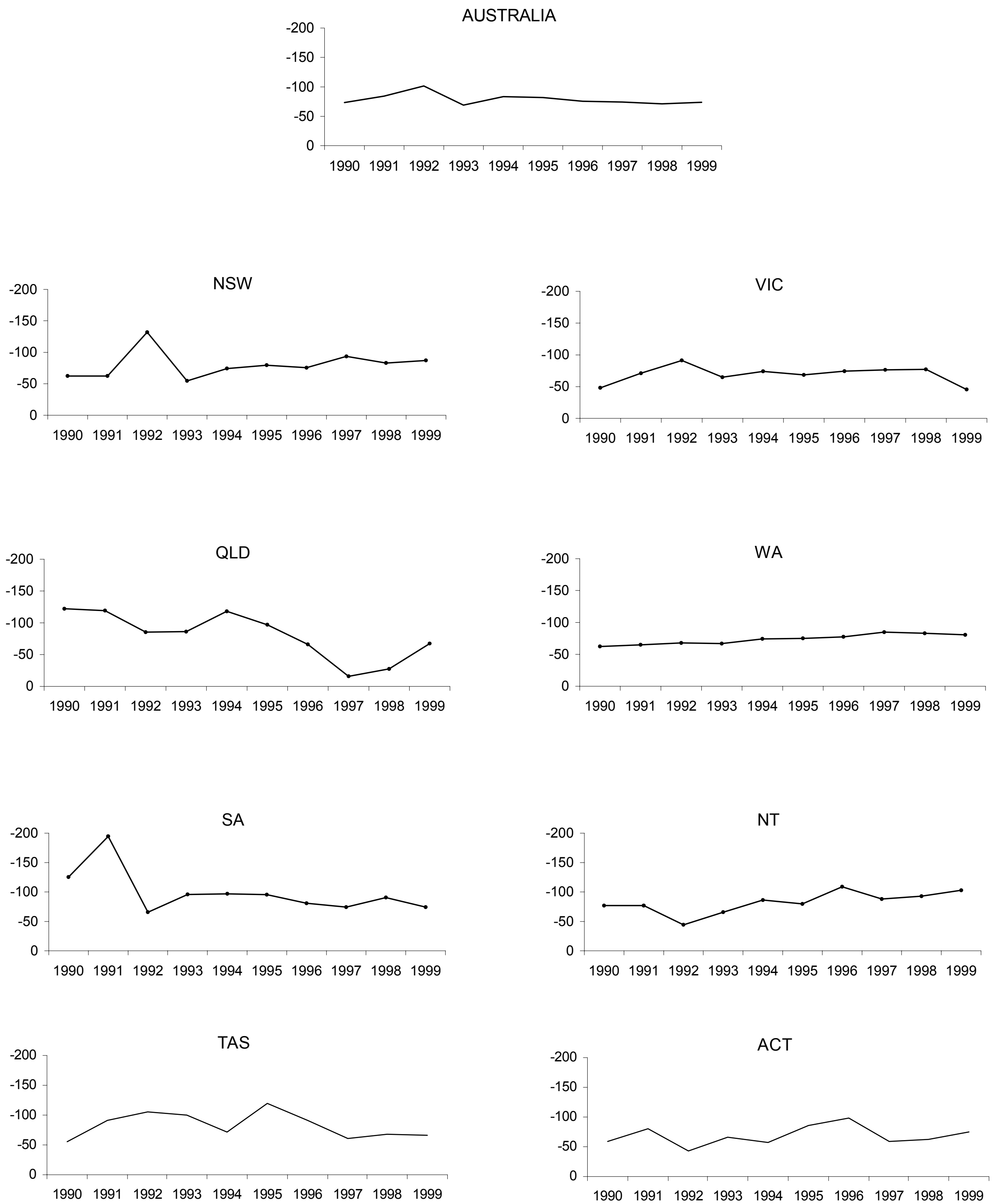

TABLE A3

MARIJUANA PRICE EQUATIONS BY YEAR

$$\log p_s^r = \alpha + \beta \log s^r + \text{regional and product dummies}$$

(Standard errors in parentheses)

Year	Constant	Discount elasticity	Leaf dummy	Regional dummy							R^2	SEE	No. of obs.
	α	β		VIC	QLD	WA	SA	NT	TAS	ACT			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						I. Leaf							
1990	6.765 (.193)	-.241 (.039)		.056 (.258)	-.381 (.258)	-.347 (.258)	-.108 (.258)	-.280 (.258)	-.084 (.258)	-.130 (.258)	.863	.258	16
1991	7.016 (.179)	-.274 (.036)		-.182 (.239)	-.599 (.239)	-.669 (.239)	-.289 (.239)	-.476 (.239)	-.153 (.239)	-.436 (.239)	.911	.239	16
1992	6.887 (.140)	-.275 (.028)		-.206 (.187)	-.588 (.187)	-.239 (.187)	-.557 (.187)	-.301 (.187)	-.535 (.187)	-.277 (.187)	.942	.187	16
1993	6.597 (.198)	-.264 (.040)		.132 (.265)	-.333 (.265)	-.268 (.265)	.045 (.265)	-.089 (.265)	-.367 (.265)	-.203 (.265)	.879	.265	16
1994	6.900 (.123)	-.257 (.025)		-.210 (.164)	-.636 (.164)	-.365 (.164)	-.357 (.164)	-.473 (.164)	-.857 (.164)	-.164 (.164)	.955	.164	16
1995	6.800 (.174)	-.254 (.035)		-.106 (.233)	-.218 (.233)	-.237 (.233)	-.230 (.233)	-.236 (.233)	-.666 (.233)	-.293 (.233)	.899	.233	16
1996	6.949 (.165)	-.261 (.033)		-.202 (.220)	-.335 (.220)	-.379 (.220)	-.362 (.220)	-.393 (.220)	-.750 (.220)	-.233 (.220)	.916	.220	16
1997	6.803 (.227)	-.210 (.045)		-.530 (.303)	-.257 (.303)	-.427 (.303)	-.302 (.303)	-.334 (.303)	-.358 (.303)	-.266 (.303)	.781	.303	16
1998	6.728 (.150)	-.194 (.030)		-.157 (.200)	-.218 (.200)	-.570 (.200)	-.234 (.200)	-.289 (.200)	-.368 (.200)	-.058 (.200)	.883	.200	16
1999	6.720 (.169)	-.232 (.034)		-.234 (.225)	-.011 (.225)	-.413 (.225)	-.182 (.225)	-.207 (.225)	-.318 (.225)	-.004 (.225)	.885	.225	16

Continued on next page

TABLE A3 (continued)

MARIJUANA PRICE EQUATIONS BY YEAR

$$\log p_s^r = \alpha + \beta \log s^r + \text{regional and product dummies}$$

(Standard errors in parentheses)

Year	Constant	Discount elasticity	Leaf dummy	Regional dummy							R^2	SEE	No. of obs.
	α	β		VIC	QLD	WA	SA	NT	TAS	ACT			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						II. Heads							
1990	7.091 (.161)	-.229 (.032)		.008 (.214)	-.075 (.214)	.000 (.214)	-.091 (.214)	-.542 (.214)	-.171 (.214)	-.273 (.214)	.898	.214	16
1991	7.185 (.234)	-.285 (.047)		-.044 (.312)	-.061 (.312)	-.165 (.312)	-.438 (.312)	-.542 (.312)	-.144 (.312)	-.379 (.312)	.861	.312	16
1992	6.982 (.161)	-.238 (.032)		-.020 (.215)	-.198 (.215)	-.279 (.215)	-.363 (.215)	-.255 (.215)	-.004 (.215)	-.155 (.215)	.896	.215	16
1993	6.862 (.087)	-.225 (.017)		-.312 (.116)	-.163 (.116)	-.088 (.116)	.101 (.116)	-.265 (.116)	-.151 (.116)	-.205 (.116)	.964	.116	16
1994	7.088 (.099)	-.245 (.020)		-.405 (.132)	-.298 (.132)	-.318 (.132)	-.144 (.132)	-.466 (.132)	-.434 (.132)	-.082 (.132)	.962	.132	16
1995	7.122 (.086)	-.263 (.017)		-.351 (.114)	-.432 (.114)	-.441 (.114)	-.125 (.114)	-.407 (.114)	-.230 (.114)	-.174 (.114)	.974	.114	16
1996	7.108 (.075)	-.252 (.015)		-.325 (.100)	-.371 (.100)	-.517 (.100)	-.278 (.100)	-.498 (.100)	-.272 (.100)	.066 (.100)	.980	.100	16
1997	7.122 (.131)	-.207 (.026)		-.404 (.175)	-.410 (.175)	-.650 (.175)	-.415 (.175)	-.457 (.175)	-.528 (.175)	-.394 (.175)	.917	.175	16
1998	6.971 (.112)	-.219 (.022)		-.258 (.150)	-.159 (.150)	-.574 (.150)	-.325 (.150)	-.357 (.150)	-.361 (.150)	-.184 (.150)	.942	.150	16
1999	7.049 (.089)	-.224 (.018)		-.456 (.119)	-.634 (.119)	-.750 (.119)	-.313 (.119)	-.456 (.119)	-.560 (.119)	-.132 (.119)	.970	.119	16

Continued on next page

TABLE A3 (continued)

MARIJUANA PRICE EQUATIONS BY YEAR

$$\log p_s^r = \alpha + \beta \log s^r + \text{regional and product dummies}$$

(Standard errors in parentheses)

Year	Constant	Discount elasticity	Leaf dummy	Regional dummy							R^2	SEE	No of obs
	α	β		VIC	QLD	WA	SA	NT	TAS	ACT			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						III. Leaf and Heads							
1990	7.109 (.125)	-.235 (.024)	-.361 (.079)	.032 (.158)	-.228 (.158)	-.174 (.158)	-.100 (.158)	-.411 (.158)	-.128 (.158)	-.202 (.158)	.855	.224	32
1991	7.239 (.148)	-.280 (.028)	-.278 (.094)	-.113 (.187)	-.330 (.187)	-.417 (.187)	-.363 (.187)	-.509 (.187)	-.148 (.187)	-.407 (.187)	.846	.265	32
1992	7.102 (.111)	-.256 (.021)	-.335 (.070)	-.113 (.140)	-.393 (.140)	-.259 (.140)	-.460 (.140)	-.278 (.140)	-.270 (.140)	-.216 (.140)	.894	.199	32
1993	6.894 (.117)	-.244 (.022)	-.329 (.074)	-.090 (.147)	-.248 (.147)	-.178 (.147)	.073 (.147)	-.177 (.147)	-.259 (.147)	-.204 (.147)	.873	.208	32
1994	7.156 (.092)	-.251 (.017)	-.323 (.058)	-.307 (.116)	-.467 (.116)	-.342 (.116)	-.251 (.116)	-.470 (.116)	-.645 (.116)	-.123 (.116)	.927	.165	32
1995	7.104 (.111)	-.258 (.021)	-.286 (.070)	-.229 (.140)	-.325 (.140)	-.339 (.140)	-.177 (.140)	-.321 (.140)	-.448 (.140)	-.233 (.140)	.892	.198	32
1996	7.144 (.104)	-.257 (.020)	-.231 (.066)	-.264 (.131)	-.353 (.131)	-.448 (.131)	-.320 (.131)	-.446 (.131)	-.511 (.131)	-.083 (.131)	.905	.185	32
1997	7.075 (.116)	-.208 (.022)	-.226 (.073)	-.467 (.146)	-.333 (.146)	-.538 (.146)	-.358 (.146)	-.395 (.146)	-.443 (.146)	-.330 (.146)	.841	.207	32
1998	6.930 (.083)	-.207 (.016)	-.161 (.052)	-.208 (.105)	-.188 (.105)	-.572 (.105)	-.280 (.105)	-.323 (.105)	-.364 (.105)	-.121 (.105)	.910	.148	32
1999	6.934 (.099)	-.228 (.019)	-.099 (.063)	-.345 (.125)	-.322 (.125)	-.582 (.125)	-.248 (.125)	-.332 (.125)	-.439 (.125)	-.068 (.125)	.891	.177	32

Notes: NSW is the base for the regional dummies. The leaf dummy takes the value one for leaf and zero otherwise.

TABLE A4

MARIJUANA PRICE EQUATIONS BY REGION

$$\log p_{st} = \alpha + \beta \log s_t + \text{time and product dummies}$$

(Standard errors in parentheses)

Region	Constant	Discount elasticity	Leaf dummy	Time Dummy									R^2	SEE	No. of obs.
	α	β		1991	1992	1993	1994	1995	1996	1997	1998	1999			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
							I. Leaf								
NSW	6.895 (.205)	-.318 (.037)		.196 (.277)	.065 (.277)	-.206 (.277)	.108 (.277)	.013 (.277)	.150 (.277)	.089 (.277)	.040 (.277)	-.030 (.277)	.895	.277	20
VIC	6.716 (.058)	-.178 (.011)		-.042 (.079)	-.197 (.079)	-.130 (.079)	-.158 (.079)	-.149 (.079)	-.108 (.079)	-.497 (.079)	-.173 (.079)	-.319 (.079)	.974	.079	20
QLD	6.404 (.229)	-.253 (.042)		-.023 (.309)	-.143 (.309)	-.158 (.309)	-.147 (.309)	.176 (.309)	.195 (.309)	.213 (.309)	.203 (.309)	.340 (.309)	.827	.309	20
WA	6.506 (.148)	-.293 (.027)		-.126 (.199)	.173 (.199)	-.127 (.199)	.090 (.199)	.123 (.199)	.118 (.199)	.010 (.199)	-.183 (.199)	-.096 (.199)	.934	.199	20
SA	6.566 (.059)	-.186 (.011)		.015 (.079)	-.384 (.079)	-.053 (.079)	-.141 (.079)	-.109 (.079)	-.104 (.079)	-.104 (.079)	-.086 (.079)	-.104 (.079)	.974	.079	20
NT	6.543 (.044)	-.275 (.008)		.000 (.059)	.044 (.059)	-.015 (.059)	-.085 (.059)	.058 (.059)	.037 (.059)	.036 (.059)	.031 (.059)	.044 (.059)	.993	.059	20
TAS	6.745 (.196)	-.279 (.035)		.127 (.264)	-.386 (.264)	-.488 (.264)	-.665 (.264)	-.569 (.264)	-.515 (.264)	-.185 (.264)	-.243 (.264)	-.263 (.264)	.898	.264	20
ACT	6.544 (.111)	-.186 (.020)		-.110 (.149)	-.083 (.149)	-.280 (.149)	.073 (.149)	-.150 (.149)	.047 (.149)	-.047 (.149)	.112 (.149)	.096 (.149)	.916	.149	20

Continued next page

TABLE A4 (continued)

MARIJUANA PRICE EQUATIONS BY REGION

$$\log p_{st} = \alpha + \beta \log s_t + \text{time and product dummies}$$

(Standard errors in parentheses)

Region	Constant	Discount elasticity	Leaf dummy	Time Dummy									R^2	SEE	No. of obs.
	α	β		1991	1992	1993	1994	1995	1996	1997	1998	1999			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
								II. Heads							
NSW	7.111 (.114)	-.241 (.021)		.000 (.153)	-.123 (.153)	-.221 (.153)	-.028 (.153)	-.024 (.153)	-.021 (.153)	.068 (.153)	-.103 (.153)	-.034 (.153)	.941	.153	20
VIC	7.062 (.072)	-.207 (.013)		-.051 (.097)	-.152 (.097)	-.541 (.097)	-.441 (.097)	-.383 (.097)	-.354 (.097)	-.344 (.097)	-.370 (.097)	-.498 (.097)	.973	.097	20
QLD	7.036 (.194)	-.241 (.035)		.014 (.262)	-.247 (.262)	-.309 (.262)	-.251 (.262)	-.381 (.262)	-.317 (.262)	-.267 (.262)	-.187 (.262)	-.593 (.262)	.860	.262	20
WA	7.077 (.041)	-.221 (.007)		-.165 (.055)	-.403 (.055)	-.309 (.055)	-.347 (.055)	-.465 (.055)	-.539 (.055)	-.582 (.055)	-.678 (.055)	-.784 (.055)	.993	.055	20
SA	7.114 (.196)	-.298 (.036)		-.347 (.265)	-.395 (.265)	-.030 (.265)	-.081 (.265)	-.058 (.265)	-.208 (.265)	-.255 (.265)	-.337 (.265)	-.255 (.265)	.894	.265	20
NT	6.578 (.097)	-.247 (.018)		.000 (.131)	.163 (.131)	.055 (.131)	.048 (.131)	.111 (.131)	.022 (.131)	.153 (.131)	.081 (.131)	.051 (.131)	.957	.131	20
TAS	6.952 (.113)	-.248 (.021)		.027 (.153)	.043 (.153)	-.202 (.153)	-.291 (.153)	-.084 (.153)	-.123 (.153)	-.289 (.153)	-.294 (.153)	-.424 (.153)	.949	.153	20
ACT	6.779 (.084)	-.206 (.015)		-.105 (.114)	-.005 (.114)	-.154 (.114)	.163 (.114)	.076 (.114)	.318 (.114)	-.052 (.114)	-.014 (.114)	.107 (.114)	.959	.114	20

Continued next page

TABLE A4 (continued)

MARIJUANA PRICE EQUATIONS BY REGION

$$\log p_{st} = \alpha + \beta \log s_t + \text{time and product dummies}$$

(Standard errors in parentheses)

Region	Constant	Discount elasticity	Leaf dummy	Time Dummy									R^2	SEE	No. of obs.
	α	β		1991	1992	1993	1994	1995	1996	1997	1998	1999			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
III. Leaf and Heads															
NSW	7.130 (.110)	-.280 (.019)	-.254 (.063)	.098 (.142)	-.029 (.142)	-.214 (.142)	.040 (.142)	-.006 (.142)	.064 (.142)	.079 (.142)	-.032 (.142)	-.032 (.142)	.895	.201	40
VIC	6.969 (.069)	-.193 (.012)	-.161 (.040)	-.047 (.089)	-.174 (.089)	-.335 (.089)	-.299 (.089)	-.266 (.089)	-.231 (.089)	-.420 (.089)	-.271 (.089)	-.409 (.089)	.920	.125	40
QLD	6.886 (.158)	-.247 (.027)	-.331 (.091)	-.004 (.204)	-.195 (.204)	-.234 (.204)	-.199 (.204)	-.103 (.204)	-.061 (.204)	-.027 (.204)	.008 (.204)	-.126 (.204)	.778	.289	40
WA	6.925 (.110)	-.257 (.019)	-.267 (.063)	-.146 (.142)	-.115 (.142)	-.218 (.142)	-.128 (.142)	-.171 (.142)	-.211 (.142)	-.286 (.142)	-.430 (.142)	-.440 (.142)	.886	.200	40
SA	6.976 (.114)	-.242 (.020)	-.272 (.066)	-.166 (.147)	-.390 (.147)	-.041 (.147)	-.111 (.147)	-.083 (.147)	-.156 (.147)	-.180 (.147)	-.211 (.147)	-.180 (.147)	.863	.208	40
NT	6.629 (.050)	-.261 (.009)	-.137 (.029)	.000 (.065)	.103 (.065)	.020 (.065)	-.019 (.065)	.084 (.065)	.029 (.065)	.094 (.065)	.056 (.065)	.047 (.065)	.971	.092	40
TAS	7.055 (.125)	-.264 (.022)	-.414 (.072)	.077 (.162)	-.172 (.162)	-.345 (.162)	-.478 (.162)	-.326 (.162)	-.319 (.162)	-.237 (.162)	-.269 (.162)	-.344 (.162)	.877	.229	40
ACT	6.796 (.070)	-.196 (.012)	-.269 (.040)	-.108 (.090)	-.044 (.090)	-.217 (.090)	.118 (.090)	-.037 (.090)	.182 (.090)	-.050 (.090)	.049 (.090)	.101 (.090)	.924	.127	40

Note: 1990 is the base for the time dummies. The leaf dummy takes the value of one for leaf and zero otherwise.

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