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Three facts about marijuana prices*

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Australians are among the largest consumers of marijuana in the world, and estimates show that their expenditure on marijuana is approximately twice that on wine. In the present paper, the evolution of Australian marijuana prices over the last decade is analysed, and a decline in real terms by almost 40 per cent is shown. This decline is far above that experienced by most agricultural products. Why has this occurred and what are the implications? One possible reason is the adoption of hydroponic growing techniques that have enhanced productivity and lowered costs and prices. Another reason is that laws have become softer and penalties reduced. Patterns in prices are found that divide the country into three broad regions: (i) Sydney, where prices are highest; (ii) Melbourne and Canberra, which have somewhat lower prices; and (iii) everywhere else, where marijuana is cheapest. An exploratory analysis indicates the extent to which the price declines have stimulated marijuana consumption and inhibited the consumption of a substitute product, alcohol.

1. Introduction

Over the longer term, higher productivity, together with Engel's law, has led to average annual price declines of many agricultural products of the order of 1–2%. In the present paper, we demonstrate that a similar process seems to have operated for marijuana, with one important difference. Marijuana prices have declined much more rapidly than those of most other agricultural products – by approximately 5 per cent per annum in real terms over the past decade. Research on the behaviour of marijuana prices is of interest because of the widespread use of the product. Surveys indicate that in some

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countries up to one third of the adult population have used marijuana and in Australia, one of world's biggest consumers, over 40 per cent of people favour its decriminalisation. Expenditure on marijuana by Australians has been estimated to be approximately twice that on wine.[1]

Why have marijuana prices fallen so much? What is the nature of the marijuana market in Australia? To what extent has the decline in marijuana prices been responsible for the high level of consumption? In this paper we address these issues and argue that there are three defining characteristics of the behaviour of marijuana prices, which we refer to as 'three facts':

1. *There seems to exist regional markets for marijuana, rather than one national market*. Prices are substantially more expensive in the Sydney market, followed by Melbourne and Canberra, and then the rest of Australia.
2. *The real price of marijuana has fallen by almost 40 per cent over the 1990s in Australia*. As indicated, this fall is much more than that of most agricultural products. One explanation for the substantial fall is the widespread adoption of hydroponic techniques of production, which has enhanced productivity and lowered costs. Another explanation is that because of changing community attitudes, laws have become softer and penalties reduced, thus lowering part of the 'expected full cost' of transacting marijuana.
3. *Lower prices have stimulated marijuana consumption and reduced alcohol consumption*. As marijuana and alcohol would appear to both satisfy a similar want of the consumer, they are probably substitutes in consumption. Under certain scenarios, the lower marijuana prices would have resulted in a substantial rise in marijuana consumption and a corresponding fall in alcohol consumption.

Section 2 of the present paper provides information regarding the data on marijuana prices. Section 3 deals with the identification of regional markets of marijuana. The substantial decline in prices is analysed in some depth in Section 4 and compared to the behaviour of the prices of other commodities. Section 5 provides an exploratory analysis of the extent to which lower prices have encouraged marijuana usage and discouraged the consumption of a substitute product, alcohol. Section 6 contains some concluding comments.

[1] For details, see Clements and Daryal (2003). Australian marijuana prices have been analysed previously in the context of the demand for marijuana, tobacco and alcohol by Cameron and Williams (2001) and Zhao and Harris (2003).

2. The prices

The data on Australian marijuana prices were generously supplied by Mark Hazell of the Australian Bureau of Criminal Intelligence. These prices were collected by law enforcement agencies in the various states and territories during undercover buys. In general, the data are quarterly and refer to the period 1990–1999, for each state and territory. The different types of marijuana identified separately are leaf, heads, hydroponics, skunk, hash resin and hash oil. However, we focus on only the prices of 'leaf' and 'heads', as these products are the most popular. The data are described by Australian Bureau of Criminal Intelligence (1996), who discuss some difficulties with them regarding different recording practices used by the various agencies and missing observations. While it is unlikely that these data constitute a random sample, a common problem when studying the prices of almost any illicit good, it is not clear that they would be biased either upwards or downwards. In any event, they are the only data available.[2]

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 semiannual observations. Annualising has the effect of reducing the considerable noise in the quarterly/semiannual data. Plotting the data revealed several outliers, which probably reflect some of the mentioned recording problems. Observations are treated as outliers if they are either less than one-half of the mean for the corresponding state, or greater than twice the mean. This rule led to five outlying observations, which are omitted and replaced with the relevant means, based on the remaining observations. The data, after consolidation and editing, for each state and territory are given in tables 1 and 2 for leaf and heads, respectively, purchased in the form of either grams or ounces. Columns 2–5 of table 3 give the corresponding Australian prices (defined as population-weighted means of the state prices), while column 6 gives a weighted mean of the four prices defined as $\exp\{\sum_{i=1}^{4} w_i \log p_{it}\}$, where p_{it} is the price of product i in year t and w_i is the market share of product i, guestimated to be 0.06 for leaf/gram, 0.24 for leaf/ounce, 0.14 for head/gram and 0.56 for head/ounce. This is Stone's (1953) weighted geometric mean, with weights reflecting the relative importance of the products in consumption (see Clements 2002, for full details). As can be seen from column 6 of table 3, the index of marijuana prices exhibits a substantial decline over the 1990s, starting off at \$A577 per ounce in 1990

[2] This section draws on Clements and Daryal (2001).

Table 1 Marijuana prices: leaf (dollars per ounce)

Year	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	Weighted mean
Purchased in the form of a gram									
1990	770	735	700	802	700	700	910	630	747
1991	1050	770	700	770	700	700	1050	642	852
1992	1060	700	630	700	560	700	700	630	798
1993	583	711	683	653	630	665	613	595	645
1994	998	698	648	700	630	665	443	753	779
1995	1085	700	560	700	630	735	560	753	797
1996	1400	793	665	753	630	788	508	700	949
1997	1400	490	560	653	630	718	525	613	843
1998	1097	735	630	467	653	683	467	723	798
1999	1155	636	700	556	630	700	642	700	816
Mean	1060	697	648	675	639	705	642	674	802
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	339
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	343

Table 2 Marijuana prices: heads (dollars per ounce)

Year	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	Weighted mean
Purchased in the form of a gram									
1990	1120	1050	1400	1120	1400	700	910	840	1159
1991	1120	1120	1400	962	1400	700	1120	840	1168
1992	1400	1120	910	770	700	700	1225	770	1103
1993	863	665	858	840	1173	700	927	747	834
1994	1155	770	1068	840	1120	770	735	980	992
1995	1190	793	843	749	1138	793	1155	1033	974
1996	1171	840	771	704	910	840	963	1400	944
1997	1400	858	630	700	840	863	700	793	977
1998	1120	840	723	630	840	823	723	840	889
1999	1224	630	589	560	840	840	630	1006	841
Mean	1176	869	919	788	1036	773	909	925	988
Purchased in the form of an ounce									
1990	600	650	413	600	400	325	525	463	557
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	432
1995	538	400	320	354	438	358	350	438	430
1996	550	400	398	325	406	283	388	525	444
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	403
Mean	526	435	402	383	382	341	392	461	449

Table 3 Marijuana prices, Australia (Dollars per ounce)

	Purchase form				
	Gram		Ounce		Total (weighted mean)
Year	Leaf	Heads	Leaf	Heads	
1990	747	1159	390	557	577
1991	852	1168	381	504	547
1992	798	1103	313	401	454
1993	645	834	326	419	446
1994	779	992	341	432	475
1995	797	974	350	430	476
1996	949	944	339	444	484
1997	843	977	320	466	489
1998	798	889	344	437	473
1999	816	841	322	403	442
Mean	802	988	343	449	486

and ending up 9 years later some 23 per cent lower at $A442. More will be said about this decline in Section 4.[3]

A further aspect of the prices in table 3 is the substantial quantity discounts available when buying in bulk. In 1999, for example, the price of heads purchased in the form of grams is $A841 per ounce, while the same quantity purchased in the form of an ounce is $A403 per ounce, a discount of approximately 52 per cent. Such quantity discounts have been observed in other illicit drug markets (Brown and Silverman 1974; Caulkins and Padman 1993). One explanation for these discounts involves the pricing of risk (see, e.g., Brown and Silverman 1974). It is argued that when drugs are sold in smaller lots, the risk of being caught is not proportionally less than when dealing with larger lots. This leads to an expected penalty that rises with lot size, but less than proportionately, and quantity discounts. Another explanation is that the discounts are simply a reflection of value added as drugs flow through the distribution chain, which operates in exactly the same way as do those for licit goods (Brown and Silverman 1974). Therefore, for example, as groceries move from the wholesale to retail levels, lot sizes typically fall and unit costs rise, reflecting the costs of the retail services provided.

[3] Note that the internal relative prices of the four types of marijuana have changed quite substantially over the period. On average, the relative price of leaf/gram increased by 4 per cent per annum, head/gram decreased by 1 per cent, leaf/ounce increased by 1 per cent and head/ounce declined by 1 per cent. For details, see Clements (2002).

3. Fact 1: marijuana is expensive in New South Wales

Is the market for marijuana a nationally organised activity, or is it merely a 'cottage industry' that just satisfies local demand? To put it another way, is marijuana a (nationally) traded good, or is it non-traded? If there were a national market for marijuana, then after appropriate allowance for transport costs etc., marijuana prices should be more or less equalised across states and territories. This section investigates these issues.

South Australia decriminalised marijuana in 1987 and recent media reports have focused on Adelaide as the centre of the marijuana industry. Radio National (1999) recently noted that:

> 'Cannabis is by far and away the illicit drug of choice for Australians. There is a multi-billion dollar industry to supply it, and increasingly, the centre of action is the city of churches.'

That program quoted a person called 'David' as saying:

> 'Say 5, 10 years ago, everyone spoke of the country towns of New South Wales and the north coast, now you never hear of it; those towns have died in this regard I'd say, because they're lost out to the indoor variety, the hydro, and everyone was just saying South Australia, Adelaide, Adelaide, Adelaide, and that's where it all seems to be coming from.'

In a similar vein, the Australian Bureau of Criminal Intelligence (1999, p. 18) commented on marijuana being exported from South Australia to other states as follows:

> 'New South Wales Police reported that cannabis has been found secreted in the body parts of motor vehicles from South Australia … It is reported that cannabis originating in South Australia is transported to neighbouring jurisdictions. South Australia Police reported that large amounts of cannabis are transported from South Australia by air, truck, hire vehicles, buses and private motor vehicles.
>
> Queensland Police reported that South Australian cannabis is sold on the Gold Coast. New South Wales Police reported South Australian vehicles returning to that state have been found carrying large amounts of cash or amphetamines, or both. It also considers that the decrease in the amount of locally grown cannabis is the result of an increase in the quantity of South Australian cannabis in New South Wales.

The Australian Federal Police in Canberra reported that the majority of cannabis transported to the Australian Capital Territory is from the Murray Bridge area of South Australia …'

As the above comments point to Adelaide being a major exporter of marijuana to other parts of Australia, this would seem to imply that the market is a national, not local, one. In turn, this would mean that marijuana prices would tend to be equalised across Australia if transport and differences in other distribution costs were relatively minor. The validity of this hypothesis can be examined with our regional-level data, and Panel I of table 4 gives the results of regressing the prices on dummy variables for each state and territory. In this panel, the dependent variable is log p_{rt}, where p_{rt} is the price of the relevant type of marijuana in region r ($r = 1, \dots, 8$) and year t ($t = 1990, \dots, 1999$). As the data are pooled over time and regions, the total number of observations for each equation is $8 \times 10 = 80$. Given the use of the logarithm of the price and as NSW is used as the base, when multiplied by 100, the coefficient of a given dummy variable is interpreted as the approximate percentage difference between the price in the corresponding region and that in NSW.

In Panel I of table 4 there are seven dummy variable coefficients for each of the four products. Only two of these 28 coefficients are positive, leaf/ounce in Victoria and ACT, but these are both insignificantly different from zero. The vast majority of the other coefficients are significantly negative, which says that marijuana prices are significantly lower in all regions relative to NSW. While the $\bar{R}^2$ values for these equations are low, this is not necessarily a problem given that the purpose is to test for regional price differences rather than to explain how prices are determined. As the market share of head ounce is the largest (see the previous section), let us concentrate on the results for this product given in row 4 of table 4. This row reveals that for this product NT is the cheapest region with marijuana costing approximately 44 per cent less than that in NSW. Then comes WA (35 per cent less), SA (34 per cent), Tasmania (30 per cent), Queensland (28 per cent), Victoria (20 per cent) and, finally, ACT (13 per cent). The last column of table 4 gives a measure of the dispersion of prices around those in NSW, $\{(1/7)\sum_{u=1}^{7}\beta_u^2\}^{1/2} \times 100$, where β_u is the coefficient of the dummy variable for region u. This measure is approximately the percentage standard deviation of prices around NSW prices. If prices are equalised across regions, then this measure is zero. But as can be seen, the standard deviation ranges from 24 to 44 per cent.

It is clear from the significance of the regional dummies in Panel I of table 4 that marijuana prices are not equalised nationally. But this conclusion does raise the question of what could be the possible barriers to

Table 4 Estimated regional effects for marijuana prices, income and house prices (t-values in parentheses) $\log y_{rt} = \alpha + \sum_{u=2}^{8} \beta_u z_{urt}$

Dependent variable y_{rt}	Intercept α	Coefficients of dummy variables, $\beta_u \times 100$							$\bar{R}^2$	Regional dispersion $\{(1/7)\sum_{u=1}^{7} \beta_u^2\}^{1/2} \times 100$
		VIC	QLD	WA	SA	NT	TAS	ACT		
I. Marijuana prices										
1. Leaf gram	6.94	−39.80	−46.70	−43.40	−47.70	−38.00	−51.20	−42.90	0.44	44.45
	(134.60)	(−5.46)	(−6.41)	(−5.95)	(−6.54)	(−5.21)	(−7.02)	(−5.89)		
2. Leaf ounce	5.88	7.00	−24.60	−34.90	−3.60	−23.70	−37.90	1.40	0.28	23.56
	(77.70)	(0.65)	(−2.30)	(−3.26)	(−0.34)	(−2.22)	(−3.54)	(0.13)		
3. Head gram	7.06	−31.10	−28.00	−40.90	−14.40	−41.40	−27.40	−24.80	0.23	30.96
	(108.30)	(−3.37)	(−3.04)	(−4.44)	(−1.56)	(−4.49)	(−2.97)	(−2.69)		
4. Head ounce	6.26	−20.10	−28.20	−34.50	−33.50	−43.60	−29.80	−13.40	0.28	30.43
	(106.00)	(−2.41)	(−3.37)	(−4.13)	(−4.01)	(−5.22)	(−3.57)	(−1.60)		
II. Income										
5. Gross household	10.11	−2.78	−15.12	−6.98	−13.09	−9.25	−22.06	28.54	0.68	16.23
	(312.47)	(−0.61)	(−3.31)	(−1.52)	(−2.86)	(−2.02)	(−4.82)	(6.24)		
6. Gross house	9.84	−2.41	−14.56	−7.69	−12.24	−4.96	−21.42	30.34	0.67	16.17
disposable	(289.02)	(−0.50)	(−3.03)	(−1.60)	(−2.54)	(−1.03)	(−4.45)	(6.30)		
III. Housing prices										
7. Houses	5.33	−26.94	−47.24	−55.03	−60.63	−33.36	−70.02	−31.72	0.68	48.82
	(120.30)	(−4.30)	(−7.54)	(−8.78)	(−9.68)	(−5.32)	(−11.18)	(−5.06)		
8. Units	5.11	−30.80	−38.95	−65.50	−61.85	−37.39	−72.48	−31.42	0.71	51.02
	(115.40)	(−4.92)	(−6.22)	(−10.46)	(−9.87)	(−5.97)	(−11.57)	(−5.02)		

The regional dummy variable $z_{urt} = 1$ if $u = r$, 0 otherwise. In all cases, the data are annual for the period 1990–1999, pooled over the eight regions. Gross household income and gross household disposable income are in terms of nominal dollars per capita. For marijuana prices, see tables 1 and 2. For income, Australian Bureau of Statistics, *Australian National Accounts: State Accounts* (Cat. no. 5220.0, 13 November 2002), table 27. For housing prices, David Wesney, Manager, Research and Statistics, REIA, Canberra. The data refer to quarterly median sale prices of established houses and units (flats, units and townhouses) in capital cities. The quarterly data are annualised by averaging.

interregional trade that would prevent prices from being equalised? Or to put it another way, what prevents an entrepreneur buying marijuana in NT and selling in NSW to realise a (gross) profit of more than 40 per cent for head ounce? While such a transaction is certainly not risk free, is it plausible for the risk premium to be more than 40 per cent? Are there other substantial costs to be paid that would rule out arbitraging away the price differential? To what extent do the regional differences in marijuana prices reflect the cost of living in the location where it is sold? Panels II and III of table 4 explore this issue by using per capita incomes and housing prices as proxies for regional living costs.[4] In Panel II, we regress the logarithm of income on seven regional dummies. All the coefficients are negative, except those for the ACT. As can be seen from the last column of Panel II, the dispersion of income regionally is considerably less than that of marijuana prices, approximately one half, which could reflect the operation of the fiscal equalisation feature of the federal system. Panel III repeats the analysis with housing prices replacing incomes, and the results in the last column show that the regional dispersion of housing prices is of the same order of magnitude of that of marijuana prices.

The comparison of prices for marijuana and housing is facilitated in figure 1, which plots the two sets of prices relative to NSW/Sydney by using the regional dummy-variable coefficients for head ounce (given in row 4 of table 4) and those for houses (row 7 of table 4). As the housing prices refer to capital cities in each region, while the marijuana prices refer to regions as a whole, for ease of exposition in what follows we shall refer to just capital cities rather than the region (for marijuana prices) and the corresponding capital city (for housing prices) simultaneously. The broken ray from the origin has a slope of 45° and as the scales of both axes are inverted, the vertical distance between this line and any point measures the difference in the housing-marijuana relative price between the city in question and that in Sydney. This relative price is thus higher for Darwin, and lower for the rest. An equivalent way of interpreting the figure is to note that as the two price differences, relative to Sydney, are equal along the 45° line, all points on the line correspond to the elasticity of marijuana prices with respect to housing prices being equal to unity; and for the points above (below) the line the elasticity is greater than (less than) unity. Accordingly, in all cities other than Darwin this elasticity is less than unity. The solid line in figure 1 is the least-squares regression line, constrained to pass through the

[4] While the Australian Bureau of Statistics publish a consumer price index (CPI) for each of the six capital cities, these indexes are not harmonised. Accordingly, the levels of the CPI cannot be compared across cities to provide information on the level of regional living costs.

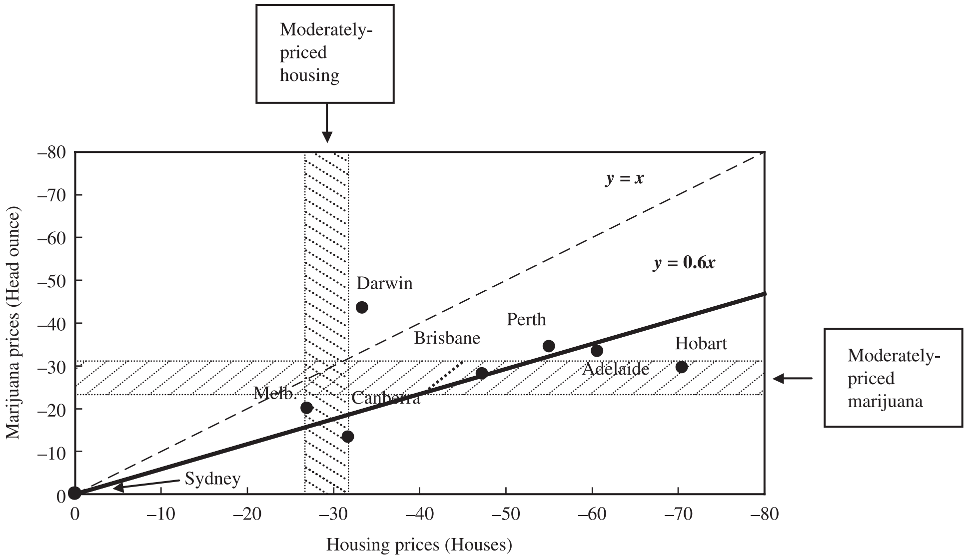

Figure 1 Marijuana and housing prices (Logarithmic ratios to Sydney × 100; inverted scales).

origin.[5] As can be seen, the slope of this line is positive, but substantially less than unity. The estimated elasticity is 0.59 and has a standard error of 0.09, so that the elasticity is significantly different from both unity and zero. As the observation for Darwin lies substantially above the regression line, we can say that marijuana prices in that city are cheap given its housing prices, or that housing is expensive in view of the cost of marijuana. Among the seven non-Sydney cities, given its housing prices, marijuana would seem to be most overpriced, or housing most underpriced, in Hobart.[6] The final interesting feature of the figure is that it can be used to naturally divide up Australia into three super regions/cities: (i) NSW/Sydney – expensive marijuana and housing, (ii) Victoria/Melbourne and ACT/Canberra – moderately priced marijuana and housing, and (iii) the remaining – cheap marijuana and housing.

[5] As prices are all expressed in terms of logarithmic ratios to Sydney, any fixed effects drop out.

[6] The slope of a ray from the origin to any of the seven cities in figure 1 is the elasticity of marijuana prices with respect to housing prices for the city in question. Visually, it can be seen that this elasticity is a bit lower for Canberra than Hobart. But as this elasticity is the percentage change in marijuana prices for a unit percentage change in housing prices, it should not be confused with using the regression line to identify anomalies in the pricing of marijuana. The vertical distance between any observation and the regression line represents the extent of mispricing.

The above discussion shows that to the extent that housing costs are a good proxy for living costs, marijuana prices are at least partially related to costs in general. As a substantial part of the overall price of marijuana is likely to reflect local distribution activities, which differ significantly across different regions, this could explain the finding that the market is not a national one, but a series of regional markets that are not too closely linked. Understanding the pricing of marijuana is enhanced if we split the product into: (i) a (nationally) traded component comprising mainly the 'raw' product, whose price is likely to be approximately equalised in different regions, and (ii) a non-traded component associated with packaging and local distribution, the price of which is less likely to be equalised. As such services are likely to be labour intensive, their prices will mainly reflect local wages which, in turn, would partly reflect local living costs. The results of this section point to the importance of the non-traded component of marijuana prices.

4. Fact 2: marijuana has become substantially cheaper

This section documents the fall in marijuana prices and canvases some possible explanations for the fall. Table 5 shows that over the 1990s marijuana prices have fallen by approximately 23 per cent in nominal terms (column 2), and 35 per cent relative to the CPI (column 5). The last entries in columns

Table 5 Marijuana, consumer and alcohol price indexes

	Levels					Log-changes (×100)				
	Nominal Prices			Relative Prices		Nominal Prices			Relative Prices	
Year	MPI	CPI	API	MPI/ CPI	MPI/ API	MPI	CPI	API	MPI/ CPI	MPI/ API
1990	100.00	100.00	100.00	100.00	100.00					
1991	94.80	103.20	104.50	91.90	90.70	−5.34	3.17	4.39	−8.49	−9.73
1992	78.70	104.20	107.50	75.50	73.20	−18.64	0.98	2.85	−19.60	−21.49
1993	77.30	106.10	111.10	72.90	69.60	−1.78	1.80	3.28	−3.58	−5.06
1994	82.30	108.10	114.80	76.20	71.70	6.30	1.88	3.25	4.43	3.05
1995	82.50	113.20	119.30	72.90	69.20	0.21	4.53	3.86	−4.40	−3.65
1996	83.90	116.10	124.20	72.20	67.50	1.67	2.58	4.02	−0.86	−2.36
1997	84.70	116.40	127.30	72.80	66.60	1.03	0.25	2.44	0.77	−1.41
1998	82.00	117.40	128.90	69.80	63.60	−3.33	0.85	1.24	−4.18	−4.57
1999	76.60	118.70	–	64.50	–	−6.78	1.13	–	−7.88	–
Mean	–	–	–	–	–	−2.96	1.91	3.17	−4.87	−5.65

MPI, marijuana price index; CPI, consumer price index; API, alcohol price index. The MPI is from column 6 of table 3 with 1990 = 100; the CPI is from the DX database, rebased such that 1990 = 100; and the API is a levels version of a Divisia index of the prices of beer, wine and spirits, from Clements and Daryal (2003).

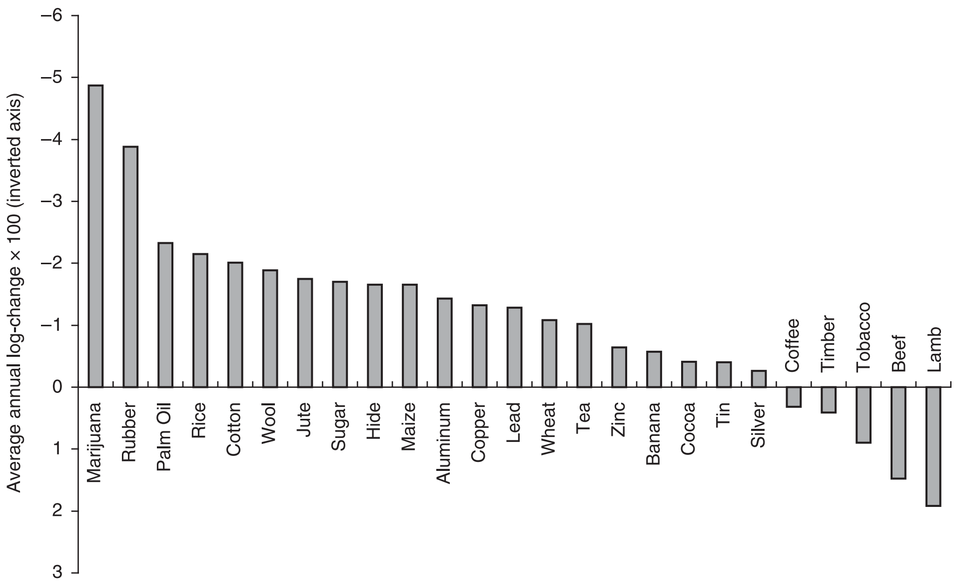

Figure 2 Marijuana and commodity relative price changes.

10 and 11 of this table reveal that on average over the decade, marijuana prices in terms of consumer prices fell by 4.9 per cent p.a and by 5.7 per cent per annum in terms of alcohol prices. No matter if the CPI or alcohol prices are used as the deflator, the result is the same: The relative price of marijuana has fallen substantially.[7]

How do marijuana prices compare with those of other commodities? In an influential article, Grilli and Yang (1988) analyse the prices of 24 commodities that are traded internationally. We convert these to relative prices (using the USA CPI) and then compute the average annual log-changes over the period 1914–1986. Figure 2 gives the price changes for the 24 commodities plus marijuana. The striking feature of this graph is that marijuana prices have fallen the most by far. The only commodity to come close is rubber, but even then its average price fall is one percentage point less than that for marijuana (−3.9 vs. −4.9% p.a) There is a substantial drop off in the price declines after rubber: palm oil (–2.3 per cent), rice (–2.2 per cent), cotton (–2.0 per cent), and so on. Surprisingly, the price of tobacco, which might be considered to be related to marijuana in both consumption and production, increased by 0.9 per cent per annum The declines in most of the commodity prices reflect the impact of productivity enhancement

[7] The first part of this section is based on Clements and Daryal (2001), except that here we use population-weighted marijuana prices.

coupled with low income elasticities of demand. Additionally, in earlier parts of the twentieth century, the area devoted to agriculture was still rising in some countries, and this would have contributed to the downward pressure on commodity prices.[8]

Why did marijuana prices fall by so much? One reason is that the growing of marijuana has been subject to productivity enhancement by the adoption of hydroponic techniques,[9] which lead to a higher-quality product containing higher *Delta-9-tetrahydrocannabinol* (THC) levels.[10] For example, hydroponically grown marijuana from northern Tasmania has been analysed as containing 16 per cent of THC, while that grown outdoors in the south of the state contained 12.8% (Australian Bureau of Criminal Intelligence, ABCI 1996). The ease of concealment and near ideal growing conditions, which produce good-quality plants, are the main reasons for the shift to hydroponic systems. According to the ABCI (1996),

> 'Hydroponic systems are being used to grow cannabis on a relatively large scale. Unlike external plantations, hydroponic cultivation can be used in any region and is not regulated by growing seasons. Both residential and industrial areas are used to establish these indoor sites. Cellars and concealed rooms in existing residential and commercial properties are also used … The use of shipping containers to grow cannabis with hydroponic equipment has been seen in many cases. The containers are sometimes buried on rural properties to reduce chances of detection.' (pp. 30–31)

Other anecdotal evidence also points to the rise of hydroponic activity over this period. For example, according to the *Yellow Pages* telephone directory, in 1999 Victoria had 149 hydroponics suppliers, NSW 115, SA 69, Queensland 59 and WA 58. One suspects that many of these operations supply marijuana growers. For a further discussion of this anecdotal evidence, see Clements (2002).

[8] For a further comparison of the evolution of the price of marijuana with that of the prices of 30 goods that are not traded (The Economist 2000/01), as well as with the price of light over the past 200 years (Nordhaus 1997), and the prices of personal computers (Berndt and Rappaport 2001), see Clements (2002). This comparison shows that on average only the prices of phone calls and PCs fell by more than those of marijuana.

[9] The word *hydroponic* means 'water working'. For details of hydroponic techniques see, for example, Asher and Edwards (1981) and Ashley's Sister (1997).

[10] The content of the main psychoactive chemical THC determines the potency and the quality of marijuana. This is evidenced by the fact that flowers (so-called 'heads' or 'buds'), which contain more THC than leaves, are considerably more expensive.

Table 6 Infringement notices for minor cannabis offences (rate per 100 000 population)

Year	SA	NT	ACT	Australia
1996	1114	–	96	92
1997	857	124	103	72
1998	725	115	76	60
1999	631	179	49	53
2000	579	401	–	50
2001	580	208	59	48
Mean	748	205	77	63

Sources: ABCI (2002); Australian Bureau of Statistics (2002); Australian Bureau of Statistics (1998–2003).

A second possible reason for the decline in marijuana prices is that, because of changing community attitudes, laws have become softer and penalties reduced. Information on the enforcement of marijuana laws distinguishes between (i) infringement notices issued for minor offences and (ii) arrests. Table 6 presents the available data on infringement notices for the three states/territories that use them, SA, NT and ACT. As can be seen, per capita infringement notices have declined substantially in SA since 1996, increased in NT, first increased and then declined in ACT, and declined noticeably for Australia as a whole, where they have fallen by almost 50 per cent. This information points in the direction of a lower policing effort. Data on arrests and prosecution for marijuana offences are given in table 7. Panel I shows that the arrest rate for NSW was more or less stable over the 6-year period, while that for Victoria fell substantially as a result of a 'redirection of police resources away from minor cannabis offences' (ABCI 1998). For Queensland, the arrest rate rose by more than 50 per cent in 1997, and then fell back to a more or less stable value, but in WA the rate fell markedly in 1999 with the introduction of a trial of cautioning and mandatory education to 'reduce the resources previously used to pursue prosecutions for simple cannabis offences' (ABCI 2000). For Australia, the arrest rate fell from 342 in 1996 to 232 in 2001 (per 100 000 population), a decline of 32 per cent. Data on successful prosecution of marijuana cases for three states are given in Panel II of table 7 (data for the other states/territories are not available). For both NSW and SA, the prosecution rate has fallen substantially. Not only has the prosecution rate fallen, lighter sentences have become much more common. Interestingly, in the early 1990s the prosecution rate was much higher in SA than in NSW, but by the end of the decade the rate was approximately the same in the two states. In WA, the prosecution rate is fairly stable, but the period is much shorter. No clear pattern emerges from the information on the percentage of arrests that result in a successful prosecution, as shown in Panel III of table 7.

Table 7 Arrests and prosecutions for marijuana offences

Year	NSW	VIC	QLD	WA	SA	NT	TAS	ACT	Australia
I. Arrests (per 100 000 population)									
1996	238	421	286	795	141	210	531	47	342
1997	227	199	441	713	232	245	228	54	304
1998	245	195	380	633	182	222	253	45	287
1999	247	198	385	330	172	183	156	28	256
2000	220	157	386	363	210	62	170	–	242
2001	211	136	366	389	151	224	223	48	232
Mean	231	218	374	537	181	191	260	37	277
II. Successful prosecutions (per 100 000 population)									
1991	112	–	–	–	–	–	–	–	–
1992	123	–	–	–	273	–	–	–	–
1993	113	–	–	–	315	–	–	–	–
1994	94	–	–	–	350	–	–	–	–
1995	83	–	–	–	326	–	–	–	–
1996	90	–	–	–	304	–	–	–	–
1997	81	–	–	–	205	–	–	–	–
1998	85	–	–	222	46	–	–	–	–
1999	92	–	–	234	38	–	–	–	–
2000	77	–	–	251	59	–	–	–	–
2001	73	–	–	238	76	–	–	–	–
Mean	93	–	–	236	199	–	–	–	–
III. Prosecutions/Arrests (Percentages)									
1996	38	–	–	–	215	–	–	–	–
1997	36	–	–	–	88	–	–	–	–
1998	35	–	–	35	25	–	–	–	–
1999	37	–	–	71	22	–	–	–	–
2000	35	–	–	69	28	–	–	–	–
2001	35	–	–	61	51	–	–	–	–
Mean	36	–	–	59	72	–	–	–	–

Arrests exclude the issuing of Cannabis Expiation Notices, Simple Cannabis Offence Notices and Infringement Notices, which are used in SA, NT and ACT. For details of these, see table 6. The arrests data for 1996 for SA seem to be problematic and need to be treated with caution. According to *Australian Illicit Drug Report 2000–01*, arrests were 2076, which when divided by the population of SA of 1474 253 yields 141 per 100 000, as reported above. However, according to the 2001–02 edition of the above mentioned publication, arrests for the same state in the same year were 18 477, or 1253 per 100 000. We used the 141 figure as it appeared to be more consistent with data for adjacent years; however, the use of this figure leads to a prosecutions/arrests rate of 215%, as reported in Panel III of this table. Sources: ABCI (2001); NSW Bureau of Crime Statistics and Research (2001); Office of Crime Statistics and Research (2001); Crime Research Centre (2001); Australian Bureau of Statistics (2002).

To understand further the evolution of enforcement of marijuana laws, it is useful to consider a simple model. Let p^r_{it} be the penalty of type i ($i = 1, 2$, for an infringement notice and an arrest, respectively) in region r ($r = 1, \ldots , 8$) and year t ($t = 1996, \ldots , 2001$). A simple logarithm decomposition of penalties takes the form $\log p^r_{it} = \alpha_r + \beta_i + \gamma_t + \varepsilon^r_{it}$, where α_r is a regional effect, β_i a

Table 8 Estimates of penalty model $\log p_{it}^r = \delta + \sum_{s=2}^{8} \alpha_s z_{sit}^r + \beta x_{it}^r + \lambda_t$

Parameter	Estimate (standard errors in parentheses)
Intercept δ	165.36 (60.89)
Regional dummies α_s	
VIC	−0.13 (0.12)
QLD	0.47 (0.11)
WA	0.78 (0.12)
SA	0.09 (0.16)
NT	−0.55 (0.20)
TAS	0.03 (0.15)
ACT	−1.78 (0.13)
Infringement dummy β	0.70 (0.16)
Exponential time trend λ	−0.08 (0.03)
R^2	0.81
Number of observations	63

The standard errors are White heteroscedasticity adjusted.

penalty effect, γ_t a time effect, and ε_{it}^r is a disturbance term. If we suppose that the time effect is exponential, so that $\gamma_t = \lambda_t$, we can then implement this model as a regression equation,

$$\log p_{it}^r = \delta + \sum_{s=2}^{8} \alpha_s z_{sit}^r + \beta x_{it}^r + \lambda_t + \varepsilon_{it}^r, \quad (1)$$

where $z_{sit}^r = 1$ if $r = s$, 0 otherwise; $x_{it}^r = 1$ if $i =$ an infringement, 0 otherwise; and δ, α_s, β and λ are parameters. The value of the regional parameter α_s indicates the severity of penalties in region s relative to NSW (the base case); the parameter β tells us about the infringement rate in comparison to that of arrests; and λ is the residual exponential trend in all types of enforcement in all regions.

Table 8 gives the estimates of model (1), obtained with data given in tables 6 and 7. As compared to NSW, Victoria, NT and ACT are all low-penalty regions, while the other four have higher penalties on average. In Section 3 we ranked regions in terms of the cost of marijuana, which can be compared with the severity of penalties as follows:

Cost (cheapest to most expensive): NT, WA, SA, TAS, QLD, VIC, ACT, NSW
Penalties (weakest to most severe): ACT, NT, VIC, NSW, TAS, SA, QLD, WA

As the relationship between the two rankings is obviously weak, with major differences for most states, regional disparities in penalties do not seem to

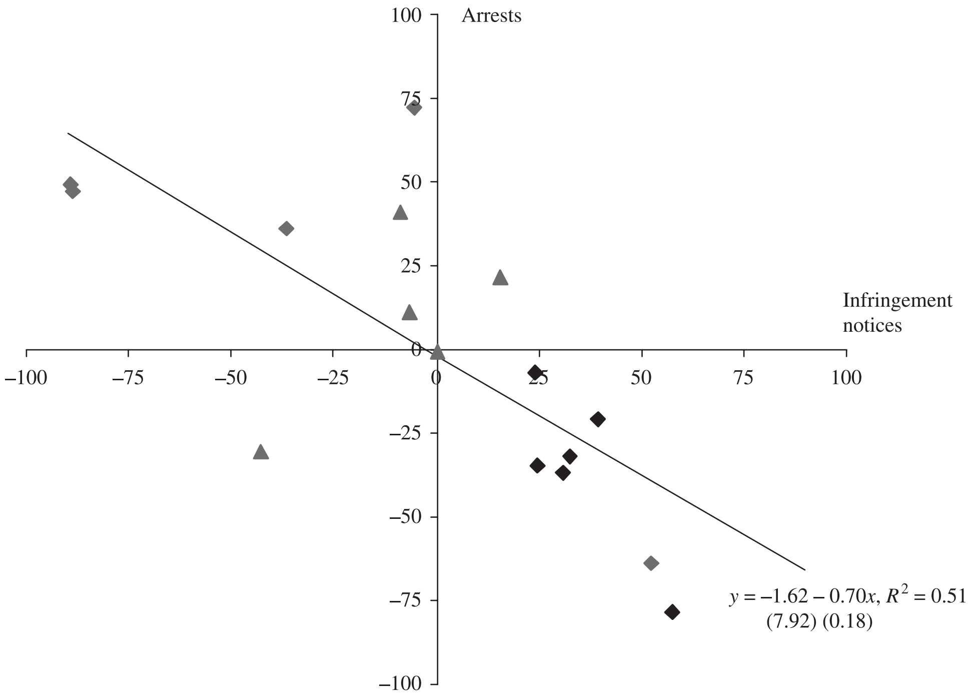

Figure 3 Relationship between unexpected arrests and infringement notices (logarithmic ratios of actual to expected × 100).

be systematically associated with regional price differences. Controlling for regional and time effects, the estimated coefficient of the infringement dummy indicates that these are significantly higher than arrests. The estimated trend term shows that all penalties are falling on average by approximately 8 per cent per annum, a fall that is significantly different from zero. Consider those three regions that have infringement notices. To what extent have infringement notices partially displaced arrests? In other words, are the two forms of penalties substitutes for one another? For example, in the NT the infringements rate rose from 179 in 1999 to 401 in 2000, while over the same period the arrest rate fell from 183 to 62. This would seem to support the idea that the two types of penalties are substitutes. However, to proceed more systematically, we need to control for all the effects of factors determining penalties in model (1) by using the residuals, and examine the comovement of infringements and arrests in the three regions over the 6 years. Figure 3 is a scatter plot of these residuals and as can be clearly seen, there is a significant negative relationship between arrests and infringements. This means that more infringement notices are associated with fewer arrests, other factors remaining unchanged. This, of course, must have been one of the key objectives associated with the introduction of the infringement regime.

Taken as a whole, the above analysis seems to support the idea that participants in the marijuana industry have faced a declining probability of being arrested and/or successfully prosecuted; and even if they are arrested and successfully prosecuted, the expected penalty is now lower. In other words, both the effort devoted to the enforcement of existing laws and penalties seem to have decreased. Accordingly, the expected value of this component of the 'full cost' of using marijuana has fallen. During the period considered, NSW, Victoria, WA and Tasmania all introduced marijuana cautioning programs (ABCI 2000) and SA, NT and ACT all issued marijuana offence notices. This seems to indicate changing community attitudes to marijuana associated with the reduced 'policing effort'. It is plausible that this has also led to lower marijuana prices. As the riskiness of buying and selling marijuana has fallen, so might have any risk premium built into prices. This explanation of lower prices has, however, been challenged by Basov *et al.* (2001) who analyse illicit drug prices in the USA. They show that while drug prohibition enforcement costs have risen substantially over the past 25 years, the relative prices of drugs have nonetheless declined. Basov *et al.* (2001) suggest four possible reasons for the decrease in prices: (i) production costs of drugs have declined, (ii) tax and regulatory cost increases have raised the prices of legal goods, but not illicit goods such as drugs, (iii) the market power of the illicit drug industry has fallen, and (iv) technologies to evade enforcement have improved. Although hard evidence is necessarily difficult to obtain, Basov *et al.* (2001) argue against explanations (i) and (ii), and favour (iii) and (iv) as realistic possibilities.[11]

[11] Miron (1999) studies the impact of prohibition on alcohol consumption in the USA during 1920–1933. Using the death rate from liver cirrhosis as a proxy for alcohol consumption, he finds that prohibition 'exerted a modest and possibly even positive effect on consumption.' This could be because prices fell for reasons given above. But there are other possibilities including a highly inelastic demand for alcohol and/or prohibition giving alcohol the status of a 'forbidden fruit', which some consumers might find attractive (Miron 1999). To shed further light on the impact of prohibition on prices, Miron (2003) also compares the markup from farmgate to retail of cocaine and heroin with that of several legal products. He finds that while the markup for cocaine is high, it is of the same order of magnitude of that of chocolate, coffee, tea and barley/beer. While there are other factors determining markups, this evidence is suggestive that illegality per se may not raise drug prices as much as some people might think. On the basis of this and other evidence, Miron (2003, p. 529) concludes that 'the black market price of cocaine is 2–4 times the price that would obtain in a legal market, and of heroin 6–19 times. In contrast, prior research has suggested that cocaine sells at 10–40 times its legal price and heroin at hundreds of times its legal price'. Consistent with this line of thinking is research that shows that increased enforcement of drug laws does not seem to result in higher prices (DiNardo 1993; Weatherburn and Lind 1997; Yuan and Caulkins 1998).

We can summarise this section as follows. First, the relative price of marijuana has fallen substantially, by more than that of many other commodities. Second, two possible explanations for this decline are (i) productivity improvement in the production of marijuana associated with the adoption of hydroponic techniques; and (ii) the lower expected penalties for buying and selling marijuana. On the basis of the evidence currently available, both explanations seem to be equally plausible.

5. Fact 3: lower prices have boosted marijuana consumption and reduced alcohol consumption

The section contains some explorations of the likely impact of lower marijuana prices on usage, as well as their role in determining the consumption of a product that shares important common characteristics, alcohol. It should be acknowledged that our price and quantity data for marijuana are imperfect and are subject to more than the usual uncertainties. Moreover, as we have data for only a decade, we are severely constrained in carrying out an econometric analysis of the price responsiveness of consumption. Although Clements and Daryal (2003) attempted such an analysis, in this section we explore the alternative approach of drawing on the previous published literature and putting sufficient structure on the problem to be able to derive numerical values of the price elasticities of demand. This approach is used extensively in the literature on computable general equilibrium and equilibrium displacement modelling.

We assume that alcohol and marijuana consumption as a group is weakly separable from all other goods in the consumer's utility function. While this rules out any specific substitutability/complementarity relationships between members of the group on the one hand, and products outside the group on the other, it is a fairly mild assumption. This assumption means that we can proceed conditionally and analyse consumption within the group independently of the prices of other goods (see, e.g., Clements 1987). Next, we make the simplifying assumption that tastes with respect to alcohol and marijuana can be characterised by a utility function of the preference independent form. This means that if there are n goods in the group, the utility function is the sum of n subutility functions, one for each good, $u(q_1, \dots, q_n) = \sum_{i=1}^{n} u_i(q_i)$, where q_i is the quantity consumed of good i. Preference independence (PI) means that the marginal utility of each good is independent of the consumption of all others. The implications of PI are that all income elasticities are positive, so that inferior goods are ruled out, and all pairs of goods are Slutsky substitutes. The hypothesis of PI has been recently tested with alcohol data for seven countries by Clements *et al.* (1997) and, using a variety of tests, they find that the hypothesis cannot be rejected.[12] There have been nine prior studies of the relationship between alcohol and marijuana consumption, eight for the USA and one for Australia (Cameron and Williams 2001). Four of the nine studies find substitutability between alcohol and marijuana (DiNardo and Lemieux 1992; Model 1993; Chaloupka and Laixuthai 1997; Cameron and Williams 2001), two find complementarity (Pacula 1997, 1998), one finds the relationship to be mostly complementarity (Saffer and Chaloupka 1998), while two are inconclusive (Thies and Register 1993; Saffer and Chaloupka 1995). Therefore, while these studies do not give a completely unambiguous picture, the weight of the evidence seems to point to alcohol and marijuana being substitutes, which is not inconsistent with the PI assumption.

The further implications of PI are as follows. Let p_i be the price of good i ($i = 1, \ldots, n$), q_i be the corresponding quantity demanded, $M = \sum_{i=1}^{n} p_i q_i$ be total expenditure ('income' for short), and $w_i = p_i q_i / M$ be the budget share of good i. Furthermore, let $\eta_{ij} = \partial(\log q_i)/\partial(\log p_j)$ be the compensated elasticity of demand for good i with respect to the price of good j, ϕ be the price elasticity of demand for the group of goods as a whole, and η_i be the income elasticity of demand for good i. We then have the fundamental relationship linking the price and income elasticities under PI,

$$\eta_{ij} = \phi \eta_i (\delta_{ij} - w_j \eta_j), \tag{2}$$

where δ_{ij} is the Kronecker delta ($\delta_{ij} = 1$ if $i = j$, 0 otherwise). For the derivation of equation (2) and more details see, for example, Clements *et al.* (1995). We shall obtain numerical values of the price elasticities by using equation (2) in conjunction with values of ϕ and η_i that have appeared in the published literature.

Table 9 presents for several countries estimates of the income elasticities for three alcoholic beverages, beer, wine and spirits, as well as the price elasticity of alcohol as a whole. These elasticities are derived from estimates of the Rotterdam model under preference independence. We use them as a guide to the values of income elasticities of the members of the broader group alcohol and marijuana, as set out in table 10. As can be seen from column 2 of table 10, beer is taken to have an income elasticity of 0.5 (so that it is a necessity), wine 1.0 (a borderline case) and spirits 2.0 (a strong luxury). We shall come back to the elasticity for marijuana. Column 3 gives the four budget shares, which are based on the means given in the last row of table 11. We derive the income elasticity of marijuana from the constraint

[12] Earlier studies tended to reject PI (see Barten 1977, for a survey), but it is now understood that the source of many of these rejections was the use of asymptotic tests, which were biased against the null (Selvanathan 1987, 1993).

Table 9 Demand elasticities for alcoholic beverages

Country	Sample period	Income elasticities			Price elasticity of alcohol as a whole
		Beer	Wine	Sprits	
Australia	1955–85	0.81	1.00	1.83	−0.50
Canada	1953–82	0.74	1.05	1.25	−0.42
Finland	1970–83	0.45	1.32	1.32	−1.35
New Zealand	1965–82	0.84	0.88	1.45	−0.44
Norway	1960–86	0.34	1.48	1.55	−0.08
Sweden	1967–84	0.21	0.69	1.52	−1.43
United Kingdom	1955–85	0.82	1.06	1.34	−0.54
Mean		0.60	1.07	1.47	−0.68

Source: Clements *et al.* (1997).

Table 10 Income elasticities and budget shares

Good	Income elasticity η_i	Budget share w_i
Beer	0.50	0.40
Wine	1.00	0.15
Spirits	2.00	0.15
Marijuana	1.20	0.30

$\sum_{i=1}^{4} w_i \eta_i = 1$. This yields $\eta_4 = 1.2$, as indicated by the last entry of column 2 of table 10, which implies that marijuana is a mild luxury.[13]

The only remaining parameter on the right-hand side of equation (2) to discuss is ϕ, the own-price elasticity of demand for the group (alcohol and marijuana) as a whole. It can be seen from equation (2) that ϕ acts as a 'scaling' parameter. Prior estimates of ϕ for alcohol are given in column 6 of table 10, and these average −0.7. As marijuana is likely to be a substitute

[13] It is appropriate to say a few words about the consumption data in table 11. The quantity consumed of marijuana is estimated on the basis of the National Drug Strategy Household Survey (1999), together with some plausible assumptions that link intensity of use to frequency of use; see Clements and Daryal (2003) for details. Although all care was taken in preparing these estimates, and they are not inconsistent with independent estimates, it must be acknowledged that they are likely to be subject to a substantial margin of error. Panel I of table 11 reveals that over the 1990s, per capita beer consumption fell from 140 to 117 L, wine increased from 22.9 to 24.6, spirits grew from 3.87 to 4.32, and marijuana consumption increased from 0.765 to 0.788 ounces per capita. In what follows, we analyse the extent to which the fall in marijuana prices caused alcohol consumption to grow at a slower rate than would otherwise be the case. The final thing to note about table 11 is that from Panel IV, on average the budget shares are roughly 0.40, 0.15, 0.15 and 0.30 for beer, wine, spirits and marijuana, respectively. Accordingly, expenditure on marijuana is approximately equal to the sum of that on wine and spirits, or to put it another way, approximately twice wine expenditure.

Table 11 Quantities consumed, prices, expenditures and budget shares of alcoholic beverages and marijuana

Year	Beer	Wine	Spirits	Marijuana
I. Quantities (litres per capita; ounces per capita)				
1990	139.9	22.85	3.870	0.7652
1991	134.9	23.01	3.614	0.8278
1992	127.8	23.23	3.595	0.7695
1993	123.8	23.14	3.982	0.7090
1994	122.1	23.19	4.168	0.7120
1995	120.2	22.96	4.130	0.6913
1996	118.7	23.29	4.106	0.7442
1997	117.6	24.18	4.158	0.7575
1998	116.9	24.63	4.318	0.7875
Mean	124.7	23.39	3.990	0.7516
II. Prices (dollars per litre; dollars per ounce)				
1990	3.12	6.80	36.60	577
1991	3.27	6.88	39.06	547
1992	3.36	7.06	40.53	454
1993	3.48	7.27	41.85	446
1994	3.58	7.60	43.04	475
1995	3.72	7.98	44.25	476
1996	3.89	8.31	45.69	484
1997	3.98	8.56	46.71	489
1998	4.02	8.75	47.09	473
Mean	3.60	7.69	42.76	491
III. Expenditures (dollars per capita)				
1990	435.93	155.40	141.65	441.52
1991	441.26	158.38	141.18	452.81
1992	429.54	163.91	145.71	349.35
1993	430.58	168.25	166.63	316.21
1994	437.48	176.17	179.41	338.20
1995	447.62	183.29	182.77	329.06
1996	461.86	193.45	187.59	360.19
1997	468.17	206.96	194.24	370.42
1998	469.94	215.64	203.33	372.49
Mean	446.93	180.16	171.39	370.03
IV. Budget shares (percentages)				
1990	37.12	13.23	12.06	37.59
1991	36.97	13.27	11.83	37.94
1992	39.46	15.06	13.39	32.09
1993	39.81	15.55	15.41	29.23
1994	38.67	15.57	15.86	29.90
1995	39.17	16.04	15.99	28.80
1996	38.39	16.08	15.59	29.94
1997	37.76	16.69	15.67	29.88
1998	37.26	17.10	16.12	29.53
Mean	38.29	15.40	14.66	31.65

Per capita refers to those 14 years and over. The marijuana prices are from column 6 of table 3. All other data are from Clements and Daryal (2003).

Table 12 Own- and cross-price elasticities for alcoholic beverages and marijuana

Good	Beer	Wine	Spirits	Marijuana
I. $\phi = -1.0$				
Beer	−0.40	0.08	0.15	0.18
Wine	0.20	−0.85	0.30	0.36
Spirits	0.40	0.30	−1.40	0.72
Marijuana	0.24	0.18	0.36	−0.77
II. $\phi = -0.6$				
Beer	−0.24	0.05	0.09	0.11
Wine	0.12	−0.51	0.18	0.22
Spirits	0.24	0.18	−0.84	0.43
Marijuana	0.14	0.11	0.22	−0.46
III. $\phi = -0.3$				
Beer	−0.12	0.02	0.05	0.05
Wine	0.06	−0.26	0.09	0.11
Spirits	0.12	0.09	−0.42	0.22
Marijuana	0.07	0.05	0.11	−0.23
IV. $\phi = -0.1$				
Beer	−0.04	0.01	0.02	0.02
Wine	0.02	−0.09	0.03	0.04
Spirits	0.04	0.03	−0.14	0.07
Marijuana	0.02	0.02	0.04	−0.08

The parameter ϕ is the own-price elasticity of demand for alcohol and marijuana as a group. The $(i, j)^{\text{th}}$ element in a given panel is η_{ij}, the compensated elasticity of demand for good i with respect to the price of good j.

for alcohol, the effect of expanding the group of goods in question from alcoholic beverages to alcohol plus marijuana would be for the price elasticity to fall in absolute value. This means that we should use for the alcohol and marijuana group a $|\phi|$-value of less than 0.7. Clements and Daryal (2003) estimate ϕ for Australia for alcohol or marijuana to be −0.4; while going in the right direction, this estimate is subject to some qualifications because of the uncertainties associated with the limited data available. It would, therefore, seem sensible to use several values of ϕ to reflect the genuine uncertainties surrounding the values of this parameter. This approach is pursued in table 12, where we apply equation (2) with four values of ϕ. As can be seen, the own-price elasticity of marijuana for example declines (in absolute value) from −0.8 (when $\phi = -1.0$), to −0.5 ($\phi = -0.6$), to −0.2 ($\phi = -0.3$), to −0.1 ($\phi = -0.1$).

We now use the cross-price elasticities to simulate consumption under the counter-factual assumption that marijuana prices did not fall as much as they did. As alcohol and marijuana are substitutes, this will have the effect of stimulating consumption of the three beverages and causing marijuana usage to grow by less. Let q_{it} be the per capita consumption of good

i ($i = 1, 2, 3, 4$; for beer, wine, spirits and marijuana) in year t ($t = 1, \dots, T$) and let $Dq_i = \log q_{iT} - \log q_{i,1}$ be the corresponding log-change from the first year in the period (1990) to the last (1998). Then, if $\eta_{ij} = \partial(\log q_i)/\partial(\log p_j)$ is the elasticity of consumption of good i with respect to the price of good j, as an approximation it follows that $Dq_i = \eta_{ij} \times Dp_j$, where Dp_j is the log-change in the j^{th} price over the 9 years. In the simulation, let all determinants of consumption be unchanged except the price of marijuana, which is specified to take the value $D\hat{p}_4$. The associated simulated value of the change in consumption of good i is then $\eta_{i4}D\hat{p}_4$. This change in consumption holds everything else constant. The impact on consumption of the observed changes in all factors, including the price of marijuana, is incorporated in the observed log-change, Dq_i. We shall allow these factors to vary as in fact they did, but we need to take out the impact of the observed changes in marijuana prices. Let the observed log-change in marijuana prices over the whole period be α. If marijuana prices were constant and the other determinants took their observed values, then the change in the consumption of good i would be $Dq_i - \eta_{i4}\alpha$. Adding back the effect as a result of the simulated price change $D\hat{p}_4$, the simulated change in consumption of good i over the whole period is

$$D\hat{q}_i = Dq_i + \eta_{i4}(D\hat{p}_4 - \alpha). \tag{3}$$

As $D\hat{q}_i = \log \hat{q}_{iT} - \log q_{i,1}$ and $Dq_i = \log q_{iT} - \log q_{i,1}$, where $\hat{q}_{iT}$ is simulated consumption of good i in year T, it follows that equation (3) simplifies to

$$\log\left(\frac{\hat{q}_{iT}}{q_{iT}}\right) = \eta_{i4}(D\hat{p}_4 - \alpha). \tag{4}$$

In words, simulated consumption in the last year, relative to actual in that year, is equal to the relevant price elasticity applied to the counterfactual change in the price of marijuana, adjusted for the observed change.

To implement equation (4), we go back to table 11, which gives in Panels I and II the observed quantities and prices in terms of levels. Columns 2–5 of table 13 convert these data to annual log-changes. Column 7 contains the Divisia volume and price indexes for alcohol and marijuana as a group, defined as

$$DQ_t = \sum_{i=1}^{4} \bar{w}_{it} Dq_{it}, \quad DP_t = \sum_{i=1}^{4} \bar{w}_{it} Dp_{it}, \tag{5}$$

where $\bar{w}_{it} = 1/2(w_{it} + w_{i,t-1})$ is the arithmetic average of the i^{th} budget share in years t, $t - 1$; and $Dq_{it} = \log q_{it} - \log q_{i,t-1}$ and $Dp_{it} = \log p_{it} - \log p_{i,t-1}$ are

Table 13 Log-changes in quantities consumed and Prices of alcoholic beverages and marijuana

					Divisia indexes	
Year	Beer	Wine	Spirits	Marijuana	Alcohol	Alcohol + marijuana
I. Quantities						
1991	−3.64	0.70	−6.84	7.86	−3.33	0.90
1992	−5.41	0.95	−0.53	−7.30	−3.07	−4.55
1993	−3.18	−0.39	10.22	−8.19	0.22	−2.36
1994	−1.38	0.22	4.57	0.42	0.29	0.33
1995	−1.57	−1.00	−0.92	−2.95	−1.29	−1.78
1996	−1.26	1.43	−0.58	7.37	−0.50	1.82
1997	−0.93	3.75	1.26	1.77	0.65	0.99
1998	−0.60	1.84	3.78	3.88	0.98	1.84
Mean	−2.25	0.94	1.37	0.36	−0.76	−0.35
Sum	−17.96	7.50	10.95	2.87	−6.05	−2.82
II. Prices						
1991	4.85	1.20	6.51	−5.34	4.39	0.72
1992	2.71	2.48	3.69	−18.64	2.85	−4.67
1993	3.42	3.00	3.19	−1.78	3.28	1.73
1994	2.97	4.39	2.82	6.30	3.25	4.15
1995	3.86	4.96	2.77	0.21	3.86	2.79
1996	4.39	3.97	3.19	1.67	4.02	3.33
1997	2.29	3.00	2.22	1.03	2.44	2.02
1998	0.97	2.26	0.80	−3.33	1.24	−0.11
Mean	3.18	3.16	3.15	−2.48	3.17	1.24
Sum	25.47	25.26	25.19	−19.87	25.35	9.95

All entries are to be divided by 100.

the annual quantity and price log-changes. As can be seen, from the second last entry in column 7 of Panel I, on average per capita consumption of the group falls by approximately 0.4 per cent per annum From column 7 of Panel II, the price index of the group increases by approximately 1.2 per cent per annum on average, while over the whole period 1990–1998 the price index grows by 10.0 per cent.[14] Denoting the alcohol group by the subscript A, the within-alcohol version of equation (5) is

$$DQ_{At} = \sum_{i=1}^{3}\left(\frac{\bar{w}_{it}}{1-\bar{w}_{4t}}\right)Dq_{it}, \quad DP_{At} = \sum_{i=1}^{3}\left(\frac{\bar{w}_{it}}{1-\bar{w}_{4t}}\right)Dp_{it}. \tag{6}$$

It follows from equations (5) and (6) that the two sets of indexes are related according to $DQ_t = (1-\bar{w}_{4t})DQ_{At} + \bar{w}_{4t}Dq_{4t}$, $DP_t = (1-\bar{w}_{4t})DP_{At} + \bar{w}_{4t}Dp_{4t}$.

[14] Note that the log-change over the whole period is just the sum of the component annual log-changes. The see this, consider T positive numbers $x_1, \ldots, x_T$. Then $\log x_T - \log x_1 = \sum_{t=2}^{T}(\log x_t - \log x_{t-1})$, as adjacent values in the sum cancel.

Table 14 Counter-factual log-changes in quantities consumed of alcoholic beverages and marijuana

Own-price elasticity of demand for alcohol and marijuana as a group, ϕ	Beer	Wine	Spirits	Marijuana
I. Marijuana prices constant ($D\hat{p}_4 = 0$)				
–1.00	3.58	7.15	14.31	–15.26
–0.60	2.15	4.29	8.59	–9.16
–0.30	1.07	2.15	4.29	–4.58
–0.10	0.36	0.72	1.43	–1.53
II. Marijuana prices grow at same rate as alcohol prices ($D\hat{p}_4 = 25.35 \times 10^{-2}$)				
–1.00	8.14	16.28	32.56	–34.73
–0.60	4.88	9.77	19.54	–20.84
–0.30	2.44	4.88	9.77	–10.42
–0.10	0.81	1.63	3.26	–3.47

The elements in this table are 100 times the logarithmic ratios of simulated consumption ($\hat{q}_{iT}$) to actual consumption (q_{iT}) in year $T = 1998$. They are therefore interpreted as approximately equal to the percentage differences between simulated and actual in that year, with the differences attributable to the counter-factual values of marijuana prices whereby these prices are: (i) held constant over the period 1990–1998 (Panel I), and (ii) grow at the same rate as alcohol prices over this period (Panel II).

The alcohol indexes are presented in column 6 of table 13. According to the price index for alcohol (Panel II, column 6), on average, the price of this group grew faster than that of alcohol plus marijuana (column 7) as marijuana prices rise much slower (in fact, they fall on average) than those of the three alcoholic beverages. Exactly the opposite situation occurs with the volume indexes of the two groups, given in Panel I.

We are now in a position to evaluate equation (4) for i = beer, wine, spirits and marijuana. From the last entry in column 5 of table 13, the log-change in the price of marijuana over the whole period 1990–1998, α, is -19.87×10^{-2}. Regarding the counter-factual trajectory of marijuana prices, we first assume that they were constant over the period, so that $D\hat{p}_4 = 0$. Using these values, together with the elasticities involving marijuana prices, η_{i4}, given in the last column of table 12, we obtain the counter-factual quantity changes.

Panel I of table 14 contains the results. According to the first row of this panel, which is based on group price elasticity ϕ taking a value of −1.0, if marijuana prices had been constant over the whole period, rather than falling by approximately 20 per cent, beer consumption in 1998 is simulated to be approximately 3.6 per cent higher than actual, wine 7.2 per cent higher, spirits 14.3 per cent higher, and marijuana 15.3 per cent lower. The differences among the three alcoholic beverages reflect the values of their elasticities with respect to the price of marijuana. Spirits consumption increases the most as it has the largest cross-price elasticities with $\eta_{34} = 0.72$ (from the last column of Panel I of table 12), then comes wine ($\eta_{24} = 0.36$), followed by beer ($\eta_{14} = 0.18$). The second, third and fourth rows of Panel I of table 14 contain the same results for different values of ϕ. As there are uncertainties about the precise value of this elasticity, as discussed, we adopt the conservative approach of focusing on a $|\phi|$-value which is likely to be on the low side, namely 0.3. According to this value, beer consumption is higher by 1.0 per cent when marijuana prices are held constant, wine is 2.2 per cent higher, spirits 4.4 per cent higher, and marijuana 4.6 per cent lower.

In the second simulation, it is assumed that marijuana prices grow at the same rate over 1990–1998 as did alcohol prices. From the last entry in column 6 of table 13, the log-change in the index of alcohol prices over this period was 25.35×10^{-2}, so that on the right-hand side of equation (4), we set $D\hat{p}_4 = 25.35 \times 10^{-2}$ and $\alpha = -19.87 \times 10^{-2}$, as before. The results are given in Panel II of table 14. Focusing again on the case where $\phi = -0.3$, it can be seen that when the alcohol: marijuana relative price is held constant, beer consumption is 2.4 per cent higher than actual in 1998, wine 4.9 per cent higher, spirits 9.8 per cent higher, and marijuana consumption is 10.4 per cent lower. While these differences are not huge, they are still far from trivial and demonstrate clearly the interrelationships between alcohol and marijuana prices.[15]

6. Concluding comments

The present paper has identified a substantial decline in the relative price of marijuana over the 1990s, discussed the possible causes and analysed some of the implications. We also investigated some regional dimensions of the market for marijuana. Rather than reiterating the findings, we comment briefly on some of their broader implications:

1. By their very nature, illicit goods and services are excluded from official statistics. If the prices of other illicit activities have fallen as much as that of marijuana, the CPI will be overstated, and real incomes and productivity measures will be understated.
2. Further studies of illicit sectors of the economy could be rewarding in understanding how incentives operate to encourage the adoption of new technology. This may provide some guidance regarding appropriate policies to boost productivity in legal activities and in the identification of impediments to the introduction of technological improvements.

[15] Note that it follows from equations (3) and (4) that the elements of table 14 are also interpreted as $D\hat{q}_i - Dq_i$, the difference between log ($\hat{q}_{iT}/q_{il}$) and log (q_{iT}/q_{il}). Accordingly, we can compute $D\hat{q}_i$ by simply adding the relevant entry in table 14 to Dq_i.

3. Our analysis indicates that the lower price of marijuana is likely to have reduced consumption of a substitute product, alcohol. In some scenarios this reduction is substantial. Producers of beer, wine and spirits might therefore be tempted to argue that on the basis of considerations of competitive neutrality, marijuana production should be legalised and subject to the same hefty taxes as they are.
4. Suppose marijuana were legalised and its production taxed. Who would bear most of the burden of this tax – growers or consumers? In view of the apparent ease with which marijuana can now be grown with hydroponic techniques and because demand is almost surely price inelastic, it would be consumers who would bear the bulk of the incidence of the tax, not growers. In such a case, maybe the incentives for growers to continue to innovate would remain more or less unchanged in a legalised regime.

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