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Marijuana and Youth

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A recent report sponsored by the National Institute on Drug Abuse and the National Institute on Alcohol Abuse and Alcoholism suggests that illicit drug use in America costs society approximately $98 billion each year (NIDA/NIAAA 1998). Adults alone do not generate these costs. Statistics from the National Household Survey on Drug Abuse (NHSDA) show that current use of illicit drugs among youths (twelve to seventeen years of age) doubled from a historic low in 1992 of 5.3 percent to 11.4 percent in 1997 before falling to 9.9 percent in 1998 (SAMHSA 1999). Data from the Monitoring the Future (MTF) study yielded even higher estimates of use and a similar sharp increase in that period (Johnston, O'Malley, and Bachman 1999). Even more disturbing, however, is the finding that, of an estimated 4.1 million people who met DSM-IV diagnostic criteria (APA

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1994) for dependence on illicit drugs in 1998, 1.1 million (26.8 percent) are youths between the ages of twelve and seventeen (SAMHSA 1999).

Marijuana is by far the most commonly used illicit substance among adolescents and has been so for the past twenty-five years.[1] Figure 6.1 shows historical data on annual alcohol, marijuana, and other illicit drug use from the MTF survey of high school seniors, one of the main national studies used to track youth substance use and abuse. The prevalence of marijuana has consistently been about half that of alcohol, far greater than the overall proportion using any of the other illicit drugs (Johnston, O'Malley, and Bachman 1999). When the other illicit drugs are broken down by type of substance (fig. 6.2), it is easy to see that no other single substance has been even half as prevalent as marijuana during the period 1975–98.

The sheer popularity of marijuana among youths makes it an interesting illicit substance to examine. However, there are other factors that motivate a closer examination of the demand for marijuana by youths. First, early marijuana use has been associated with a wide range of antisocial and dangerous behaviors, including driving under the influence, dropping out of school, engaging in crime, and destruction of property (Brook, Balka, and Whiteman 1999; SAMHSA 1998a, 1998b; Yamada, Kendix, and Yamada 1996; Spunt et al. 1994; Osgood et al. 1988). Second, there is increasing evidence that marijuana is an addictive substance and that regular use can result in dependence (DeFonseca et al. 1997; SAMHSA 1998a). Third, regular marijuana use has been associated with a number of health problems, particularly among youths, including upper-respiratory problems (Polen et al. 1993; Tashkin et al. 1990) and reproductive-system problems (Nahas and Latour 1992; Tommasello 1982). Finally, it is widely believed that marijuana is a gateway substance or that early involvement with marijuana can increase the likelihood of later use of "harder drugs." Although there is no clear evidence of a causal link between early marijuana use and subsequent illicit drug use, there is significant evidence of a strong correlation and that early marijuana use is an antecedent (Kandel

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1. Although alcohol is an illegal substance for teenagers, we use the term *illicit substance* to refer to those substances that are illegal for persons of all ages.

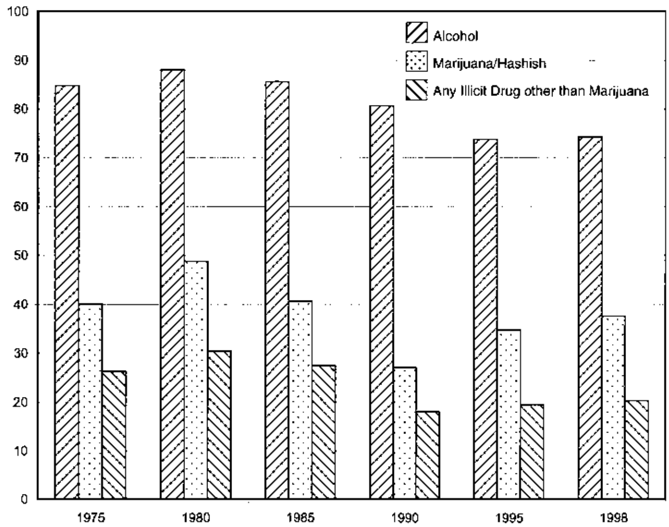

Fig. 6.1 Annual marijuana use relative to other substance use, MTF

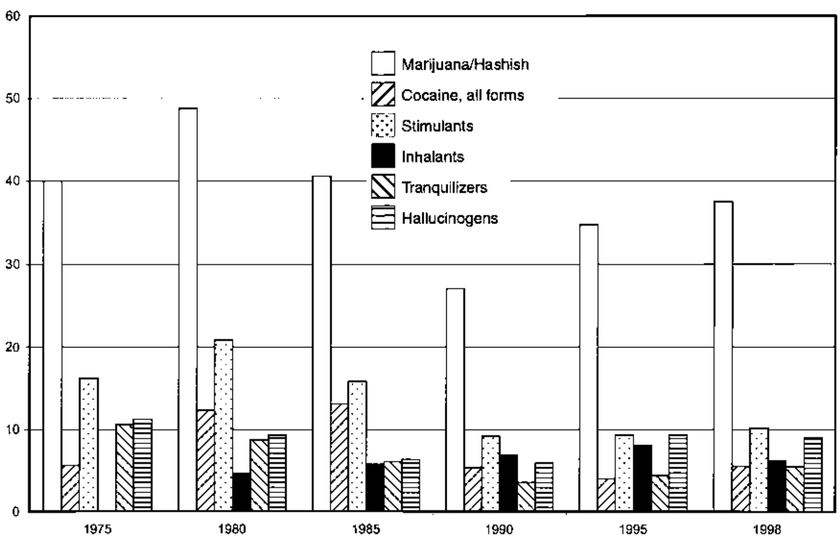

Fig. 6.2 Annual marijuana use relative to other illicit drugs, MTF

1975; Kandel, Kessler, and Margulies 1978; Ellickson, Hays, and Bell 1992; Brook, Balka, and Whiteman 1999; Ellickson and Morton, in press).

In this chapter, we explore the demand for marijuana among a nationally representative sample of American high school seniors from the MTF survey. Our main contribution is to present the first set of estimates of the price sensitivity of the prevalence of youth marijuana use. A related contribution is to assess the extent to which trends in price predict the reduction in marijuana use in the 1980s and early 1990s and the increase in use since 1992. In section 6.1, we discuss in greater detail the magnitude of the problem, presenting summary statistics of the prevalence of marijuana use and how it has changed over time. We also discuss what is currently known about the short- and long-run implications of regular and heavy marijuana use. In section 6.2, we provide a brief summary of the literature on the contemporaneous and intertemporal demand for marijuana. In section 6.3, we present findings from a new time-series analysis of the demand for marijuana by youths using data from the 1982–98 MTF survey of high school seniors. The purpose of this section is to identify factors that are significantly correlated with the trend in marijuana use over time. In section 6.4, we reexamine the importance of these factors in repeated cross-sectional analyses of the 1985–96 Monitoring the Future surveys.

6.1 Youth Marijuana Use: The Scope of the Problem

As is indicated in figure 6.2 above, marijuana is the most popular illicit substance among youths and has been for at least the past twenty-five years. Its use, however, has fluctuated quite a bit. Figure 6.3 shows lifetime, annual, and thirty-day prevalence of marijuana use among high school seniors in the MTF study from 1975 to 1998. In the late 1970s and early 1980s, marijuana use was at its peak. In 1978, 37.1 percent of American high school seniors reported using marijuana in the previous thirty days. Annual prevalence of marijuana use was 50.2 percent, and lifetime prevalence was 59.2 percent. Annual and lifetime prevalence continued to climb over the next year, although thirty-day prevalence started to decline. From 1981 to 1992, marijuana use among high school seniors was declining across all measures of use. By 1992, youth marijuana use was at an all-time record low, with 11.9 percent of high school seniors reporting use of marijuana in the previous thirty days, 21.9 percent reporting use in the past year, and 32.6 percent reporting use in their lifetime. After 1992, the trend changed, and marijuana use again began to rise. By 1997, thirty-day prevalence rates were back up to 23.7 percent, and annual and lifetime prevalence rates were 38.5 percent and 49.6 percent, respectively. The 1998 data from the MTF survey suggest that the upward trend may be leveling off. In that year, 22.8 percent of high school seniors reported use of marijuana in the past thirty days, while 37.5 percent reported using in the past year, and 49.1 percent reported using in their lifetime.

Although current prevalence estimates are still well below their peak in the late 1970s, the recent upward trend in marijuana use among youths is disturbing for a number of reasons. First, the increase can be seen across

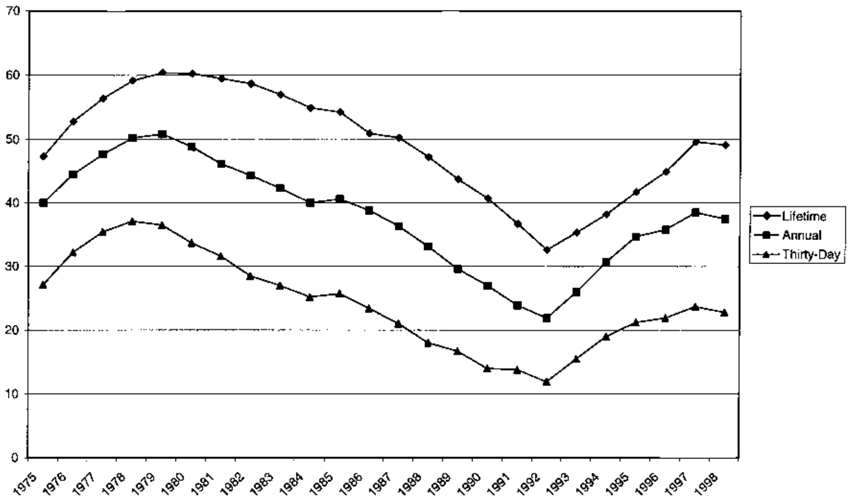

Fig. 6.3 Lifetime, annual, and thirty-day marijuana prevalence, MTF high school seniors

both genders and all ethnic groups, suggesting that this is not a trend being driven by a small subgroup of the youth population (Johnston et al. 1999; SAMHSA 1996). Second, the average age of first marijuana use has been declining during this period, with an average age of initiation of 17.7 in 1992 and 16.4 in 1996 (ONDCP 1999).

Finally, we may not yet really understand all the factors that led to the recent increase in marijuana use or, for that matter, the decline that occurred during the 1980s. Some factors, such as perceived harm, disapproval, and availability of marijuana, have been shown to be significantly correlated with marijuana use over time (Bachman, Johnston, and O'Malley 1998; Caulkins 1999; Johnston et al. 1999). Johnston and his colleagues (Johnston et al. 1999; Johnston 1991) have offered several explanations for why perceived harm, in particular, may have changed in the ways in which it did. These include increased media attention to the consequences of marijuana use beginning in the late 1970s; the large number of heavy users found in most schools by the late 1970s, affording peers the opportunity to directly observe the consequences of their drug use; and the active containment efforts by many sectors of society during the 1980s that included the antidrug advertising campaigns of the mid- to late 1980s. Similarly, for the upturn in the 1990s, Johnston and his colleagues hypothesize that several of the factors that may have contributed to the decline in the 1980s were reversed, including reduced attention from the national media beginning with the buildup to the Gulf War in 1991 and continuing afterward, reduced rates of use among peers providing fewer opportunities for vicarious learning in the immediate social environment, sizable cuts in federal funding for drug-prevention programs in schools in the early 1990s, and the substantial decline in the media placement of the national antidrug advertising campaign of the Partnership for a Drug Free America. In addition, they point to the increased glamorization of drug use in the lyrics, performances, and offstage behavior of many rock, grunge, and rap groups as a factor likely to have contributed to the rise in youth drug use in the 1990s.

To the extent that there is some degree of covariation among the various substances in their intertemporal trends (see fig. 6.4), there may be some common determinants of their use. This covariation was perhaps most apparent during the 1990s, when nearly all forms of licit and illicit drug use rose to some degree among high school seniors. However, there are enough differences among their cross-time usage profiles to conclude that there are also unique factors influencing their use (Johnston et al. 1999). Price, for example, is a logical candidate.

Unlike alcohol, cigarettes, or cocaine, for which the harmful consequences of youth use have been clearly established, there is tremendous uncertainty regarding the short- and long-term consequences of youth marijuana use. This uncertainty has led some to question why we should even be concerned that marijuana use is on the rise. Most regular or heavy marijuana users also use alcohol or other substances regularly, so it is difficult to identify a causal link between particular negative consequences and regular marijuana use. Nonetheless, two reports commissioned by the National Institute on Drug Abuse in the United States and the National Task

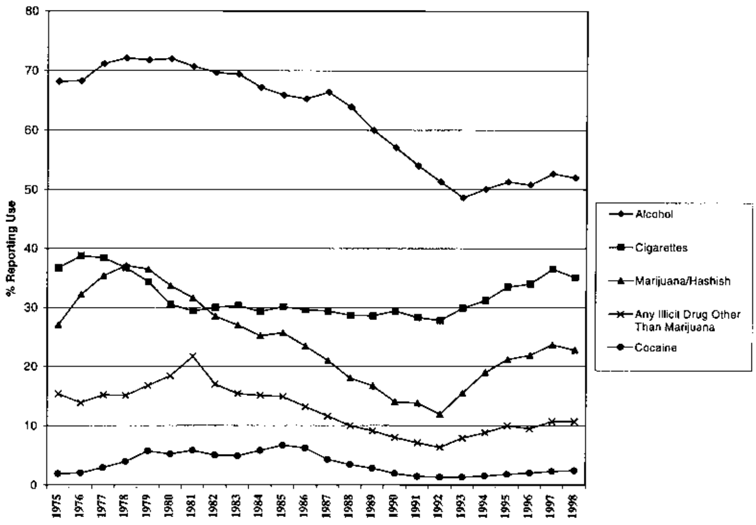

Fig. 6.4 Trends in thirty-day prevalence, MTF

Force on Cannabis in Australia review the existing scientific literature and identify several psychological and health effects that can be generally attributed to regular and/or chronic marijuana use and that can lead to negative outcomes, particularly among youths (NIDA 1995; Hall, Solowij, and Lemmon 1994). These areas include diminished cognitive functioning, diminished psychomotor performance, increased health-services utilization, and the development of dependence. In addition, both reviews cite the significant correlation between early marijuana use and subsequent harder drug use as a further reason to be concerned about the use of marijuana among youths.

6.1.1 Diminished Cognitive Functioning

One of the major reasons for the widespread recreational use of marijuana is that it produces a high associated with mild euphoria, relaxation, and perceptual alterations. Cognitive changes also occur during the high, including impaired short-term memory and a loosening of associations, which makes it possible for the user to become lost in pleasant reverie and fantasy. Recent studies have identified that this diminished cognitive functioning can be attributed to the presence of cannabinoid receptor sites in the areas of the brain that control memory (Matsuda, Bonner, and Lolait 1993; Heyser, Hampson, and Deadwyler 1993). Activation of these receptors interrupts normal brain motor and cognitive function, thus affecting attention, concentration, and short-term memory during the period of intoxication.

It is this negative effect on concentration, attention, and short-term memory that has led many to conclude that marijuana use diminishes human-capital formation for youths. Indeed, research shows that there is a significant contemporaneous correlation between marijuana use and poor grades and dropping out of school (Bachman, Johnston, and O'Malley 1998; Mensch and Kandel 1988; Yamada, Kendix, and Yamada 1996). However, findings from longitudinal studies suggest that these negative associations disappear when other factors, such as lower education aspirations, academic performance, and problem behavior, are controlled for (Ellickson et al. 1998; Newcombe and Bentler 1988; Kandel et al. 1986). One longitudinal study found the negative association to persist after controls were included for motivational factors, but it persisted for only one population subgroup: Latinos (Ellickson et al. 1998). Marijuana use remained insignificant for the general sample of young adults and for the other ethnic subgroups.

There are several shortcomings in these studies that make the interpretation of their findings suspect. In particular, early use of alcohol, cigarettes, and marijuana is consistently treated as an exogenous variable. Only one study to date explicitly tests this assumption, but it does so using a different measure of marijuana use than that typically examined by other studies. In a longitudinal analysis of the relation between marijuana initiation and dropping out of high school, Bray et al. (2000) examine the effect of initiating marijuana use by ages sixteen, seventeen, and eighteen on the likelihood of dropping out of school. They find that marijuana initiation is positively related to dropping out of high school, although the magnitude and significance of the relation varies with the age at which the individual drops out and with the other substances used. They test the possible endogeneity of marijuana initiation and find that they cannot reject exogeneity. However, because their measure does not distinguish new experimenters from regular or long-time users, their finding of exogeneity should not be generalized.

6.1.2 Diminished Psychomotor Performance

It is clear that marijuana use impairs judgment and motor skills by distorting perceptions of space and time. The extent of the impairment, of course, is largely determined by the inhaled or ingested dose, as in the case of alcohol. The question then becomes to what extent the impaired performance translates into accidental injury to the users or those around them. Much of the research in this area has focused on automobile accidents and fatalities. Epidemiological studies that try to identify an association between THC level and crashes and/or fatalities are problematic for two reasons. First, the vast majority of individuals involved in accidents test positive for alcohol use as well. One recent review of the epidemiology literature showed that, although 4–12 percent of drivers who sustained injury or death in crashes tested positive for THC, at least 50 percent, and in some cases 90 percent, of the drivers also tested positive for alcohol (Robbe and O'Hanlon 1999).[2] There have been relatively few studies that contain large enough samples of non-alcohol-impaired drivers to examine this issue. One study of drivers arrested for reckless driving who were not alcohol impaired did find that half these individuals tested positive for marijuana (Brookoff et al. 1994). A second problem with these studies, however, is that a positive test for marijuana does not necessarily mean that the individual was under the influence at the time of the accident. THC stays in the bloodstream much longer than other intoxicants, so a positive test may simply indicate recent use.

Experimental studies that use driving simulators and closed-course driving environments try to overcome these problems. In a review of this literature, Smiley (1986) concludes that, although drivers under the influence of marijuana are more likely to make errors (such as leaving their lane), they also drive more slowly than sober drivers and keep a greater distance from the car in front of them. Drunk drivers, on the other hand, are more likely

2. The authors note that higher values have been found among certain high-risk populations, such as young men and people living in large cities.

to increase their speed, which perhaps explains the comparatively smaller number of marijuana-related accidents on the road.

The preceding conclusion continues to be supported in more recent studies (e.g., Robbe and O'Hanlon 1993) and is consistent with findings from a recent econometric study using reduced-form equations to examine the relation between alcohol and marijuana use and the probability of nonfatal and fatal accidents among youths (Chaloupka and Laixuthai 1997). Using self-reported information on nonfatal accidents in the MTF survey, Chaloupka and Laixuthai (1997) find that a reduction in marijuana prices (which they show reduces youth drinking and presumably increases youth marijuana use) leads to a significant drop in the probability of a nonfatal motor-vehicle accident. They interpret this net negative effect as evidence that the substitution of marijuana for alcohol generates an increase in the probability of a nonfatal accident that is smaller than the decrease associated with the decline in drinking and driving. They draw a similar conclusion, using data from the Fatal Accident Reporting System, when examining the effects of marijuana decriminalization on the probability of a fatal motor-vehicle accident among youths. So, although there is significant evidence suggesting that marijuana intoxication leads to an increased risk of motor-vehicle accidents, the risk is not believed to be anywhere near as large as the risk associated with drinking and driving.

6.1.3 Increased Health-Services Utilization

There is increasing, albeit controversial, evidence that regular marijuana use is associated with upper-respiratory problems, such as chronic bronchitis, inflamed sinuses, and frequent chest colds (Nahas and Latour 1992; Tashkin et al. 1990), and reproductive-system problems, such as reduced sperm production and delay of puberty (Nahas and Latour 1992; Tommasello 1982). A significant problem in identifying the health effects associated with marijuana use is that the vast majority of marijuana users also use other substances, particularly alcohol and cigarettes. It is difficult, therefore, to identify whether particular substances or certain combinations generate specific health outcomes. Two approaches have been generally used to try to tease out the relation. The first approach relies on individual-level data where there is a high incidence of marijuana users who do not use other substances. For example, Polen et al. (1993) were able to identify 452 Kaiser Permanente enrollees who were daily marijuana smokers who never smoked tobacco. They compared the health-service utilization among these daily marijuana-only smokers to nonsmokers with similar demographics screened at Kaiser Permanente medical centers between July 1979 and December 1985. They examined medical-care utilization for a number of health-specific outcomes over a one- to two-year follow-up and found that marijuana smokers have a 19 percent increased risk of outpatient visits for respiratory illnesses, a 32 percent increased risk of injury, and a 9 percent increased risk of other illnesses and were 50 percent more likely to be admitted to the hospital than were nonsmokers. These results were adjusted for sex, age, race, education, marital status, and alcohol consumption.

The second approach to understanding the relation between marijuana use and health has focused on examining the correlation between general consumption rates and health-care utilization. For example, Model (1993) examined the effect of marijuana decriminalization status on the incidence of marijuana-related hospital-emergency-room episodes using data from the 1975–78 Drug Abuse Warning Network (DAWN). During the mid-1970s, several states chose to decriminalize possession of small amounts of marijuana, thus reducing the penalties associated with using it. Model (1993) found that states that had chosen to decriminalize experienced significantly higher rates of marijuana-related emergency-room episodes.

Although both approaches clearly establish a positive association between marijuana use and health-service utilization, they have yet to demonstrate a direct link between marijuana use and particular health outcomes or illnesses.

6.1.4 Development of Dependence

Until the late 1970s and early 1980s, the general-consensus opinion regarding marijuana was that it was not a drug of dependence because marijuana users did not exhibit tolerance and withdrawal symptoms analogous to those seen in alcohol and opiate dependence. In the late 1970s, however, expert opinion regarding marijuana dependence began to change as a new, more liberal definition of *drug dependence,* embodied in Edwards and Gross's (1976) alcohol-dependence syndrome, was extended to all psychoactive drugs (Edwards, Arif, and Hadgson 1981). This new definition reduced the emphasis on tolerance and withdrawal and attached greater emphasis on the continued use of the drug in the face of its adverse effects. It is this new conception of dependence that is reflected in DSM-III-R and DSM-IV, the third revised and fourth editions of the *Diagnostic and Statistical Manual* of the American Psychiatric Association (APA 1987, 1994). A diagnosis of psychoactive-substance dependence is made if any three of nine criteria are present for a month or longer. It is therefore not necessary that a person exhibit physical dependence on a drug for her to be diagnosed as dependent (Hall, Solowij, and Lemmon 1994).

Studies employing these new criteria for marijuana dependence have determined that marijuana-dependence syndrome occurs much more frequently than previously believed. According to data from the 1993 National Comorbidity Study, 9 percent of those who reported trying marijuana reported dependence at some stage (Anthony, Warner, and Kessler 1994). Data from the Epidemiologic Catchment Area study found that half those classified as having experienced drug dependence in their lifetime reported using only marijuana, suggesting that marijuana users constitute a substantial fraction of all those dependent on illicit drugs (Anthony and Helzer 1991).

Although tolerance and withdrawal symptoms are not required within the DSM-III-R and DSM-IV definitions, there is evidence that both can occur for chronic heavy cannabis users (Jones and Benowitz 1976; Georgotas and Zeidenberg 1979; Weller and Halikas 1982). There is also clinical and epidemiological evidence that some heavy marijuana users experience problems controlling their use despite the experience of adverse personal consequences (Stephens and Roffman 1993; Kandel and Davies 1992; Jones 1984). However, many researchers note that the physical withdrawal symptoms for those suffering from a physical dependence on marijuana are minor and typically pass within a few days if they are experienced at all (Jones 1987, 1992; Compton, Dewey, and Martin 1990).

Given that the predominant social pattern of marijuana use is recreational and/or the intermittent use of relatively low doses of THC, the actual risk of developing a dependence syndrome is relatively small for most individuals using marijuana. Further, assuming that the physical-withdrawal symptoms are truly minor, marijuana dependence would be fairly easy to treat. However, the addictive nature of marijuana is clearly underestimated by most individuals who decide to use the drug.

6.1.5 Marijuana as a Gateway Drug

The importance of marijuana as a gateway drug remains highly controversial, despite tremendous evidence of a correlation between early marijuana use and later hard drug use. The finding that marijuana use precedes harder drug use and that this sequencing persists across youths of different gender, race, and ethnicity is well established (Kandel 1975; Kandel, Kessler, and Margulies 1978; Ellickson, Hays, and Bell 1992; Kandel, Yamaguchi, and Chen 1992; Ellickson and Morton, in press). However, the proper interpretation of this consistent finding remains debatable. Temporal precedence and statistical correlation are only necessary conditions for establishing causality, not sufficient conditions. It might very well be the case that this consistent finding in the literature is the result of a spurious correlation driven by other individual factors or problem behaviors, such as truancy, poor grades, and delinquency. Debate ensues regarding the plausibility of alternative proposed causal mechanisms. These mechanisms can be grouped into two general categories: physiological and sociological factors.

The physiological arguments are based on findings from two recent papers in *Science* that demonstrate that cannabis activates neurochemical processes in rats that respond in a qualitatively similar way to cocaine, heroin, tobacco, and alcohol (DeFonseca et al. 1997; Tanda, Pontieri, and DiChiara 1997). These findings support the argument that favorable experimentation with and regular consumption of marijuana will make youths more receptive to experimenting with other types of intoxicants, particularly those that offer similar psychological effects. However, neither study actually examined the relation between rats' cannabis consumption and their consumption of harder drugs or their motivation to use these drugs, so their findings cannot be interpreted as definitive proof of causality.

Sociological arguments generally tend to focus on the information that is learned when experimenting with marijuana (Kaplan 1970; MacCoun, Reuter, and Schelling 1996). For example, it may be the case that seemingly safe experiences with marijuana might reduce the adolescent's perceptions regarding the perceived harmfulness, in terms of both legal risks and health risks, of using harder drugs. Alternatively, exposure to the marijuana marketplace may bring casual marijuana users into contact with hard-drug sellers, again influencing their perceptions regarding the legal risks of using illicit drugs. It was this latter argument that persuaded the Dutch to separate the soft- and hard-drug markets by permitting low-level cannabis sales in coffee shops and nightclubs (Ministry of Foreign Affairs 1995).

Despite the numerous theories that propose specific causal mechanisms for this observed sequencing, very little empirical work has been done trying to verify the existence of a causal mechanism. At least one published study reports a structural relation between prior marijuana use and current demand for cocaine, although it does not attempt to identify the causal mechanism (DeSimone 1998). Using data from the 1988 National Longitudinal Survey of Youth (NLSY), DeSimone (1998) estimates the current demand for cocaine as a function of past marijuana use (use reported in the 1984 survey) and current values of other correlates of cocaine demand using a sample of individuals who had not previously used cocaine. A two-stage instrumental-variables approach is used to account for the potential correlation between past marijuana use and the current-period error term. Instruments for the past use of marijuana included two measures of state-level penalties for marijuana possession, the beer tax, and an indicator of parents' alcoholism or problem drinking. Estimates from this model suggest that prior use of marijuana increases the probability of using cocaine by more than 29 percent, even after one controls for unobserved individual characteristics, providing the strongest evidence that the observed sequencing in use is not being driven by a spurious correlation between demand equations.

As the discussion above demonstrates, regular and/or heavy marijuana use is associated with a number of negative short- and long-term consequences, including reduced education attainment, increased risk of accidents, increased use of health-care services, increased risk of dependence, and a possible increased risk of the use of harder substances. The problem is that the literature exploring a causal link between marijuana and these potential consequences is still relatively sparse and much remains to be explored.

6.2 The Demand for Marijuana by Youths: Key Insights from the Literature

Few economic studies analyzing the determinants of marijuana demand were conducted prior to the 1990s because of the limited information available on the price of marijuana. Nonetheless, a significant literature developed thanks to the work of epidemiologists and other social scientists who were interested in exploring other correlates and causes of marijuana use. Most of these studies examine how individual and environmental characteristics, lifestyle factors (grades, truancy, religious commitment, evenings out for recreation), and proximate factors (perceptions and attitudes about marijuana) correlate with current use of marijuana among adolescents.

It is not surprising that a key finding from this literature is that the same general background and lifestyle factors that are significantly correlated with the early use of alcohol and other drugs are also correlated with marijuana use. Although gender and ethnicity are consistently significantly correlated with marijuana use, with men being significantly more likely to use marijuana than women and blacks being much less likely to use marijuana than whites, they are not viewed as leading determinants of marijuana use. Instead, truancy, frequent evenings away from home for recreation, low religiosity, and low perceived harmfulness or disapproval (Bachman et al. 1988; Bachman, Johnston, and O'Malley 1981; Jessor, Chase, and Donovan 1980) are considered to be the most significant correlates of marijuana use. Part-time employment and income are considered to be more moderate correlates, with youths who report working more hours per week and higher incomes being more likely to use marijuana (Bachman et al. 1988; Bachman, Johnston, and O'Malley 1981). Social factors, such as use by peers or family members and reduced family attachment, are also significantly correlated with marijuana use (Brook, Cohen, and Jaeger 1998; Kandel 1985; Jessor, Chase, and Donovan 1980).

Nisbet and Vakil (1972) contributed the first economic study to this literature. They used a self-administered survey of 926 University of California, Los Angeles, students in an effort to obtain information on the price of marijuana in addition to the quantity of marijuana consumed. Students were asked how many ounces of marijuana they purchased at current prices as well as how much they would buy if faced with alternative hypothetical price changes. Two alternative functional forms of very basic demand curves were estimated that included measures of the quantity of marijuana consumed in a month, the price per ounce, mean monthly total expenditures, and an expenditure-dispersion measure. Price was found to be a significant determinant of quantity consumed. Estimates of the price elasticity of demand ranged from −0.40 to −1.51 when information on hypothetical prices was included. When the data were restricted to just actual purchase data, the price elasticity of demand fell into a narrower range of −1.01 to −1.51.

The Nisbet and Vakil (1972) study provides us with the only published price elasticity of demand for marijuana. However, the findings from this study cannot be generalized because they are based on a very small convenience sample of college students, do not account for other important demand factors, and employ data that are almost thirty years old. In addition, the estimated price elasticities are likely to be overstated in absolute value because students who consume relatively large amounts of marijuana have incentives to search for lower prices.[3]

More recent studies by economists and other researchers that use nationally representative samples and include other demand factors lack information on the money price of marijuana. Most try to overcome this data shortcoming by focusing on other aspects of the full price of this substance. For example, several studies use cross-state variation in marijuana decriminalization status to examine the effect of reduced legal sanctions on the demand for marijuana. The findings with respect to the effect of decriminalization on the use of marijuana by youths and young adults are generally mixed. Early studies focusing on youth populations generally found that decriminalization had no significant effect on demand. For example, Johnston, O'Malley, and Bachman (1981) compared changes in marijuana use in decriminalized states to that in nondecriminalized states using data from the MTF survey of high school seniors and found no significant difference.

DiNardo and Lemieux (1992) came to a similar conclusion using state-level aggregated data from the 1980–89 MTF survey. They estimated log-linear and bivariate probit models of the likelihood of using alcohol and marijuana. In addition to including marijuana-decriminalization status, they included a regional price of alcohol and the minimum legal purchase age for beer in all specifications. They found that the marijuana-decriminalization variable had no significant effect on marijuana use. Thies and Register (1993) similarly found no significant effect of marijuana decriminalization on the demand for marijuana among a sample of young adults from the 1984 and 1988 NLSY. They estimated logit and tobit specifications of the demand for marijuana, binge drinking, and cocaine and included cross-price effects in all the regressions. Pacula (1998b) also found no significant effect of marijuana decriminalization in her two-part

3. The estimated price elasticities reported in secs. 6.3 and 6.4 below are not subject to this bias because they employ prevailing market prices rather than prices paid by individual consumers.

model specification of the demand for marijuana using data from the 1984 NLSY.

Two recent studies using youth samples from the MTF study and including information on the median fines imposed for possession of marijuana have found a positive effect of decriminalization on marijuana use. Chaloupka, Grossman, and Tauras (1999) used data from the 1982 and 1989 MTF to estimate annual and thirty-day prevalence of marijuana and cocaine use among high school seniors. Their models included measures of the median fines for possession of marijuana and showed that individuals living in decriminalized states were significantly more likely to report use of marijuana in the past year. They found no significant effect on thirty-day prevalence, however. In a separate study examining the relation between the demand for cigarettes and the demand for marijuana, Chaloupka, Pacula, et al. (1999) used data from the 1992–94 eighth-, tenth-, and twelfth-grade surveys to estimate a two-part model of the current demand for cigarettes and marijuana. They found that marijuana decriminalization had a positive and significant effect on both the prevalence and the quantity consumed of marijuana when median jail terms and fines were also included in the model.

Studies employing data on the overall population have generated more consistent findings with respect to the effects of marijuana decriminalization on the consumption of marijuana. For example, Model (1993) analyzed the effect of marijuana decriminalization on drug mentions in hospital-emergency-room episodes using data from the 1975–78 DAWN. Although she did not directly estimate demand functions for marijuana, results from multiple variants of her model consistently showed that cities in states that had decriminalized marijuana experienced higher marijuana emergency-room mentions and lower other drug mentions than nondecriminalized cities. Saffer and Chaloupka (1999) estimated individual-level prevalence equations for past-year and past-month use of marijuana, alcohol, cocaine, and heroin using data from the 1988, 1990, and 1991 NHSDA. They found that marijuana decriminalization had a positive and significant effect on marijuana prevalence, supporting the conclusion made by Model that individuals in the general population are responsive to changes in the legal treatment of illicit drugs.

Studies examining other components of the legal risk of using marijuana, such as fines for possession and marijuana arrest rates, have generated similarly mixed findings in terms of youth responsiveness. For example, using different samples from the MTF, Chaloupka, Grossman, and Tauras (1999) and Chaloupka, Pacula, et al. (1999) both found that youths were responsive to median fines for possession of marijuana. However, using individual-level data from the 1990–96 NHSDA to estimate state fixed-effects models of the prevalence of marijuana and cigarette use, Farrelly et al. (1999) found that higher median fines for possession of marijuana had no significant effect on youths between the ages of twelve and twenty. They did find a statistically significant effect on young adults between the ages of twenty-one and thirty. They further found that young adults, but not youths, were responsive to marijuana arrest rates. Individuals living in areas where marijuana arrests were a higher fraction of total arrests were significantly less likely to use marijuana.

Pacula (1998a) provided further evidence that young adults are sensitive to general enforcement risk, using data from the 1983 and 1984 NLSY. In her models of the intertemporal demand for alcohol and marijuana, she used a measure comparing common crime to the number of police officers at the SMSA (standard metropolitan statistical area) level as an indicator of the enforcement risk of using marijuana. She found that higher crime-per-officer ratios were associated with increased use of marijuana for young adults.

Unlike the economic literature on the demand for other intoxicating substances, in which the focus of the research has been on estimating the own-price elasticity of demand, much of the economic literature on the demand for marijuana has focused on analyzing cross-price effects because of the unavailability of marijuana-price data. The goal of this research has been to determine whether marijuana is an economic substitute for or complement to other substances that are believed to have more harmful consequences associated with use. The findings with respect to the relation between marijuana and cigarettes have been consistent so far. Higher cigarette prices lead to lower cigarette and marijuana use among youths and young adults (Chaloupka, Pacula, et al. 1999; Farrelly et al. 1999).

Findings are mixed, however, when it comes to other substances. Initial research on the relation between the demand for alcohol and the demand for marijuana suggested that these two goods were economic substitutes for youths. Using aggregated data from the MTF, DiNardo and Lemieux (1992) found that higher minimum legal purchase ages reduced alcohol consumption and increased marijuana consumption over time. They further found that individuals living in decriminalized states were significantly less likely to use alcohol, which they interpreted as evidence of a substitution effect even though decriminalization did not statistically influence marijuana consumption. Using individual-level data from the 1982 and 1989 MTF, Chaloupka and Laixuthai (1997) similarly found evidence of a substitution effect between alcohol and marijuana. They estimated ordered and dichotomous probits of drinking frequency and found that marijuana decriminalization had a consistent negative effect. In restricted models that incorporated information on marijuana prices, they further found that higher marijuana prices were generally associated with an increased likelihood of drinking and drinking heavily.

Subsequent research that analyzes individual-level demand equations for marijuana has raised some doubt of a substitution effect. In both her contemporaneous and her intertemporal demand models using the 1984 NLSY, Pacula (1998a, 1998b) finds that higher beer prices are associated with reduced levels of drinking and marijuana use. She interprets this as evidence of a complementary relation between alcohol and marijuana. Farrelly et al. (1999) similarly find that higher beer taxes reduce the probability of currently using marijuana among their sample of twelve- to twenty-year-olds from the 1990–96 NHSDA. However, they also find that higher beer taxes have no significant effect on the demand for marijuana among their young-adult sample (ages twenty-one to thirty). The finding of no significant effect among older populations is consistent with what was found by Saffer and Chaloupka (1999) when they estimated annual and thirty-day prevalence of marijuana use using the 1988, 1990, and 1991 NHSDA.

Although Model's (1993) research examining emergency-room episodes suggests that marijuana is an economic substitute for other illicit substances in general, studies that actually estimate individual-level demand equations generate mixed findings with respect to cross-price effects for specific substances. Saffer and Chaloupka (1999) find that higher cocaine prices are associated with reduced marijuana participation in the past month and the past year while marijuana decriminalization is generally associated with increased cocaine consumption, suggesting that these two goods are economic complements. The findings regarding marijuana and heroin, however, are more mixed. Higher heroin prices are found generally to reduce marijuana participation, although the findings are sensitive to other prices included in the model. Marijuana decriminalization, on the other hand, has no significant effect on heroin participation.

Of course, a major concern in trying to interpret the findings from all these studies is the fact that all but one (Chaloupka and Laixuthai 1997) exclude a measure for the monetary price of marijuana. Thus, it is difficult to know whether the estimates from these models are biased and, if so, in what direction.

Most of the research just reviewed focuses on determinants of the contemporaneous demand for marijuana. Research examining changes in the trend of marijuana use over time suggests that significant predictors of contemporaneous demand cannot account for the change that we have seen in demand over time (Bachman, Johnston, and O'Malley 1998; Bachman et al. 1988). Using data from the 1976–86 MTF survey of high school seniors, Bachman et al. (1988) use multivariate analysis to examine the influence of lifestyle factors (grades, truancy, hours worked per week, weekly income, religious commitment, political conservatism, and evenings out per week), attitudes (perceived harmfulness and disapproval of regular marijuana use), and secular trends (mean marijuana use among high school seniors for that year) on variation in individual use of marijuana over time. They find that attitudinal measures are by far the most powerful predictors of change. When attitudinal measures are included in the regression, the influence of the secular trend becomes insignificant, suggesting that the secular trend can be entirely explained by measures of perceived risk or disapproval. Similarly, the influence of lifestyle factors as a group diminishes with the inclusion of the attitudinal variables, although some factors, such as truancy and evenings out, continue to have large effects. The fact that lifestyle factors alone could not diminish the influence of the secular trend on individual marijuana use suggests that attitudes and not lifestyle factors are more important in determining trends in marijuana use over time.

In a follow-up study that expanded the previous research by examining a longer time period and replicated the analysis on eighth and tenth graders, Bachman, Johnston, and O'Malley (1998) reaffirm their previous findings. Using data from the period 1976–96, they again find evidence that the influence of lifestyle variables on marijuana use occurs primarily through disapproval and perceived risk. Further, they also find that the secular trends in marijuana use can be completely explained by changes in attitudes over time.

In the light of these findings and the fact that self-reported perceived availability did not change significantly during the periods being examined, Bachman, Johnston, and O'Malley (1998) concluded that supply reduction has limited potential to influence use over time and that the focus of government efforts should be on trying to influence perceived harm and disapproval. Caulkins (1999) challenged this conclusion by arguing that the MTF indicator of availability may not be properly calibrated to detect significant changes in perceived availability. He showed that there is indeed a strong negative correlation between median national marijuana prices and high school seniors' self-reported use between 1981 and 1997. Depending on the measure of use, Caulkins found a correlation coefficient between -0.79 and -0.95, which overlaps with the simple correlation coefficients obtained between participation and perceived harm. Although this is not definitive evidence that supply factors substantially influence marijuana use by youths over time, Caulkins argued that it suggests that further analyses exploring the relative importance of supply factors over time are needed. We conduct such analyses in the remainder of this paper.

6.3 Time-Series Analysis

In this section, we focus on national trends in marijuana participation in the past year (annual participation) and in the past thirty days (thirty-day participation) by MTF high school seniors for the period from 1982 through 1998. We relate these trends to trends in the real price of marijuana, the purity of marijuana as measured by its delta-9-tetrahydro-cannabinol (THC) potency, and the perceived risk of great harm from regular marijuana use as reported by the MTF seniors.[4] Included are multiple regressions of past-year or past-month participation on the three variables just mentioned and a time trend. We begin with data for 1982 because that is the first year in which potency and prices are available.

Compared to the repeated cross-sectional analysis that follows, the national analysis has certain advantages. First, it covers a longer period of time. Second, it puts purity on equal footing with other determinants since this variable is available only at the national level. Third, we can examine whether changes in price and the perceived harm from regular marijuana use have the potential to account for a significant share of the observed changes in youth marijuana use over time.

The disadvantages of the time series are that there are a small number of observations and a considerable amount of intercorrelation among the variables. In addition, this analysis is limited by the lack of data on marijuana prices prior to 1982, particularly when comparing the contributions of price and perceived harm in predicting the downward trend in marijuana use in the 1980s. Starting in 1982 misses the early part of the downturn in use that began in 1979 and the 25 percentage point increase in the proportion of youths seeing great risk from regular marijuana use that occurred between 1978 and 1982. Any conclusions reached from these analyses must be interpreted with caution.

6.3.1 MTF Prevalence Data

The MTF survey is a nationally representative, annual school-based survey of approximately sixteen thousand high school seniors in approximately 130 public and private high schools each year. One of the main purposes of the study is to explore changes in youths' perceptions of, attitudes toward, and use of alcohol, tobacco, and other drugs. As such, great care is taken to ensure that responses pertaining to the use of each of these substances are valid and reliable. Students complete self-administered, machine-readable questionnaires in their normal classroom, so parents are not present when the students are filling out the questionnaires, nor are they informed of the students' responses. The survey was developed and is conducted by the Institute for Social Research at the University of Michigan. Detailed information pertaining to survey design and sampling methods is available in Johnston, O'Malley, and Bachman (1999). Further

4. The MTF data contain other measures of youth attitudes toward marijuana, including the risk of harm from occasional marijuana use, the risk of harm from experimental use, and disapproval of regular, occasional, or daily use. Given the length of this chapter and the complexity of the analyses that it contains, a more complete treatment of the attitudinal variables is not included. While these measures are highly correlated, the use of different attitudinal measures is likely to have some effect on the estimates reported below. Further consideration of these variables deserves high priority in future research.

information regarding the validity of these data is available in Johnston and O'Malley (1985). The University of Michigan team reports aggregate measures of use from the survey annually (Johnston, O'Malley, and Bachman [1999] is the most recent in this annual monograph series).

6.3.2 Data on Marijuana Prices and Potency

There are two sources of data on marijuana prices: the System to Retrieve Information from Drug Evidence (STRIDE) and the *Illegal Drug Price/Purity Report* (*IDPPR*). The Drug Enforcement Administration (DEA) of the U.S. Department of Justice maintains both. DEA and FBI agents and state and local police narcotics officers purchase illicit drugs on a regular basis in order to apprehend dealers. Taubman (1991) argues that DEA agents must make transactions at close to the street prices of the drugs in order to make an arrest because an atypical price can cause suspicion on the part of dealers.

Information on the date and city of the purchase, total cost, total weight in grams, and purity (as a percentage) for certain drugs is recorded in STRIDE for each of approximately 140 cities. Most of the data pertain to cocaine or heroin because DEA agents have focused their efforts on apprehending cocaine and heroin dealers since STRIDE was created in 1977. Cocaine purchases are the most numerous: approximately thirty thousand in the period from 1981 through 1998, compared to only three thousand for marijuana. No information on the purity of marijuana is recorded. In addition, no distinction is made between wholesale and retail purchases, although the latter involve smaller quantities than the former.

Given the small number of marijuana purchases, and given that almost 30 percent are made in the District of Columbia, STRIDE cannot be used to develop marijuana prices at the state or local level. Moreover, this database cannot be used to adjust price for purity and to distinguish between retail and wholesale purchases. Therefore, in the repeated cross-sectional analysis in the next section, and in the trend analysis in this section, prices are taken from the following publications of the DEA Office of Intelligence or Intelligence Division of the U.S. Department of Justice: *The Domestic Cities Report* (1982–1985:3); the *Illicit Drug Wholesale/Retail Price Report* (1985:4–1990:4); and the *Illegal Drug Price/Purity Report* (1991:1–1998:4). The publications just mentioned contain data for nineteen cities in sixteen states. In general, the prices are reported quarterly. In 1982, 1983, and 1984, a single city-specific figure is given for each of the four marijuana-price series (for more details, see below), and the quarter for which the figure pertains is not given.[5] Data for the first and third quarters of 1985, the second quarter of 1988, and the second quarter of 1996 are missing. The cities are as follows: Atlanta; Boston; Chicago; Dallas; Denver; De-

5. We assume that the data for 1982, 1983, and 1984 pertain to the second quarter of each year.

troit; Houston; Los Angeles; Miami; Newark, New Jersey; New Orleans; New York; Philadelphia; Phoenix; San Diego; San Francisco; Seattle; St. Louis; and the District of Columbia.

Four marijuana-price series are contained in these publications: the wholesale price (price per pound) of commercial-grade marijuana, the wholesale price of a more potent grade called *sinsemilla,* and the retail price (price per ounce) of each of these two grades. In most cases, the price range (minimum and maximum price) is reported. In some cases, a single price is quoted. The number of observations on which the price range or price is based is not reported.

For convenience, we refer to prices from the sources just described as *IDPPR* or *nineteen-cities* prices from now on. The purchases on which these prices are based are sent to a laboratory at the University of Mississippi, which distinguishes between commercial marijuana and sinsemella and ascertains the THC content of each purchase as a percentage. Annual average percentages for commercial marijuana and sinsemilla potency are published, but figures for the individual cities are not given.[6] No distinction is made between potency at the wholesale and potency at the retail levels. In our sample period, the mean potency of commercial marijuana was 4.09 percent, and the mean potency of sinsemilla was 8.39 percent, with the simple pairwise correlation coefficient between the two equal to 0.43.

We obtain four annual price series from *IDPPR* by taking the midpoint of each price range (defined as the simple average of the maximum and minimum price), converting all prices into prices per gram, and converting to real prices by dividing by the annual consumer price index for the United States as a whole (1982–84 = 1). The four prices are highly correlated. The pairwise simple correlation coefficients between them range from 0.73 in the case of the retail commercial price and the retail sinsemilla price to 0.92 in the case of the wholesale and retail sinsemilla prices. In the trend and regression analyses reported in this section, we employ the retail commercial price and the potency of commercial marijuana. The retail price is clearly the most relevant one for youth-consumption decisions. There are no data, however, to indicate whether commercial marijuana or sinsemilla is more commonly consumed by young marijuana users. Given the evidence that commercial marijuana dominates the U.S. marijuana market for the period covered by these analyses (Kleiman 1992; NNICC 1998), we suspect that commercial marijuana is likely to be the type most used by high school seniors.[7]

6. Information on the nineteen-cities prices and the publications that contain them were kindly supplied by Nick Mastrocinque and Mark Redding of the DEA Intelligence Division. It is not clear why the purchases on which these prices are based are not contained in STRIDE.

7. If youths are more likely to use sinsemilla rather than commercial marijuana, then an additional source of measurement error is introduced into our models. However, given the relatively high correlations between price and potency, the regression results obtained with

For the period as a whole, the average nominal price of retail commercial marijuana was $5.97 per gram, and the average nominal price of wholesale commercial marijuana was $3.15 per gram. The corresponding prices for sinsemilla were $10.41 per gram at the retail level and $6.71 per gram at the wholesale level. Since a marijuana cigarette (a joint) typically contains 0.5 grams (Rhodes, Hyatt, and Scheiman 1994), one retail commercial joint costs approximately $3.00 in nominal terms in our sample period. For comparative purposes, a six-pack (six twelve-ounce cans) of beer costs approximately $3.50. If one assumes that a joint produces the same high as two or three cans of beer, the purchase of marijuana puts at least as great a dent in a youth's budget as the purchase of beer.

6.3.3 Trends

Trends in annual marijuana participation as a percentage, thirty-day marijuana participation as a percentage, and the percentage reporting great risk of harm from regular marijuana use (termed *harm* from now on) are shown in figure 6.5. These data reveal a cycle in use in the period at issue: a contraction from 1982 through 1992 followed by an expansion from 1992 through 1998. Annual prevalence fell from 44.3 percent in 1982 to 21.9 percent in 1992 and then rose to 37.5 percent in 1998. Thirty-day prevalence followed a similar pattern. It declined from 28.5 percent in 1982 to 11.9 percent in 1992 and then grew to 22.8 percent in 1998.

The trend in the harm measure leads the trends in the two participation series. It grew from 60.4 percent in 1982 to 76.5 percent in 1992 and then shrank to 58.5 percent in 1998. This suggests that the trend in harm has the potential to help explain the differential trend in the number of users in the two subperiods 1982–92 and 1992–98. This is particularly true because the peak in harm (78.6 percent in 1991) leads the trough in annual or thirty-day participation by one year.

The real price of commercial retail marijuana and the potency of commercial marijuana are plotted in figure 6.6. These two series are more erratic than the three presented in figure 6.5 above. Their behavior during the two subperiods, however, has the potential to help explain the cycle in participation. From 1982 to 1992, price more than tripled, while potency fell by 22 percent. Since 1992, real price fell by 16 percent, and potency increased by 53 percent. Moreover, the peak in the real price of one gram of marijuana ($7.64 in 1991) leads the trough in participation by one year.

Between 1982 and 1998, the number of high school seniors using marijuana in the past year declined by 15 percent, and the number using marijuana in the past thirty days declined by 20 percent. At the same time, price almost tripled, potency increased by approximately 20 percent, and

alternative series are very similar to those reported in this chapter, suggesting that this is not a significant problem.

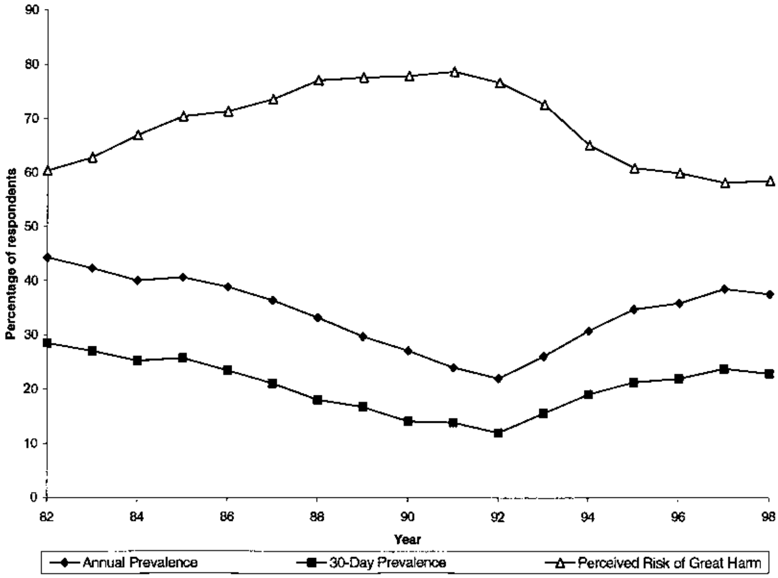

Fig. 6.5 Annual prevalence of marijuana use, thirty-day prevalence of marijuana use, and the perceived risk of great harm from regular marijuana use, 1982–98

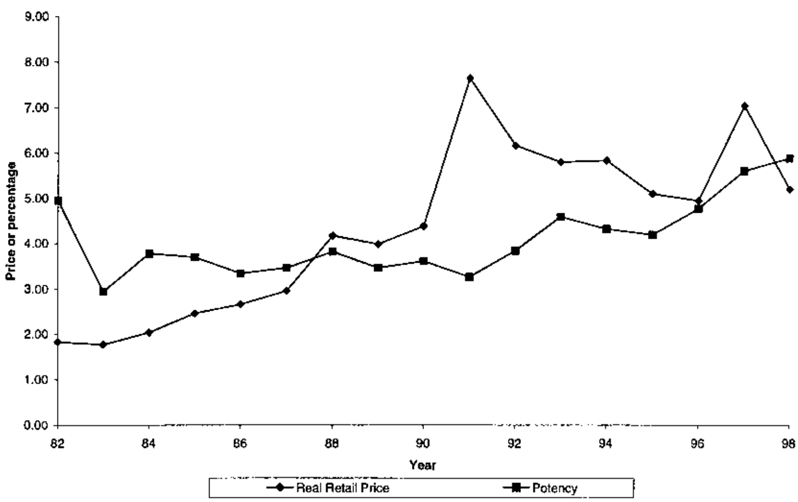

Fig. 6.6 Real retail price of commercial marijuana and potency of commercial marijuana, 1982–98

the number reporting harm from regular marijuana use fell by 3 percent. If we compare only the two end points (1982 and 1998), the price rise is consistent with the decline in the prevalence of marijuana use, but the increase in potency and the decline in perceived risk are not. In our view, however, it is misleading to focus on the end points given the considerable change within the interval. Given this change, it is much more meaningful to examine the 1982–92 contraction and the 1992–98 expansion separately.

In theory, price and potency should be positively correlated. The simple correlation between these two variables is 0.35 for the entire period, but they are negatively correlated in each of the two subperiods. This is likely to reflect the considerable measurement error in these data, particularly in the potency data (Kleiman 1992).

Limited information is available to explain trends in price and potency. Presumably, price varies over time owing, in part, to variations in resources allocated to apprehension and conviction of dealers and to crop reduction. Pacula (1998b) documents that the first factor explains differences in the price of marijuana among cities in 1987, and Grossman and Chaloupka (1998) report a similar finding in the case of cocaine prices in 1991. Crane, Rivolo, and Comfort (1997) show that increases in interdiction led to increases in the real price of cocaine in a time series for the years 1985–96. Kleiman (1989) presents evidence suggesting a positive correlation between resources allocated to enforcing marijuana laws and the real price of marijuana in the 1980s.

The DEA (1999) hypothesizes that the increase in potency over this time period can be at least partially attributed to the implementation of its Domestic Cannabis Eradication and Suppression Program in 1979. The program began as an aggressive eradication effort in just two states, Hawaii and California. By 1982, it had grown to include eradication efforts in twenty-five states. By 1985, all fifty states were receiving funding for similar eradication programs. Although the program targets both outdoor and indoor cultivation, indoor cultivation is more difficult to detect. One of the main outcomes of this program, therefore, has been the abandonment of large outdoor plots for indoor cultivating areas that are safer and easier to conceal. This movement indoors has led to the more widespread use of hydroponic cultivation, a cultivation method employing a nutrient solution instead of soil that enables growers to produce a more potent form of marijuana.

6.3.4 Conceptual Issues

Three conceptual issues need to be addressed in specifying time-series demand functions for marijuana participation. The first pertains to the appropriateness of including the harm measure in these demand functions. High school seniors' perceptions about the perceived risk of great harm from regular marijuana use are not formed in a vacuum.[8] Instead, these perceptions are likely to depend on attitudes and behaviors of parents, older siblings, and peers. If this is the case, then harm is an endogenous variable that may be correlated with the disturbance term in the structural demand function for marijuana participation that includes it. One factor is that harm may be correlated with an unmeasured characteristic, such as a thrill-seeking personality, that causes both marijuana participation and perceptions of risk. A second factor is that there may be true reverse causality from participation to risk. A youth who smokes marijuana may be less likely to report that it is a harmful behavior than a youth who does not smoke marijuana.

We term the first factor *statistical endogeneity* arising from a recursive model with correlated errors and the second factor *structural endogeneity.* Both factors cause the coefficient of harm in the demand function to be biased and inconsistent. In addition, the price coefficient is biased if it is correlated with harm. A relation between price and harm in which a reduction in the real price leads to a reduction in perceived harm is quite plausible. For example, suppose that a reduction in price encourages participation or consumption given participation by older peers. This should lower high school seniors' perception of harm and increase their participation.[9]

In principle, one could employ simultaneous-equations methods, such as two-stage least squares, to obtain consistent estimates of the structural demand function. However, we lack an instrument for harm. Since harm is endogenous, one wants to allow both for a direct effect of price on participation with harm held constant and for an indirect effect that operates through harm. In this section, we estimate demand functions with and without the harm variable by ordinary least squares. We also estimate equations that include harm but exclude price and potency. This allows us to examine the importance of price as a determinant of youth marijuana participation and to determine how the price coefficients change when harm is included or excluded from the models.

A second conceptual issue pertains to biases in the price coefficient due to measurement error and the endogeneity of this variable. It is plausible that price is subject to measurement error because only its midpoint is available. Moreover, we do not know the quantity employed to calculate the retail price of a one-gram purchase of marijuana. A distinguishing

8. Becker and Mulligan (1997) develop an economic framework that highlights the incentives of parents to make investments that raise the future orientation of their children. Clearly, these investments can also alter attitudes and perceptions governing potentially risky behaviors.

9. A positive correlation between price and harm is also possible. Suppose that an increase in price is due to an expansion in resources allocated to enforcing marijuana laws. If the expected penalty for possession of marijuana rises, and if this penalty is one of the harms associated with use, price and harm would be positively related.

characteristic of the market for illegal drugs is that the average cost of a purchase falls as the size of the purchase increases (DiNardo 1993; Caulkins 1994; Rhodes, Hyatt, and Scheiman 1994; Grossman and Chaloupka 1998). If youths typically purchase one or two grams (two or four joints) at a time and the retail price is estimated from a larger purchase, we underestimate the price actually paid by youths. Trends in the purchase size on which the *IDPPR* price is calculated or trends in the purchase size made by youths create biases due to measurement error. If the error due to these factors or to the absence of mean or median prices is random, the price coefficient is biased toward 0.

We assume that the supply function of marijuana is infinitely elastic and that price varies over time owing to variations in resources allocated to apprehension and conviction of dealers and to crop reduction. Even if the supply function is not infinitely elastic, high school seniors can be viewed as price takers if they represent a small fraction of marijuana users. If this is not the case and the supply function slopes upward, we understate the price coefficient or elasticity in the demand function in absolute value. If the supply function slopes downward owing to externalities (the greater is market consumption, the smaller is the probability of catching a given dealer), the price coefficient or elasticity in the demand function is overstated. On balance, we believe that biases due to measurement error are the most important and that the price coefficients or elasticities that we report are conservative lower-bound estimates.

The final conceptual issue deals with the incorporation of purity or potency into the demand function. Here, it is natural to view purity as an index of quality and to appeal to the literature on the demand for the quantity and quality of a good (Houthakker 1952–53; Theil 1952–53; Rosen 1974). The simplest model in this literature is one in which consumers demand quality-adjusted quantity and base consumption decisions on quality-adjusted price. In our context, quality-adjusted quantity is given by $Q = mq$, where m is the number of marijuana cigarettes smoked, and q is quality or potency as measured by THC content. Quality-adjusted price is given by $p^* = p/q$, where p is the price of a joint. This model suggests a conditional demand function for m by marijuana users whose arguments are p and q. With p held constant, an increase in q lowers, raises, or has no effect on m as the price elasticity of demand for m is less than, greater than, or equal to 1 in absolute value.[10] The model also suggests a demand

10. The simplest way to prove this is to write the demand function as

$$\ln Q = \alpha - \varepsilon \ln p^*,$$

where α is a constant. Using the definitions of Q and p^* offered in the text, one can rewrite this demand function as

$$\ln m = \alpha - \varepsilon \ln p + (\varepsilon - 1)\ln q.$$

Table 6.1 **Definitions, Means, and Standard Deviations of Variables in Time-Series Regressions**

Variable	Definition	Mean	Standard Deviation
Annual marijuana participation	Percentage who used marijuana in past year	34.176	6.666
Thirty-day marijuana participation	Percentage who used marijuana in past thirty days	20.547	4.944
Price	Real retail price of one gram of commercial marijuana in 1982–84 dollars	4.349	1.840
Potency	THC potency of commercial marijuana as a percentage	4.088	.828
Harm	Percentage reporting great risk of harm from regular use of marijuana	68.676	7.550
Time	Time in years, 1982 = 1	9.000	5.050
Time squared	Square of time	105.000	93.523

function for participation in which this decision is a negative function of p^*. Hence, participation is more likely the smaller is p and the larger is q.[11]

6.3.5 Results

Definitions, means, and standard deviations of the variables in the time-series regressions are shown in table 6.1. Tables 6.2 and 6.3 contain demand functions for annual and thirty-day marijuana participation, respectively. The t-ratios of all regression coefficients in these tables are based on Newey and West (1987) standard errors, which allow for heteroscedasticity and for autocorrelation up to and including a lag of three. Standard errors based on longer lags were very similar to those contained in the tables. The first regression in panel A of either table 6.2 or table 6.3 includes the real retail price of commercial marijuana and the potency of commercial marijuana. The second regression adds a linear time trend, and the third adds the square of time. Regressions 4–6 delete price and potency from regressions 1–3 and add the percentage of high school seniors reporting great risk of harm from regular marijuana use. Panel B of either table employs price, potency, and harm in the same models.

According to the first three models in panel A of table 6.2, price always has a negative effect on annual participation that is significant at conven-

11. In terms of the model specified in the preceding note, the elasticity of participation with respect to q should equal the elasticity of participation with respect to p with the sign reversed. This constraint could be imposed by employing p/q as the regressor in the demand function. We do not take this approach because our measure of q does not distinguish between wholesale and retail potency and because THC content may not be the only determinant of quality.

Table 6.2 Annual Marijuana Participation Regressions

A. Price and Harm Entered Separately

	(1)	(2)	(3)	(4)	(5)	(6)
Price	−3.205	−3.167	−2.122			
	(−7.83)	(−3.27)	(−2.59)			
Potency	4.074	4.120	−.406			
	(4.04)	(2.59)	(−.37)			
Time		−.020	−3.326		−.861	−1.400
		(−.06)	(−3.10)		(−4.50)	(−1.08)
Time squared			.192			.032
			(3.30)			(.41)
Harm				−.590	−.746	−.656
				(−2.95)	(−5.91)	(−3.19)
R^2	.723	.723	.851	.446	.839	.841
F-statistic	93.54	60.70	31.96	8.70	20.27	12.03
Price elasticity[a]	−.407	−.402	−.269			

B. Price and Harm Entered Together

	(7)	(8)	(9)
Price	−2.408	−1.595	−1.626
	(−5.81)	(−2.08)	(−2.01)
Potency	.263	.776	.411
	(.26)	(.76)	(.32)
Time		−.385	−.949
		(−1.28)	(−.79)
Time squared			.036
			(.53)
Harm	−.517	−.567	−.485
	(−4.47)	(−4.20)	(−3.55)
R^2	.866	.881	.882
F-statistic	96.74	45.94	42.38
Price elasticity[a]	−.306	−.203	−.206

Note: Newey-West (1987) *t*-statistics are given in parentheses. Standard errors on which they are based allow for heteroscedasticity and for autocorrelation up to and including a lag of 3. Intercepts are not shown.

[a]Evaluated at sample means.

tional levels. As expected, the regression coefficient of potency is positive and significant except in the model that includes a quadratic time trend. Evaluated at the sample means, the price elasticity of annual marijuana participation ranges between −0.27 and −0.41. In the two models in which the potency coefficient is positive, its elasticity equals 0.49. This is somewhat larger than the absolute value of the price elasticity of 0.41 in model 1 or 0.40 in model 2, but the price and potency elasticities do not differ dramatically. This gives some support to the notion that participation depends on quality-adjusted price.

Table 6.3 **Thirty-Day Marijuana Participation Regressions**

A. Price and Harm Entered Separately

	(1)	(2)	(3)	(4)	(5)	(6)
Price	−2.280	−2.079	−1.156			
	(−6.73)	(−2.80)	(−2.16)			
Potency	3.100	3.341	−0.657			
	(4.31)	(2.85)	(−1.04)			
Time		−.105	−3.025		−.632	−.881
		(−.38)	(−4.28)		(−5.76)	(−1.20)
Time squared			.169			.015
			(4.49)			(.34)
Harm				−.471	−.586	−.545
				(−3.32)	(−8.79)	(−4.79)
R^2	.679	.682	.863	.518	.904	.904
F-statistic	78.02	57.30	26.30	11.03	40.74	26.55
Price elasticity[a]	−.483	−.441	−.245			

B. Price and Harm Entered Together

	(7)	(8)	(9)
Price	−1.577	−.658	−.673
	(−4.47)	(−1.33)	(−1.34)
Potency	−.263	.318	.140
	(−.31)	(.52)	(.21)
Time		−.435	−.710
		(−2.15)	(−1.07)
Time squared			.017
			(.51)
Harm	−.456	−.512	−.473
	(−5.18)	(−6.04)	(−5.66)
R^2	.855	.916	.917
F-statistic	155.50	73.65	57.86
Price elasticity[a]	−.331	−.139	−.143

Note: Newey-West (1987) *t*-statistics are given in parentheses. Standard errors on which they are based allow for heteroscedasticity and for autocorrelation up to and including a lag of 3. Intercepts are not shown.

[a]Evaluated at sample means.

The regression coefficient of harm is negative and significant in the last three models in panel A of table 6.2. A 10 percentage point increase in the harm measure lowers annual participation by between 6 and 7 percentage points.

When harm is entered together with price and potency in the models in panel B of table 6.2, the price coefficient retains its negative sign and is significant at the 5 percent level on a one-tailed test. The price elasticities are reduced by between 23 and 50 percent and now range from −0.20 to −0.31. The potency effects are positive but not significant when harm is held constant. The two positive potency coefficients in panel A are much larger than the corresponding coefficients in panel B. Harm retains its significance when price and potency are held constant, but the magnitude of the effect is reduced by between 12 and 24 percent.

The results in table 6.3 are similar to those in table 6.2. The price elasticity of thirty-day participation is somewhat larger than the price elasticity of annual participation except in models that include a quadratic time trend or harm and time. But the observed differences are not substantial. The largest occurs when the only other regressor is potency: −0.48 for the price elasticity of thirty-day participation compared to −0.41 for the elasticity of annual participation.

One way in which to evaluate the nine models in each table is to see how well they predict the reduction in marijuana participation between 1982 and 1992 and the increase between 1992 and 1998. Table 6.4 contains estimates of the predicted changes in annual and thirty-day marijuana prevalence based on the estimates contained in tables 6.2 and 6.3 above. The component labeled *price* is obtained by multiplying the change in price between the initial and the terminal years by the regression coefficient of price. The *potency* and *harm* components have similar interpretations. In general, the predicted changes in participation associated with the changes in perceived risk are relatively stable across specifications, while those associated with price and potency are more sensitive to the choice of specification.

Between 1982 and 1992, annual participation declined by 22.4 percentage points. On the basis of the estimates from the specifications that include price, potency, and harm, the changes in price during this period suggest a 6.9–10.4 percentage point reduction in annual participation, while those in potency imply a reduction of 0.3–0.9 percentage points. Similarly, the changes in harm during this period suggest a 7.8–9.1 percentage point reduction in annual prevalence. Because an increase in price unadjusted for potency or a reduction in potency raises quality-adjusted price, the price and potency components can be summed to form a single, quality-adjusted price component. In the most complete specifications that control for time trends (linearly or quadratically), the quality-adjusted price changes predict a 7.5–7.8 percentage point reduction in prevalence, while the changes in harm predict a 7.8–9.1 percentage point reduction.

Similarly, in the period 1982–92, monthly participation declined by 16.6 percentage points. On the basis of the estimates from specifications that include price, potency, and harm, with or without controlling for time trends, the changes in price during this period predict a 2.8–6.8 percentage point reduction in monthly participation, while the changes in potency suggest relatively little change. The changes in harm predict a 7.3–8.2 percentage point reduction in monthly prevalence. In the specifications that include a linear or quadratic time trend, the changes in quality-adjusted

Table 6.4 Percentage-Point Effects of Price, Potency, and Harm on Marijuana Participation

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A. Annual Participation									
1981–92, Observed Change in Participation = 22.40									
Marijuana price	−13.88	−13.72	−9.19				−10.43	−6.91	−7.04
Marijuana potency	−4.52	−4.57	.45				−.29	−.86	−.46
Harm				−9.49	−12.02	−10.57	−8.32	−9.12	−7.81
Total predicted change	−18.41	−18.29	−8.74	−9.49	−12.02	−10.57	−19.04	−16.90	−15.31
1992–98, Observed Change in Participation = 15.60									
Marijuana price	3.10	3.06	2.05				2.33	1.54	1.57
Marijuana potency	8.31	8.40	−.83				0.54	1.58	.84
Harm				10.61	13.44	11.81	9.30	10.20	8.74
Total predicted change	11.41	11.46	1.22	10.61	13.44	11.81	12.16	13.33	11.55
B. Thirty-Day Participation									
1982–92, Observed Change in Participation = −16.60									
Marijuana price	−9.88	−9.01	−5.01				−6.83	−2.85	−2.91
Marijuana potency	−3.44	−3.71	.73				.29	−.35	−.16
Harm				−7.59	−9.44	−8.11	−7.34	−8.25	−7.61
Total predicted change	−13.32	−12.72	−4.28	−7.59	−9.44	−8.11	−13.88	−11.45	−10.68
1992–98, Observed Change in Participation = 10.90									
Marijuana price	2.20	2.01	1.12				1.52	.64	.65
Marijuana potency	6.32	6.82	−1.34				−.54	.65	.29
Harm				8.48	10.56	9.80	8.21	9.22	8.51
Total predicted change	8.53	8.82	−.22	8.48	10.56	9.80	9.19	10.51	9.45

Note: Estimates for annual participation are based on the specifications in table 6.2; estimates for thirty-day participation are based on the specifications in table 6.3.

price predict a 3.1–3.2 percentage point reduction in participation, while those in harm predict a 7.6–8.2 percent reduction.

Between 1992 and 1998, annual participation rose by 15.6 percentage points, while monthly participation rose by 10.9 percentage points. Focusing on models comparable to those discussed for the earlier period, the changes in the quality-adjusted price during this period predict an increase of between 2.4 and 3.1 percentage points in annual participation and an increase of between 0.9 and 1.3 percentage points in monthly participation. Similarly, the changes in harm predict increases of 8.7–10.2 percentage points in annual participation and 8.2–9.2 percentage points in monthly participation.

To summarize, the changes in quality-adjusted price and perceived risk predict much of the contraction in youth marijuana use in the period 1982–92 and the expansion in use after 1992. Both factors appear roughly equally important in accounting for the reduction in annual participation in the earlier period, with perceived risk somewhat more important in accounting for the reduction in monthly participation during this period. Changes in harm, however, appear to play a much stronger role than changes in quality-adjusted price during the more recent expansion in youth marijuana use.

6.4 Repeated Cross-Sectional Analysis of Marijuana Demand

To investigate individual demand for marijuana among youths, we use micro-level data from the 1985–96 MTF. These data allow us to incorporate more determinants than those employed in the time-series analysis. At the same time, we base estimates of the price elasticity of demand for marijuana on prices that vary among cities as well as over time in the context of a fixed-effects estimation strategy. By employing a set of dichotomous indicators for states of the United States in all models, we hold constant unmeasured variables that may be correlated with consumption and price. Finally, we include measures of cigarette and beer prices to investigate whether marijuana, cigarettes, and beer are substitutes or complements for youths. We examine two outcomes: past-year participation and past-month participation, as in the time-series analyses presented above.[12]

6.4.1 Measurement of Variables and Empirical Implementation

Table 6.5 contains definitions, means, and standard deviations of all variables. MTF survey respondents report the number of occasions in the

12. Additional measures of youth marijuana use, including frequency of use and participation in daily use, could be constructed from the MTF data. Given the focus of this chapter, these outcomes are not considered. A more complete analysis of these measures should be a priority for future research.

Table 6.5 **Descriptive Statistics**

Variable	Pooled Sample (N = 138,933) Mean	S.D.
Indicators of marijuana use		
Annual prevalence of marijuana use	.311	.463
Thirty-day prevalence of marijuana use	.184	.388
Demographics		
Male	.484	.500
Black non-Hispanic	.097	.296
Hispanic	.063	.242
Other race	.068	.251
Age	17.948	.559
Siblings: total number of siblings	2.490	1.839
Father had some high school	.115	.319
Father finished high school plus (finished high school or attended or graduated college)	.840	.367
Mother had some high school	.101	.302
Mother finished high school plus	.867	.340
Mother worked full-time	.515	.500
Mother worked part-time	.266	.442
Live alone	.006	.079
Live with father only	.035	.184
Live with mother only	.158	.364
Other living arrangement	.044	.205
City: live in a city	.591	.492
Suburb: live in a suburb	.211	.408
Lifestyle factors		
Infrequent religious service attendance	.538	.499
Frequent religious service attendance	.335	.472
Married or engaged	.075	.263
Hours worked per week	13.298	10.521
Earned income: real weekly earned income	37.299	34.221
Other income: real weekly other income	10.842	17.882
Attitudes and perceptions		
Harm: perceived risk of harm from regular marijuana use (0 = no risk, 1 = slight risk, 2 = moderate risk, 3 = great risk)	2.607	.742
Measures of peer use		
Peer marijuana use: fraction who used marijuana in past month in respondent's school	.180	.090
Price of marijuana		
Marijuana price: real retail price of one gram of commercial marijuana	3.325	1.280
Marijuana potency: THC potency of commercial marijuana as a percentage	3.856	.470
Substitute/complement prices		
Cigarette tax: real state tax on a pack of cigarettes	.180	.085
Beer tax: real state tax on case of 24 12-ounce cans of beer	.493	.498
Drinking age: state minimum legal age for purchase and consumption of beer, alcohol content 3.2 percent or less	20.812	.567

past year and in the past thirty days on which they used marijuana (grass, pot) or hashish (hash, hash oil). These are ordered categorical variables with seven outcomes: no occasions, one to two occasions, three to five occasions, six to nine occasions, ten to nineteen occasions, twenty to thirty-nine occasions, and forty or more occasions. Participants are youths who reported a positive number of occasions.[13]

Demographic characteristics included in this analysis are gender (male or female), race (white non-Hispanic, black non-Hispanic, Hispanic, and other), age, parents' education (less than a high school education, at least a high school education), total number of siblings, family structure (live alone, live with mother, live with father, both parents present, or other living arrangement), mother's work status while growing up (full-time, part-time, or stay-at-home), and place of residence (rural, suburb, city). Lifestyle factors include marital status (married or engaged vs. being single), attendance at religious services (no attendance, infrequent attendance, and frequent attendance), hours worked per week, real weekly earned income, and real weekly other income (primarily income from allowances).[14] The labels given to certain variables are somewhat arbitrary. For example, weekly earnings and other income reflect command over real resources. We use each income measure and hours of work as regressors because exposure to the work environment may affect marijuana consumption by channels other than pure income effects.

To capture youths' perceptions of and attitudes toward marijuana, we include an index of the perceived risk of harm from regular use of marijuana. This item was not included on all survey forms in all survey years, so the sample size is reduced when it is included in the analysis.[15] The indicator of perceived risk is set equal to 0 for youths who report no risk, equal to 1 for youths who report a slight risk, equal to 2 for those who report moderate risk, and equal to 3 for those who report great risk associated with regular marijuana use.

It is clear from the existing literature that peer use of substances has an important effect on the susceptibility of youths to the use of different substances. Although we do not have any direct measure of friends' use of particular substances, it is possible to construct school-level measures by

13. One-sixth of the MTF sample are asked separate questions about marijuana and hashish. These answers have been aggregated to form indicators of the use of any form of marijuana.

14. As in sec. 6.3 above, variables are converted from nominal to real dollars by deflating by the consumer price index for the United States as a whole (1982–84 = 1).

15. From 1985 to 1989, five different questionnaires were administered in each year, enabling investigators to increase the range of questions being asked without making any given questionnaire too long. From 1985 to 1988, only one form included the question on perceived risk (form 5). In 1989, a sixth questionnaire form was added to the survey, and the risk item was included on this sixth form. In 1990, the perceived-risk question was added to three of the existing forms, making it available on five of the forms. As noted above, additional attitudinal measures are contained in the MTF surveys, and the use of alternative measures could

aggregating responses to each of these questions for all youths in the same school that participated in the survey.[16] An indicator of the fraction of individuals reporting marijuana use in the past thirty days is used as a proxy for peer use of marijuana. This variable is almost certainly endogenous. Unfortunately, appropriate instruments are not available. Given this, some of the models presented below do not include the peer-marijuana-use measure.

There were originally 193,796 observations in the 1985–96 pooled sample. Approximately 28 percent of this sample is lost owing to missing observations on gender, race, age, marital status, number of siblings, parents' education, mother's work status, living arrangements, place of residence, religious participation, employment status, and income. Means of all variables except for marijuana participation and harm are based on 138,933 observations. Marijuana participation is known for 136,595 of these cases. The harm measure is available for 73,068 cases.

The commercial marijuana prices described in the last section are matched to MTF counties in which the high schools are located on the basis of an algorithm that matches each county in the United States to the three nearest cities in the nineteen-cities database. Three matches are made rather than one owing to missing data for certain cities in some years.[17] The price of marijuana in a given year is taken from the best or closest match. Since the wholesale commercial price has fewer missing values than the retail commercial price, the former price is used in the demand functions estimated in this section. All price coefficients in the tables have, however, been multiplied by 0.5—the coefficient of the retail price in a regression in which the wholesale price is the dependent variable.[18] The potency of commercial marijuana is the same variable employed in section 6.3 above and varies by time but not by city.

To capture potential cross-price effects associated with the consumption of cigarettes and alcohol, we include the real state tax on a pack of twenty cigarettes, the real state tax on a case of twenty-four twelve-ounce cans of beer, and the state minimum legal age for the purchase and consumption of beer with an alcohol content of 3.2 percent or less. The beer tax and legal drinking age are employed as measures of the cost of alcohol because beer is the beverage of choice among youths who consume alcohol. Nominal state-level cigarette taxes were obtained from the Tobacco Institute's annual *Tax Burden on Tobacco* and deflated by the national CPI (1982–

have some effect on the estimates presented in this chapter. However, space constraints prohibit a complete examination of all these measures. Further examination of these alternative attitudinal measures should be a high priority for future research in this area.

16. Classes are chosen within each school to be representative of the high school students within that school. This is a standard part of the multistage random-sampling procedure.

17. If the price is missing for all three matches, the observation is deleted.

18. Let r be the retail price, w be the wholesale price, and m be a measure of marijuana consumption. Then $\partial m/\partial r = (\partial m/\partial w)(\partial w/\partial r)$.

84 = 1). Since taxes are reported as of 1 November and the MTF interviews take place in the spring of each year, we use the average of the current year's tax and the last year's tax to obtain a better estimate of the tax at the time of the MTF interview. We similarly construct a measure of the average real state tax on a case of twenty-four twelve-ounce cans of beer using quarterly tax information from the Beer Institute's *Brewers' Almanac.* The real state tax in a given year is calculated as the average of the current year's first and second quarter and the previous year's third and fourth quarter.[19]

The minimum legal drinking age for beer was taken from Chaloupka, Saffer, and Grossman (1993). By July 1988, all states had minimum drinking ages of twenty-one. Many enacted grandfather clauses, however, exempting state residents of legal age prior to the increase. The drinking-age measure accounts for these clauses and does not become twenty-one in all states until 1991.[20]

The full price of consuming marijuana consists of the money price and the monetary value of the expected penalties for possession or use (the probability of apprehension and conviction multiplied by the fine or the monetary value of the prison sentence). For a variety of reasons, we have excluded measures of expected penalties for possession of marijuana from the demand functions. The marijuana decriminalization indicator discussed in section 6.2 above is a time-invariant variable during our sample period. Thus, it is perfectly collinear with the set of state dummies that are included in all models.[21]

In the case of monetary fines for possession of marijuana, Chaloupka, Grossman, and Tauras (1999) find that youths who reside in states with higher fines are less likely to consume marijuana. Their estimated effects are, however, very small and do not control for unmeasured state characteristics. Farrelly et al. (1999) find no effects when these controls are included. The fine measure assembled by Farrelly and his colleagues is missing for all states for the years 1986, 1987, and 1989. There is no trend in the real fine during the sample period. Therefore, it cannot explain the trend in marijuana use. Moreover, preliminary results for the period 1990–96 revealed that the real fine for the possession of one ounce of marijuana did not have a significant effect on participation or frequency when state fixed effects were included.

19. The benefits of adopting similar algorithms in the case of the marijuana price were outweighed by the amount of measurement error that they would create in an already "noisy" variable.

20. The drinking age is a weighted average of the daily effective drinking age in the state and takes account of the month in which the age was raised.

21. Alaska recriminalized the possession of a small quantity of marijuana in 1990, but that state does not appear in the MTF survey during the period 1985–96. Arizona decriminalized marijuana possession in 1996 but is not contained in the MTF survey after that year.

The probability of arrest for marijuana possession in an area is not observed since the number of users is not known. The arrest rate for possession (arrests divided by population) is available at the county level and could be employed as a regressor. A natural objection to this measure is that it reflects reverse causality: an increase in the number of users causes the number of arrests to rise. A somewhat more subtle analysis recognizes that, if the arrest rate replaces the probability of arrest in the demand function, the coefficient of the former variable is positive if the elasticity of the probability of use with respect to the probability of arrest is greater than 1 in absolute value. On the other hand, the arrest coefficient is negative if the elasticity just defined is less than 1 in absolute value. Nevertheless, the estimated arrest coefficient is inconsistent unless an instrumental-variables procedure is employed. This is because the arrest rate is correlated with unmeasured determinants of marijuana participation and because of reverse causality from participation to arrests.

These points are spelled out in more detail in the appendix. Here, we note that we lack a suitable instrument for the arrest rate. We also note that there is no trend in this measure during the sample period. Finally, in preliminary estimates, we included the state-specific per capita number of juveniles in custody for the years 1985, 1987, 1989, 1991, and 1993, obtained from Levitt (1998). This variable has a negative and significant effect on marijuana participation, but it results in the loss of seven of the twelve cross sections and has no trend. Moreover, it reflects the combined effect of the removal of potential users from the noninstitutional population and deterrence. Therefore, we do not employ it in the final models presented in section 6.4.2 below.

To parallel the models obtained in section 6.3 above, and to include marijuana potency as a determinant, we obtain three basic equations. The first omits a time trend, the second includes a linear trend in which 1985 = 0 and 1996 = 11, and the third includes time and time squared. All equations contain dichotomous variables for forty-five of the forty-six states in the repeat cross sections. Robust or Huber (1967) standard errors of logit coefficients are obtained. They allow for state/year clustering.

The conceptual issues raised with regard to the appropriateness of including the harm measure in the time-series demand functions in section 6.3.4 above also apply to the micro-level demand functions. This same concern applies to including the measure of peer marijuana use. The many pitfalls involved in obtaining peer effects have been discussed in detail by Manski (1993), and our estimated effects should be interpreted with caution.

6.4.2 Results

Table 6.6 contains maximum-likelihood logit equations for annual marijuana participation, and table 6.7 contains comparable estimates for

Table 6.6 Annual Marijuana Participation Logit Equations (N = 135,970)

	(1)	(2)	(3)
Male	.176	.177	.182
	(10.34)	(10.48)	(10.83)
Black	−.738	−.739	−.739
	(−16.58)	(−16.68)	(−17.16)
Hispanic	−.187	−.179	−.161
	(−4.11)	(−3.94)	(−3.61)
Other race	−.547	−.540	−.540
	(−11.11)	(−11.02)	(−11.43)
Age	−.026	−.022	−.021
	(−2.31)	(−1.96)	(−1.85)
Siblings	.046	.044	.043
	(11.31)	(10.93)	(10.50)
Father had some high school	.100	.100	.103
	(2.48)	(2.49)	(2.53)
Father finished high school plus	.114	.118	.120
	(3.01)	(3.09)	(3.10)
Mother had some high school	.304	.298	.305
	(6.15)	(6.06)	(6.16)
Mother finished high school plus	.370	.366	.370
	(7.79)	(7.76)	(7.83)
Mother worked part-time	.101	.101	.098
	(5.49)	(5.50)	(5.27)
Mother worked full-time	.137	.142	.137
	(8.92)	(9.23)	(8.84)
Live alone	.434	.439	.441
	(5.75)	(5.83)	(5.82)
Live with father only	.254	.256	.260
	(7.76)	(7.80)	(7.98)
Live with mother only	.176	.176	.178
	(9.87)	(9.89)	(9.99)
Other living arrangement	.335	.335	.340
	(10.93)	(10.89)	(11.06)
City	.377	.374	.375
	(14.04)	(14.00)	(14.33)
Suburb	.474	.471	.483
	(15.08)	(15.23)	(15.76)
Infrequent religious service attendance	−.190	−.194	−.193
	(−9.89)	(−9.99)	(−9.96)
Frequent religious service attendance	−.991	−.995	−1.002
	(−40.08)	(−40.35)	(−40.74)
Married or engaged	−.082	−.082	−.086
	(−3.06)	(−3.05)	(−3.18)
Hours worked per week	.011	.011	.011
	(11.31)	(11.67)	(11.77)
Earned income	.002	.002	.002
	(7.65)	(7.23)	(7.26)
Other income	.009	.009	.009
	(23.53)	(23.50)	(23.44)

Table 6.6 (continued)

	(1)	(2)	(3)
Cigarette tax	−.042	.337	.068
	(−.08)	(.69)	(.26)
Beer tax	−.679	−.416	−.198
	(−2.29)	(−1.34)	(−1.26)
Drinking age	−.129	−.063	.096
	(−3.64)	(−1.65)	(2.74)
Marijuana price	−.145	−.103	−.027
	(−7.95)	(−5.15)	(−1.77)
Marijuana potency	.181	.331	.002
	(4.80)	(6.21)	(.05)
Time		−.043	−.286
		(−3.78)	(−17.68)
Time squared			.023
			(16.52)
Pseudo-R^2	.066	.067	.071
χ^2	8,355.91	8,425.21	8,633.30
Price elasticity[a]	−.331	−.235	−.063

Note: All equations include state dummies. Asymptotic *t*-ratios are in parentheses. Huber (1967) or robust standard errors on which they are based allow for state/year clustering. Intercepts are not shown.

[a]Evaluated at sample means.

thirty-day marijuana participation. Three models are shown in each table. The first omits a time trend, the second includes a linear trend, and the third includes the trend and its square. The harm and peer-marijuana-use variables are excluded from the models reported in these tables.

Given the pronounced trends in the real price of marijuana, the potency of marijuana, and the minimum legal drinking age during the relatively short period at issue, the coefficients of these variables are sensitive to the exclusion or inclusion of a trend term and to the exact specification of the trend. A case can be made that the specifications with the quadratic trend represent an “overparameterization” of the data since the computations presented in section 6.3 above and those at the end of this section suggest that trends in the variables just mentioned provide plausible explanations of trends in participation. Moreover, we have reasonably good proxies for such hard-to-measure variables as attitudes (as indicated by perceived risk of harm) and peer behavior. Nevertheless, we present all three models to indicate the degree to which the estimates vary and to allow readers to make up their own minds on this issue.

The marijuana price coefficient is negative and significant in the three models in table 6.6 and in the first two models in table 6.7. Evaluated at sample means, the price elasticity of annual marijuana participation

Table 6.7 Thirty-Day Marijuana-Participation Logit Equations (N = 135,946)

	(1)	(2)	(3)
Male	.280	.281	.286
	(14.89)	(15.07)	(15.49)
Black	−.659	−.660	−.658
	(−12.35)	(−12.38)	(−12.83)
Hispanic	−.197	−.189	−.169
	(−4.04)	(−3.94)	(−3.62)
Other race	−.471	−.464	−.465
	(−8.88)	(−8.78)	(−9.13)
Age	−.025	−.021	−.020
	(−1.90)	(−1.62)	(−1.51)
Siblings	.042	.041	.039
	(9.14)	(8.85)	(8.43)
Father had some high school	.134	.134	.138
	(2.64)	(2.65)	(2.71)
Father finished high school plus	.108	.111	.113
	(2.37)	(2.43)	(2.47)
Mother had some high school	.345	.339	.346
	(5.62)	(5.55)	(5.64)
Mother finished high school plus	.395	.392	.396
	(6.44)	(6.42)	(6.50)
Mother worked part-time	.077	.078	.074
	(3.37)	(3.39)	(3.17)
Mother worked full-time	.101	.106	.100
	(5.14)	(5.33)	(4.99)
Live alone	.603	.607	.611
	(6.65)	(6.70)	(6.69)
Live with father only	.229	.231	.236
	(5.94)	(5.97)	(6.15)
Live with mother only	.186	.186	.187
	(9.56)	(9.58)	(9.73)
Other living arrangement	.335	.335	.339
	(9.66)	(9.66)	(9.73)
City	.373	.371	.373
	(12.51)	(12.52)	(13.11)
Suburb	.468	.466	.481
	(12.54)	(12.67)	(13.52)
Infrequent religious service attendance	−.293	−.297	−.296
	(−13.66)	(−13.82)	(−13.82)
Frequent religious service attendance	−1.114	−1.117	−1.124
	(−39.15)	(−39.41)	(−39.77)
Married or engaged	−.185	−.185	−.189
	(−5.77)	(−5.76)	(−5.88)
Hours worked per week	.010	.010	.011
	(9.49)	(9.78)	(9.86)
Earned income	.002	.002	.002
	(6.36)	(5.99)	(5.98)
Other income	.010	.010	.010
	(24.64)	(24.59)	(24.40)

Table 6.7 (continued)

	(1)	(2)	(3)
Cigarette tax	.200	.532	.187
	(.38)	(1.08)	(.76)
Beer tax	−.523	−.281	−.021
	(−1.72)	(−.89)	(−.12)
Drinking age	−.137	−.078	.095
	(−3.71)	(−1.86)	(2.56)
Marijuana price	−.123	−.085	−.001
	(−6.15)	(−4.00)	(−.04)
Marijuana potency	.227	.364	−.010
	(5.70)	(6.22)	(−.22)
Time		−.039	−.307
		(−3.08)	(−17.18)
Time squared			.026
			(16.74)
Pseudo-R^2	.062	.063	.068
F-statistic	79.21	79.57	85.59
Price elasticity[a]	−.335	−.228	−.002

Note: All equations include state dummies. Asymptotic t-ratios are in parentheses. Huber (1967) or robust standard errors on which they are based allow for state/year clustering. Intercepts are not shown.

[a]Evaluated at sample means.

ranges from −0.33 in the equation with no trend to −0.06 in the equation with a quadratic trend. The elasticity estimates for thirty-day participation are quite similar and follow the same pattern, ranging from −0.34 in the equation with no trend to −0.002 in the equation with a quadratic trend. The estimates in tables 6.6 and 6.7 are much more sensitive to the inclusion of trend terms than are those in tables 6.2 and 6.3 above, most likely because the data in the latter span a longer period of time.

As in the time-series regressions, an increase in the potency of commercial marijuana increases participation, except when a quadratic trend is entered. The potency elasticity of 0.48 in model 1 for annual participation is fairly similar to the absolute value of the price elasticity of 0.33 in that specification. These results are consistent with the framework outlined in section 6.3 above in which participation decisions are based on quality-adjusted price. The potency elasticity of 0.88 in the second model in table 6.6 is not consistent with this framework. A similar pattern is observed for thirty-day participation.

There is some evidence from both tables that beer and marijuana are complements. All six of the beer-tax coefficients are negative, albeit generally not significant. In the annual-participation models that control for time, the beer-tax participation effects are significant at approximately the

20 percent level on a two-tailed test but not at the 10 percent level.[22] An increase in the legal drinking age has significant negative effects on annual and thirty-day participation, except in the models with the quadratic time trend. In those models, the effect is positive and significant, implying substitution rather than complementarity. This finding again suggests that it is difficult to sort out unmeasured trend effects from those of variables with significant trends.

Five of the six cigarette-tax coefficients are positive, but none are close to significant at conventional levels, suggesting that cigarettes and marijuana are neither substitutes nor complements.

Our finding of negative beer-tax effects is similar to that reported by Pacula (1998a, 1998b) and Farrelly et al. (1999). Pacula also reports an inverse relation between the drinking age and marijuana participation. DiNardo and Lemieux (1992) report a positive relation between these two variables, and we have no explanation of why their results differ from ours. Chaloupka et al. (1999) and Farrelly et al. (1999) contain evidence of either no relation or complementarity between cigarettes and marijuana. The former study does not, however, control for state fixed effects, and neither study includes a measure of the money price of marijuana.

The effects of the individual and family characteristics are consistent with those found in the literature and will not be discussed in any detail. Youths with more-educated parents, youths who do not live with both parents, and youths whose mothers worked full- or part-time while they grew up are more likely to have tried marijuana in the past year, while youths who are married or engaged are less likely to have done so. Similar differentials are observed for thirty-day participation.

Hours worked per week, weekly earned income, and weekly other income (primarily income from allowances) have positive coefficients in all demand functions. The earned-income effect would be larger if hours worked were omitted. As already pointed out, the effect of earnings might reflect forces associated with the workplace environment. This comment does not apply to other income, so its coefficients can be attributed to command over real resources. The other-income elasticity of annual participation equals 0.03. While this elasticity is modest, other income accounts for only 22.5 percent of total weekly income. Hence, the corresponding elasticity with respect to total income is 0.13.

On the basis of *t*-ratios, frequent religious-service attendance is the most important correlate of marijuana participation. The ratio of the odds of annual marijuana participation for those who attend services frequently compared to those who do not of 0.36 is dramatic. Evaluated at sample means, the probability of annual marijuana participation for a youth who

22. A two-tailed test is appropriate because the sign of the coefficient is ambiguous in theory.

never attends religious services is 0.41, while the probability for a youth who attends these services frequently is 0.21. A similar pattern is observed for thirty-day participation.

Since there is no cross-sectional variation in potency, we also explored a specification in which potency was deleted from the set of independent variables and dichotomous indicators for each of the twelve years from 1985 through 1996 were included. This logit equation was forced through the origin. The results (not shown) are very similar to those in the specifications with the quadratic time trend in tables 6.6 and 6.7 and produce similar elasticity estimates.

Following Moulton (1986), we regressed the coefficients of the time dummies on potency. These regressions, which contained twelve observations, were weighted by the square root of the inverse of the standard errors of the coefficients of the time dummies. The potency coefficient was positive and not significant, suggesting that the time effects cannot be explained by the trend in potency. A positive and insignificant potency effect also emerges from the model with the quadratic trend. These findings imply that the most flexible trend specification adds little to the quadratic specification.

Table 6.8 contains selected coefficients from annual- and thirty-day-participation logit equations that include the index of perceived risk of harm from the regular use of marijuana (harm) and peer marijuana use in specifications that are otherwise the same as those in tables 6.6 and 6.7 above. The sample size is reduced by approximately 50 percent when the harm index is included because it is not included on all MTF forms. When the models excluding harm and peer marijuana use in tables 6.6 and 6.7 were estimated on the smaller sample, the coefficients of the variables in the price vector were almost identical to those presented in the tables.

The models in table 6.8 show that harm and peer marijuana use are highly correlated with marijuana participation. An increase in the perceived risk of harm significantly lowers the probability of participation, while an increase in peer marijuana use significantly raises this probability. Evaluated at sample means, the marginal effect of an increase in peer marijuana use on the probability of marijuana use in the past year is approximately equal to 0.55 in each of the three models. In other words, if the fraction of peers who used marijuana rose from 0.31 (the sample mean) to 0.47 (a one-standard-deviation increase), the probability that a youth used marijuana in the past year would rise from 0.31 to 0.39. Similar effects are observed for thirty-day participation.

Not surprisingly, the significant price effects are reduced in absolute value when harm and peer marijuana use are added to the set of regressors. In discussing this phenomenon, we focus on the models without the quadratic trend term. Unlike the pseudo R^2 measures in tables 6.6 and 6.7 above, those in table 6.8 are the same (to three decimal places) in models

Table 6.8 **Selected Logit Coefficients from Marijuana Participation Equations with Harm and Peer Marijuana Use**

	(1)	(2)	(3)
A. Annual Participation (N = 71,452)			
Marijuana price	−.092	−.064	−.053
	(−6.80)	(−4.65)	(−3.37)
Marijuana potency	−.134	−.008	−.035
	(−6.26)	(−.26)	(−1.14)
Harm	−1.100	−1.104	−1.103
	(−65.64)	(−65.89)	(−65.92)
Peer marijuana use	4.498	4.484	4.383
	(30.59)	(30.14)	(27.97)
Pseudo R^2	.188	.188	.188
Price elasticity[a]	−.210	−.146	−.121
Market price elasticity[a]	−.466	−.322	−.260
B. Thirty-Day Participation (N = 71,478)			
Marijuana price	−.076	−.011	−.029
	(−2.72)	(−.38)	(−.93)
Marijuana potency	−.187	−.042	−.018
	(−8.29)	(−1.20)	(−.50)
Harm	−1.135	−1.139	−1.140
	(−71.19)	(−71.20)	(−71.24)
Peer marijuana use	5.665	5.647	5.731
	(34.22)	(34.05)	(32.40)
Pseudo R^2	.221	.222	.222
Price elasticity[a]	−.102	−.014	−.040
Market price elasticity[a]	−.694	−.093	−.292

Note: All equations include state dummies, real cigarette and beer taxes, minimum legal drinking age, and the family and individual characteristics contained in the equations in tables 6.6 and 6.7. Asymptotic t-ratios are given in parentheses. Huber (1967) or robust standard errors on which they are based allow for state/year clustering.

[a]Evaluated at sample means.

with and without the quadratic trend. The coefficients on the time-squared variable in model 3 are almost 90 percent smaller than the corresponding coefficients in tables 6.6 and 6.7. The coefficients of time itself in model 3 are over more than 70 percent smaller than the same coefficients in the third model in tables 6.6 and 6.7. While the inclusion of the square of time has a dramatic effect on the coefficient of time in table 6.6, it has less of an effect in the specifications contained in table 6.8. These results imply that the quadratic trend specification adds little in equations that include harm and peer marijuana use.

The price elasticities of marijuana participation in table 6.8 are smaller than those contained in tables 6.6 and 6.7. The estimates in table 6.8, however, hold peer participation constant. When the price of marijuana falls, peer participation increases. Thus, there is both a direct effect of price on participation with peer participation held constant and an indirect effect that operates through peer participation. The price elasticity of the market demand function for participation incorporates both effects.

Let ε be the price elasticity of the demand function that holds peer participation constant, and let α be the marginal effect of peer participation. Then the market price elasticity is $\varepsilon/(1 - \alpha)$. The market price elasticity in each of the models is contained in the last row of each panel in table 6.8. The annual-participation market price elasticities range from −0.466 to −0.260, while those for thirty-day participation range from −0.694 to −0.093. These estimates are larger than the corresponding values in tables 6.6 and 6.7, with the exception of the second model for thirty-day participation. They suggest that the market price elasticity may be underestimated when it is obtained by simply excluding peer participation from the demand function. This conclusion is very tentative given the likely endogeneity of the peer-marijuana-use measure.

We conclude this section by evaluating the contribution of key determinants to the reduction in marijuana participation between 1982 and 1992 and to the expansion in participation since 1992. National values of marijuana participation and the determinants considered in 1982, 1992, and 1998 are shown in table 6.9. Our analysis is based on the three models in tables 6.6–6.8 above.

Before the results are presented, a number of comments on the computations that underlie them are in order. First, the figures in table 6.10 pertain to a period that is longer than the one spanned by the repeated cross sections. Results for the 1985–92 contraction and the 1992–96 expansion are, however, very similar to those reported in table 6.10. Second, the percentage of youths who used marijuana in the past year or the past thirty days (the probability of participation multiplied by 100) are nonlinear functions of their determinants in the logit functions. Given this and our aim to isolate the contribution of specific variables, we base our computations on linear-probability-of-participation equations estimated by ordinary least squares. Marginal effects that emerge from the logit equations are very similar to the corresponding regression coefficients in the linear-

Table 6.9 **National Values of Selected Variables, 1982, 1992, and 1998**

Variable	1982	1992	1998
Annual prevalence of marijuana use	44.30	21.90	37.50
Thirty-day prevalence of marijuana use	28.50	11.90	22.80
Harm	2.45	2.70	2.37
Marijuana price	1.83	6.16	5.19
Marijuana potency	4.95	3.84	5.88

Table 6.10 Percentage Point Effects of Selected Variables on Marijuana Participation

Model Number[a]	(1)	(2)	(3)	(4)	(5)	(6)
			A. Annual Participation			
		1982–92, Observed Change in Participation = −22.40				
Marijuana price	−12.74	−9.18	−.22	−18.89	−13.04	−10.53
Marijuana potency	−3.92	−6.73	−.06	4.46	.32	.97
Harm				−9.85	−9.87	−9.65
Total predicted change	−16.66	−15.91	−.28	−24.28	−22.59	−19.21
		1992–98, Observed Change in Participation = 15.60				
Marijuana price	2.84	2.05	.05	4.21	2.91	2.35
Marijuana potency	7.20	12.36	.10	−8.19	−.59	−1.78
Harm				13.05	13.08	12.78
Total predicted change	10.04	14.41	.15	9.07	15.40	13.35
			B. Thirty-Day Participation			
		1982–92, Observed Change in Participation = −16.60				
Marijuana price	−7.86	−5.54	−.04	−13.56	−.99	−7.10
Marijuana potency	−3.44	−5.56	.23	8.31	1.56	.89
Harm				−16.22	−16.23	−16.63
Total predicted change	−11.30	−11.10	.19	−21.47	−15.63	−22.84
		1992–98, Observed Change in Participation = 10.90				
Marijuana price	1.75	1.24	.01	3.02	.22	1.58
Marijuana potency	6.32	10.22	−.43	−15.28	−2.86	−1.64
Harm				21.48	21.51	22.03
Total predicted change	8.07	11.46	−.42	9.22	18.87	21.97

[a]Models 1, 2, and 3 are based on the specifications in tables 6.6 and 6.7 above. These specifications exclude harm and peer marijuana use. Model 1 omits a trend. Model 2 includes a linear trend. Model 3 includes a quadratic trend. Models 4, 5, and 6 are based on the specifications in table 6.8 and on coefficients that take account of the effect of a given variable on peer marijuana use. Model 4 omits a trend. Model 5 includes a linear trend. Model 6 includes a quadratic trend.

probability equations. The same comment applies to elasticities at sample means in the logit and linear-probability models.

Third, given our focus on marijuana price, potency, and harm, we exclude the individual and family characteristics, the cigarette and beer taxes, and the minimum legal drinking age from the computations, although the regressions from which they are derived include these variables.

Finally, the computations based on regressions that include peer marijuana use employ coefficients from the market demand function. These are coefficients that hold peer participation constant divided by 1 minus the coefficient of peer participation. This is appropriate because basic determinants may have important indirect effects operating through peer participation. Moreover, at the national level, the mean value of peer participation coincides with the fraction of high school seniors who used marijuana.

Clearly, one does not want to hold this variable constant when examining national trends in participation.

Models 4, 5, and 6 in table 6.10 allow one to compare the predicted effects of changes in the real quality-adjusted price of marijuana and the perceived risk of harm from regular use on participation, holding all else constant. An average of the components in these three models suggests that changes in the quality-adjusted price predict approximately 55 percent of the 50 percent decline in the annual participation rate between 1982 and 1992. The changes in harm predict more than 40 percent of this decline. The comparable estimates for the nearly 60 percent decline in thirty-day participation during this period are 22 percent for quality-adjusted price and nearly 100 percent for harm.

With regard to the recent expansion in marijuana participation, changes in quality-adjusted price appear to have little predictive power in explaining the increases in use, largely because of the opposing effects of price and potency on participation during this period. If the effects of potency are ignored (given the insignificant effects of potency in the models including time trends), the changes in the real price of marijuana predict about 20 percent of the approximate doubling in the annual participation rate between 1992 and 1998 and approximately 15 percent of the somewhat larger increase in the thirty-day participation rate. The observed changes in harm predict over 80 percent of the growth in annual participation but imply more than double the observed increases in thirty-day participation.

We interpret these estimates as generally similar to those based on the time-series regressions in section 6.3 above. It should be kept in mind that these estimates are biased and perhaps overstated if the coefficient of the endogenous peer-marijuana-participation measure is biased upward.

One additional aspect of the results in table 6.10 is worth mentioning. The price components (not adjusted for quality) in models 1, 2, and 3, which exclude harm and peer participation, are usually smaller than the corresponding components in models 4, 5, and 6. This is not surprising and is consistent with our finding that the market price elasticity obtained from a demand function that includes peer participation is larger than the elasticity obtained by omitting peer participation as a regressor.

6.5 Discussion

Our most important contribution in this paper is to present the first estimates of the price elasticity of demand for the prevalence of marijuana use by high school seniors. Our estimates of this parameter span a fairly wide range (from −0.06 to −0.47) for annual participation and a similarly wide range (from −0.002 to −0.69) for thirty-day participation. These wide ranges can be attributed to a variety of factors. The price and potency variables are subject to considerable measurement error. Pronounced trends in price and several other key determinants make it difficult to sort out their effects from those due to unmeasured time effects. Indeed, it may be inappropriate to include trend terms since we have very good proxies for hard-to-measure variables in a short time series. Peer marijuana participation and perceptions concerning the risk of harm from regular marijuana use have large effects on the probability of participation. Yet these two variables potentially are endogenous, and their coefficients, as well as those for price, may be biased. Given these considerations, a conservative lower-bound estimate of the price elasticity of demand for marijuana participation is -0.30.

Our estimates imply that cycles in the real (inflation-adjusted) price of marijuana and in the perceived risk of harm from regular marijuana use contribute to an understanding of cycles in the number of high school seniors who use marijuana. The estimation of the relative effects of price and harm is complicated by a variety of factors. Price and potency are measured with error. Several key determinants are endogenous. Attitudinal variables other than a single indicator of perceived risk of harm from regular marijuana use and other potentially important variables that are correlated with harm and price have been omitted. In addition, analyses of different time periods could produce somewhat different estimates; the analyses contained in this paper (given the limited data available on price) begin in 1982, several years after the start of the downturn in marijuana use and the substantial rise in perceived risk that preceded it. Given these considerations, we have provided a wide range of estimates. These estimates clearly imply that changes in the real, quality-adjusted price of marijuana contributed significantly to the trends in youth marijuana use between 1982 and 1998, particularly during the contraction in use from 1982 to 1992. Similarly, changes in youth perceptions of the harms associated with regular marijuana use had a substantial effect on both the contraction in use during the period 1982–92 and the subsequent expansion in use after 1992.

As clearly described above, our estimates of the magnitudes of the price and attitudine effects are subject to significant variation and should not be considered definitive. Research that focuses on outcomes other than annual and thirty-day participation and that employs a wider range of attitudine measures, better data on price and potency, and additional measures of the full price of youth marijuana use is required to provide a more complete understanding of the relative effect of price and attitudes on youth marijuana use. Similarly, studies that construct and estimate structural models that treat peer behavior, risk perceptions, and marijuana-consumption decisions as endogenous deserve high priority in future investigations. These studies would be especially valuable if they could identify the basic forces that cause attitudes and perhaps price and potency to vary. In the absence of this research, and as a prelude to it, the main message of this paper is that it is useful to consider price in addition to more traditional determinants in any analysis of marijuana-consumption decisions made by youths.

Appendix

In this appendix, we examine problems that arise when the marijuana arrest rate (marijuana-possession arrests divided by population) replaces the probability of arrest (arrests divided by the number of marijuana users) in the demand function for the probability of marijuana participation. We assume that the probability of use of a representative individual or the number of users divided by the population (u) at the aggregate level depends on the probability of arrest (π):

$$u = u(\pi), \partial u/\partial \pi < 0. \tag{A1}$$

Note that we do not distinguish between the probability of arrest and the probability of conviction given apprehension and ignore components of the full price of marijuana other than π.

If a is the arrest rate (arrests divided by population), then

$$a = u\pi. \tag{A2}$$

From equation (A1),

$$\partial \ln u/\partial \ln a = (\partial \ln u/\partial \ln \pi) \times (\partial \ln \pi/\partial \ln a). \tag{A3}$$

Define the elasticity of u with respect to π as

$$\varepsilon \equiv \partial \ln u/\partial \ln \pi. \tag{A4}$$

Note that ε is analogous to the price elasticity of demand. As we have defined this elasticity, it is negative. From equation (A2),

$$(\partial \ln a/\partial \ln \pi) = 1 + \varepsilon. \tag{A5}$$

An increase in the probability of arrest increases the arrest rate if ε is smaller than 1 in absolute value but decreases the arrest rate if ε exceeds 1 in absolute value. This is perfectly analogous to the effect of an increase in price on total revenue. Revenue rises if the price elasticity of demand is less than 1 in absolute value and falls if the price elasticity of demand exceeds 1. Of course, this is because the arrest rate corresponds to total revenue and the probability of arrest corresponds to price. The arrest rate is a *positive* correlate of the probability of arrest if $-\varepsilon < 1$, but the arrest rate is a *negative* correlate of the probability of arrest if $-\varepsilon > 1$. For $-\varepsilon = 1$, there is no relation between these two variables; an increase in π lowers u but has no effect on a.

From equations (A4) and (A5),

$$\text{(A6)} \qquad \phi \equiv (\partial \ln u / \partial \ln a) = \varepsilon/(1 + \varepsilon).$$

In other words, a regression of ln u on ln a gives an estimate of $\phi = \varepsilon/(1 + \varepsilon)$. The parameter ϕ is negative if ε is smaller than 1 in absolute value, while ϕ is positive and greater than 1 if ε is greater than 1 in absolute value.

Given ϕ, one can obtain ε from

$$\text{(A7)} \qquad \varepsilon = \phi/(1 - \phi).$$

This shows why ϕ must exceed 1 if it is positive. Given $\phi > 0$, ε is negative if and only if $\phi > 1$. Put differently, the theory places restrictions on the value of ϕ.

To explore estimation issues in more detail, consider a demand function for u that is linear in the ln u and ln π:

$$\text{(A8)} \qquad \ln u = \varepsilon \ln \pi + x,$$

where x stands for an unobserved factor or the disturbance term in the regression. Other observed determinants are suppressed. Since $\ln \pi = \ln a - \ln u$,

$$\text{(A9)} \qquad \ln u = [\varepsilon/(1 + \varepsilon)]\ln a + [1/(1 + \varepsilon)]x.$$

With π held constant, an increase in x raises u by assumption. But, with a held constant, an increase in x raises u only if ε is smaller than 1 in absolute value. The reason is that the only way to fix a when u varies is for π to vary. Indeed, since $\ln a = \ln u + \ln \pi$,

$$\text{(A10)} \qquad \ln a = (\varepsilon + 1)\ln \pi + x.$$

With π held constant, x and a are positively related; unmeasured factors that increase use will also increase arrests. This is the intuition behind the proposition that the coefficient of ln a is biased upward because arrests are high when use is high. Arrests and x are positively related, but the coefficient of the omitted variable x is positive only if ε is smaller than 1 in absolute value. In that case, the estimate of ϕ, which is a negative parameter, is biased upward. When $-\varepsilon > 1$, the coefficient of the omitted variable x is negative. Hence, the estimate of ϕ, which now is a positive parameter that exceeds 1, is biased downward. Indeed, since the coefficient of x on ln a is normalized at 1, the expected value of the coefficient of ln a in the demand function is equal to 1 regardless of the value of ε.

So far we have assumed that π is exogenous. Now we follow Ehrlich (1973) and specify a production function for the probability of apprehension and conviction:

(A11) $$\ln \pi = \alpha \ln g + \beta \ln u + y.$$

The new variable, g, stands for resources allocated to police and courts, and α is positive. The variable y stands for an unmeasured determinant. Ehrlich assumes that β is negative. He argues that the productivity of g is likely to be lower at higher levels of criminal activity because more offenders must then be apprehended, charged, and tried in court in order to achieve a given level of π. Thus, with g held constant, u and π might be negatively correlated, but the causality runs from u to π.

Since $\ln \pi = \ln a - \ln u$,

(A12) $$\ln a = \alpha \ln g + (\beta + 1)\ln u + y.$$

The coefficient of $\ln u$ is positive if $-\beta < 1$ and negative if $-\beta > 1$. For $-\beta = 1$, the coefficient is 0. Consider equations (A9) and (A12) as a simultaneous system with two endogenous variables: u and a. From equation (A12), the estimate of ϕ is biased upward if $-\beta < 1$ both because of reverse causality from an increase in u to an increase in a and because of the positive correlation between x and a. When $-\beta > 1$, these two biases go in opposite directions.

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