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ALCOHOL, MARIJUANA, AND AMERICAN YOUTH: THE UNINTENDED EFFECTS OF GOVERNMENT REGULATION

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ABSTRACT

This paper analyzes the impact of increases in the minimum drinking age on the prevalence of alcohol and marijuana consumption among high school seniors in the United States. The empirical analysis is based on a large sample of students from 43 states over the years 1980-1989. We find that increases in the minimum drinking age did reduce the prevalence of alcohol consumption. We also find, however, that increased legal minimum drinking ages had the unintended consequence of *increasing* the prevalence of marijuana consumption. We estimate a model based on the canonical theory of the consumer. Estimates from this model suggest that this unintended consequence is attributable to standard substitution effects.

The estimates of the structural model also suggest that an increased drinking age helps create a climate of societal disapproval for all drug use, not only alcohol. We find that, holding the consumption of alcohol constant, an increase in the drinking age reduces the prevalence of marijuana consumption. This effect is not large enough, however, to offset the large substitution toward marijuana induced by the decreased prevalence of alcohol consumption.

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1 Introduction

Evaluating any rational drug policy requires consideration of the policy's intended and unintended effects. A drug policy that successfully discourages heavy drinking at the expense of increased abuse of crack cocaine would presumably be less desirable to a majority of persons than a policy that discourages heavy drinking but *does not* lead to an increased use of cocaine. Almost without exception, however, studies of the "cost" of alcohol abuse or of drug abuse implicitly consider the use of psychoactive substances in isolation [6]. As such studies play an important role in the development of U.S. drug policy [7] it is useful to consider whether policies intended to discourage alcohol use, for example, might also affect the use of other drugs.

The canonical theory of the consumer suggests that policies which successfully ration demand for one drug may generate (an unintended) increased demand for another, if, for example, the two drugs are substitutes. Contemporary epidemiological research on abusable substances, however, is remarkably silent on the issue of the extent of substitutability or complementarity of alcohol and other drugs. Taylor [14],for instance, reports that at the request of *The U.S. Journal of Drug and Alcohol Dependence*, the National Institute of Alcoholism and Alcohol Abuse (NIAAA) recently searched over 70,000 research papers for evidence on substitution and found nothing.

In this paper, we begin to fill this substantial gap by considering the joint consumption of alcohol and marijuana. In particular, we evaluate the effect of a specific government intervention — the minimum legal drinking age — on the consumption of both substances in a simple demand theoretic framework. To the best of our knowledge, this paper is the first to consider consumption of these two goods simultaneously in an economic framework.

Using data from a large series of cross-sections on the alcohol and marijuana consumption of high school seniors, we find that the legal drinking age did indeed have an impact on the consumption of both alcohol and marijuana. As in previous studies in the epidemiology of alcohol use, we find that higher minimum legal drinking ages reduced the prevalence of alcohol use. We also find, however, that this decrease in the prevalence of alcohol use was accompanied by an *increase* in the prevalence of marijuana use.

As a more general proposition, we find that it is not sufficient to consider the consumption of these goods independently. By working with the standard model of the consumer, we develop a statistical model that allows us to evaluate the impact of these interventions jointly and provides a coherent explanation of the mechanisms by which the legal minimum drinking age affects the decision to use both alcohol and marijuana.

2 Related evidence on the relationship between alcohol and marijuana

The proposition that alcohol and marijuana may satisfy similar needs and that as a consequence restricting the consumption of one may lead to increases in the consumption of the other is not new. In the United States, the leading example of such a phenomenon is the passing of the Eighteenth Amendment and the Volstead Act of 1920 which together made the sale and production of alcohol illegal. Several authors [3, 13] have argued that Prohibition led to the first signs of "large scale marketing of marijuana for recreational use." [3] The evidence comes from reports of the sudden appearance of marijuana "tea pads" in New York City in 1920. These tea pads were tolerated much as alcohol speakeasies were tolerated, although prices for marijuana were reported to be very low compared to alcohol. [3].

Other evidence comes from a study of a "natural experiment". In September 1969, the Nixon Administration launched an ambitious and highly publicized attempt to restrict the flow of marijuana from Mexico. Named "Operation Intercept," it was reportedly the largest "peacetime search and seizure operation by civil authorities" [11]. Timed to coincide with the marijuana harvest, the effort lasted for 10 days until protest from Mexico and other Latin American countries about the damage to tourism, commerce, and civil liberties led the government to suspend operations. Three UCLA researchers later conducted a study of marijuana users to see what impact, if any, Operation Intercept had on the consumption of marijuana and other drugs[9]. Of the 50 percent of students and clients to the "Free Clinic" who reported that the operation led to a decline in their normal consumption of marijuana, over 50 percent reported that they increased their consumption of alcohol.

Additional evidence comes from a more recent clinical study of 16 subjects by Mello and Mendelson [10]. Young men were at different times allowed to earn money that they could devote to marijuana only, alcohol only, and then alcohol and marijuana in combination. In 14 of the 16 cases, the subjects consumed significantly less alcohol when both alcohol and marijuana were concurrently available.

3 The Data

3.1 Monitoring the Future

The data we use, the Monitoring the Future data (henceforth MTF), is in many respects uniquely well suited to the present study. Since the data collection is described well in other published work [1] only a brief synopsis is provided here. MTF is a representative sample of high school seniors from high schools across the United States. The survey instrument has questions on demographic characteristics, family background, and legal and illegal drug use. It utilizes a multi-stage cluster sampling procedure which is designed to produce a sample representative in terms of sex, SMSA, and the broad (4 category) census regions. Since MTF was intended, *inter alia*, to collect information on illegal drug use, extra attention was paid to ensure informative responses to obviously sensitive questions. A typical year has answers from 15,000 individuals, and the data set we use in this paper has information on the responses of over 156,000 individuals covering the years 1980-1989.

One deficiency of the public use version is the lack of state of residence codes (only codes for the broad census regions are included). As a safeguard for confidentiality of the respondents, data with these codes are not generally made available to researchers. However, for this project, the authors of Monitoring the Future have graciously provided us with state-year tabulations of a subset of the variables in the data set, and it is these tabulations that comprise the data we analyze in this paper. Although individual-level data have several advantages, the state-year cross-tabulations are adequate for the purposes in this paper as the variation in the key variables of interest (the minimum drinking age and the "decriminalization" status of marijuana) vary at only at the state level. The data for this paper is described in more detail below.

3.2 The Minimum Legal Drinking Age.

In April of 1982, the Reagan Administration established a Presidential Commission on Drunken Driving. By 1983, the commission had produced a final report which, among other things, recommended that the minimum age for purchase and public possession of any alcoholic beverage be increased from 18 to 21. The majority of members of Congress were sympathetic to this particular recommendation and subsequently enacted legislation that restricted provision of federal highway trust funds to states that did not enact a minimum drinking age law. As a consequence, states raised their drinking age limits and by 1988 all states had a 21-year-old legal minimum. Our focus is on changes in the legal minimum induced by these legislative actions and as a consequence we restrict our attention to the roughly balanced set of transitions before and after this sequence of events. Cook & Tauchen [5], as an example of other studies which make use of the minimum drinking age, consider the effects of the minimum drinking age on youth auto fatalities for the period 1970-1977. Unlike the use of that earlier period, our time frame has the advantage that changes in the legal minimum are less likely to have arisen in direct response to unobserved factors that were changing in states and that also affect alcohol consumption.

Table 1 presents a summary of the changes in the drinking age. Although legal minimums did not increase *immediately* in response to the recommendations of the Presidential Commission or the restrictions on federal funds, it is clear that states rapidly "got the message." [1]

[1] Consistent with our focus on the Presidential Commission recommendations, it should be noted that we are considering the legal minimum for hard liquor. Over this period, a few states had different legal minimums for beer that had less than 3.2 percent alcohol content, wine, and fortified wine. In all cases, the legal minimum for hard liquor was greater than or equal to the legal minimum for other types of alcohol.

Table 1: Drinking Age in 43 Sample States

Number of States In Each Category										
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Age 18	8	6	5	3	2	1	1	1	0	0
Age 19	8	9	10	11	11	10	6	1	0	0
Age 20	4	5	5	5	5	4	1	0	0	0
Age 21	23	23	23	24	25	28	35	41	43	43

3.3 Marijuana Decriminalization

It is also interesting to consider the opposite experiment, that is, the effect of easing restrictions on marijuana consumption. Some states and localities have "decriminalized" marijuana. This is clearly not the same as "legalizing" marijuana. In fact, the status of marijuana in decriminalized states most closely resembles the status of alcohol during Prohibition. In all cases, the decriminalization statutes define the consumption of marijuana as a crime, although the penalties are small, and in some states marijuana is only a misdemeanor offense rather than a felony.

There is considerably less variation in laws regarding consumption of marijuana. In particular, over this period only 11 states had decriminalization statutes, and the majority of these were enacted by the beginning of the sample

Table 2: Enactment of Decriminalization Statutes in the Sample

States with decriminalization statutes by May, 1976
California, Colorado, Maine, Minnesota, Missouri, Ohio, Oregon
States with decriminalization statutes by May, 1978
North Carolina, New York
States with decriminalization statutes by May, 1979
Nebraska

period. Table 2 summarizes the relevant statutes and when they are enacted. To the extent that we are able to identify the effect of decriminalization, it is from intra-region variation. Consequently, we restrict our attention primarily to the effect of the legal minimum drinking age.

3.4 Descriptive Analysis

Our raw data are the state-year cross-tabulations of a series of demographic characteristics, the state unemployment rate, the state drinking age laws, the presence or absence of a decriminalization statute, a series of geographic and year dummy variables, a regional time series for alcohol prices (the regional CPI for all alcoholic beverages) and a two-by-two contingency table of the number of students who have had only alcohol in the last 30 days, only marijuana in the last 30 days, both alcohol and marijuana in the last 30 days, or neither in the last 30 days. For this study, we were not able to locate a useful regional time series for marijuana prices. The mostly widely cited source of prices, the Drug Enforcement Administration's *Illegal Drug Wholesale and Retail Price Report*, presents the data in extremely broad ranges, too broad to be useful for the current study. The best we are able to do is hope that the inclusion of region and year dummies will absorb the effect of changes in the price of marijuana.

For most states, we have complete data for all 10 years. For some states, we have fewer than 10 years, and for others we have no observations. In all, 43 of the 50 states and the District of Columbia are covered for some portion of the sample period. Table 3 presents the summary statistics for our sample. In our sample, 25% report having smoked marijuana in the last 30 days. The corresponding number for alcohol is 66%. The other variables in Table 3 come from the MTF survey except for the state unemployment rate which we get from tabulations of the Current Population Survey.

Table 4 provides a summary of the raw data for analysis which are the cross-tabulations of alcohol and marijuana participation in the last 30 days. The majority of students are alcohol–only consumers, although of those who consume alcohol 35% have also consumed some marijuana in the last 30 days. A very small minority of the sample, 1.3%, report having consumed only marijuana and 31.7% have consumed neither.

Table 5 presents three different measures of correlation between alcohol and drug use. The first measure is the correlation across both years and states. The

Table 3: Summary Statistics of the *Monitoring the Future Survey* : 1980–1989

Variable	Mean	Std. Dev.	Variable	Mean	Std. Dev.
Used alcohol last 30 days	0.6697	0.0920	State unemployment rate	0.0738	0.0248
Used marijuana last 30 days	0.2540	0.0823	Northeast	0.2251	0.4182
Drinking age	20.4840	0.9599	Midwest	0.2854	0.4522
Decriminalized marijuana	0.3207	0.4674	South	0.3152	0.4653
% white	0.8668	0.1452	West	0.1733	0.1433
Age < 18	0.0155	0.0129	New England	0.0667	0.2498
Age = 18	0.7211	0.2011	Middle Atlantic	0.1584	0.3657
Age > 18	0.2634	0.0814	East North Central	0.2044	0.4039
% male	0.4911	0.0510	West North Central	0.0809	0.2731
% in SMSA	0.7047	0.2844	South Atlantic	0.1636	0.3704
Father education less than HS	0.1953	0.0757	East South Central	0.0548	0.2279
Father education High School	0.2986	0.2094	West South Central	0.0969	0.2962
Father education more than HS	0.4534	0.1252	Mountain	0.0446	0.2068
Father not present	0.0527	0.0270	Pacific	0.1296	0.3364
Mother education less than HS	0.1683	0.0703			
Mother education High School	0.3952	0.2390	Weekly hours of work	14.7508	1.9189
Mother education more than HS	0.4085	0.1127	Job income (100$ 1981)	0.3586	0.0644
Mother not present	0.0280	0.0145	Other income (100$ 1981)	0.1014	0.0216

Average observations per cell 437.73
State/year cells 357
Total observations 156,268

Table 4: Prevalence of Drug Use over the Last 30 Days

		Marijuana	
		yes	no
Alcohol	yes	.2410	.4288
	no	.0130	.3172

second measure is the correlation across time, which is 93%. That is, years that are associated with high marijuana use are also associated with high alcohol use. The third measure is the correlation across states. Although much lower at 58%, this measure indicates that states which are associated with high levels of marijuana use are also associated with high levels of alcohol use. Note that these raw correlations do not provide *prima facie* evidence for substitution. Of course, they are not definitive evidence against substitution either, but might merely indicate the presence of some factor that is positively correlated with both the propensity to consume alcohol and marijuana.

Table 5: Correlation Between Alcohol and Marijuana Use

Raw correlation of prevalence of alcohol and marijuana use 0.6200
Correlation across years of prevalence of alcohol and marijuana use 0.9353
Correlation across states of prevalence of alcohol and marijuana use 0.5829

4 The Model

In this section, we develop a utility maximizing model of the joint decision to consume alcohol and marijuana. The model formalizes the definition of substitution between alcohol and marijuana using standard tools from the neoclassical theory of the consumer. In particular, we show that the substitution hypothesis generates testable implications in an econometric model of the joint decision to consume alcohol and/or marijuana.

4.1 Maximization Problem

The preferences of a teenager are represented by a utility function separable in a composite consumption good q_0 and a 2-tuple (q_a, q_m) of psychoactive substances:

$$G(q) = u(q_0) + v(q_a, q_m) \tag{1}$$

where q_a is the quantity of alcohol consumed and q_m is the quantity of marijuana consumed. The sub-utility function $v(q_a, q_m)$ is assumed to be quadratic in q_a and q_m:

$$v(q_a, q_m) = \gamma_0 + \gamma_a q_a + \gamma_m q_m + \gamma_{am} q_a q_m + (\frac{\gamma_{aa}}{2}) q_a\ 2 + (\frac{\gamma_{mm}}{2}) q_m\ 2. \tag{2}$$

This quadratic specification can be viewed as a local approximation of an arbitrary utility function. The parameter γ_{am} determines whether alcohol and marijuana are Frisch substitutes ($\gamma_{am} < 0$) or Frisch complements ($\gamma_{am} > 0$). [2] The parameters γ_a and γ_m) represent the marginal utility of alcohol and marijuana respectively when $q_a = q_m = 0$. The curvature parameters γ_{aa} and γ_{mm} are negative in the usual case where the marginal utilities decline in consumption. The teenager also faces the following budget constraint:

$$I = q_0 + p_a q_a + p_m q_m \tag{3}$$

where I is total income, p_a is the price of alcohol and p_m is the price of marijuana. The teenager's problem can be stated as:

$$\max_q G(q) \qquad \text{s.t.}$$

[2]See Browning et. al. [4] for a discussion of the properties of Frischian demand functions.

$$
\begin{aligned}
I &= q_0 + p_a q_a + p_m q_m \\
q_a &\geq 0 \\
q_m &\geq 0.
\end{aligned}
$$

The solution to this program is characterized by the Kuhn-Tucker conditions:

$$u'(q_0) - \lambda = 0 \tag{4}$$

$$\gamma_a + \gamma_{am} q_m + \gamma_{aa} q_a - \lambda p_a - \varphi_a = 0 \tag{5}$$

$$\gamma_m + \gamma_{am} q_a + \gamma_{mm} q_m - \lambda p_m - \varphi_m = 0 \tag{6}$$

where λ, φ_a, and φ_m are the Lagrange multipliers corresponding to the constraints $I = q_0 + p_a q_a + p_m q_m$, $q_a \geq 0$, and $q_m \geq 0$ respectively. By complementary slackness:

$$\varphi_a q_a = 0 \tag{7}$$

and

$$\varphi_m q_m = 0. \tag{8}$$

The complementary slackness conditions (7) and (8) yield four possible solutions or regimes to the consumer's problem. Intuitively, the decision to consume alcohol depends on whether the marginal utility of alcohol is larger than the price of alcohol in utility terms (λp_a). The same is true of the decision to consume marijuana. Comparing marginal utilities and prices yields four possible outcomes: abstinence, consume marijuana only, consume alcohol only, or consume both. The following participation conditions are obtained by solving explicitly the Kuhn-Tucker conditions:

Regime 1 (abstinence):

$$\gamma_a < \lambda p_a \tag{9}$$

$$\gamma_m < \lambda p_m \tag{10}$$

Regime 2 (marijuana only):

$$\gamma_a - (\gamma_{am}/\gamma_{mm})\gamma_m < \lambda p_a - (\gamma_{am}/\gamma_{mm})\lambda p_m \tag{11}$$

$$\gamma_m > \lambda p_m \tag{12}$$

Regime 3 (alcohol only):

$$\gamma_a > \lambda p_a \tag{13}$$

$$\gamma_m - (\gamma_{am}/\gamma_{aa})\gamma_a < \lambda p_m - (\gamma_{am}/\gamma_{aa})\lambda p_a \tag{14}$$

Regime 4 (marijuana and alcohol):

$$\gamma_a - (\gamma_{am}/\gamma_{mm})\gamma_m > \lambda p_a - (\gamma_{am}/\gamma_{mm})\lambda p_m \tag{15}$$

$$\gamma_m - (\gamma_{am}/\gamma_{aa})\gamma_a > \lambda p_m - (\gamma_{am}/\gamma_{aa})\lambda p_a. \tag{16}$$

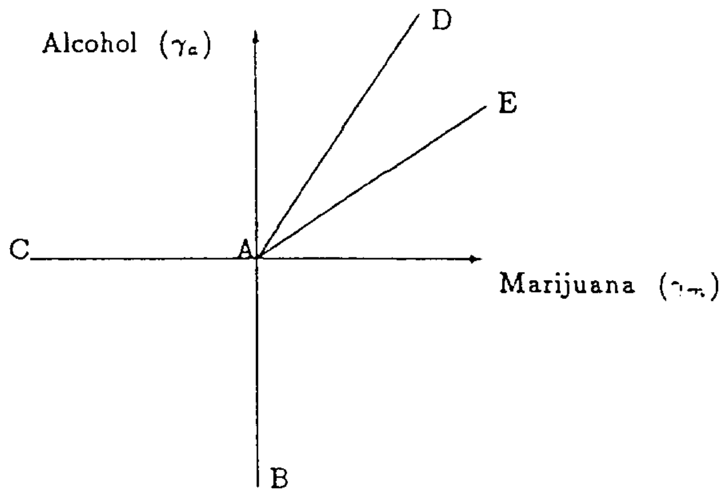
For each regime, these participation conditions are derived by comparing the marginal utility of a good when its quantity consumed is zero to its implicit price evaluated in utility terms. For example, equation (11) is obtained by solving for q_m in the first order condition for marijuana (5). This value is then used in evaluating the marginal utility of alcohol when q_a is equal to zero. Condition

(11) indicates that the resulting value of the marginal utility of alcohol at $q_a = 0$ is lower than its implicit price in utility terms (λp_a). As a result, the teenager does not use any alcohol.

When alcohol and marijuana are separable ($\gamma_{am}=0$), these conditions reduce to the four possible permutations of the inequalities $\gamma_a < \lambda p_a$ and $\gamma_m < \lambda p_m$. Participation conditions of this type might also be obtained by specifying a non-structural discrete choice model in which the decision to consume alcohol and marijuana are each determined by a threshold equation. When the disturbance term in each threshold equation is normally distributed, this "two-threshold" model reduces to a bivariate probit model [8]. Such a model has important limitations that will be discussed below.

The participation conditions are more complex when alcohol and marijuana are either substitutes or complements, since the marginal utility of consuming one good now depends on the amount of the other good being consumed. In Figure 1, the participation conditions are illustrated in the case where alcohol and marijuana are substitutes ($\gamma_{am} < 0$). The line BAD defines the threshold that the marginal utility of marijuana, γ_m, at $q_a = q_m = 0$ has to exceed for the teenager to consume a positive amount of the substance. CAE defines a similar threshold for alcohol. The segment AD of the threshold curve for marijuana is positively sloped (γ_{aa}/γ_{am}) because the teenager also consumes a positive amount of alcohol in that region of the graph. More specifically, the larger alcohol consumption is, the larger the marginal utility of marijuana has to be

Figure 1: Alcohol and Marijuana are Substitutes



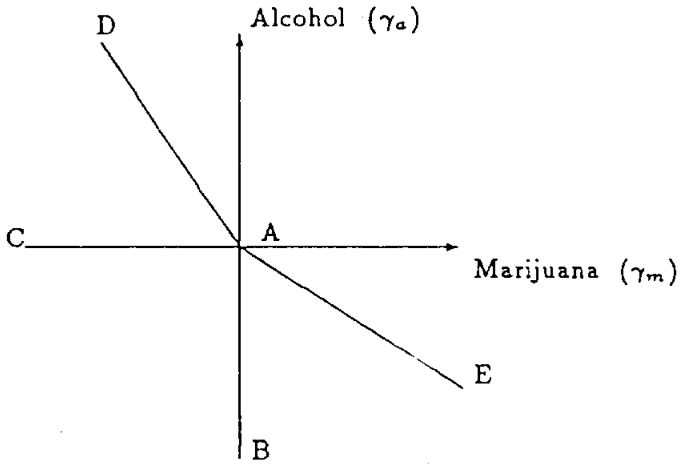
for the teenager to consume some of it, everything else being equal. The point is that the "marginal need" for marijuana declines as the consumption of a highly substitutable substance, alcohol, increases.

The case in which alcohol and marijuana are complements is illustrated in Figure 2. The segments AD and AE are negatively sloped since the threshold for consuming one substance goes down as the consumption of the other complementary substance increases.

4.2 Comparative Statics: Effects of Prices and Drinking Age Laws

Drinking age laws never eliminate completely alcohol consumption of under aged youth. It is thus useful to model a change in the drinking age as a change in the

Figure 2: Alcohol and Marijuana are Complements



implicit price of alcohol, p_a, which affects alcohol consumption through standard substitution and income effects. Alternatively, higher minimum drinking ages might reduce the marginal utility of alcohol at any level of consumption (social disapproval, guilt, etc.). These two channels are conceptually different but have very similar implications for the decision to consume alcohol or marijuana.

Formally, the decision to consume alcohol (or marijuana) depends on inequalities like $\gamma_a < \lambda p_a$ (as in equation (9) for example). A 1% increase in λp_a has the same effect on the inequality as a 1% reduction in γ_a. In the special case where λ, the marginal utility of income, is a constant, changes in λp_a are solely driven by changes in the implicit price p_a, so that a 1% increase in the implicit price has the same impact as a 1% reduction in the marginal utility at zero, γ_a. When λ is constant, the effects of the drinking age that operate through p_a and γ_a cannot be separated empirically. We will thus discuss the results as if drinking age laws have an impact on the implicit price p_a alone. Similarly, drinking age laws can also be interpreted as having an effect on the implicit price of marijuana due to social disapproval effects, for example.

We will thus assume for the remainder of the paper that the marginal utility of income, λ, is parametric with respect to a change in prices.[3] This assumption is not as strong as assuming that the marginal utility of income is a constant as λ may well depend on both labor and non-labor income, as long as it is not a function of prices. In addition, there is little empirical gain in letting λ depend on prices, since the information necessary to estimate a full demand system for alcohol, marijuana, and other goods is not available.[4] Finally, an important fraction of teenager's consumption, in particular food and shelter, is provided by parents or guardians. One interpretation of the assumption that λ is parametric is simply that consumption of other goods is determined outside of the model.

The impact of an increase in drinking age on the decision to consume alcohol and marijuana is illustrated in Figure 3 in the case where alcohol and marijuana are substitutes. For the purpose of this exercise, let γ_a and γ_m be stochastically distributed across people. The fraction of teenagers in the four regimes Absti-

[3]The assumption that the marginal utility of income, λ, is constant has also been used by Becker et. al. [2] in their empirical work on rational addiction.

[4]It should be recalled that we do not have data on marijuana prices or consumption of other goods. Furthermore, we have only measures of the prevalence of alcohol and marijuana consumption, not measures of the quantity consumed. We could otherwise estimate the whole demand system à la Wales and Woodland [15].

nence, Marijuana Only, Alcohol Only, and Both, correspond to the fraction of γ_a and γ_m's drawn in each of the four corresponding regions of Figure 3. The coordinates of Point A in Figure 3 are simply the two threshold points λp_m and λp_a. Consider an increase in the drinking age that raises the price of alcohol, p_a, and shifts the intersection point A up to A'. As a result, the region corresponding to Abstinence increases by the area $CAA'C'$. Similarly, the area for Marijuana Only increases by $EAA'E'$ while the area for Alcohol Only decreases by $CAEE'A'C'$. On the other hand, the area in which the teenager consumes both alcohol and marijuana (EAD) remains of the same size: it simply moves from EAD to $E'A'D'$. Whether the number of teenagers consuming both alcohol and marijuana increases or decreases depend on the distribution function for γ_a and γ_m. All the other effects are unambiguous, irrespective of the distribution function for γ_a and γ_m. The case in which alcohol and marijuana are complements rather than substitutes is illustrated in Figure 4. The predicted effect of an increase in the drinking age is summarized in Table 6:

The key difference between the cases in which alcohol and marijuana are substitutes and complements is the predicted effect on the probability of consuming marijuana only: it is positive when the goods are substitutes, but negative when the goods are complements. The sign of the effect of raising the drinking age on the probability of consuming both alcohol and marijuana is always ambiguous. It can only be determined empirically. Finally, the comparative statics results reported in Table 6 are only valid when drinking age laws do not affect

Figure 3: Comparative Statics: The Case of Substitution

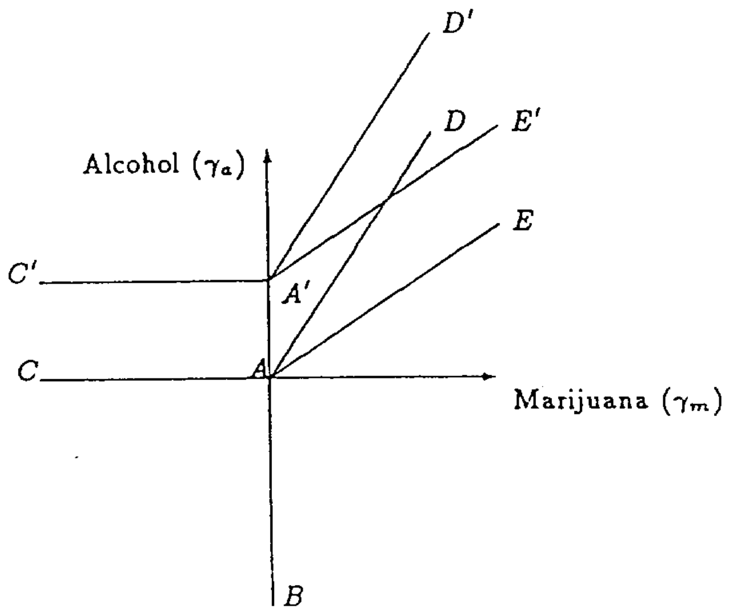


Figure 4: Comparative Statics: The Case of Complementarity

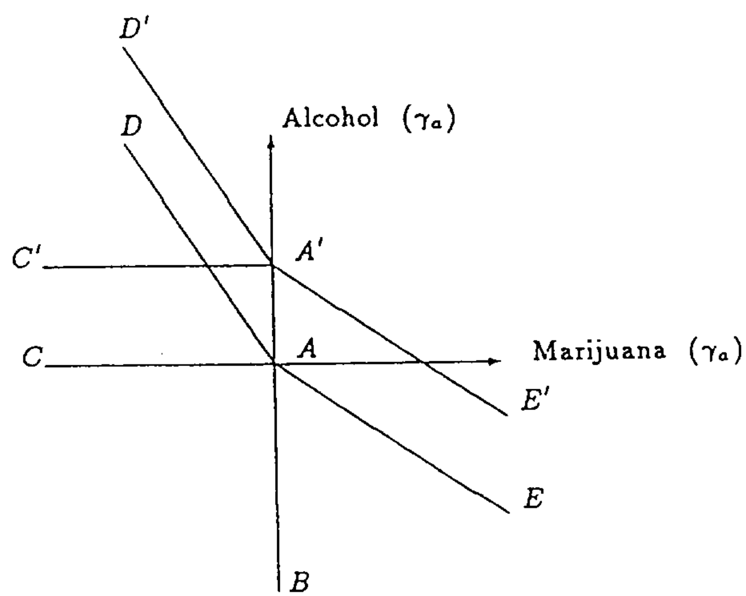


Table 6: Effect of Raising the Drinking Age on the Probability of Abstinence, Marijuana Only, Alcohol Only, and Both

	Alcohol and Marijuana are Substitutes	Alcohol and Marijuana are Complements
Abstinence	+	+
Marijuana Only	+	−
Alcohol Only	−	−
Both	?	?

the implicit price of marijuana, p_m. If increases in drinking age signal disapproval for all drugs, the implicit price of marijuana might increase and offset the substitution effect from alcohol to marijuana.

5 Stochastic Specification

Because of confidentiality issues, only the means of the variables of interest are available by state and by year. The probability model used to estimate the impact of drinking age laws on the prevalence of alcohol and marijuana consumption has to be adjusted accordingly. To simplify the aggregation of choices at the state/year level, we assume that the marginal utilities γ_a and γ_m are normally distributed around their state/year means, and that each teenager faces a deterministic choice problem, conditional on his or her particular draw of γ_a and γ_m. This approach differs slightly from standard random utility models in which choices of a given individual are characterized by a non-degenerate probability distribution.

More specifically, consider γ_{ait} and γ_{mit}, the mean values of γ_a and γ_m for each state i and year t. We assume that γ_{ait} and γ_{mit} are linear functions of a vector of average state characteristics, X_{it}. Dropping the subscripts i and t for convenience, the average marginal utilities are thus defined as follows:

$$\gamma_a = X\beta_a + \epsilon_a \tag{17}$$

$$\gamma_m = X\beta_m + \epsilon_m \tag{18}$$

where ϵ_a and ϵ_m are normally distributed random variables with mean zero. The final assumption used to implement the model in the data is that the marginal utility of income, λ, does not depend on prices but only on income. A first order approximation thus yields:

$$\lambda p_a \approx \alpha_0 \; a + \alpha_I \; aI + \alpha_a \; ap_a \tag{19}$$

$$\lambda p_m \approx \alpha_0 \; m + \alpha_I \; mI + \alpha_m \; mp_m. \tag{20}$$

The stochastic model is obtained by substituting the expressions for $\gamma_a, \gamma_m, \lambda p_c$, and λp_a into the participation conditions derived above. To simplify the algebra, define the following thresholds for the prevalence of alcohol and marijuana consumption:

$$T_a = \lambda p_a - X\beta_a \tag{21}$$

$$T_m = \lambda p_m - X\beta_m. \tag{22}$$

Now substituting the expressions in (19) and (20) into (21) and (22) yields the following linear functions for the thresholds:

$$T_a = Z\theta_a \tag{23}$$

and

$$T_m = Z\theta_m \tag{24}$$

where Z is a vector that contains *both* the covariates X and the price and income variables.

The participation conditions can now be written as follows:

Regime 1 (Abstinence)

$$\epsilon_a < T_a \tag{25}$$

$$\epsilon_m < T_m \tag{26}$$

Regime 2 (Marijuana only)

$$\epsilon_a + (\gamma_{am}/\gamma_{mm})\epsilon_m < T_a + (\gamma_{am}/\gamma_{mm})T_m \tag{27}$$

$$\epsilon_m > T_m \tag{28}$$

Regime 3 (Alcohol only)

$$\epsilon_a > T_a \tag{29}$$

$$\epsilon_m + (\gamma_{am}/\gamma_{aa})\epsilon_a < T_m + (\gamma_{am}/\gamma_{aa})T_a \tag{30}$$

Regime 4 (Both Alcohol and Marijuana)

$$\epsilon_a + (\gamma_{aa}/\gamma_{mm})\epsilon_m < T_a + (\gamma_{am}/\gamma_{mm})T_m \tag{31}$$

$$\epsilon_m + (\gamma_{am}/\gamma_{aa})\epsilon_a < T_m + (\gamma_{am}/\gamma_{aa})T_a \tag{32}$$

The random components ϵ_a, ϵ_m follow a joint normal distribution:

$$\epsilon_a, \epsilon_m \sim N[\underline{0}, \Sigma] \tag{33}$$

where

$$\Sigma = \begin{pmatrix} \sigma_a^2 & \rho\sigma_a\sigma_m \\ \rho\sigma_a\sigma_m & \sigma_m^2 \end{pmatrix}$$

For each state i and year t the probability of being in each of the four regimes is obtained by integrating ϵ_a and ϵ_m over the range defined by the participation conditions. These probabilities are then used to form the following log-likelihood function:

$$\begin{aligned} L = \quad & \textstyle\sum_{it} N_{it}[R_{it}^1 \log \Phi_2(t_{ait}, t_{mit}; \rho) \quad + \\ & R_{it}^2 \log \Phi_2(\tfrac{-t_{ait}+\Psi_a t_{mit}}{s_a}, t_{mit}; \tfrac{-\rho+\Psi_a}{s_a}) \quad + \\ & R_{it}^3 \log \Phi_2(t_{ait}, \tfrac{-t_{mit}+\Psi_m t_{ait}}{s_m}; \tfrac{-\rho+\Psi_m}{s_m}) \quad + \\ & R_{it}^4 \log \Phi_2(\tfrac{-t_{ait}+\Psi_a t_{mit}}{s_a}, \tfrac{-t_{mit}+\Psi_m t_{ait}}{s_m}; \tfrac{\rho(1+\Psi_a\Psi_m)-(\Psi_a+\Psi_m)}{s_a s_m})] \end{aligned}$$

where:

$$
\begin{aligned}
N_{it} &= \text{number of people in state } i \text{ at time } t \\
R^r_{it} &= \text{proportion of people in regime } r, \quad r = 1,2,3,4 \\
t_{ait} &= T_{ait}/\sigma_a \\
t_{mit} &= T_{mit}/\sigma_m \\
S^2_a &= 1 + \Psi^2_a - 2\rho\Psi_a \\
S^2_m &= 1 + \Psi^2_m - 2\rho\Psi_m \\
\Psi_a &= \frac{\gamma_{am}\sigma_a}{\gamma_{mm}\sigma_m} \\
\Psi_m &= \frac{\gamma_{am}\sigma_m}{\gamma_{aa}\sigma_a}.
\end{aligned}
$$

The term in the square bracket can be thought as the contribution of a representative consumer in state i at time t to the log-likelihood function. The contribution of the whole state at time t is then obtained by multiplying the contribution of each consumer by the number of independent consumers, N_{it}, sampled in that state. The assumption that consumers are independent rules out the presence of common factors in the error terms ϵ_a and ϵ_m at the state or at the school level. As long as these common factors are not correlated with the regressors included in the thresholds t_{ait} and t_{mit}, they do not affect the consistency of the estimates obtained by numerically maximizing the log-likelihood function. The presence of common factors does affect, however, inference based on these estimates by overstating the number of degrees of freedom of the model.

The contribution of each state to the likelihood function is thus appropriately adjusted in the estimation to account for that problem. [5]

As is the case with most discrete choice models, the parameters of interest in the log-likelihood function L can be estimated only up to scale. It is easy to show that the following normalizations of the parameters are identified $\frac{\theta_a}{\sigma_a}, \frac{\theta_m}{\sigma_m}, \Psi_m, \Psi_a$, and ρ. The parameter γ_{am}, which determines whether alcohol and marijuana are substitutes or complements holding the marginal utility of income constant, is not identified. It is easy to show, however, that γ_{am} is positive when both Ψ_a and Ψ_m are negative, and negative when Ψ_a and Ψ_m are positive. The test of the substitution hypothesis is thus equivalent to a test that both Ψ_a and Ψ_m are positive.

6 Results

This section analyses the relationship between the enactment of minimum drinking age laws and the prevalence of alcohol and marijuana consumption among high school seniors. The empirical analysis is based on the MTF survey and pro-

[5]Consider P_{it}^r, the predicted probability that a consumer is in regime r, and R_{it}^r, the actual proportion of consumers from the sample who are in regime r. The assumption that consumers are independently distributed implies that $E[(R_{it}^r - P_{it}^r)^2] = \frac{P_{it}^r(1-P_{it}^r)}{N_{it}}$. In the case where $\rho = \Psi_a = \Psi_m = 0$, we found that the actual value of $E[(R_{it}^r - P_{it}^r)^2]$ was on average 8.73 times bigger than its predicted value. This is consistent with the presence of common factors in the error terms ϵ_a and ϵ_m. These common factors imply that the variance of the residual $R_{it}^r - P_{it}^r$ does not vanish as N_{it} goes to infinity. The degrees of freedom of the econometric model were thus adjusted by dividing N_{it} in the log-likelihood function by 8.73. As was noted in the text, the presence of common factors does not affect the consistency of the estimates. Hence, the likelihood function in the text has been derived under the assumption that the ϵ are independently distributed.

ceeds in three steps. First, we compare the prevalence of alcohol and marijuana consumption before and after the enactment of a minimum drinking age of 21 using an event study approach. Second, we introduce covariates and evaluate the robustness of our results by estimating a variety of log-linear models of the probability of consuming alcohol or marijuana. The goal of these first two steps is to provide evidence that the measured effects of the drinking age on the use of alcohol and marijuana do not merely reflect the endogeneity of state drinking age laws. After having established a causal effect of drinking age laws on drugs use, we then analyze the determinants of the joint decision to consume alcohol and/or marijuana using the structural probit model developed in the previous section.

6.1 Event Study

A natural way to analyze the impact of drinking age laws on alcohol and marijuana consumption is to compare states in which the drinking age is increased to states in which it remains constant. This before and after approach has also been used by O'Malley et. al. [12] in a related study based on the MTF data for 1976 to 1987. Call the states in which the drinking age is raised to 21 years "treatments" and states in which the drinking age remains constant at 21 throughout the 1980-89 period "controls". The empirical task is to contrast the prevalence of alcohol and marijuana consumption in treatment states relative to control states, before and after a law is enacted. The advantage of this approach over simple cross-sectional comparisons is that it allows for the possibility that states with low values of the error terms ϵ_a and ϵ_m are more (or less) likely to have a drinking age of 21 over the whole sample period (controls) than states with high values of ϵ_a and ϵ_m.

The empirical analysis is performed for treatment states included in the MTF sample in the three years preceding and the three years following the increase in the drinking age law. A three year horizon should be long enough for a newly enacted minimum drinking age law to reach its full long-term effect on drug use. Twelve states satisfy this sample selection criterion.[6]

We empirically implement this procedure by specifying the proportion of seniors consuming good j, $\frac{N_j}{N}$, (where a = alcohol and m = marijuana) as follows: [7]

$$\log(\frac{N_{jit}}{N_{it}}) = \sum R_{its}\gamma_{js} + \sum D_{itp}\delta_{jp} + \epsilon_{jit} \tag{34}$$

where

$$D_{itp} = 1 \quad \text{if } t = p$$

[6] Using a balanced sample of treatment states (exactly three years before and three years after the change in the drinking age law) is also necessary to keep the composition of that sample homogeneous over time. Otherwise, the composition of the treatment sample would be systematically related with the time at which states enact increases in the minimum drinking age. This sample composition problem would bias the results of the event study in the likely case where the timing of the enactment of drinking age laws is related to the underlying prevalence of drug consumption in the state. This sample composition problem has typically been ignored in other studies, which might explain why our results differ from those of O'Malley et. al. [12].

[7] As in a standard log-linear model, the equation is estimated by weighted least squares, using $\frac{1-p}{pN}$ as weights.

$$= 0 \quad \text{otherwise}$$

and where

$$R_{its} = 1 \quad \text{if the drinking age is increased at time } t - s$$

$$= 0 \quad \text{otherwise.}$$

The parameters δ_p, $p = 80, \ldots, 89$ are a set of unrestricted year effects that capture time series variation in the prevalence of alcohol (marijuana) use in the control states. The set of effects (γ_{js} , $s = -2.5, -1.5, -.5, .5, 1.5, 2.5$) captures the difference in the prevalence of alcohol and marijuana use between treatment and control states at each s. [8]

The estimates of γ_{js} and δ_{jp} are reported in detail in the appendix table. The estimates of γ_{js} are also graphed in Figures 5 and 6. The point estimates of the γ_{js} suggest that the prevalence of alcohol use tends to decrease after the minimum drinking age is raised to 21. On the other hand, the prevalence of marijuana use tend to increase when the minimum drinking age is raised to 21. These patterns are consistent with the hypothesis that alcohol and marijuana are substitutes. The results also seem to indicate an abnormally high prevalence of alcohol and marijuana consumption in the year immediately preceding the enactment of a new minimum drinking age. This suggests that minimum drinking age laws are enacted partially in response to an upsurge in the consumption

[8] We are implicitly assuming that the drinking age increases exactly in between two interview dates. If the drinking age went up between the interviews in 85 and 86, we would say that the event happened at time 85.5 so that R_{its} equals one when t equals 86 and s equals .5, etc.

of psychoactive substances by teenagers.

This interpretation of the results is solely based on the point estimates graphed in Figure 5. The point estimate of each γ_{js} is quite imprecise, however, since it is only based on twelve observations. We next try to improve the efficiency of these estimates by fitting standard log-linear models on the whole MTF sample. We also model the drinking age as a continuous variable, instead of a simple dichotomous variable for whether the state has a twenty-one year old legal minimum or not.

6.2 Log-Linear Models

We now consider more general specifications of the following type:

$$\log(\frac{N_{jit}}{N_{it}}) = Z_{it}\theta_j + f_j(t) + g_j(i) + \epsilon_{jit} \tag{35}$$

for $j = a, m$ where Z_{it} consists of a set of policy variables and a set of state characteristics. The policy variables consist of the drinking age entered linearly, an indicator variable for the marijuana decriminalization statutes, and the real price of alcohol in the region (four census regions). The state characteristics consists of the state unemployment rate, and a set of average characteristics of the state–year cell from the MTF data: percent white, percent male, percent living in a SMSA, and the average real income of seniors (labor and non-labor income). Two types of controls are used for time effects $f_j(t)$: unrestricted year effects, and a quadratic time trend. In addition, four type of controls are used for region effects $g_j(i)$: none, dummies for 4 regions, dummies for 9 regions, and

Figure 5: Event Study: Alcohol

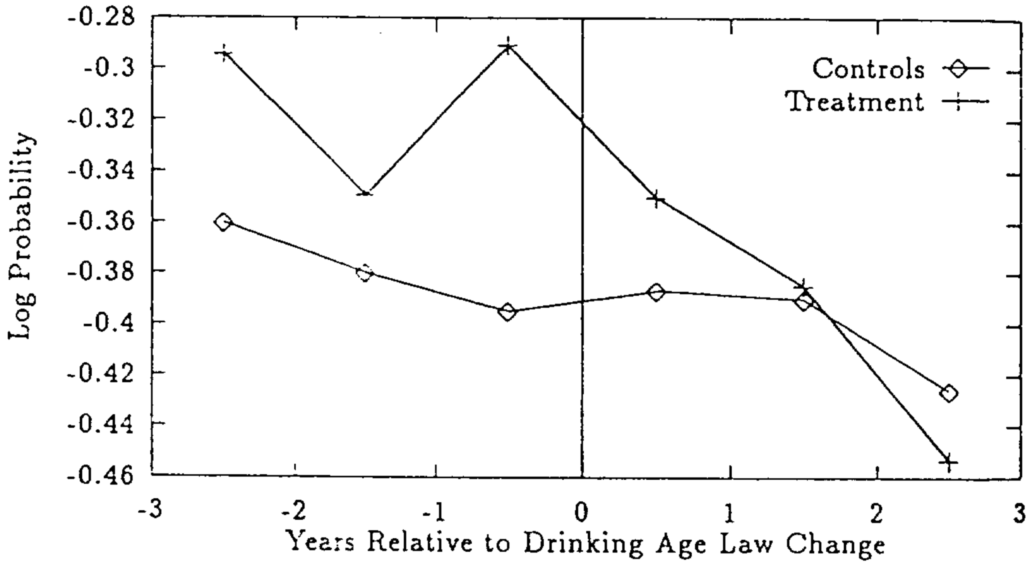
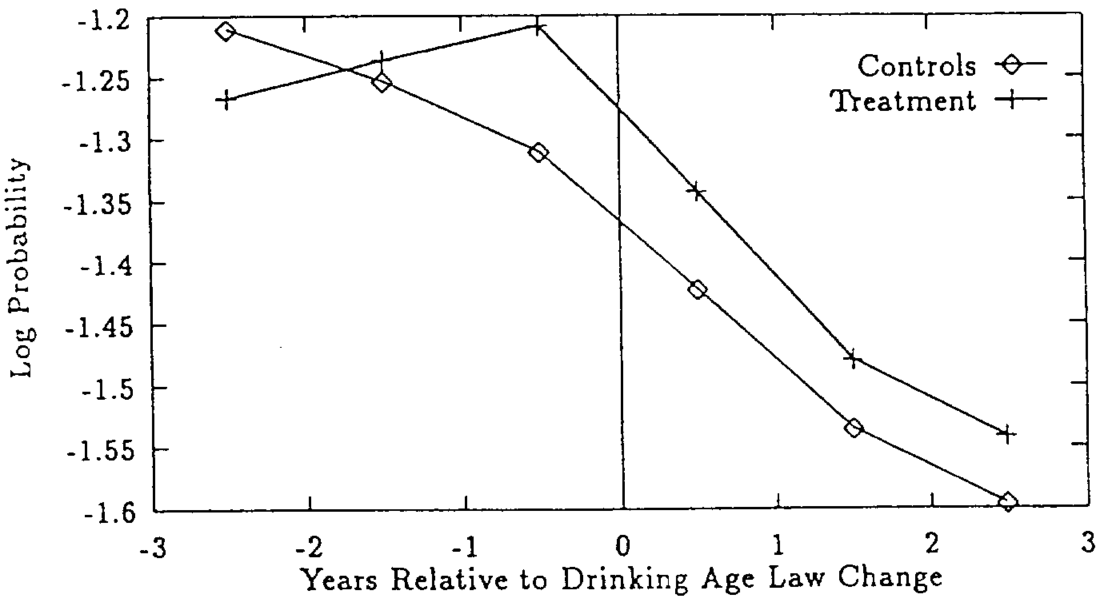


Figure 6: Event Study: Marijuana



unrestricted states dummies.

For the sake of comparison, note that the event study approach implicitly controlled for state effects by splitting the sample into controls and a balanced set of treatments. The disadvantage of that approach is that it does not utilize all the observations available in the data.

The estimated effect of the state drinking age on the prevalence of alcohol and marijuana use are reported for a variety of specifications in Table 7. These specifications are estimated for both the whole sample as well as for the balanced sample of states [9] All the specifications are fitted by weighted least squares, using $\frac{1-p}{pN}$ as weights. The standard errors are computed by normalizing the average weights to one.

A clear pattern emerges from Table 7: a higher drinking age reduces the prevalence of alcohol use, but increases the prevalence of marijuana use among high school seniors. In fact, the estimated effect of the drinking age on alcohol consumption is always negative, while it is always positive for marijuana. In addition, the estimated effects are always statistically different from zero for specifications that include no region controls, four region dummies, and nine region dummies. The estimated effects are more imprecise when a full set of state dummies is included, but they tend to remain significant at a 90% confidence level (except for alcohol with state characteristics included in the specification).

The efficiency gain over the simple event study is quite substantial. For

[9] The balanced sample is limited to states that are in the sample in all ten years.

Table 7: Log-Linear Estimates of the Effect of the Drinking Age on the Use of Alcohol and Marijuana

No Covariates, Quadratic Trend								
Marijuana	.03462	.03814	.02540	.03046	.03628	.03309	.02560	.02052
	(.01373)	(.01216)	(.01193)	(.01748)	(.01462)	(.01228)	(.01243)	(.01777)
Alcohol	-.02948	-.03102	-.02783	-.01030	-.03042	-.03493	-.03270	-.01682
	(.00640)	(.00549)	(.00553)	(.00747)	(.00665)	(.00557)	(.00566)	(.00773)
Balanced	No	No	No	No	Yes	Yes	Yes	Yes
Controls	–	4 reg	9 reg	State	–	4 reg	9 reg	State
Covariates, Quadratic Trend								
Marijuana	.03811	.04535	.02997	.03650	.04255	.04578	.03470	.03101
	(.01334)	(.01231)	(.01185)	(.01708)	(.01404)	(.01260)	(.01261)	(.01780)
Alcohol	-.02601	-.02257	-.02211	-.00473	-.03037	-.02478	-.02533	-.01005
	(.00538)	(.00487)	(.00489)	(.00674)	(.00550)	(.00490)	(.00502)	(.00706)
Balanced	No	No	No	No	Yes	Yes	Yes	Yes
Controls	–	4 reg	9 reg	State	–	4 reg	9 reg	State
No Covariates, Time Dummies								
Marijuana	.03688	.03951	.02639	.03379	.03714	.03445	.02661	.02459
	(.01380)	(.01210)	(.01185)	(.01748)	(.01477)	(.01220)	(.01232)	(.01773)
Alcohol	-.03054	-.03206	-.02896	-.01324	-.03143	-.03552	-.03340	-.01897
	(.00642)	(.00547)	(.00551)	(.00753)	(.00673)	(.00560)	(.00570)	(.00783)
Balanced	No	No	No	No	Yes	Yes	Yes	Yes
Controls	–	4 reg	9 reg	State	–	4 reg	9 reg	State
Covariates, Time Dummies								
Marijuana	.03839	.04551	.03104	.03745	.04112	.04561	.03416	.03151
	(.01343)	(.01226)	(.01177)	(.01722)	(.01422)	(.01265)	(.01264)	(.01793)
Alcohol	-.02664	-.02345	-.02312	-.00721	-.03072	-.02502	-.02540	-.01183
	(.00537)	(.00483)	(.00485)	(.00681)	(.00553)	(.00490)	(.00506)	(.00719)
Balanced	No	No	No	No	Yes	Yes	Yes	Yes
Controls	–	4 reg	9 reg	State	–	4 reg	9 reg	State

instance, the estimates from the specification reported in column 4 of the third panel of results (state dummies, year dummies, no covariates) are quite similar to the model estimated in the event study. In this case, however, the effect of the drinking age on both marijuana (.03379) and alcohol (-.01324) is statistically different from zero at a 90% confidence level.

Finally, the estimated effects of the other covariates on the prevalence of alcohol and marijuana use are reported for a variety of region and year controls in Table 8 . These results indicate that income increases the prevalence of marijuana use. The prevalence of both alcohol and marijuana is also higher for whites than for non-whites. In addition, the results of column 4 indicate that the prevalence of alcohol use is lower in states in which marijuana is decriminalized. This finding is consistent with the hypothesis that alcohol and marijuana are substitutes.

6.3 Estimates of the Structural Probit Model

The empirical results from the event study and the log-linear models show that increases in the minimum drinking age reduce the prevalence of alcohol use but increase the prevalence of marijuana use. This evidence suggests that alcohol and marijuana are substitutes in consumption. It is not clear, however, that this measured effect of the drinking age laws on the prevalence of marijuana consumption indicates the full magnitude of the substitution effect. In fact, many researchers have argued that increases in the drinking age signal societal

Table 8: Detailed Estimates of Log-Linear Models for the Use of Alcohol and Marijuana

Specification	1	2	3	4	5	6
Dependent Variable	Marijuana	Marijuana	Marijuana	Alcohol	Alcohol	Alcohol
Drinking Age	0.0453	0.0365	0.0375	-0.0226	-0.0047	-0.0072
	(0.0123)	(0.0170)	(0.0172)	(0.0049)	(0.0067)	(0.0068)
Decriminalized	-0.0310	—	—	-0.0447	—	—
	(0.0257)	—	—	(0.0110)	—	—
Alcohol Price	-0.4764	-0.5326	-1.1556	0.0243	-0.0670	-0.6846
	(0.9524)	(0.8616)	(1.2809)	(0.4125)	(0.3662)	(0.5410)
Unemployment Rate	-0.0017	-1.1728	0.3190	-0.8662	-0.3732	-0.5086
	(0.6218)	(0.8102)	(1.0932)	(0.2570)	(0.3386)	(0.4498)
Male	0.2378	0.2996	0.3061	0.1756	0.0784	0.0693
	(0.2095)	(0.1947)	(0.1936)	(0.0831)	(0.0788)	(0.0783)
SMSA	0.0421	0.1755	0.1783	-0.0277	0.0230	0.0192
	(0.0434)	(0.0677)	(0.0676)	(0.0170)	(0.0246)	(0.0247)
Income	0.6266	0.7508	0.8405	0.0643	0.1172	0.1101
	(0.2574)	(0.2613)	(0.2667)	(0.1048)	(0.1039)	(0.1056)
White	0.2248	0.2821	0.2349	0.4349	0.4417	0.4392
	(0.0957)	(0.1078)	(0.1089)	(0.0439)	(0.0474)	(0.0478)
Region Controls	3 regions	state dumm	state dumm	3 reg	state dumm	state dumm
Time Controls	Qu. trend	Qu. trend	Year dumm	Qu. trend	Qu. trend	Year dumm
R^2	0.6221	0.7551	0.7637	0.6288	0.7739	0.7822
Observations	357	357	357	357	357	357

disapproval for all drugs, not only alcohol. In the context of our model, this means that increases in the drinking age also increase the implicit price of marijuana. This would partially offset the increased prevalence that results from the substitution effect. Naive estimates of the effect of the drinking age on the prevalence of marijuana consumption will thus understate the importance of substitution effects.

Our structural model enables us to untangle the three channels by which increases in the drinking age affect the prevalence of alcohol and marijuana consumption among high school seniors. These three channels consist of

1. the direct effect of the drinking age on the implicit price of alcohol.
2. the direct effect of the drinking age on the implicit price of marijuana.
3. the substitution between alcohol and marijuana induced by changes in the relative prices of alcohol and marijuana.

The first two effects operate by shifting the thresholds T_a and T_i respectively (equations (21) and (22)), while the third effect operates via the substitution parameter γ_{am}. As mentioned above, the empirical implication of alcohol and marijuana being substitutes (γ_{am} negative) is that the estimated values of the parameters Ψ_a and Ψ_m should be positive. We estimate a particular specification of the structural model that includes the same covariates as in the log-linear models, as well as a quadratic time trend and four region dummies. The results are reported in Table 9.

Table 9: Maximum Likelihood Estimates of the Structural Model

	1	2	3
Marijuana			
Drinking Age	0.0445	0.0425	-0.0227
	(0.0124)	(0.0124)	(0.0220)
Decriminalized	-0.0056	-0.0098	-0.0421
	(0.0259)	(0.0258)	(0.0256)
Alcohol Price	-0.1973	-0.1407	-0.3580
	(0.9522)	(0.9480)	(0.9253)
Unemployment Rate	0.5881	0.5192	-1.0857
	(0.6242)	(0.6204)	(0.7229)
Male	0.2361	0.2175	0.1934
	(0.2119)	(0.2095)	(0.2040)
Smsa	0.0708	0.0701	0.0105
	(0.0426)	(0.0422)	(0.0444)
Income	0.6299	0.6179	0.2348
	(0.2429)	(0.2413)	(0.2739)
White	0.2005	0.1953	0.6664
	(0.0885)	(0.0879)	(0.1145)
Alcohol			
Drinking Age	-0.0363	-0.0348	-0.0349
	(0.0121)	(0.0121)	(0.0140)
Decriminalized	-0.0448	-0.0413	-0.0453
	(0.0251)	(0.0249)	(0.0251)
Alcohol Price	-0.3801	-0.3562	-0.3761
	(0.9051)	(0.9026)	(0.9516)
Unemployment Rate	-1.3706	-1.2539	-1.3370
	(0.6024)	(0.5996)	(0.6220)
Male	0.1712	0.1747	0.1669
	(0.2031)	(0.2017)	(0.2028)
Smsa	-0.0058	-0.0034	-0.0031
	(0.0399)	(0.0398)	(0.0403)
Income	0.1144	0.1451	0.1279
	(0.2272)	(0.2257)	(0.2342)
White	0.7278	0.7280	0.7136
	(0.0800)	(0.0797)	(0.0819)
Correlation	0	0.6752	0.9869
		(0.0100)	(0.0522)
Ψ_m	0	0	0.9390
			(0.1514)
Ψ_a	0	0	0.3353
			(1.4313)
Number of Parameters	28	29	31
Log Likelihood	-21098.96	-19832.81	-19830.09

We first report in column 1 the estimates from a model in which the parameters Ψ_a and Ψ_m, as well as the correlation coefficient, ρ, are constrained to equal zero. This model is simply an uncorrelated bivariate probit that can be estimated by fitting two simple probit models for the prevalence of alcohol and marijuana consumption. The results are qualitatively similar to those obtained by fitting a similar specification of the log-linear model (second panel, column 2 of Table 8).

The estimates of a bivariate probit model in which the correlation coefficient ρ is not constrained to zero are reported in column 2. Although the estimated value of ρ is positive (.675), relaxing the constraint that ρ equals zero does not substantially change the estimates of the other parameters. In both columns 1 and 2, the coefficient associated with the drinking age is positive and significant in the marijuana equation (.045 and .043) but negative and significant in the alcohol equation (-.036 and -.034).

We have already noted that the bivariate probit model is only consistent with economic theory when alcohol and marijuana are separable in consumption. In column 3, we report the estimates from our structural model in which alcohol and marijuana are allowed to be either substitutes or complements. The point estimates of the parameters Ψ_a and Ψ_m are both positive, indicating that alcohol and marijuana are substitutes. In addition, the null hypothesis that Ψ_a and Ψ_m are jointly different from zero cannot be rejected at a 90% confidence level by a likelihood ratio test (chi-square statistic of 5.44, two degrees of freedom).[10]

The estimate of the coefficient associated with the drinking age in the marijuana threshold is negative, but not significant, in column 3. Since the drinking age affects the marijuana threshold through its effect on the implicit price of marijuana, this means that increases in the drinking age increase the implicit price of marijuana, just like it does for alcohol. This result is in sharp contrast with the results reported in columns 1 and 2, where the drinking age has a positive and significant effect on the threshold for marijuana. A naive interpretation of the results in column 1 and 2 would suggest that an increase in the drinking age *decreases* the implicit price of marijuana; this would seem to be inconsistent with the notion that increasing legal minimum drinking ages also discourages consumption of other drugs. However, this interpretation confounds the substitution effect with the effect on the implicit price of marijuana. The estimates from the complete structural model indicate that higher drinking ages *do discourage* marijuana consumption. However, this effect is more than offset by the substitution effect.

It is also interesting to note that the parameters in the alcohol threshold equation are very similar in columns 1 to 3. For instance, the effect of the state unemployment rate is always negative and significant. Suppose that the unemployment rate in the state is negatively related to the income at the disposal of the average high school senior in that state. Then these results are consistent

[10] A one-sided version of the test would presumably reject the null hypothesis that Ψ_a and Ψ_m are both negative at a standard 95% confidence level.

with alcohol and marijuana being normal goods.

The parameter estimates in the marijuana threshold are not as stable as in the alcohol threshold. In particular, the effect of the unemployment rate is positive in columns 1 and 2, but negative in column 3. Just as in the case of the drinking age, the effect of the unemployment rate is thus reversed when substitution between alcohol and marijuana is incorporated in the discrete choice model (column 3). If it is reasonable to assume that both alcohol and marijuana are normal goods, this sign reversal provides additional evidence on the importance of correctly modeling the substitutability between alcohol and marijuana.

A final remark is that the estimated value of the correlation coefficient ρ is quite high (.987) in column 3. This suggests that the model has some difficulties in separating the true substitution effects from the correlation in the error terms. Note, however, that the null hypothesis $\rho = 1$ is rejected by a standard likelihood ratio test. In addition, the finding that both Ψ_a and Ψ_m are positive was replicated by fixing the parameter $\rho = 1$ at various reasonable values (these results are in an appendix available on request).

7 Conclusion

This paper analyzes the impact of increases in the minimum drinking age on the prevalence of alcohol and marijuana use among high school seniors in the United States. The empirical analysis is based on a large sample of students from 43 states over the years 1980–1989. We find that increases in the legal minimum drinking age did reduce the prevalence of alcohol consumption. We also find, however, that increased legal minimum drinking ages also had the unintended consequence of *increasing* the prevalence of marijuana consumption. We estimate a structural model of consumption based on the canonical theory of the consumer. Estimates from this model show that this unintended consequence is completely attributable to standard substitution effects.

The structural estimation also supports the idea that an increased drinking age helps create a climate of societal disapproval for all drug use, not only alcohol. In the case of marijuana, this change in societal "climate" is not sufficient to offset the large substitution induced by the decreased prevalence of alcohol consumption.

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Appendix Table 1: Detailed Estimates for the Event Study

	Marijuana	Alcohol
Year	Effects	($\delta_j p$)
1980	0.7071	0.1562
	(0.0733)	(0.0382)
1981	0.6163	0.1396
	(0.0737)	(0.0379)
1982	0.5323	0.1307
	(0.0744)	(0.0375)
1983	0.4846	0.1149
	(0.0750)	(0.0375)
1984	0.4032	0.0858
	(0.0751)	(0.0375)
1985	0.4254	0.0686
	(0.0737)	(0.0377)
1986	0.2670	0.0600
	(0.0785)	(0.0388)
1987	0.1895	0.0961
	(0.0791)	(0.0377)
1988	0.0304	0.0611
	(0.0801)	(0.0375)
Treatment	Effects	($\gamma_{j,}$)
t-2.5	-0.0563	0.0660
	(0.0721)	(0.0354)
t-1.5	0.0177	0.0307
	(0.0726)	(0.0387)
t-.5	0.1031	0.1043
	(0.0664)	(0.0337)
t+.5	0.0802	0.0365
	(0.0701)	(0.0351)
t+1.5	0.0559	0.0056
	(0.0791)	(0.0376)
t+2.5	0.0555	-0.0272
	(0.0814)	(0.0408)
Constant	-1.7115	-0.4709
	(0.0611)	(0.0293)
Observations	261	261
R-square	0.4646	0.1572
Root MSE	0.2235	0.1185