

Alcohol, Marijuana, and American Youth: the Unintended Consequences 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 use among high school seniors. 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 slightly reduce the prevalence of alcohol consumption. We also find, however, that increased legal minimum drinking ages had the unintended consequence of slightly *increasing* the prevalence of marijuana consumption. Estimates from a structural model suggest that this unintended consequence is attributable to standard substitution effects.

JEL Classification: I10, I18, I19.

*We would like to thank Paul Gertler, Dan Levy, Anthony Pascal, and participants at workshops at University of California, Irvine and the Industrial Relations Section at Princeton University as well special thanks to Jon Gruber, Michael Grossman, and an anonymous referee. We would also like to thank the authors of Monitoring the Future, Jerald Bachman, Patrick O'Malley, and Lloyd Johnston, for allowing us limited access to the data. Thanks to Jerry Hiniker for technical assistance with the data. Both authors would also like to thank the NIAAA for funding this research. Additional funding for this work for DiNardo came from RAND's Drug Policy Research Center which is supported by the Ford and Weingart foundations. None of the persons mentioned above should bear any responsibility for the analysis herein. *Corresponding Author:* John DiNardo, Department of Economics, University of California, Irvine, 92697-5100. Email: jdinardo@uci.edu, Phone: (949) 824-3191, Fax (949) 824-2182.

I 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. Such an unintended effect may sound surprising at first glance. It naturally arises, however, in a standard model of consumer behavior if the two drugs are substitutes. When two goods are substitutes, policies which successfully ration demand for one good will generate an increased demand for the other good.

Until recently, however, studies of the “cost” of alcohol abuse or of drug abuse have implicitly considered the use of psychoactive substances in isolation.¹ As such studies play an important role in the development of U.S. drug policy (Heien and Pittman 1989) it is useful to consider whether policies intended to discourage alcohol use, for example, might also affect the use of other drugs.

In this paper, we consider 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. We focus on the impact of increases in the minimum legal drinking age induced by the federal legislation in the 1980s that restricted provision of federal highway trust funds to states that did not enact a minimum drinking age law. We believe that this “natural experiment” is essential for obtaining credible estimates of the causal effect of changes in the minimum legal drinking age on marijuana and alcohol consumption.

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

¹See DiNardo (1994) for a survey of the literature up to the mid-1990s. We discuss more recent work in the area in Section II.

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.

II Related evidence on the relationship among alcohol, marijuana, and other drugs

A Historical and clinical evidence

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 (Brecher and the Editors of Consumer Reports 1972, Siegel 1989) have argued that Prohibition led to the first signs of “large scale marketing of marijuana for recreational use.” (Brecher and the Editors of Consumer Reports 1972) 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. (Brecher and the Editors of Consumer Reports 1972).

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” (Belair 1969). 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 (McGlothlin, Jamison and Rosenblatt 1970). 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 clinical study of 16 subjects by Mello and Mendelson (Mendelson and Mello 1985). 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.

B Recent econometric research

In our original working paper version (1992) we observed:

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 (1991), for instance, reported 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.

Since the publication of the original working paper, a growing literature has started to examine this issue in more depth. This literature includes Pacula, Grossman, Chaloupka, O'Malley, Johnston and Farrelly (2000), DeSimone (1998), Chaloupka and Laixuthai (1997), Pacula (1998b), Pacula (1998a), Saffer and Chaloupka (1999a), Saffer and Chaloupka (1999b), Dee (1999), Farrelly, Bray, Zarkin, Wendling and Pacula (1999), and Chaloupka, Pacula, Farrelly, Johnston, O'Malley and Bray (1999).

It would take another large ambitious study (which we think would be quite valuable) to sort out the reasons for the conflicting results.² An informal meta-analysis of the subsequent literature suggests some potential (econometric) explanations, which it should be understood, do not (easily) explain all the results:

1. The inclusion of *potentially* endogenous regressors such as “perceived” harm, “religious beliefs”, etc. or price.
2. The treatment of state *and* year fixed effects.
3. Sampling error.

As to (1) there is not even agreement on what might be considered exogenous. Pacula (1998a) in her useful comparisons of results with the NLSY includes income as a potentially endogenous regressor (the suggestion is that drug use leads to changes in one's ability to command a wage in the labor market) but treats beer taxes as exogenous. Our suspicion is that the inclusion of such regressors would obscure evidence for substitutability of alcohol and marijuana (if indeed, they are substitutes). For example, one potential troubling possibility with the inclusion of such regressors, is that they are highly correlated with the measurement error: for example, one who reports being “highly religious” to a doctrine which prohibits or discourages psychoactive substance use may be less likely to inform an

²Perhaps, unique to this literature, there are (potentially) conflicting results *both* within and between data sets and researchers. The type of analysis in Pacula (1998b), for example, is a very valuable step in resolving the inconsistencies.

interviewer of this fact. A different sort of problem bedevils the literature that uses the price of alcohol or other drugs, and “enforcement”. DiNardo (1993), for example, finds that increased enforcement leads to both lower prices and lower consumption while estimating the demand for cocaine in a model which includes the price of cocaine instrumented with various measures of enforcement. While this can not be ruled out *a priori*, another simple explanation is that enforcement responds to demand and not the other way. A similar possibility exists for using tax variables: it is not obvious that the “within” variation which is left after absorbing state and year effects is exogenous. Unlike the case of the legal drinking age, where a federal government mandate clearly moved some states with low drinking ages to have higher ones, it is not as clear why states chose to raise their tax rates.³

There is slightly more evidence regarding (2), although further study is warranted. In Farrelly et al. (1999), which uses NHSDA data, the authors specifically note “the sensitivity of [the] results to the inclusion of state effects” especially with regards to adults. Pacula (1998b) which includes state effects, finds the results sensitive to the inclusion of time effects. Pacula et al. (2000), perhaps comes closest to the specifications we employ here. When they include a (precisely estimated) quadratic time trend (their most flexible specification of the year effect), Pacula et al. (2000) also find that higher drinking ages led to increased marijuana use (measured as annual participation). This result is reversed however, when the quadratic time trend is removed.

In our working paper version (DiNardo and Lemieux 1992) we took up this issue in great length. In general, omission of state and/or year effects increased the measured negative

³Although we do not report the results here, the general effect of including beer taxes in the regressions was generally to increase the precision of the coefficient on the drinking age in the marijuana regression and *decrease* the precision in the alcohol regression. The effect of the beer tax itself, however, was very variable. For example, in the marijuana specification including covariates and a full set of year and state dummy variables the coefficient on the drinking age is 0.0325 (0.0172) while the beer tax is 0.0870 (0.155). The coefficients for the corresponding alcohol regression are -.010 (.007) for the drinking age and .046 (.066) (wrong signed) for the beer tax.

effect of the drinking age on alcohol participation and generated results more supportive of a complementary relationship between marijuana and alcohol. Part of the difficulty, which we document below, stems from two correlations: first, states which generally have low consumption of both alcohol and marijuana are more likely to have higher drinking ages in a particular cross-section. Second, time trends in marijuana and alcohol consumption are positively correlated.

On the more substantive side, our focus on alcohol and marijuana is quite different from several studies that have looked at complementarities between cigarette and drugs consumption. It is quite possible that for most users (especially those we study in this paper) marijuana and alcohol are two alternative ways of “pursuing shorter term pleasure”, while cigarettes represent a qualitatively different experience, including the potential for serious “addiction.”

Lastly, we have little to say about the possible existence of a gateway effect – the notion that prior exposure to one drug makes it more likely that one will try a different (and possibly more dangerous) psychoactive substance.⁴ In our view, the problem is coming up with an *a priori* credible research design that could distinguish a positive correlation due to the omission of factors correlated positively with the propensity to use psychoactive substances and a “gateway effect.”

As to (3), we think the possibility of sampling error cannot be ignored; a research design that employs *large* exogenous changes in the price or availability of alcohol and marijuana would be especially valuable. Indeed, as we discuss in detail below, our results do not suggest a particularly large role for higher legal minimum drinking ages on either alcohol or marijuana use.

⁴See Pacula (1998a) for a recent look at this issue.

III The Data

A 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 (Bachman and Johnston 1978) only a brief synopsis is provided here. MTF is a representative sample of high school seniors from high schools across the United States.⁵ 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 of the MTF 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 only at the state level. The data for this paper is described in more detail below.

⁵MTF is not quite a representative sample of the youth population, however, as it excludes those you have left school before the spring of their senior year.

B 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 (Cook and Tauchen 1984), 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.”⁶

⁶Consistent 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.

C 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 10 states had decriminalization statutes, and the majority of these were enacted by the beginning of the sample 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.

D Descriptive Statistics

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 two-by-two contingency tables 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. This information is sufficient for studying the participation decisions (whether or not to consume alcohol and marijuana) which is the focus of the paper. Though the MTF also contains some information on quantities consumed, we do

not exploit it in this paper.⁷

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 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 factors like tastes or peer pressure that are positively correlated with both the propensity to consume alcohol and marijuana.

⁷The MTF contains categorical information on the quantity of alcohol and marijuana consumed that has been used by, for example Chaloupka et al. (1999). Access to this information, however, appears to require collaboration with those who control access to the data.

IV Structural 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.

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:

$$G(q) = u(q_0) + v(q_a, q_m) \quad (1)$$

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 :

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

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 substitutes ($\gamma_{am} < 0$) or complements ($\gamma_{am} > 0$). The parameters γ_a and γ_m represent the marginal utility of alcohol and marijuana 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:

$$I = q_0 + p_a q_a + p_m q_m \quad (3)$$

where I is total income, p_a is the price of alcohol and p_m is the price of marijuana. With a quadratic utility function, it is easy to find the interior solution (demand functions) when the teenager consumes both alcohol and marijuana. Generally speaking, the participation

conditions are obtained by comparing the marginal utilities at zero consumption to the prices multiplied by the marginal utility of income (λ). Consider the latent variables y_a^* and y_m^* that represent the difference between the marginal utilities at zero and the prices (in utility terms):

$$y_a^* = \gamma_a - \lambda p_a \quad (4)$$

$$y_m^* = \gamma_m - \lambda p_m \quad (5)$$

Four regimes can arise, depending on the values of these two latent variables: abstinence, consume marijuana only, consume alcohol only, or consume both. The following participation conditions are obtained by solving explicitly the consumer problem: ⁸

Regime 1 (abstinence):

$$y_a^* < 0 \quad , \quad y_m^* < 0 \quad (6)$$

Regime 2 (marijuana only):

$$y_a^* - (\gamma_{am}/\gamma_{mm})y_m^* < 0 \quad , \quad y_m^* > 0 \quad (7)$$

Regime 3 (alcohol only):

$$y_a^* > 0 \quad , \quad y_m^* - (\gamma_{am}/\gamma_{aa})y_a^* < 0 \quad (8)$$

Regime 4 (marijuana and alcohol):

$$y_a^* - (\gamma_{am}/\gamma_{mm})y_m^* > 0 \quad , \quad y_m^* - (\gamma_{am}/\gamma_{aa})y_a^* > 0. \quad (9)$$

⁸See DiNardo and Lemieux (1992) for details.

When alcohol and marijuana are separable ($\gamma_{am}=0$), these conditions reduce to the four possible permutations of the inequalities $y_a^* < 0$ and $y_m^* < 0$.⁹

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 latent variable for marijuana, y_m^* , 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. The larger alcohol consumption is, the larger the marginal utility of marijuana has to be 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.

A Stochastic Specification

An estimable choice model is readily obtained by specifying the latent variables y_a^* and y_m^* as functions of observable characteristics and stochastic components. Consider the following specifications for the marginal utilities at zero consumption:

$$\gamma_a = X\beta_a + \epsilon_a, \tag{10}$$

⁹Participation conditions of this type might also be obtained by specifying a standard 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 standard bivariate probit model.

$$\gamma_m = X\beta_m + \epsilon_m, \quad (11)$$

where X is a set of observed covariates while ϵ_a and ϵ_m are random components with zero mean that are assumed to follow a joint normal distribution with a correlation coefficient ρ . Since the marginal utility of income, λ , is a function of income, we use the following first order approximations for λp_a and λp_m :¹⁰

$$\lambda p_a \approx \alpha_{0a} + \alpha_{Ia}I + \alpha_{aa}p_a \quad (12)$$

$$\lambda p_m \approx \alpha_{0m} + \alpha_{Im}I + \alpha_{mm}p_m. \quad (13)$$

Substituting the expressions in (10), (11), (12), and (13) into the equations for the latent variables yield:

$$y_a^* = Z\theta_a + \epsilon_a, \quad (14)$$

and

$$y_m^* = Z\theta_m + \epsilon_m, \quad (15)$$

where Z is a vector that contains *both* the covariates X and the price and income variables. Since the price of marijuana does not appear in equation (12), however, the element of θ_a corresponding to this variable in equation (14) is equal to zero. Similarly, the element of θ_m corresponding to the price of alcohol is equal to zero.

As mentioned in Section III, we do not use direct measures of the price of marijuana in our empirical analysis. However, we treat marijuana decriminalization as a proxy for the

¹⁰The implicit assumption used for these approximations is that the marginal utility of income, λ , depends on income but not on the prices of marijuana and alcohol. This can be justified on the grounds that alcohol and marijuana consumption only represent a small share of total consumption expenditures. A similar assumption has been used in the context of a dynamic model by Becker, Grossman and Murphy (1994) in their empirical work on rational addiction.

implicit price of marijuana since it reduces the expected cost (price plus expected penalty if caught) of consuming marijuana. Similarly, the implicit price of alcohol depends both on its monetary cost and the implicit cost associated with the drinking age for under age youth. In what follows, we focus on the drinking age and the marijuana decriminalization status as our key measures of the “price” of alcohol and marijuana, respectively.

In the next section, we estimate this structural model of participation using maximum likelihood.¹¹ Before presenting the results it is useful, however, to rewrite the participation conditions as follows to better understand how the model is identified:

$$Q_a = 1 \iff y_a^* - (\gamma_{am}/\gamma_{mm})Q_m y_m^* > 0, \quad (16)$$

$$Q_m = 1 \iff y_m^* - (\gamma_{am}/\gamma_{aa})Q_a y_a^* > 0, \quad (17)$$

where Q_a and Q_m are two dummy variables that indicate whether the teenager consumes alcohol and marijuana, respectively. These (structural) equations show how the decisions to consume alcohol and marijuana are jointly determined since the decision to consume alcohol (marijuana) depends on the dummy variable for marijuana (alcohol). Under the assumption that the disturbance terms are normal, this system of equations can be identified on the basis of functional form only. It is also possible, however, to use the identification restrictions implicit in equations (14) and (15) to help identify the model. Intuitively, the idea is to use the price of marijuana as an instrument for Q_m in the alcohol equation and use the price of alcohol as an instrument for Q_a in the marijuana equation. In a maximum likelihood context, both these exclusion restrictions and functional form assumptions

¹¹See the technical appendix for detail.

contribute to the identification of the model.

Equations (16) and (17) also help clarify the different channels through which changes in the drinking age (alcohol price) may affect the decision to consume both alcohol and marijuana. Under the above assumption that the drinking age does not affect the latent variable for marijuana consumption (y_m^*), all the effect of the drinking age must come indirectly through its impact on alcohol consumption captured by the term $(\gamma_{am}/\gamma_{aa})Q_a y_a^*$ in equation (17). For individuals who do not consume alcohol ($Q_a = 0$), a change in the drinking age should have no impact on marijuana consumption. For individuals who do consume alcohol ($Q_a = 1$), an increase in the drinking age should increase the probability of consuming marijuana if alcohol and marijuana are substitutes (i.e. if $-(\gamma_{am}/\gamma_{aa}) < 0$) since a higher drinking age has a negative effect on the latent variable for alcohol (y_a^*).

In addition to this indirect substitution effect, the drinking age may also have a direct effect on marijuana consumption through different channels. One such mechanism is that the increase in the drinking age is correlated with societal disapproval for psychoactive drugs more generally.¹² In this case, the drinking age should have a direct negative effect on y_m^* . The coefficient associated with the drinking age in θ_m should be negative. One advantage of structural estimation is that, in principle, it is possible to distinguish the direct effect of the drinking age on y_m^* from the indirect effect on marijuana consumption induced by the substitution effect. However, this comes at the price of solely relying on functional form assumptions to identify the parameters of interest of the model.

V 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 proceeds in two steps. First, we

¹²See, for example, O'Malley and Wagenaar (1990).

perform a reduced form analysis in which we use log-linear regression models to estimate the overall impact of the drinking age on the alcohol and marijuana consumption. The goal of this first step 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. This is achieved by controlling for state and year effects in the regression models. After having established a causal effect of drinking age laws on drugs use, we move to the second step and analyze the determinants of the joint decision to consume alcohol and/or marijuana using the structural probit model developed in the previous section.

A Reduced form analysis

We take a first look at the impact of the drinking age laws on alcohol and marijuana consumption by fitting log-linear regression models. More specifically, we consider the following model for the proportion of seniors consuming good j in state i at time t :

$$\log\left(\frac{N_{jit}}{N_{it}}\right) = Z_{it}\theta_j + f_j(t) + g_j(i) + \epsilon_{jit} \quad (18)$$

for $j = a, m$, where N_{it} is the number of seniors sampled in state i at time t , and N_{jit} is the number of the seniors who consume good j . Z_{it} consists of a set of policy variables and a set of state-level covariates. 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).¹³ The state-level covariates 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). We also control for unrestricted year

¹³In most specifications we estimated, we could not reject the null hypothesis that the drinking age has a linear effect against an alternative unrestricted model with a set of dummy variables for the different drinking ages.

effects ($f_j(t)$) and for four type of controls for region effects $g_j(i)$: none, dummies for 4 regions, dummies for 9 regions, and unrestricted states dummies.

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 6. All the specifications are fitted by weighted least squares, using $\frac{pN}{1-p}$ as weights.¹⁴ The standard errors are computed by normalizing the average weights to one.

A clear pattern emerges from Table 6: 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).

One surprising result is that the effect of the drinking age is systematically larger, in absolute value, in the marijuana models than in the alcohol models. Remember, however, that we are estimating log-linear models where the coefficients represent semi-elasticities with respect to change in the drinking age. Since the fraction of teenagers consuming alcohol (67 percent) is much larger than for marijuana (25 percent), the estimated coefficients generally translate into larger absolute effects for alcohol than marijuana. For example, the estimates in column 3 of the last panel of Table 6 imply that increasing the drinking age from 18 to 21 increases marijuana prevalence by 2.4 percentage points but decreases alcohol prevalence by 4.5 percentage points.

Finally, the estimated effects of the other covariates on the prevalence of alcohol and marijuana use for the models with state and year effects are reported in Table 7. These

¹⁴ $\frac{pN}{1-p}$ is the inverse of the residual variance in the log-linear model.

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.

B Estimates of the Structural Probit Model

The empirical results from 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. As mentioned earlier, if increases in the drinking age signalled societal disapproval for all drugs, this would partially offset the increased marijuana 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, in principle, 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 on the implicit price of alcohol that operates through the latent demand for alcohol (y_a^*).
2. the “societal disapproval” effect that operates through the latent demand for of marijuana (y_m^*).
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 $Z\theta_a$ and $Z\theta_m$, respectively, while the third effect operates via the substitution parameter γ_{am} . In the appendix, we define Ψ_a and Ψ_m as up to scale versions of the coefficients $\frac{\gamma_{am}}{\gamma_{mm}}$ and $\frac{\gamma_{am}}{\gamma_{aa}}$ that appear in equations (16)

and (17). Since γ_{aa} and γ_{mm} are both negative, 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 8.

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.

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 standard bivariate probit model is only consistent with economic theory when alcohol and marijuana are separable in consumption. In this case, we implicitly have $\Psi_a = \Psi_m = 0$. 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).

The estimate of the coefficient associated with the drinking age for marijuana becomes *negative* in column 3, which is consistent with the idea that a higher drinking age is a

signal of more general societal disapproval of psychoactive substance use. The estimated effect is not statistically significant, however.¹⁵ We take this results as a strong indication that it is mostly through the substitution effect, as opposed to other unmodelled factors, that a higher drinking age leads to increased prevalence of marijuana consumption.

This conclusion is reinforced by the finding that the direct effect of the drinking age on alcohol consumption remains negative and significant throughout columns 1 to 3. The pattern of results moving from the non-structural models of columns 1 and 2 to the structural model of column 3 is exactly what the substitution hypothesis would predict. The negative effect of the drinking age for alcohol is consistent with a standard negative own-price effect. The positive effect for marijuana in columns 1 and 2 is spurious consequence, however, of the fact that substitution is not properly modeled. When substitution is properly modeled in column 3, the marijuana effect essentially goes to zero, as expected.

More generally, most of the parameters for alcohol are quite 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 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.

¹⁵This indicates that the exclusion restriction discussed in Section IV (price of alcohol being excluded from the marijuana equation) is valid.

The effect of marijuana decriminalization status is always negative, which is inconsistent with our expectations in the case of marijuana. Note, however, that the estimated coefficients are never significant at the 95 percent confidence level. Remember also that these effects are purely driven by cross-state variation in the data. For these two reasons, we do not think much can be concluded from these negative estimates.

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 in the absence of explicit exclusion restrictions. 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 ρ at various reasonable values.

VI 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 slightly reduce the prevalence of alcohol consumption. We also find, however, that increased legal minimum drinking ages also had the unintended consequence of slightly *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 provides very weak support for the view that an increased drinking age helped 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.

This last finding may help reconcile our result that alcohol and marijuana are substitutes with recent papers like Dee (1999) and Chaloupka et al. (1999) who find that cigarettes are complements with both alcohol and marijuana. It is quite possible that marijuana and alcohol are most often two alternative ways of “pursuing shorter term pleasure” among high school seniors, while cigarettes is such a qualitatively different experience from alcohol and marijuana that it is not obviously a substitute for them. Moreover, it is possible that whatever substitution effects there are between alcohol (or marijuana) and cigarettes may not be large enough to offset the impact of changes in societal “climate” on cigarette consumption. This conjecture would be worth exploring in future research.

A Appendix: Maximum Likelihood Estimation

Because of confidentiality issues, only the means of the variables (covariates or choice variables) are available by state and year. Individuals in the same state and year share exactly the same covariates. We take account of this in forming the likelihood function by first computing the contribution to the likelihood of a representative consumer in each state/year cell. We then simply multiply this likelihood contribution by the number of individuals in the cell. The resulting log likelihood function is:¹⁶

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

¹⁶More details on the derivation of the likelihood function are provided in DiNardo and Lemieux (1992).

where:

$$\begin{aligned}
N_{it} &= \text{number of people in state } i \text{ at time } t \\
R_{it}^r &= \text{proportion of people in regime } r, \quad r = 1, 2, 3, 4 \\
t_{ait} &= Z_{it}\theta_a/\sigma_a \\
t_{mit} &= Z_{it}\theta_m/\sigma_m \\
S_a^2 &= 1 + \Psi_a^2 - 2\rho\Psi_a \\
S_m^2 &= 1 + \Psi_m^2 - 2\rho\Psi_m \\
\Psi_a &= \frac{\gamma_{am}\sigma_a}{\gamma_{mm}\sigma_m} \\
\Psi_m &= \frac{\gamma_{am}\sigma_m}{\gamma_{aa}\sigma_a}.
\end{aligned}$$

and where σ_a and σ_m are the standard deviations of ϵ_a and ϵ_m , respectively. 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.¹⁷

¹⁷Consider 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

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.

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.

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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

Table 2: Enactment of Decriminalization Statutes in the Sample

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

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

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

Figure 1: Alcohol and Marijuana are Substitutes

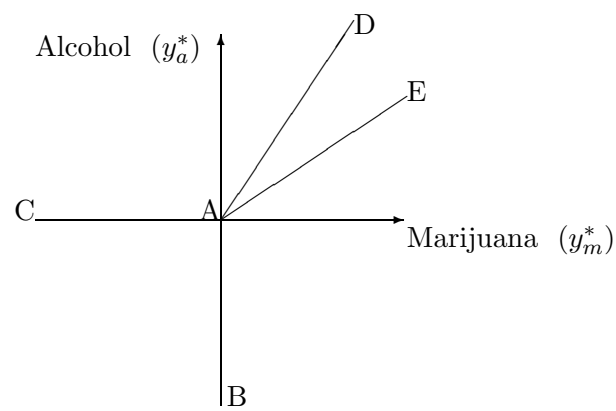


Figure 2: Alcohol and Marijuana are Complements

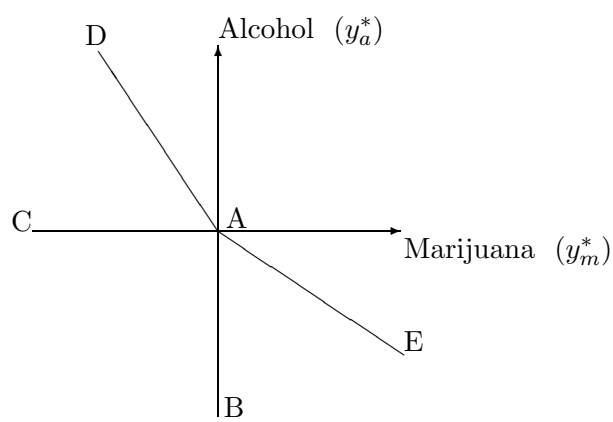


Table 6: Log-Linear Estimates of the Effect of the Drinking Age on the Use of Alcohol and Marijuana

No Covariates, Year Dummies				
Marijuana	.03688 (.01380)	.03951 (.01210)	.02639 (.01185)	.03379 (.01748)
Alcohol	-.03054 (.00642)	-.03206 (.00547)	-.02896 (.00551)	-.01324 (.00753)
Controls	–	4 reg	9 reg	State
Covariates, Year Dummies				
Marijuana	.03839 (.01343)	.04551 (.01226)	.03104 (.01177)	.03745 (.01722)
Alcohol	-.02664 (.00537)	-.02345 (.00483)	-.02312 (.00485)	-.00721 (.00681)
Controls	–	4 reg	9 reg	State

Table 7: Detailed Estimates of Log-Linear Models for the Use of Alcohol and Marijuana

Specification	1	2
Dependent Variable	Marijuana	Alcohol
Drinking Age	0.0375 (0.0172)	-0.0226 (0.0049)
Alcohol Price	-1.1556 (1.2809)	0.0243 (0.4125)
Unemployment Rate	0.3190 (1.0932)	-0.8662 (0.2570)
Male	0.3061 (0.1936)	0.1756 (0.0831)
SMSA	0.1783 (0.0676)	-0.0277 (0.0170)
Total income	0.8405 (0.2667)	0.0643 (0.1048)
White	0.2349 (0.1089)	0.4349 (0.0439)
State dummies	yes	yes
Year dummies	yes	yes
R^2	0.7637	0.7822
Observations	357	357

Table 8: Maximum Likelihood Estimates of the Structural Model

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