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Does Marijuana Use Impair Human Capital Formation?
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ABSTRACT

In this paper we examine the relationship between marijuana use and human capital formation by examining performance on standardized tests among a nationally representative sample of youths from the National Education Longitudinal Survey. We find that much of the negative association between cross-sectional measures of marijuana use and cognitive ability appears to be attenuated by individual differences in school attachment and general deviance. However, difference-in-difference estimates examining changes in test scores across 10th and 12th grade reveal that marijuana use remains statistically associated with a 15% reduction in performance on standardized math tests.

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I. Introduction

There is a generally held notion that early involvement with marijuana will negatively impair human capital formation and result in poor schooling outcomes because marijuana use impairs memory and attention and thus interferes with learning. Indeed, there is a large literature documenting a significant positive correlation between early involvement with marijuana and high school dropout status as well as other negative schooling outcomes (Bray et al., 2000; Ellickson et al., 1998; Yamada, Kendix and Yamada, 1996; Mensch and Kandel, 1988). The causality of the relationship between marijuana use and schooling, however, has been brought into question by empirical evidence showing that poor schooling outcomes precede regular and/or heavy marijuana use (Sander, 2000; Fergusson and Horwood, 1997; Hawkins et al, 1992; Newcomb & Bentler, 1988).

The question of causality is further complicated by conflicting findings from clinical studies that examine the impact of persistent and heavy marijuana use on individual cognitive functioning (Solowij, 1998). Although neuroscientists have been able to identify the part of the brain that is affected by marijuana use and have shown that activation of cannabinoid receptor sites in the part of the brain that control memory interrupts normal brain cognitive functioning and memory (Matsuda, Bonner and Lolait 1993; Heyser, Hampson, and Deadwyler 1993), studies examining the effects of cannabis on cognitive functioning in specific small populations have not consistently shown a negative long term effect of persistent and/or heavy marijuana use (Solowij, 1998). Some studies have shown that heavy and regular marijuana use do impair long and short term cognitive functioning (Block et al, 1990; Pope and Yurgelun-Todd, 1996; Solowij1998), while others show no statistically significant effect (Lekitsos et al, 1999; Mendelson, Rossi and Meyer, 1974; Dornbush et al, 1972). A number of factors appear to be related to these mixed findings, including the length of time the individual has been using cannabis heavily and measurement of the actual doses taken (Solowij, 1998). Thus, the long-term consequences of regular and heavy use of marijuana on cognitive functioning are still being explored.

Given the uncertainty of a long term association between marijuana use and cognitive functioning from the physical sciences, the proper interpretation of a negative association between early marijuana use and subsequent academic achievement identified by the social sciences remains in question. The possibility of an unobserved underlying third factor explaining 100% of the association between poor academic performance and marijuana use behavior cannot be easily refuted.

In this paper we revisit the question of whether marijuana use causes cognitive impairment using a large, nationally representative sample of youths from the National Education Longitudinal Survey (NELS:88). Unlike previous analyses examining this association in large populations, we examine the association between marijuana use and students' performance on standardized tests, a more direct measure of the student's cognitive ability and a variable that is less sensitive to other individual psychosocial behaviors. Moreover, studies have shown that standardized test scores are predictive of future earnings lending weight to the argument that test scores are important variables to examine.

We begin our examination by presenting cross-sectional models of the effects of marijuana use on standardized test scores in the 10^{th} grade. We find that marijuana use has a small and statistically significant negative association with composite, math, and reading standardized test scores. However, the statistical significance of these findings goes away when potentially endogenous variables capturing general academic performance, deviant behavior, and school attachment are included as additional regressors in the model. Given that the inclusion of these endogenous variables are likely to bias coefficient estimates from this long form model, we also consider difference-in-differences (DD) analyses, which reduce potential biases associated with time-invariant unobservable characteristics. These difference-in-difference models confirm that the association between marijuana use and test scores is substantially reduced; the negative association between marijuana use and math scores, however, remains.

The rest of the paper is organized as follows. In Section II we discuss the literature examining the relationship between marijuana use and schooling, highlighting the fact that many previous analyses focus on obtuse measures of cognitive function (high school drop out status) and exclude important school-level measures associated with schooling performance. In Section III we present our empirical modeling approach in light of the previous literature. In Section IV we discuss the specific variables being used from the National Educational Longitudinal Survey (NELS:88). The results and some additional sensitivity analyses are presented and discussed in Section V and we conclude in Section VI with a summary and policy implications.

II. The Literature on Marijuana Use and Schooling

If marijuana use truly does impact cognitive functioning, then one would expect that heavy marijuana use during adolescence would reduce general performance in school and educational achievement. The empirical relationship between marijuana use and school performance, however, is confounded by a number of other factors, including desire to fit in, reliance on coping mechanisms, natural ability, tastes for deviance, and rates of time preference (Fergusson & Horwood, 1997; Farrell & Fuchs, 1982; Schulenberg, et al 1994; Sanders, 2000).

These confounding factors make it difficult to interpret the true nature of the relationship between marijuana use and schooling.

The limited economics literature that has explicitly examined the relationship between marijuana use and educational attainment has generally focused on the impact of marijuana use on high school completion (Yamada, Kendix and Yamada, 1996; Bray et al, 2000; Register et al, 2001), presuming the causal relationship is one way. Yamada, Kendix and Yamada (1996), for example, employ a subsample of 1035 twelfth grade students from the 1982 National Longitudinal Survey of Youth (NLSY) to examine the impact of current alcohol and marijuana use on the probability of high school graduation. Although information on current/recent marijuana use was not obtained in the 1982 survey, it could be reconstructed using retrospective data collected in 1984. They estimate various models of high school graduation, entering recent alcohol and marijuana use into different model specifications, and find that marijuana (as well as alcohol) use diminishes the likelihood of graduating from high school. Additional controls in their model include gender, race, family structure, number of siblings, parental income, poverty, and ability (as measured by ASVAB scores). There are a number of significant limitations with this study, however, including the fact that recent alcohol and marijuana use are treated as exogenous variables without explicitly showing tests supporting this assumption. In addition, the sample size is relatively small given the number of individuals in the NLSY who could have been used for this analysis. Finally, the data set precluded them from including information on important school factors that are likely to be related to both high school completion and individual substance use.

Mensch and Kandel (1988) use a much larger sample of 12,000 young adults from the 1984 NLSY to estimate the impact of cigarette, alcohol, marijuana, and other illicit drug use on high school dropout status. They estimated models that accounted for parent's education, race, ethnicity, family structure, self-esteem, academic ability and delinquency and found that prior use of cigarettes, marijuana and other illicit drugs each increased the propensity to drop out of school. They did not find a significant relationship between prior alcohol use and dropping out, which they interpreted as evidence of the pervasiveness of alcohol use in American high schools. Here again, however, substance use is treated as an exogenous predictor without a test of this assumption and important school characteristics are omitted.

Bray et al. (2000) examine the relationship between marijuana initiation and dropping out of high school for a sample of 1392 students who participated in a longitudinal study in a Southeastern U.S. school system. In their analysis, they examine the effects of age of initiation of alcohol, cigarettes, marijuana and other illicit drugs on age-specific probabilities of dropping out of high school controlling for a series of sociodemographic variables including race, gender, enrollment in a rural versus an urban school, parents' education, number of parents living in the household, and the youths' self-report of typical grades earned in school. Marijuana initiation prior to the age of dropout has a positive and statistically significant effect on the probability of dropping out at age 16 and at age18 even after you control for age of initiation of cigarettes, alcohol, and other drugs. Marijuana initiation only affects dropping out for 17 year olds when other substance use is omitted from the equation; however it remains negative and significant in the model for the combined sample. They conclude from their results that marijuana initiators are 2.3 times more likely to subsequently drop out of high school than nonusers.

Following on work by Mensch and Kandel, Register, Williams & Grimes (2001) differentiate the effects of "hard drugs" from "soft drugs" in their examination of the impact of early illicit drug use on subsequent educational attainment. Using a sample of young males from the National Longitudinal Survey of Youth, they employ a two stage regression model that first predicts separate likelihood functions for the probability of using any illicit drug, any hard drug, and marijuana use only using data from 1984 when the respondents were 18 years of age or younger. Variables in the first stage include urbanicity (at age 14 and in 1992), family structure (living with both parents, number of siblings), parental education, age, ethnicity, marital status, number of dependents, region, religiosity, and an indicator of living in a state where marijuana has been decriminalized at age 14. They then construct predicted probabilities for each of these measures and evaluate their effects on subsequent total educational attainment in 1992, when the respondents are between the ages of 27 and 34 years of age. The models are also presented separately for Whites, Blacks and Hispanics. For each measure of drug use they find a negative and statistically significant effect on educational attainment in the full sample. However, when the models are run for specific ethnic groups, it shows that the negative and statistically significant effect only holds for the sample of Whites. The effects generally remain negative for the other groups, but they are not statistically significant.

A problem with the economic literature so far is its focus on drop out status as its main measure of educational attainment. Although completion of high school does have important economic implications on future earnings, it is also an outcome that is significantly confounded by other underlying behavioral factors that are difficult to statistically differentiate from observed drug use behavior. More importantly, high school drop out status is an imprecise measure of the impact of marijuana use on cognitive functioning because the decision to drop out is often based on a culmination of events, only one of which may be related to low or impaired cognitive ability.

In this paper, we propose examining the effects of marijuana use on a more direct measure of cognitive functioning, performance on standardized tests. By focusing on standardized test scores, we can assess whether regular marijuana use impacts performance and to what extent, looking for both big and small effects. Real effects of marijuana use on performance that are small might easily go unnoticed or be undetectable because of differences in natural ability across students. In addition, we consider a continuous measure of marijuana use that enables us to distinguish between light infrequent use of marijuana and more regular, frequent use, enabling us to differentiate the possible effects of light and heavy use. Finally, we include additional school-level measures that have been found to be important correlates of educational attainment and school performance, such as school environment. School environment has been found to have a significant impact on both adolescent substance use and educational attainment (Bachman, Johnston and O'Malley, 1998; Curran, Stice, and Chassin, 1997).

III. The Empirical Model

One could construct a theoretical framework demonstrating a causal relationship between marijuana use and student achievement by modifying the standard model of human capital formation. Ultimately, however, the relationship between marijuana use and educational achievement is an empirical question. If we assume that marijuana use is exogenous to the process determining student achievement, then we can express the relationship as follows:

(1) $$Y_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 Z_{jt} + \gamma_1 MJ_{ijt} + \varepsilon_{ijt}$$

where Y_{ijt} represents the measure of student achievement (ie. test score) for individual *i* in school *j* at time *t*, X_{ijt} is a vector of individual-level characteristics measured at time t, Z_{jt} is a vector of school-level characteristics measured at time t, MJ_{ijt} represents the use of marijuana by individual i in school j at time t, and ε_{ijt} is a random error term. The parameter γ_1 measures the effect of marijuana use on student achievement.

As discussed in the previous literature, there are at least two problems that could cause standard OLS estimation of γ_1 to generate a biased estimate of marijuana use on student achievement. First, it may be the case that low academic achievement encourages some youth to get involved with marijuana, in which case $\text{corr}(M_{ijt}, \varepsilon_{ijt}) \neq 0$. If this is the case than marijuana use is structurally endogenous and the causality could run both ways. We use a simple Hausman test of exogeneity to determine if this problem does indeed exist. Instruments used to perform this test are described in detail in the next section.

A second sort of bias can result if academic achievement and marijuana use are both associated with a common, but yet unaccounted for, third factor that generates a spurious correlation between these two observed variables. Plausible sources of unobserved heterogeneity include differences in ability, rates of time preference, coping mechanisms, and tastes for deviance. Unlike other measures of academic achievement that are more closely tied to student's behaviors, standardized test scores are expected to be less correlated with some of the unobserved factors that are more behaviorally based. Nonetheless, the potential for an omitted variable bias still remains.

To overcome bias that may be caused by an omitted variable problem, we employ two alternative approaches. First, we consider a "long form specification" of equation (1) that includes additional individual-level variables capturing observable aspects of the hypothesized source of the unobserved heterogeneity (W_{it}). The model can be written as follows:

(2) $Y_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 Z_{jt} + \beta_3 W_{it} + \gamma_1 MJ_{ijt} + \varepsilon_{ijt}$

Although the inclusion of these variables may reduce the bias caused by an omitted variable problem, they may also introduce new bias due to the probable endogeneity of these new variables. So while the estimates from the long-form model can be suggestive, they must be interpreted with some caution. An alternative method for addressing the omitted variable problem employs a difference-in-differences (DD) estimation strategy, which takes advantage of the panel nature of the data. The DD model that we estimate can be written as follows:

(3) $$\Delta Y_{ijt} = \beta_1 \Delta X_{ijt} + \beta_2 \Delta Z_{jt} + \gamma_1 \Delta MJ_{ijt} + e_{ijt}$$

where ΔY_{ijt} is the change in student achievement between time t and t-1, ΔX_{ijt} is a vector of the changes in individual-level variables over the same time period, ΔZ_{jt} is a vector of the changes in school-level variables over the same time period, ΔMJ_{iit} represents the change in marijuana use over the same period, and e_{ijt} is a random error term. The principal advantage of this model is that it will remove the influence of time-persistent unobserved heterogeneity without introducing any new bias to the estimates.

IV. The Data

The data we examine are taken from the National Education Longitudinal Study of 1988 (hereafter NELS:88), conducted by the National Center for Education Statistics. NELS:88 is a two-stage stratified, nationally representative sample of approximately 1,052 schools and 24,500 students who were eighth graders in 1988. The first follow-up included approximately 19,000 students, of which slightly more than one thousand had dropped out. The NELS:88 is designed to collect information regarding the educational experiences, aspirations, and activities of American eighth graders, as well as their immediate transition to high school. Students were resurveyed in 1990, 1992, and 1994, allowing researchers to track students from 8^{th} grade through high school, including those who dropout, up through their post-high school experiences. In addition, additional students were surveyed in 1990 and 1992 to enable nationally representative cross sectional analyses of 8th, 10th, and 12th graders.

In each of the first three waves, respondents completed a questionnaire and a battery of cognitive tests that were administered by the Educational Testing Service. Standardized tests were given in reading, mathematics, history and science. In this analysis we use performance on these standardized tests as a measure of academic achievement. To consider the possible differential influence marijuana could have on specific cognitive skills, we examine performance in terms of three different scores: their composite score, their math score, and their reading score.

While the primary focus of NELS:88 is on students' school experiences and achievement, there is a good deal of information available on students' substance use. In the 10th and 12th grade questionnaire information was collected on the number of times the person used marijuana in the past 30 days, the past 12 months and in their lifetime. We use the responses to these questions to generate two different measures of marijuana use for the contemporaneous (henceforth "10th grade") analyses of test scores and one measure of marijuana use for the DD models. For the 10th grade analyses, we first construct a simple dichotomous indicator of use in the past 30 days. This is the measure of use most commonly employed in the literature and is therefore used for the purposes of comparing our results to those of the previous literature. A second measure, which we refer to as the marijuana index variable, is constructed so that we can capture both the timing and intensity of marijuana use. The index can take a value from 0 to 4, where 0 represents having never used marijuana, 1 indicates lifetime use, but no use in the past year, 2 indicates use in the past year, but not in the past 30 days; 3 represents use of marijuana one to two times in the past 30 days, and a value of 4 indicates use of marijuana three or more times in the past month. The advantage of using the marijuana index is that it allows us to distinguish between light or infrequent users and heavy users.

For the DD models we drop individuals who report ever using marijuana in the 10th grade and construct a new dichotomous indicator of marijuana initiation that is set equal to 1 if the individual reports using marijuana in the past year or in the past month in the 12th grade and zero otherwise. This variable therefore captures the behavior of those individuals who chose to initiate marijuana use between 10th and 12th grade although it provides no information on the degree of involvement.[1]

To control for the socioeconomic and demographic characteristics of the individual NELS respondents, we also include the following measures in all of our models: race/ethnicity, age, sex, a composite measure of socioeconomic status[2], number of parents in the household, parent's highest educational attainment, a measure of religiousity (how often the respondent attends religious services), number of older siblings, and the type of high school program the student is enrolled in (i.e. college prep, vocational, regular). In the long form specification of our 10th grade model we include a wider array of individual characteristics that are frequently omitted in economic analyses because of their probable endogeneity.[3] Additional measures include current use of alcohol and frequency of binge drinking, 8th grade GPA, hours spent on homework in 8th grade, time spent working at a job, an index of 8th grade negative behaviors (i.e. getting sent to the office, disrupting class), the number of stressors that a student faced over the

[1] Individuals who report in 12th grade that they used marijuana in their lifetime were coded as non-users in the analyses presented here. The results presented here are not sensitive to how we code these individuals.
[2] The SES composite is created by NCES using information from questions on the parent questionnaire in 1988. It includes information on the parents' education level, parents' occupation, and family income. If all information on these items were missing from the parent's response then information from the student questionnaire on these items were used to generate the SES variable.
[3] Although we recognize that all of these variables are likely to be endogenous our purpose in including them is to test the sensitivity of the coefficients on the marijuana use indicators to their inclusion to help us understand the reliability of estimates obtained in the short form models.

past two years (i.e. parental divorce, death in the family, school change, serious illness), and indicator of whether the student had ever been offered drugs at school, a baseline assessment of the individual's risk of dropout, and an indicator for whether the student had initiated cigarette consumption in the 8th grade.

One of the principal advantages associated with using the NELS data is the wealth of information on the characteristics of the respondent's school, which enable us to develop fairly reasonable proxies for school quality that are known to have a statistical association with student achievement (e.g. Lee and Bryk, 1989; Card and Krueger, 1992). In all of our analyses we include measures of percent of the student body that is white, the percent of the student body receiving free or reduced-price lunches, the percent of 10th graders in the 1988-1989 school year that dropped out by 1990, the minimum salary paid to teachers in the school, the type of school (i.e., Catholic, other private, public), and a measure of the urbanicity of the school location.

For the purposes of testing the exogeneity of marijuana use, various price and policy variables that have been shown to be important for predicting marijuana use are merged into the NELS based on the county and state fipscodes of the respondent's address. Specific variables used as instruments include the geometric mean price of an ounce of commercial grade marijuana, the maximum fine and minimum jail time statutorily imposed for marijuana possession offences involving 10 grams of marijuana, and state decriminalization status. Information on the price of marijuana is available for 19 cities using various publications of the Drug Enforcement Agency's Office of Intelligence or Intelligence Division.[4] Given that missing data is reported for many regions in specific quarters, regression techniques are used to impute quarterly prices from 1985 through 2000. These imputed prices are then matched to students

[4] The name of the publication including the price data has changed over time. In 1990, the publication was entitled, "Illicit Drug Wholesale/Retail Price Report." Price information for wholesale and retail level sinsemilla marijuana is also available in this report.

based on the student's proximity to one of the satellite offices of the 19 division offices. Statutory penalty information (i.e. minimum jail, maximum fine and state decriminalization status) was obtained through original legal research conducted by the MayaTech Corporation for the purposes of this project.

The 10th grade analyses use data on all students surveyed in 1990 (10th grade) who had complete information on standardized test scores and had responded to questions pertaining to marijuana use in the 10th grade. For the DD analysis, the sample is further restricted to students that were still enrolled in school in 1992 (12th grade), had complete information on 12th grade test scores and marijuana use, and who did not use marijuana during the 10th grade year. Table 1 provides descriptive statistics for the samples used in the 10th grade and DD analyses. The means presented in Table 1 and all estimates presented in this paper are weighted so that the sample is nationally representative. The 10th grade sample includes 10,018 individuals. A sizable number of observations are lost from the original sample due to missing values. In an effort to maintain the sample size we have imputed values for some of the individual and school characteristics.[5] In such cases, we include the measure with imputed values and a dummy variable indicating observations for which the value was imputed. We, however, do not impute values for the main variables of interest, test scores or marijuana use.

As shown in Table 1, only 7.2% of our 10th grade sample has reported use of marijuana in the past 30 days. Annual prevalence among these 10th graders, which can be calculated by summing up the last three components of the MJ Index (past year use, past month use, 3+ times in the past month), is equal to 13.3%. These prevalence rates are slightly lower than the annual and thirty day prevalence obtained from 10th graders in the 1991 Monitoring the Future (MTF)

[5] We impute values for the minimum salary paid to teachers at the student's school, the hours spent on homework in the 8th grade, and the measure of negative school performance in 8th grade.

Survey, the first year in which data on the 10th graders was collected. These differences may be due to differences in sampling, however, since the MTF does not include youths from schools in each state in each year. Table 1 also shows that 12.1% of the nonusers in 10th grade initiated use by 12th grade.

Table 2 provides a preliminary look at the relationship between marijuana use and test scores for our sample of 10th graders. The first row shows average 10th grade composite, math and reading test scores for the full sample. It then shows how these average test scores vary by marijuana use involvement. The difference in test scores across use categories is statistically significant. Specifically, we find that those individuals reporting having never used marijuana in their lifetime (MJ index = 0) have higher average test scores across all tests. Average test scores generally decline as marijuana involvement increases, with the exception of lifetime users, who have lower test scores than respondents reporting use of marijuana in the past year and the past month. Given that our measure of lifetime use represents those that reported use in their lifetime, but not in the past year, this may be picking up the negative effect of being an early experimenter with marijuana. Heavier marijuana users who report use on three or more occasions in the past month have lower test scores than non-users, past year users, and past month users for all three scores. Only lifetime users have lower test scores, and this is only for math and the composite test score.

If we simply look at mean test scores by marijuana prevalence in the past thirty days, we again see that marijuana use is associated with lower test scores across all tests, although the differences between users and nonusers are not as large in absolute magnitude as those seen between never users and heavy users in the previous rows. Although the differences in mean test scores are suggestive, there are numerous confounding factors that may be generating these differences. In this next section we consider the extent to which these observed trends remain once confounding factors have been accounted for.

V. Results

We begin our exploration of the relationship between cognitive ability and marijuana use using simple OLS estimation of various forms of equation (1). Table 3 presents results from models examining performance on composite, math, and reading tests using three alternative measures of marijuana use. All models are weighted and adjust for the clustering observations at the school level using the svyreg command in STATA 7.0.

The results presented in Panel A of Table 3 represent the short form specification of our 10^{th} grade model. The first three columns present results of different marijuana use measures on the combined score for all the standardized tests, while the next three show results of these same marijuana use measures on standardized math scores and the final three show results on the standardized reading scores. In columns labeled "M1" the marijuana use index is entered linearly into the model, and in columns labeled "M2" it is entered as a series of dummy variables, with nonuse as the omitted category. Finally in columns labeled "M3" a simple dichotomous indicator of marijuana use in the past 30 days is used. All models in Panel A include as additional controls age, race, gender, socioeconomic status, number of siblings, religiousity, single parent household indicator, type of high school program, school ethnic composition, percent of students receiving reduced or free lunches, minimum salary paid to teachers, private school indicators and a measure of urbanicity of the school.

The results in Panel A are consistent with the literature. Generally we show a negative and statistically significant association between marijuana use and test scores regardless of how marijuana use and test scores are measured. When entered linearly, our marijuana index shows a smaller association than implied by either the series of dummy variables (M2) or our indicator of use in the previous thirty days (M3). The results presented in the columns labeled M2 suggest that the relationship between marijuana use and test scores is likely to be nonlinear, with experimenters (lifetime users) and heavy users (3+ times in the past 30 days) having an even lower test score than past year users for all three test scores. All marijuana users, regardless of their level of involvement, have lower scores on average than nonusers, however, as all of the dummy variables are negative and statistically different from zero. When only use in the past thirty days is considered (M3), we see that current marijuana users have lower scores, with their marijuana use influencing their math score more than reading scores.

A Hausman test is used to test the exogeneity of the marijuana use index and the dichotomous indicator of use in the past 30 days. Instruments for this test include the geometric mean price of an ounce of commercial grade marijuana, an indicator for decriminalization, the maximum fine and minimum jail time statutorily imposed for possession of 10 grams of marijuana. We verified the validity of these instruments using an overidentification test.[6] The computed test statistic for the Hausman tests of the marijuana index and 30-day prevalence measure were 0.24 and 0.31, showing that we could not reject the exogeneity of either of these measures. We therefore conclude that the single-equation estimates presented in Table 3 do not suffer from a structural endogeneity bias.

Although the inclusion of these marijuana use measures in the test score equations may not generate bias due to structural endogeneity, bias may still exist due to omitted confounding factors. As was described earlier, one way of dealing with this problem is to include observable aspects of potential confounding factors directly in the model. In Panel B of Table 3 we adopt

[6] The Hansen J statistic for the overidentifcation test was 3.388 (p-value= 0.495) in the model with the marijuana index treated as endogenous and 3.115 (p-value=0.539) in the model with the 30-day prevalence measure.

this approach to the problem and include as additional regressors indicators of early school performance (base year grades), school attachment (time spent doing homework in 8th grade, hours worked, 8th grade risk of dropping out of school), general tastes for deviance (use of cigarettes in 8th grade, 10th grade use of alcohol, 10th grade frequency of binge drinking, 8th grade index of negative behavior), and a measure of general life stress that captures the number of stressful events that occurred between 8th and 10th grade.

The inclusion of these additional regressors eliminates the association between marijuana use and performance on standardized tests. The marijuana use index (M1) and indicator of use in the past thirty days (M3) become positive and statistically insignificant in all three test score equations. When the marijuana use index is entered as a series of dummy variables (M2), only the indicator for lifetime use is negative and statistically significant, but this appears to be driven by an association with performance on the math test. The association is not statistically significant for reading tests. Additional sensitivity analyses conducted on the long form specification reveal that the main variables reducing the association between marijuana use and test scores are deviance measures (10th grade alcohol use, frequency of binge drinking and index of negative behaviors), base year grades, and school attachment measures (hours spent on homework and risk of drop out in the 8th grade) suggesting that these variables capture important aspects of unobserved heterogeneity that attenuate the relationship.

One interpretation of the findings presented in Panel B of Table 3 is that unobserved heterogeneity causes a spurious correlation between marijuana use and measures of cognitive functioning and that no real association exists. This is entirely plausible. However, one must be careful drawing such a conclusion from the evidence presented in Panel B, as the inclusion of these additional endogenous variables in the long form model may cause OLS methods to generate biased estimates. The nature of this bias cannot be precisely determined because of the different dimensions of unobserved heterogeneity that appear to attenuate the relationship.

We therefore also explore the robustness of these findings using an alternative approach for dealing with unobserved heterogeneity: difference-in-difference modeling. The primary advantage of this approach is that it enables us to control for unobserved factors without generating biased coefficient estimates. However, it is limited in that it can only account for unobservable factors that do not change over time.

In Table 4 we take a preliminary look at the average change in test scores for the combined, math and reading scores by level of marijuana use in the 10^{th} grade. Although there was a slight negative change on average in the composite test score between 10^{th} and 12^{th} grade, the students on average saw an increase in their math and reading scores. When we look at the relative changes in test scores by level of use, we see that individuals who used marijuana monthly or more frequently in the 10^{th} grade had smaller changes in math scores and larger changes in reading scores on average. These differences in average changes in test scores are not statistically significant from each other in the case of the marijuana use index, but they are in the case of our measure of thirty-day prevalence. This may be due to the fact that we have so few observations in the top two use categories of our marijuana use index and that we get more statistical power by grouping them. If we presume that this is the case, the results in Table 4 suggest that individuals who use marijuana more regularly in 10^{th} grade do relatively poorer on standardized math tests over time than non-current users, while they do better on reading tests, suggesting that marijuana use may have differential effects on specific cognitive skills. One needs to control for other facts that may be confounding these results, however.

There is a problem when you try to look for the impact of changes in marijuana use over time when use is measured as a simple dichotomous indicator. Individuals who do not use in both periods get assigned the same numerical value as individuals who use the substance in both periods because MJ(t) – MJ (t-1) = 0 in both these cases. To avoid problems with interpretation and to make sure we focus on the behavior of interest, we narrow our sample to just individuals who report having never used marijuana in their lifetime in the 10^{th} grade for the DD models. We then differentiate initiators, or those who reported using marijuana at least once in the past year in the 12^{th} grade, from non-users, or those who report never using marijuana in the 12^{th} grade. Table 5 examines the simple changes in mean test scores between 10^{th} and 12^{th} grade for these two separate groups. Here we see by comparing the average grade 10 score in row (2) to that in row (1), that on average individuals who initiated marijuana use between 10^{th} and 12^{th} grade have slightly lower combined, math and reading test scores in the 10^{th} grade than those students who never initiate marijuana. Furthermore, the change in test scores between 10^{th} and 12^{th} grade is smaller on average. When we estimate the impact of marijuana use on changes in test scores (DD estimates) for these simple averages, we find that the only statistically significant difference in test scores over time is that for math scores. The other differences in changes in test scores are not statistically significant.

In Table 6 we repeat the examination of difference in test scores between initiators and non-users over time, but now we control for other individual and school level factors that are known to change over time. Results are only shown for math and reading scores given that the combined test score is a composite of all tests taken and these two tests have previously shown a potential for a differential relationship with marijuana use.[7] In Model 1 we simply examine the

[7] We find a negative but insignificant impact of marijuana initiation on changes in the combined test score. These results are available from the authors upon request.

impact of being an initiator on changes in test scores, ignoring the level of the individual's baseline score. We find that individuals who initiate marijuana between 10th and 12th grade have significantly lower improvement in standardized math test scores than non-users. In addition we see a negative association between marijuana initiation and changes in reading scores, but this is not statistically significant.

A problem with the results presented in Model 1 is that they ignore the heterogeneity in individuals' baseline scores and the possibility of regression to the mean in test scores over time. Say, for example, that marijuana initiators have higher math test scores to start with. If this is indeed the case, then there is less room for improvement among marijuana users than non-users and that would generate a negative result. The results presented in Row (2) of Table 5 do not actually support this, but to account for the possible confounding effect of regression to the mean, we include in Model 2 two additional variables. The first is the average score of the individual's 10th and 12th grade subject-specific test. We use the average test score across the two grades as opposed to the individual's score in 10th grade score to reduce the negative correlation between change scores and initial values that might exist because of measurement error in the test score variable. The second term is simply the square of the first term, enabling a quadratic relationship between changes in test scores and levels of test scores.

The results presented for Model 2 in Table 6 confirm previous findings. Marijuana initiators again are found to have lower changes in math scores than non-users. Although the statistical significance of the effect is reduced slightly in Model 2, the magnitude of the effect remains relatively unchanged and is surprisingly consistent with the simple average difference-in-difference results presented in Table 5. Marijuana initiation between 10th and 12th grade is associated with a 0.65 percentage point smaller change in test scores. Given the average change in test scores for the sample is 4.415, this represents a 15% reduction. According to a paper by Murnane et al (1995) this could translate into a reduction in wages six years after high school from anywhere between 0.5 – 1.9% for those not going on to college.[8] We find no significant association between marijuana initiation and changes in reading (or composite) test scores.

VI. Conclusions

The results from all of our models combined suggest that much of the negative association between marijuana use and cognitive ability appears to be attenuated by individual level factors that are often not captured in empirical models, particularly individual differences related to school attachment and general deviance. Results from the long form specification of our model show that the negative association between marijuana use and test scores disappears when these additional measures are included in the model in almost all of the models. However, it is possible that these long form models suffer from endogeneity bias due to the inclusion of the additional variables. An alternative specification of the model that addresses unobserved heterogeneity by differencing it out shows that the negative association between marijuana use and math scores remains. The effect could translate into much as a 2% decline in wages after high school. (Murnane, Willett and Levy, 1995).

As we explained previously, there are strengths and weaknesses with each of the approaches that are employed. The use of a long form method for addressing unobserved heterogeneity introduces new bias due to endogeneity while DD models cannot account for unobserved heterogeneity that changes over time. Neither of these methods are perfect. Nonetheless, they

[8] Findings suggest that a 10 point reduction in standardized math score translates to a 7% reduction in wages six years after high school for men graduating high school in 1980 and not going on to college. The effect of math scores on wages for females not going on to college was even higher, with a 10 point reduction in math scores associated with a 19% reduction in wages six years after high school (Table 6, p. 263).

do tell a relatively consistent story in terms of the association between marijuana use and composite and reading test scores. The association between marijuana use and these measures of cognitive functioning appear to be explained by third factors. The association between marijuana use and math scores, however, remains an issue.

There are at least two limitations of the current study. First, standardized test scores are used as the only measures of cognitive ability. Test scores may be a weak measure of cognitive ability for a number of reasons, such as school teacher's "teaching to the test." However, we believe that standardized test scores are a substantially better indicator of cognitive ability than high school drop out status and are generally free of many of the problems associated with student grades. Nonetheless, further investigation using alternative measures of schooling performance is probably warranted.

Second, the study only considers the short-term effects of teenage marijuana use on cognitive functioning, examining performance on school tests in one grade and then looking at changes over a two-year period. The clinical research suggests that the harmful effects of marijuana use are typically seen in longer-term evaluations. This suggests that the results obtained in this study showing a short-term impact of marijuana use on test scores probably underestimate the true effect of marijuana use on cognitive functioning in the long run.

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Table 1: Summary Statistics

	10th Grade Sample		DD Sample	
	Weighted Mean	Std Err	Weighted Mean	Std Err
10th Grade Test Composite	52.591	0.194	54.465	0.225
10th Grade Reading Score	32.046	0.187	33.713	0.218
10th Grade Math Score	45.716	0.273	48.305	0.317
10th grade - Marijuana Use in Past 30 Days	0.072	0.004	0.000	0.000
10th grade - Marijuana Use Index -- 10th grade use	0.436	0.016	0.065	0.005
Never used	0.800	0.007	0.935	0.005
Life time use	0.066	0.004	0.065	0.005
Past year use	0.062	0.003		
Past month use	0.041	0.003		
3+ times in past month	0.030	0.002		
MJ initiation between 10th & 12th grades			0.121	0.008
Asian or Pacific Islander	0.039	0.003	0.042	0.004
Hispanic	0.083	0.008	0.071	0.008
African American	0.089	0.007	0.085	0.008
White	0.779	0.011	0.796	0.012
American Indian or Alaskan Native	0.010	0.002	0.006	0.001
Year of birth	73.686	0.009	73.740	0.010
Female	0.523	0.007	0.545	0.010
Socioeconomic Status (quartile)	2.658	0.027	2.735	0.030
Parents education	2.986	0.021	3.046	0.023
Single Parent Family	0.157	0.005	0.127	0.006
Number of Older Siblings	1.180	0.021	1.158	0.026
10th Grade - Student Hours Worked	1.290	0.024	1.207	0.025
Very Religious	0.446	0.009	0.511	0.011
Moderately Religious	0.180	0.006	0.175	0.007
Not Religious	0.374	0.009	0.314	0.010
10th Grade - General High School Program	0.462	0.011	0.436	0.013
10th Grade - Academic High School Program	0.392	0.011	0.455	0.013
10th Grade - Vocational High School Program	0.091	0.005	0.066	0.005
10th Grade - Other High School program	0.055	0.004	0.044	0.004
8th Grade - Cigarette Use in Past Month	0.041	0.003	0.016	0.002
10th Grade - Alcohol Use in Past Month	0.444	0.008	0.379	0.010
10th Grade - Binge Drinking in Past 2 Weeks	0.238	0.007	0.164	0.008
8th Grade Grades	2.817	0.021	3.025	0.022
8th Grade - Hours Spent on Homework	4.177	0.026	4.244	0.030
8th Grade - Hours Spent on Homework Missing	0.041	0.004	0.034	0.004
8th Grade - Negative School Performance Index	1.066	0.028	0.800	0.028
8th Grade - Negative School Performance Index Missing	0.014	0.002	0.011	0.002
Number of Stressors between 8th and 10th Grade	0.874	0.016	0.770	0.018
8th Grade - Risk of Drop Out	0.580	0.016	0.470	0.017

Table 1: Summary Statistics Continued

	10th Grade Sample		DD Sample	
	Weighted Mean	Std Err	Weighted Mean	Std Err
10th Grade - School % White	75.518	1.118	77.393	1.254
10th Grade - School % Free Lunch	18.270	0.743	17.664	0.805
10th Grade - School % Drop Out	6.838	0.328	6.734	0.383
Minimum Teacher Salary at High School	19,809	134.04	19,569	172.13
Mimimum Salary Information Missing	0.177	0.016	0.168	0.019
Public School	0.900	0.010	0.884	0.014
Catholic School	0.060	0.008	0.067	0.010
Other Private School	0.040	0.007	0.049	0.011
School in Urban Setting	0.253	0.017	0.248	0.020
School in a Suburban Setting	0.414	0.020	0.393	0.022
School in a Rural Setting	0.333	0.019	0.360	0.023
Number of Observations for all Variables	10,018		5,595	

Table 2: Standardized Test Scores by Marijuana Use (N=10,018)	Mean MJ Measure	Composite	Math	Reading
Average Test Scores for Entire Sample		52.59	45.72	32.05
Marijuana Use Index				
Never Used (MJ Index = 0)	0.80	53.31	46.74	32.67
Life time use (MJ Index=1)	0.07	48.72	39.93	28.92
Past year use (MJ Index = 2)	0.06	51.31	43.85	30.98
Past month use (MJ Index = 3)	0.04	49.57	41.61	29.31
3+ times in past month (MJ Index = 4)	0.03	48.77	40.76	28.42
F-value for test of equality across use categories		32.57	34.51	20.23
p-value		0.000	0.000	0.000
Marijuana Use in Past 30 Days				
No (MJ Prev = 0)	0.93	52.85	46.06	32.29
Yes (MJ Prev = 1)	0.07	49.23	41.25	28.93
F-value for test of equality across use categories		44.56	42.49	37.48
p-value		0.000	0.000	0.000

Table 3

Impact of Marijuana Use on Schooling: MJ Treated Exogenously

FULL Sample

Panel A: Short Form Specification

	Combined Test Scores			Math Scores			Reading Scores		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
MJ use index - linear	-0.839 [a]			-1.217 [a]			-0.705 [a]		
	(0.111)			(0.156)			(0.114)		
MJ use index - nonlinear									
Life time use		-2.287 [a]			-3.782 [a]			-1.583 [a]	
		(0.392)			(0.596)			(0.494)	
Past year use		-1.282 [a]			-2.042 [a]			-0.944 [b]	
		(0.394)			(0.561)			(0.428)	
Past month use		-2.456 [a]			-3.553 [a]			-2.069 [a]	
		(0.534)			(0.767)			(0.544)	
3+ times in past month		-3.350 [a]			-4.573 [a]			-3.018 [a]	
		(0.622)			(0.873)			(0.645)	
MJ use in past 30 days			-2.504 [a]			-3.446 [a]			-2.236 [a]
			(0.408)			(0.581)			(0.415)
R-squared	0.347	0.349	0.344	0.338	0.340	0.334	0.277	0.278	0.275
N	10018	10018	10018	10018	10018	10018	10018	10018	10018
F-stat	132.89 [a]	122.14 [a]	128.31 [a]	114.59 [a]	106.43 [a]	111.44 [a]	111.30 [a]	100.41 [a]	108.06 [a]

Panel B: Long Form Specification

	Combined Test Scores			Math Scores			Reading Scores		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
MJ use index - linear	0.070			0.018			0.120		
	(0.111)			(0.156)			(0.119)		
MJ use index - nonlinear									
Life time use		-0.851 [b]			-1.794 [a]			-0.310	
		(0.384)			(0.586)			(0.486)	
Past year use		0.386			0.187			0.594	
		(0.344)			(0.455)			(0.417)	
Past month use		0.144			-0.069			0.324	
		(0.511)			(0.732)			(0.535)	
3+ times in past month		0.315			0.406			0.301	
		(0.605)			(0.832)			(0.654)	
MJ use in past 30 days			0.278			0.374			0.255
			(0.404)			(0.567)			(0.425)
Cigarette use in grade 8	-0.549	-0.528	0.542	-0.904	-0.866	-0.967	-0.383	-0.371	-0.324
	(0.473)	(0.474)	(0.469)	(0.704)	(0.706)	(0.691)	(0.517)	(0.517)	(0.515)
Alcohol use in the past 30 days	0.057	0.083	0.061	0.370	0.425	0.36	-0.159	-0.151	-0.144
	(0.230)	(0.229)	(0.229)	(0.328)	(0.321)	(0.327)	(0.265)	(0.265)	(0.265)
Binge drinking in past 2 weeks	2.116 [a]	-2.124 [a]	-2.112 [a]	-2.620 [a]	-2.636 [a]	-2.662 [a]	-2.103 [a]	-2.105 [a]	-2.065 [a]
	(0.299)	(0.298)	(0.297)	(0.432)	(0.426)	(0.427)	(0.332)	(0.331)	(0.328)
R-squared	0.461	0.462	0.461	0.459	0.461	0.460	0.356	0.356	0.356
N	10018	10018	10018	10018	10018	10018	10018	10018	10018
F-stat	136.70 [a]	128.26 [a]	136.79 [a]	124.32 [a]	117.38 [a]	124.19 [a]	106.81 [a]	100.22 [a]	106.95 [a]

Notes: (1) Additional regressors in short form specification include the following: age, race, gender, socioeconomic status, single parent household, number of older siblings, religiousity, type of high school program, school ethnic composition, % receiving reduced/free lunch, minimum salary paid to teachers, private school indicators, and a measure of urbanicity of the school.

(2) Additional regressors in long form specification include those in the short form specification as well as the following: base year grades, time spent doing homework, index of negative behavior, baseline risk of dropping out, hours worked, number of stressful life events between 8th and 10th grade, current use of alcohol, frequency of binge drinking, and 8th grade cigarette use in the past 30 days.

(3) Significance of coefficients are indicated using the following superscripts: a= significant at 0.01 level (two-tailed), b = significance at 0.05 level (two-tailed), c = significance at 0.10 level (two-tailed).

Table 4
Change in Test Scores Between 10th & 12th Grade

	Number of obs	Change in Combined Scores	Change in Math Scores	Change in Reading Scores
Overall	7809	-0.279	4.415	2.237
		(0.068)	(0.087)	(0.101)
10th Grade Marijuana Use				
Never use	6412	-0.31	4.54	2.13
		(0.072)	(0.091)	(0.109)
Life time use	463	0.06	4.12	2.87
		(0.224)	(0.480)	(0.267)
Past year use	461	-0.33	3.93	2.40
		(0.259)	(0.288)	(0.420)
Past month use	280	-0.22	3.69	2.67
		(0.311)	(0.462)	(0.462)
3+ times in past month	193	0.02	3.41	3.25
		(0.353)	(0.556)	(0.448)
F test for equality of means across levels		0.56	0.38	0.73
p-value		0.64	0.76	0.53
30 Day Prevalence of Marijuana Use at 10th Grade				
No recent use	7336	-0.29	4.47	2.19
		(0.069)	(0.088)	(0.100)
Recent use	473	-0.12	3.58	2.90
		(0.236)	(0.350)	(0.325)
F test for equality of means across levels		0.49	6.27	4.87
p-value		0.49	0.01	0.03

Table 5
Changes in Mean Test Scores Between 10th and 12th Grade
by Marijuana Use Behavior in 10th and 12th Grade

		Number of Observations	Combined Test Scores	Math Test Scores	Reading Test Scores
Overall					
	Never used marijuana	*Avg grade 10 score*	54.31	48.05	33.62
(1)	N=5326	*Avg. change*	-0.252	4.674	2.178
	Initiated use between grades 10 & 12	*Avg grade 10 score*	53.41	47.43	32.36
(2)	N=726	*Avg. change*	-0.526	3.967	2.100
			Difference in Difference Estimates of the Effects of MJ Use on Test Scores		
	Effect of MJ use initiation,		-0.274	-0.707 [b]	-0.078
	Row (2) - Row (1)		(0.233)	(0.312)	(0.314)

Table 6
Difference-in-Difference Models

	Model 1		Model 2	
	Change in Math	Change in Reading	Change in Math	Change in Reading
Initiator	-0.674 [b]	-0.023	-0.650 [c]	0.017
	(0.332)	(0.333)	(0.334)	(0.338)
Average of 10th and 12th grade scores			0.239 [a]	0.547 [a]
			(0.050)	(0.074)
Average score*Average score			-0.002 [a]	-0.008 [a]
			(0.001)	(0.001)
Change in School Demographics/ Percent White	-0.001	0.004	-0.002	0.003
	(0.006)	(0.006)	(0.006)	(0.006)
Change in % School receiving Free or reduced lunch	0.000	-0.004	0.001	-0.005
	(0.008)	(0.008)	(0.008)	(0.008)
Change in lowest salary paid to Teachers	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Change in School Type/				
Catholic	2.378 [b]	0.408	2.262 [b]	0.406
	(0.983)	(1.508)	(0.990)	(1.522)
Other	-1.358	0.218	-1.202	0.634
	(1.709)	(2.028)	(1.723)	(2.025)
Public	*ref*	*ref*	*ref*	*ref*
Change in Type of High School Program				
Academic program	0.470 [c]	0.043	0.375	0.033
	(0.245)	(0.216)	(0.243)	(0.220)
Vocational program	-0.353	0.038	-0.348	-0.063
	(0.269)	(0.311)	(0.266)	(0.301)
Other program	0.420	-0.417	0.198	-0.478
	(0.440)	(0.514)	(0.459)	(0.532)
General Education program	*ref*	*ref*	*ref*	*ref*
Change in rural/urban status				
Suburban	0.222	2.080 [c]	0.089	1.937
	(1.013)	(1.181)	(0.980)	(1.178)
Rural	-0.008	2.475	-0.363	2.321
	(2.311)	(2.892)	(2.302)	(2.886)
Urban	*ref*	*ref*	*ref*	*ref*
Number of Observations	5591	5589	5591	5589
R-squared	0.006	0.002	0.016	0.015

Notes: (1) Significance of coefficients are indicated using the following superscripts: a = significant at the 0.01 level (two-tailed test), b = significance at 0.05 level (two-tailed test), c = significant at the 0.10 level (two-tailed test).