Economic Inquiry

GETTING INTO THE WEEDS: DOES LEGAL MARIJUANA ACCESS BLUNT ACADEMIC PERFORMANCE IN COLLEGE?

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This paper examines the effect of legal access to marijuana on student performance stemming from a voter-approved initiative legalizing marijuana for those 21 and older in the State of Washington. Using panel data from a medium-sized public university, we use a within-student and within-class estimator to show that legalization reduces students' grades, with an effect size about one-half the impact of gaining legal access to alcohol. Consistent with how marijuana consumption affects cognitive functioning, we find that students' grades fall furthest in courses that require more quantitative skills. These effects are largely driven by men and low performers. (*JEL* I23, I18, K32)

I. INTRODUCTION

Legal access to recreational marijuana has spread rapidly both across the United States and internationally. Since 2012, nine states and the District of Columbia have legalized small amounts of recreational marijuana and, as of July 2018, 20 states have bills before their state legislatures that would continue this trend.[1] Internationally, laws prohibiting personal cannabis consumption have disappeared in some countries (e.g., Uruguay, Colombia, and Spain) and have been decriminalized in many more. While the pharmacology of cannabis is relatively well understood, much less is known about the impacts of moving marijuana from a controlled substance to one that is legally available. In the United States, legalization efforts have focused on those aged 21 and over, typically the age of individuals in the process of building human capital through higher education and job training. Many open questions surround the impact of legalization on education outcomes and human capital accumulation of individuals in this age range.

In this paper, we measure the effect of legal access to marijuana on collegiate academic performance by employing transcript-level data of students enrolled in a comprehensive, 4-year, public university. These data cover the period before, during, and after marijuana legalization in the State of Washington, one of the first two U.S. states to legalize possession of small amounts of marijuana. Our identification strategy exploits two sources of variation not previously employed in marijuana policy research: student-level fixed effects and class-level fixed effects. Specifically, we identify the effect of legal access to marijuana by comparing the relative performance of a student to her classmates before she turns 21 with her relative performance after she turns 21 on the assumption that the best counterfactual for a student's post-21 performance is her earlier performance, while controlling for expected changes in performance as progress is made toward degree completion. Our identification strategy is similar to the preferred strategy of Lindo et al. (2013), who study the academic impact of legal alcohol access among 21-year-olds at the University of

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1. National Conference of State Legislatures, http://www.ncsl.org/research/civil-and-criminal-justice/marijuana-overview.aspx.

ABBREVIATIONS

GPA: Grade Point Average
NCHA: National College Health Assessment
STEM: Science, Technology, Engineering, or Math
THC: Tetrahydrocannabinol
WWU: Western Washington University

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Oregon.[2] Because our data span the legalization of marijuana in the State of Washington, we are able to separately identify an alcohol and marijuana effect. We demonstrate that the trend in these post-21 effects was nearing zero prior to marijuana legalization, thus ruling out the possibility that we mistakenly assign an unobserved trend in post-21 effects to marijuana legalization.

In the only paper of which we are aware that investigates marijuana access and student performance, Marie and Zölitz (2017) examine the impact on foreign students' grades at Maastricht University when they were banned from buying cannabis at state-sanctioned retailers. This restriction allowed Marie and Zölitz to make before-and-after comparisons of native students' grades, who were unaffected by the prohibition, with foreign students who were prohibited from purchasing marijuana. They find that the prohibition raised foreign students' grades by about one-tenth of a standard deviation and increased the probability of passing a course by about 5 percentage points. When applying Marie and Zölitz's findings to the United States, at least a few concerns can be raised. First, it is unclear whether going from a legalized to a prohibited environment produces the same behavior and effects as moving from a prohibited to legalized environment as is happening in the United States. Second, Marie and Zölitz report that almost 60% of Dutch students have smoked marijuana in the past year, an amount much higher than typically found in the United States, which raises questions of the applicability of the Dutch experiment to the United States. Lastly, our analytical sample contains approximately 20 times the number of observations used in the Dutch study, allowing for more precise treatment-effect estimations.

Our main results document a post-21 decline in relative-grade performance among Washington undergraduates, an effect that increases significantly after marijuana legalization. Prior to legalization, students' grades are estimated to fall by approximately 0.03 standard deviations after turning 21 relative to their earlier grades. This decline is nearly identical to Lindo et al.'s estimate of the effect of turning 21—an effect that they (and we) attribute to legal alcohol access. After marijuana legalization, our estimates indicate that the post-21 effect grows by about half to 0.046 standard deviations, suggesting that legalization further reduces student performance by 0.016 standard deviations. Our marijuana-effect size is about one-sixth that of Marie and Zölitz, a fact which we attribute to the likely lower proportion of students who actually respond to the change in marijuana's legal status in our study context and, possibly, to differences that arise from moving toward legalization rather than away from it as was done in the Netherlands. We further examine the marijuana effect by examining the pre- and postlegalization distribution of grades and find that legalization leads to an increased incidence in the assignment of D and F grades. Specifically, we estimate that Ds and Fs are given about 7% more frequently to students 21 and older after legalization relative to the period prior to legalization.

In order to determine whether our estimated performance declines genuinely arise from access to marijuana, we make use of what is known about marijuana's impact on human cognition and its change in prevalence over time. First, earlier research documents marijuana has larger negative impacts on abstract and quantitative skills than other academic skills.[3] To determine whether our results are consistent with this, we split our sample into quantitative and nonquantitative courses and show that the marijuana effect is as large as the alcohol effect in quantitative courses but is not present in nonquantitative courses. Second, there is considerable research that demonstrates marijuana use is higher for males than females. For instance, men are about 70% more likely than women to have used marijuana at least once in a given year (11% vs. 6.7%).[4] Further research suggests that the male–female marijuana gap has widened over the prior decade,[5] the period of time our data set covers. This increase in prevalence is consistent with the fact that in our sample, marijuana legalization has a much stronger effect on grades of men than women.

Prior research has also documented that frequent use of marijuana is associated with decreased ambition and motivation.[6] While decreases in these characteristics would be consistent with lower grades, there could be

2. Carrell, Hoekstra, and West (2011) also study the effect of legal access to alcohol on academic performance, choosing instead to exploit the sharp change in legal access at age 21 with a regression discontinuity design. See Lindo et al. (2013) for a review of the literature on alcohol consumption and student outcomes.

3. See Block and Ghoneim (1993), Pope and Yurgelun-Todd (1996), Pacula, Ringel, and Ross (2003).

4. SAMHSA (2014).

5. Carliner et al. (2017).

6. See Bloomfield et al. (2014) and van Hell et al. (2010).

additional academic effects. We investigate the impact of marijuana legalization on quarterly credits attempted, course withdrawal rates, enrollment in pass/no-pass grading, and a measure of the ease-of-grading expected during each quarter a student is enrolled. We find that after gaining legal access marijuana, students attempt fewer course credits and enroll in courses that are expected to offer higher grades. Under these conditions, our finding that marijuana reduces student grades may understate the actual effect of legalization.

In the next section, we outline the scope of marijuana legalization in the State of Washington and then describe the academic setting of our investigation in Section III. Section IV introduces our empirical model. Section V explains our results. Finally, Section VI offers concluding remarks.

II. MARIJUANA LEGALIZATION

As a result of passing citizens' Initiative 502 (I-502) on the November 2012 general election ballot with 56% support, the State of Washington legalized possession of small amounts of cannabis and cannabis-related products for individuals aged 21 and older starting on December 6, 2012.[7] I-502 provided for the growing and retail sales of marijuana after a 1-year period during which the state established a licensing system for growers and retailers. Retailers began receiving licenses in November 2013 and the first retail store opened on July 8, 2014. As of 2018, 528 marijuana retailers were active in Washington with total sales of nearly $1.4 billion.[8] For reference, this translates to one marijuana retail store for every 1.4 Starbucks locations in the state.[9] Whatcom County, the home of the university in this study, accounted for 3.8% of total marijuana sales in the state despite containing 2.9% of the state's population.[10]

While legal marijuana access in Washington seems to be increasing rapidly through expanding retail operations, the average potency of marijuana also appears to be increasing. One estimate of the average tetrahydrocannabinol (THC, the primary psychoactive component in cannabis) concentration in legal cannabis flower sold in Washington was recently put at 20.6%, over twice the THC strength of illegal cannabis confiscated in the United States.[11] Additionally, the Washington State Liquor and Cannabis Board estimates that due to genetic modifications, average marijuana potency has doubled since 1998.[12]

III. DATA DESCRIPTION

Data for this project come from Western Washington University (WWU), a regional, comprehensive university that annually enrolls about 14,000 undergraduates in 160 different bachelor's programs. The university also offers graduate degrees in some subjects, though for this project all graduate students and graduate-only courses are excluded. In the most recent year, WWU admitted 85% of freshmen applicants, about one-third of whom actually enrolled. The average math and verbal SAT score of incoming freshmen is about 1,170.[13] WWU is routinely among the top five regional, comprehensive universities in the *U.S. News and World Report* rankings.

WWU operates on a quarter system and, in an effort to maintain small classes, typically offers many sections of the same course each quarter. This is particularly true of lower-division introductory courses, which also tend to draw larger enrollments and serve as prerequisites for upper-division courses. The average class size is 17.5 students and the median class enrolls 12 students. Most students attend three quarters per year (fall, winter, and spring). During the summer quarter, enrollment is about one-fourth that of the other three quarters.

Every 2 years, WWU participates in the National College Health Assessment (NCHA) which is an anonymous survey given to students

7. Medical marijuana was legalized in the State of Washington through a citizen's initiative process in 1998. However, this legalized possession of marijuana only for patients with terminal or debilitating illnesses including chemotherapy-related nausea, AIDS, epilepsy, multiple sclerosis, glaucoma, and some forms of intractable pain.

8. Various reports from the Washington State Liquor and Cannabis Board at https://lcb.wa.gov/records/frequently-requested-lists.

9. https://rpubs.com/umeshjn/starbucks-stores.

10. Various reports from the Washington State Liquor and Cannabis Board at https://lcb.wa.gov/records/frequently-requested-lists.

11. Smart et al. (2017) use THC concentration data from 30 million cannabis sales in Washington State from July 2014 to September 2016. The United Nations Office of Drugs and Crimes (2012) reports an average THC concentration of 8.6% in illegal cannabis.

12. https://lcb.wa.gov/mj-education/safety.

13. Using the SAT scale introduced in March 2016.

TABLE 1
Responses to "Within the Last Thirty Days, on How Many Days Did You Use Marijuana?"

	Prelegalization WWU		Postlegalization WWU		National Data
	2010	2012	2014	2016	2017
Not used in last 30 days	74.2%	69.6%	67.5%	66.8%	78.0%
1–2 days	9.2%	11.7%	9.5%	9.5%	8.1%
3–5 days	3.4%	4.6%	6.0%	6.2%	3.9%
6–9 days	3.5%	3.6%	4.9%	3.9%	2.8%
10–19 days	3.2%	3.4%	4.7%	4.9%	2.6%
20–29 days	2.6%	2.7%	3.0%	3.9%	1.8%
Used daily	3.8%	4.4%	4.5%	4.9%	2.7%
Observations	650	523	938	613	14,369

Notes: All survey data come from the National College Health Assessment. The first four columns contain data from WWU students who were randomly selected to participate in the survey. The last column contains data from U.S. college students who were either randomly selected or were surveyed in randomly selected classrooms.

that assesses health and substance abuse.[14] Table 1 summarizes a question from this survey which asks, "Within the last thirty days, on how many days did you use marijuana?" In 2010, prior to legalization, 74% of WWU students had not used marijuana in the past 30 days. This fell to 67% in 2016, 4 years after legalization. There also appears to be a small change in frequent marijuana use; in 2010, 9% of students used more than 10 days in a month while in 2016 this rose to 14%. Table 1 also produces the most recent national figures computed by the NCHA which reveals that students at WWU are more frequent and more heavy users than average students in the United States. For instance, in 2017, 22% of college students nationwide had used marijuana at least once in the past month whereas about 33% of WWU students had done so in 2016. While higher use of marijuana may pose issues with regard to external validity, the marijuana use reported at WWU is lower than that at Maastricht University, the setting of Marie and Zölitz's study.[15]

In order to explore the effect of marijuana's impact on grades, we make use of administrative student-course level transcript data from WWU spanning summer quarter, 2003 through spring quarter, 2017. Because we make use of the academic history of students, we exclude all students who entered the university prior to the summer of 2003. Our identification strategy relies upon comparing student grades earned before turning 21 with those earned after. As students who either leave the university before turning 21 or who enter after turning 21 do not help identify the legal marijuana effect, we drop these observations as well.[16] Like many universities, WWU offers a number of practicum and small applied courses.[17] We exclude these courses from our sample and focus on courses described as labs, lectures, seminars, or any combination of these.[18] Our final data restriction has to do with the timing of marijuana legalization. As explained above, marijuana products became legal on December 6, 2012, during the last few weeks of WWU's fall quarter. In order to make pre- and postlegalization comparisons as distinct as possible, we drop all observations from this quarter, though our results are robust to their inclusion in the sample. Our final sample contains 1,150,285 student-course observations over 29,481 students for an average of just over 39 courses taken per student.[19]

Descriptive statistics for the analytical sample are given in Table 2. Like most 4-year public U.S. institutions, WWU's students are over half female and predominantly white.[20] Our primary measure of academic performance is the

14. NCHA is a nationally recognized research survey developed by the American College Health Association. More information can be found at http://www.acha-ncha.org/overview.html.

15. Marie and Zölitz (2017) report that 35.4% of students at Maastricht University consumed cannabis within the last 30 days in 2014–2015, whereas WWU students report a 32.5% 30-day usage rate in 2014.

16. This restriction includes individuals who entered the university at age 20 but turned 21 before earning grades during their first quarter on campus.

17. These small, applied courses include one-on-one music instrument courses, field experiences, independent studies, senior theses, and internships.

18. This set of courses accounts for 94.7% of courses taught at WWU.

19. When we estimate our preferred model without these sample restrictions, we find the impact of marijuana legalization is even larger than with these restrictions.

20. See Lindo et al. 2013.

TABLE 2
Descriptive Statistics

	Mean	Standard Deviation	Number of Unique Students	Total Number of Observations
Panel A: Student characteristics				
Fraction female	0.56	0.50	29,481	1,150,285
Fraction white	0.77	0.42	28,574	1,116,102
Fraction black	0.03	0.16	28,574	1,116,102
Fraction Hispanic	0.05	0.22	28,574	1,116,102
Fraction Asian	0.10	0.30	28,574	1,116,102
Age (months)	251	17.1	29,481	1,150,285
SAT composite score	1,120	138	25,058	1,018,495
ACT composite score	24.3	3.81	6,972	281,326
Panel B: Student outcomes				
Standardized grade	0	1	29,478	1,051,836
100-level courses	−0.249	1.078	28,412	303,629
200-level courses	−0.053	0.996	29,106	301,920
300-level courses	0.111	0.928	28,854	297,359
400-level courses	0.384	0.814	24,767	144,945
Course withdrawal	0.030	0.170	29,481	1,150,285
Pass/no-pass grading	0.054	0.226	29,481	1,150,285
Number of credits attempted	14.7	2.59	29,481	344,023

Notes: All variables are measured at the student-by-course level except number of credit hours attempted, which is measured at the student-by-term level. There are 3,983 total observations from courses below the 100-level.

grade earned in a class. WWU assigns grades on a 4-point scale with the possibility of "plusses" and "minuses" for all grades except A which cannot receive a "plus."[21] To make our research comparable with others, we standardize these grades to be mean zero and variance equal to one across the entire sample. Looking at grades across course levels, average standardized grades are higher in more advanced courses: grades increase from −0.249 standard deviations in 100-level courses to 0.384 standard deviations in 400-level courses. The variances of standardized grades falls as the course level increases, likely a consequence of attrition of weaker students and better matching between students and their fields of interest at higher course levels.[22]

Among our observations, grades lending themselves to standardization were assigned 91.4% of the time. Of the remaining 8.6% of observations, 63.3% enrolled in a pass/fail course (and hence do not have a numerical grade assigned to their course) and 34.8% withdrew from the course prior to grade assignment. The remainder had not received grades at the time we received our data. Because marijuana legalization could influence patterns of course withdrawal or enrollment in pass/fail courses, we keep these students in the sample and explore the impact of legalization on these measures later. However, because they were not assigned numerical grades, these observations are excluded from empirical models estimating students' grades. We are also interested in how changes in marijuana policy affect other course-taking behavior, such as the number of credits taken in a quarter. On average, WWU students in our sample enrolled in 14.77 credits each quarter prior to legalization and 14.49 credits after legalization.

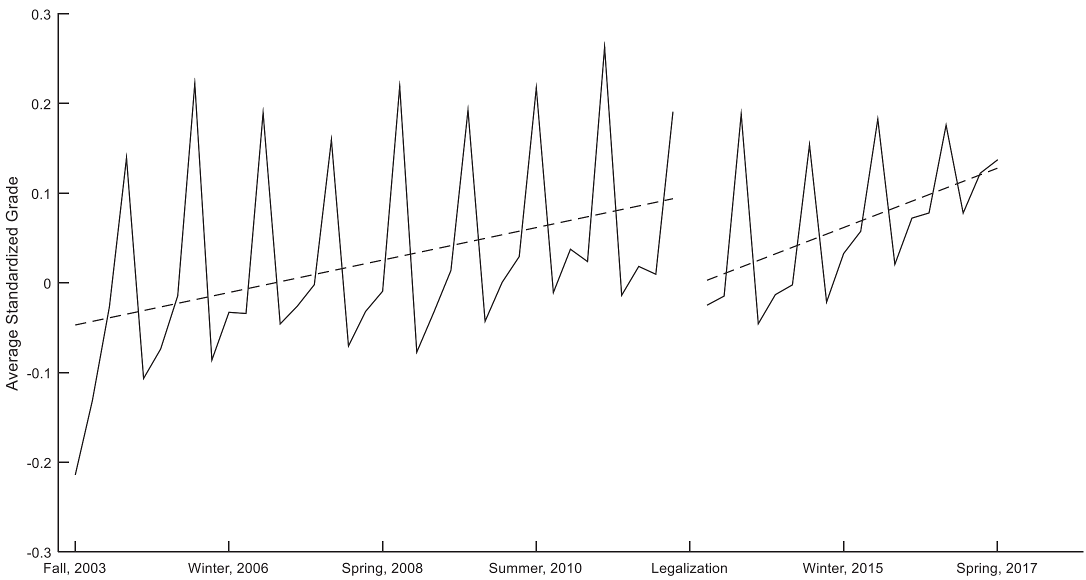
Figure 1 presents the standardized grades averaged across our sample over time. Superimposed on these averages are two regression lines each measuring the trend in the average grade given, one before and one after legalization. Four important facts are seen in this figure. First, the vertical distance between both regression lines declined by nearly one-tenth of a standard deviation between the pre- and postlegalization periods suggesting that average grades were lower after marijuana legalization. Second, over both the pre- and postlegalization periods, grades have been rising over time, which is consistent with grade inflation observed in other contexts.[23] Third, the grade time trend is steeper

21. "Plusses" add .3 grade points to the student's course grade and "minuses" reduce grade points by the same amount.

22. We find that standardizing grades by course level rather than across the entire sample produces nearly identical results.

23. For example, see Rojstaczer and Healy (2012).

FIGURE 1
Average Standardized Grades over Time



Notes: The solid line in this graph plots the average standardized grade (grades are standardized over the entire sample period to have mean zero and variance one) by term. Marijuana legalization occurred during the fall quarter of 2012. The two dashed lines are fitted values measuring the trend over time in the average grade given, one before legalization and the other after legalization.

after legalization.[24] Finally, there is considerable deviation in average grades across quarters within years. The average grades given during summer quarters (the sharp, positive spikes in Figure 1) are often more than two-tenths of a standard deviation higher than those given in the following fall which, in turn, are usually lower than grades given in winter and spring quarters.[25] This pattern is a function of at least two items: a composition effect and a course-advancement effect. The composition effect is a combination of self-selection into summer courses as well as weaker students dropping out after fall quarter leaving relatively stronger students in later quarters. The course-advancement effect tends to raise grades as students progress through a course of study over the academic year. Given the different trends in average grades, as well as significant variation in grades within a year, identifying the marijuana effect must account for these patterns. We describe how we do this in the next section.

IV. METHODS

To estimate the effects of legal access to marijuana on student performance, we apply a difference-in-differences approach that compares changes in student performance after turning 21 during the legalized-marijuana period relative to changes in performance after turning 21 before legalization. As discussed in the previous section, Table 1 suggests that overall and frequent marijuana use increased after legalization.[26] Given the absence of student-level data on marijuana consumption, our results should be characterized as intent-to-treat estimates that measure the reduced-form effect of the change in marijuana policy on student performance.

In describing how student performance is impacted by legal access to marijuana, the

24. We find that average grades rise at nearly twice the rate each quarter after legalization (slope = 0.0073) compared to before (slope = 0.0040).

25. We show that our main results are robust to dropping summer quarters in Section V.

26. One potential issue is that this increase could be due to changes in student body composition. We address this by including student fixed effects in our preferred empirical specification.

primary outcome of interest is a student's standardized course grade. We first estimate a basic difference-in-differences model of the form:

$$(1) \quad Y_{ijct} = \alpha + \beta_1 Marijuana_t + \beta_2 Age21_{it} + \beta_3 \left(Marijuana_t \times Age21_{it}\right) + \epsilon_{ijct},$$

where Y_{ijct} is the standardized grade for student i given by instructor j in course c in term t.[27] $Marijuana_t$ is an indicator variable that takes the value one if term t occurs after fall 2012 (after marijuana legalization) and zero otherwise. $Age21_{it}$ is an indicator variable that takes the value one if student i is 21 any time during term t and zero otherwise. The variable of interest is $Marijuana_t \times Age21_{it}$ and its corresponding coefficient, β_3, gives the difference-in-differences estimate of marijuana legalization. Lastly, α is a constant and ϵ_{ijct} is a stochastic error term clustered at the term level.[28]

We improve on this basic model in a number of ways in order to arrive at our preferred econometric specification. First, Figure 1 reveals cyclical patterns in standardized grades across quarters in the same academic year and shows a steeper time trend in grades after legalization. Additionally, Table 2 reveals that average grades increase in higher-level courses. We therefore include class (instructor-by-course-by-term) fixed effects to account for grade cyclicality and inflation across time and course level. Ignoring these issues would likely lead to biased coefficient estimates. Most importantly, the difference in grade time trends would lead β_3 to be biased upward. Including class fixed effects controls for unobserved differences in instructor grading behavior and implicitly standardizes grades across classes as students' grades are compared to the average grade given within each class.

Second, we include student fixed effects to control for time-invariant unobserved student quality and to allow each student's pre-21 performance to serve as the counterfactual for her post-21 performance. Incorporating student fixed effects helps mitigate the possible issue that the observed effect of legal access to marijuana is driven by changes in student body composition, since variation in the dependent variable comes from within students rather than across students.[29]

Third, we include various controls for experience designed to capture expected grade changes as a student makes progress toward degree completion. We include these controls to separate phenomena such as changes in motivation as students approach the end of their college career from the effect of turning 21, which also tends to happen near degree completion. These experience controls include the overall number of accumulated credits, the number of credits a student has accumulated within the course's academic department, and student age at the beginning of the term (in months).[30]

Our preferred model can thus be written as:

$$(2) \quad Y_{ijct} = \alpha_i + \beta_2 Age21_{it} + \beta_3 \left(Marijuana_t \times Age21_{it}\right) + \mathbf{X}'_{it}\gamma + \delta_{jct} + \epsilon_{ijct},$$

where α_i is a student-specific fixed effect, $\mathbf{X}_{\text{it}}$ is a vector containing experience controls, and δ_{jct} is a class-specific (instructor-by-course-by-term) fixed effect. Note that since the timing of marijuana legalization does not vary within a class, $Marijuana_t$ is dropped from Equation (2).

Equation (2) identifies the impact of marijuana legalization by comparing the within-student and within-course impact of turning 21 on grades before legalization with that after legalization. Given this, the largest threat to internal validity is the potential that the impact of turning 21 on grades has been changing over

27. A term is a quarter-by-year. For example, fall 2010.

28. To avoid downward-biased standard errors, we use more aggregate clusters (Cameron and Miller 2015). Clustering at the student level as in Lindo et al. (2013) produces very similar standard errors.

29. Although student fixed effects control for time-invariant aspects of students, legalization could encourage students who are more likely to change their behavior after gaining legal access to marijuana to attend WWU. While this is possible, we have reason to believe this has small impacts on our estimates. First, since marijuana legalization affects all universities in the State of Washington, there is no change in relative demand for WWU for in-state students. Estimating our preferred specification with a sample of only Washington residents produces very similar results to those presented in Table 3. Second, out-of-state students may be more (or less) attracted to the university because of legalization; however, this is partly mitigated by a large out-of-state versus in-state tuition differential. Further, WWU enrolls a small number of out-of-state students: about 10.6% of total enrollment at the time of legalization and 11.3% four years later. Even if this climb in out-of-state enrollment was all attributable to legalization, the numbers are so small as to be unlikely to account for our findings.

30. We include linear accumulated-credit controls but modeling them as fixed effects in four-credit intervals (as in Lindo et al. 2013) produces very similar results. Similarly, we control for age with a linear specification but modeling age as a higher-order polynomial does not significantly affect our estimates. See Section V for more details.

TABLE 3
Estimated Effects of Legal Access to Marijuana on Grades

	(1)	(2)	(3)	(4)	(5)
Marijuana legal	0.020				
	(0.016)				
Age ≥ 21 during term	0.141***	−0.147***	−0.059***	−0.030***	−0.031***
	(0.008)	(0.006)	(0.004)	(0.005)	(0.005)
Marijuana × 21	−0.002	−0.016*	−0.003	−0.016**	−0.016**
	(0.013)	(0.008)	(0.007)	(0.006)	(0.006)
Accumulated credits				−0.003***	−0.003***
				(0.000)	(0.000)
Accumulated department credits					0.003***
					(0.000)
Age (months)					−0.010**
					(0.005)
Fixed effects					
Class	No	Yes	Yes	Yes	Yes
Student	No	No	Yes	Yes	Yes
Observations	1,051,836	1,051,836	1,051,836	1,051,836	1,051,836
R^2	.01	.30	.55	.55	.55

Notes: The dependent variable is the student's standardized course grade. Standard errors (in parentheses) are corrected for clustering at the term level.
$^{*}p < .1$. $^{**}p < .05$. $^{***}p < .01$.

time. For instance, if more recent students are less able to handle legal alcohol consumption or if they increase alcohol consumption relative to previous cohorts upon turning 21, then β_3 would be negatively biased and we would confound this increasing alcohol effect with the marijuana effect. A related problem would occur if there were changes in state law or university policy which impacted students aged 21 or older at the same time marijuana was legalized.[31] We are able to test for these possibilities and report our results in the next section.

V. RESULTS

This section first reports our main results on the effect of legal access to marijuana on grades. In subsequent subsections, we examine possible treatment-effect dynamics (Section V.B), check the robustness of our results and conduct subgroup analyses with particular attention given to testing whether our findings are consistent with how marijuana consumption affects cognitive functioning (Section V.C), and consider the effects of legal access to marijuana on course-taking behavior (Section V.D).

A. *Main Results*

We present our main results in Table 3. We begin by estimating the simple difference-in-differences model from Equation (1) in column (1). Because this model does not account for time trends in grades or that average grades increase in higher-level courses (which are more likely to be populated by students over age 21), the estimated effect of legal access to alcohol will be positively biased. We also expect the estimated effect of legal access to marijuana to be positively biased given the steeper time trend in grades after marijuana legalization shown in Figure 1. After including class fixed effects in column (2) (and dropping the collinear marijuana legalization indicator), the estimated alcohol-access effect takes the expected negative sign at −0.147 standard deviations and is statistically significant at the 1% level. The difference-in-differences estimate of the legal-marijuana-access effect is −0.016 and is significant at the 10% level. However, these estimates likely overstate the

31. A thorough search of university policy changes during the period 2011–2014 reveals no policy changes that would systematically impact students over 21. In 2011, the year before marijuana legalization, the State of Washington closed all of its state-owned liquor stores and allowed retail stores to sell hard alcohol. However, this did not change legal access to alcohol and was accompanied by significantly higher taxes intended to reimburse the state for the closure of state-owned stores. The end result is that taxes on liquor in Washington are the highest in the United States and the average price of liquor jumped almost 8% in the first full year of this policy. To the extent that students are price sensitive, this would suggest a decline in liquor consumption at the same time of the implementation of marijuana legalization. See Office of Financial Management (2015) for details.

TABLE 4
Estimated Effects of Legal Access to Marijuana on the Grade Distribution

	Outcome			
	A Grade	**B Grade**	**C Grade**	**D or F Grade**
Age ≥ 21 during term	−0.008***	−0.001	0.003*	0.006***
	(0.002)	(0.002)	(0.002)	(0.001)
Marijuana × 21	−0.004	−0.001	0.001	0.003**
	(0.003)	(0.003)	(0.003)	(0.001)
Sample mean of dependent variable	0.403	0.391	0.163	0.044
Observations	1,051,836	1,051,836	1,051,836	1,051,836
R^2	.49	.22	.27	.22

Notes: The dependent variable is a binary indicator for each grade category. All regression models contain class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. Standard errors (in parentheses) are corrected for clustering at the term level.
$^{*}p < .1$. $^{**}p < .05$. $^{***}p < .01$.

effects of legal access to alcohol and marijuana, as students who take longer to complete their degree (and hence are likely weaker students) will be observed more frequently after turning 21. Indeed, including student fixed effects to control for ability and other unobserved student-level time-invariant characteristics in column (3) attenuates both effects such that marijuana no longer statistically impacts grades. However, column (3) omits controls for student experience, which may lead to biased estimates of the marijuana effect. When we add accumulated credits to control for experience in column (4), we find that grades decline as students earn more academic credits, perhaps due to decreased motivation as students make progress toward degree completion. Thus, if marijuana also reduces motivation, as suggested by previous research, and if this lower motivation reduces the number of credits students earn, then omitting accumulated credits as an explanatory variable will bias column (3)'s estimates of the marijuana effect upward.[32] Indeed, after controlling for accumulated credits, the point estimate for the effect of legal access to marijuana falls to −0.016 standard deviations and is statistically significant at the 5% level. Our preferred model adds credits accumulated within the course's academic department and student age (in months) at the beginning of the term as controls, with those results given in column (5). Including age makes this last specification analogous to implementing a regression-discontinuity design with age as the running variable. Estimates of the alcohol and marijuana effects change little moving from column (4) to (5).

Before moving to additional analysis, our preferred model in column (5) of Table 3 offers other interesting results. The estimated impact of legal access to alcohol on grades is −0.031 standard deviations, an estimate that is nearly identical to the −0.033 standard deviations estimate found by Lindo et al. (2013). Additionally, grades fall with accumulated credits but rise, by about the same magnitude, in departmental accumulated credits suggesting that grades do not decline in classes offered by departments in which students have taken classes in the past. If grade declines are caused by reduced motivation as students reach the end of their academic career, this suggests that the motivation loss is less for students taking multiple courses in the same department.

We further investigate the impact of marijuana legalization by exploring the probability of receiving different letter grades. In Table 4, we estimate linear probability models using the same controls from our preferred model in Equation (2) and the fifth column of Table 3. Each column in Table 4 is a separate regression estimating the probability that a student receives an A grade, B grade, C grade, and a D or F grade, respectively. For parsimony, Table 4 shows only the coefficients associated with $Marijuana_t \times Age21_{it}$ and $Age21_{it}$. The point estimates indicate that legal access to alcohol decreases the likelihood that a student receives an A grade and increases the likelihood that a student receives a C, D, or F grade—exactly the same pattern attributed to legal alcohol access by Lindo et al. (2013). Legal access to marijuana appears to exacerbate these shifts in the grade distribution with a statistically

32. We find that the average number of accumulated credits is lower after marijuana legalization than before. We further investigate marijuana's role in course-taking behavior in Section V.D.

significant (at the 5% level) increase in the probability that a student earns a D or F grade by 0.3 percentage points. In our sample, 4.4% of students receive a D or F grade so an increase of 0.3 percentage points equates to an increase in the probability of receiving a D or F by about 7%.

B. Treatment-Effect Dynamics

We next consider the dynamic effects of legal access to marijuana. Estimates from our preferred model in column (5) of Table 3 indicate that legal access to marijuana decreases students' standardized grades relative to students with only legal access to alcohol. Put another way, we find that the effect of turning 21 on grades becomes more negative after marijuana legalization. One potential issue is that we may mistake a time trend in the effect of turning 21 for the effect of gaining legal access to marijuana. That is, if the negative effect of turning 21 was becoming more pronounced leading up to marijuana legalization in December 2012, then perhaps it would have continued to do so in the absence of marijuana legalization. We investigate this possibility in Table 5 where we replace the post-21 indicator variable and the marijuana-post-21 interaction from Equation (2) with set of indicator variables for post-21 by academic year, essentially separating the effect of turning 21 over time.[33] Notably, our estimates indicate that, if anything, the post-21 effect was becoming less negative in the years immediately preceding marijuana legalization (looking before the 2012–2013 academic year). Furthermore, the equality of the 2011–2012 post-21 effect and the 2012–2013 post-21 effect can be rejected at the 10% level (p value = .076).

We also consider the dynamic response to legal marijuana access following the first term of legal access. Specifically, we replace the post-21 indicator variable and marijuana-post-21 interaction from Equation (2) with two sets of indicators: one set corresponding to the number of terms after alcohol consumption is first legal and the other set corresponding to the number of terms after marijuana consumption is first legal for each student. For both sets of indicators, we include the term in which access is first legal, one term after, two terms after, and three-plus terms after. The omitted category is any term prior to the student turning 21. Results of this exercise are presented in Table 6.

TABLE 5
Dynamic Effects of Turning 21 by Academic Year

Before marijuana legalization	
Age ≥ 21 during term × pre-2007	−0.032***
	(0.009)
Age ≥ 21 during term × 2007	−0.041***
	(0.015)
Age ≥ 21 during term × 2008	−0.026*
	(0.013)
Age ≥ 21 during term × 2009	−0.051***
	(0.010)
Age ≥ 21 during term × 2010	−0.026***
	(0.009)
Age ≥ 21 during term × 2011	−0.013
	(0.018)
After marijuana legalization	
Age ≥ 21 during term × 2012	−0.044***
	(0.012)
Age ≥ 21 during term × 2013	−0.042***
	(0.007)
Age ≥ 21 during term × 2014	−0.047***
	(0.007)
Age ≥ 21 during term × 2015	−0.053***
	(0.007)
Age ≥ 21 during term × 2016	−0.053***
	(0.007)
Observations	1,051,836
R^2	.55

Notes: The dependent variable is the student's standardized course grade. Years stated above represent academic years. For example, "2007" is the 2007–2008 academic year. This regression model contains class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. Standard errors (in parentheses) are corrected for clustering at the term level.
$^{*}p < .1$. $^{**}p < .05$. $^{***}p < .01$.

Column (1) of Table 6 provides estimates from our preferred model of dynamic treatment effects. Grades fall significantly in the terms when students gain legal access to alcohol (by 0.03 standard deviations) and fall significantly further in the terms when students gain legal access to marijuana (by 0.014 standard deviations). These negative effects appear to get worse in subsequent terms, with both effects nearly doubling by three-plus terms after legal access.

We examine another threat to the validity of our results in column (2) of Table 6. Namely, if students' grades fall below their expected levels before gaining legal access to marijuana, then it is unlikely that we have identified the effect of legal access. To test this, we add indicator variables

33. An academic year includes consecutive fall, winter, spring, and summer quarters and is indicated by the fall year. For example, "2007" is the fall 2007 through summer 2008 academic year. The exception to this is 2012–2013, which contains only winter, spring, and summer quarters since fall 2012 (the quarter in which marijuana was legalized) is dropped from the analysis.

TABLE 6
Dynamic Effects of Legal Access to Marijuana on Grades: Term Leads and Lags

	(1)	(2)
1 term before alcohol consumption legal		0.001 (0.006)
Term in which alcohol consumption legal	−0.030*** (0.004)	−0.030*** (0.004)
1 term after alcohol consumption legal	−0.033*** (0.004)	−0.033*** (0.004)
2 terms after alcohol consumption legal	−0.040*** (0.005)	−0.040*** (0.005)
3+ terms after alcohol consumption legal	−0.056*** (0.005)	−0.056*** (0.006)
1 term before marijuana consumption legal		0.003 (0.007)
Term in which marijuana consumption legal	−0.014** (0.005)	−0.013** (0.005)
1 term after marijuana consumption legal	−0.020** (0.008)	−0.019** (0.007)
2 terms after marijuana consumption legal	−0.023*** (0.007)	−0.022*** (0.008)
3+ terms after marijuana consumption legal	−0.029*** (0.009)	−0.027** (0.010)
Observations	1,051,836	1,051,836
R^2	.55	.55

Notes: The dependent variable is the student's standardized course grade. All regression models contain class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. Standard errors (in parentheses) are corrected for clustering at the term level.

*$p < .1$. **$p < .05$. ***$p < .01$.

for the term preceding legal access to alcohol and marijuana, respectively, in column (2). The omitted category in column (2) thus becomes two-plus terms prior to turning 21.[34] Neither the pre-marijuana-access nor pre-alcohol-access estimates are significantly different from zero, which lends support for our preferred model and identification strategy.[35]

C. Subgroup Analysis and Robustness

To further investigate whether the observed decrease in student performance is attributable to legal marijuana access, we leverage previous studies that find marijuana has larger negative impacts on quantitative skills than nonquantitative skills and that males are more likely to use marijuana than females. Thus, if the decreases in performance are greater in quantitative classes and disproportionately affect males, we can be more assured that the effects are due to increased marijuana consumption. We expect to see no significant differences in the effect of legal alcohol access across quantitative/nonquantitative courses or gender.

We split our sample into quantitative and nonquantitative courses based the following criteria: courses are classified as quantitative if they are offered in a science, technology, engineering, or math (STEM) department[36] or contain a quantitative term in their course description (and are designated as nonquantitative otherwise).[37] Of the 4,177 unique courses offered in our sample, this classification procedure resulted in 1,055 quantitative courses and 3,122 nonquantitative courses.

Table 7 reports results from our preferred specification for subgroups based on the quantitative requirements of the course and gender. The first two columns reveal a significant marijuana effect only in quantitative courses. The estimates suggest that the negative effect of marijuana in quantitative courses is just as large as the effect of alcohol at about 0.03 standard deviations. Similar to Carrell, Hoekstra, and West (2011), we find that legal access to alcohol negatively affects both quantitative and nonquantitative course grades. In the next two columns, our estimates suggest that legal access to marijuana affects men but has no detectable effect on women. As expected, we see little difference in the negative effect of alcohol across gender.

In the last four columns of Table 7, we separately consider the alcohol and marijuana effects for males in quantitative courses, males in nonquantitative courses, females in quantitative courses, and females in nonquantitative courses. We find consistent negative effects of alcohol access across these groups. However, we only detect marijuana effects for males in quantitative courses, which lends credibility to

34. Although it is tempting to continue to add pre-21 indicators, doing so comes at the cost of reducing power.

35. We have also investigated whether the timing of birthdays within a quarter influences the treatment-effect estimates. To do this, we included separate post-21 indicators and interactions with the marijuana-policy indicator based on whether birthdays occurred during the first of second half of the term. Our estimates suggest that gaining legal access to alcohol or marijuana during either half of the term negatively affects grades. Furthermore, we find no statistically significant difference between the first-half and second-half effects.

36. STEM departments are biology, chemistry, computer science, materials science, environmental science, geology, mathematics, physics, engineering, and economics.

37. The quantitative terms used for searching online course descriptions are math-, statistic-, modeling, equation, comput-, numeric-, and quant-. WWU course descriptions can be found in the online catalog at https://catalog.wwu.edu/search_advanced.php.

TABLE 7
Estimated Effects of Legal Access to Marijuana on Grades, by Gender and Quantitative Requirements of Course

	Sample							
	Quantitative	Nonquantitative	Male	Female	Male Quantitative	Male Nonquantitative	Female Quantitative	Female Nonquantitative
Age ≥ 21 during term	−0.028***	−0.033***	−0.031***	−0.034***	−0.020**	−0.035***	−0.048***	−0.032***
	(0.007)	(0.006)	(0.006)	(0.006)	(0.009)	(0.008)	(0.011)	(0.007)
Marijuana × 21	−0.034***	−0.008	−0.036***	−0.003	−0.067***	−0.013	0.011	−0.006
	(0.011)	(0.009)	(0.008)	(0.008)	(0.014)	(0.015)	(0.014)	(0.009)
Observations	350,126	701,710	462,818	589,018	190,350	272,468	159,776	429,242
R^2	.59	.55	.54	.59	.58	.55	.66	.58

Notes: The dependent variable is the student's standardized course grade. All regression models contain class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. Courses are classified as quantitative if they are offered in a STEM department or contain a quantitative term in their online course description (and nonquantitative otherwise). STEM departments are biology, chemistry, computer science, materials science, environmental science, geology, mathematics, physics, engineering, and economics. Quantitative terms from course descriptions are math-, statistic-, modeling, equation, comput-, numeric-, and quant-. Standard errors (in parentheses) are corrected for clustering at the term level.

*$p < .1$. **$p < .05$. ***$p < .01$.

the notion that these effects are due to increases in marijuana consumption after legalization. Importantly, whereas the overall effect of legal access to marijuana is sensitive to inclusion of experience controls, the subgroup analysis in Table 7 is not. We find consistent negative effects of alcohol for each subgroup (male quantitative, male nonquantitative, female quantitative, female nonquantitative), but only detect marijuana effects for males in quantitative courses regardless of the inclusion or parametric form of the experience controls.

We further stratify the sample by student ability in Table 8. We designate students as "high ability" or "low ability" based on their composite ACT or SAT scores relative to their academic-year cohort (the first academic year in which a student takes at least one course). Specifically, a student is designated as high ability if her ACT or SAT composite score is above her cohort median and low ability otherwise.[38] Since not every student has an ACT or SAT score, we first report results from our preferred model with the subgroup of students that have a valid score (94.4% of the overall sample) in the first column of Table 8. The next two columns, which separately report estimates from our preferred model with the high-ability subsample and the low-ability subsample, indicate that while the grades of both ability groups were negatively impacted by legal alcohol access, only low-ability students' grades suffered after gaining legal marijuana access. The point estimates for low-ability students suggest that the marijuana effect was nearly as large as the alcohol effect (−0.024 vs. −0.028 standard deviations) for this group.

Lastly, we test the robustness of our main results by dropping summer quarters and implementing different empirical specifications in Table 9. Figure 1 reveals the cyclical nature of grades within an academic year: average grades tend to increase steadily from fall to winter to spring and then increase dramatically during summer quarters (roughly 0.2 standard deviations on average). To ensure summer grades are not driving our main results, we

38. Students who took both the ACT and SAT are designated as high ability if at least one score is above their cohort median and low ability otherwise.

TABLE 8
Estimated Effects of Legal Access to Marijuana on Grades, by Ability

	Students that Took ACT or SAT	Students above ACT/SAT Cohort Median	Students below ACT/SAT Cohort Median
Age ≥ 21 during term	−0.029***	−0.035***	−0.028***
	(0.005)	(0.006)	(0.007)
Marijuana × 21	−0.018**	−0.011	−0.024**
	(0.007)	(0.009)	(0.011)
Observations	993,053	497,308	495,745
R^2	.55	.55	.60

Notes: The dependent variable is the student's standardized course grade. All regression models contain class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. Student cohorts are defined as the academic year in which the student first took at least one course at WWU. Students who took both the ACT and SAT are designated as above their cohort median if at least one score is above the median and below otherwise. Standard errors (in parentheses) are corrected for clustering at the term level.

*$p < .1$. **$p < .05$. ***$p < .01$.

TABLE 9
Estimated Effects of Legal Access to Marijuana on Grades: Robustness

	Sample		Model	
	Full	**Drop summer quarters**	**Experience polynomials**	**Accumulated-credits fixed effects**
Age ≥ 21 during term	−0.031***	−0.033***	−0.027***	−0.018***
	(0.005)	(0.005)	(0.003)	(0.004)
Marijuana × 21	−0.016**	−0.014**	−0.011*	−0.015***
	(0.006)	(0.006)	(0.006)	(0.005)
Controls				
Experience polynomials	No	No	Yes	No
Fixed effects				
Class	Yes	Yes	Yes	Yes
Student	Yes	Yes	Yes	Yes
Accumulated credits	No	No	No	Yes
Accumulated department credits	No	No	No	Yes
Observations	1,051,836	1,013,431	1,051,836	1,051,836
R^2	.55	.55	.55	.55

Notes: The dependent variable is the student's standardized course grade. The first and second columns contain results from a regression model with class and student fixed effects as well as controls for accumulated credits, accumulated department credits, and age in months. The model in the third column adds a quadratic and cubic term for each of the experience controls: accumulated credits, accumulated department credits, and age. The model in the fourth column replaces the accumulated-credits and the accumulated-department-credits controls with accumulated-credits fixed effects and accumulated-department-credits fixed effects (both in four-credit intervals), respectively. Standard errors (in parentheses) are corrected for clustering at the term level.

*$p < .1$. **$p < .05$. ***$p < .01$.

drop summer quarters and estimate our preferred model.[39] These results are presented in the second column of Table 9. For reference, we have included the full-sample results from our preferred model—estimates from column (5) of Table 3—in the first column of Table 9. A comparison of these estimates reveals that summer grades are not significantly contributing to our main results.

To test the robustness of our preferred model, we include experience polynomials[40] in the third column of Table 9 and replace the linear controls for accumulated credits with accumulated-credits fixed effects (in four-credit intervals) in the last column of Table 9.[41] When including experience polynomials, the point estimate of the marijuana effect is slightly weaker (−0.011 standard deviations) but is still significant at the 10% level (p value = .056). Including the accumulated-credits fixed effects has little impact on the marijuana-effect point estimate but does increase its precision; it is now significantly different from zero at the one-percent level.

D. Effects on Course-Taking Behavior

The impact of marijuana may transcend student performance as measured by grades. For instance, legalization may alter student behavior with regard to course completion, number of courses attempted, and the type of grading environment selected. This section investigates these issues.

We explore course completion by examining withdrawals from individual courses by students. WWU allows students two course withdrawals per academic year where a course withdrawal is defined as dropping a course between the second and seventh week of the quarter. These withdrawals are recorded on students' official transcripts. The university does not allow students to withdraw from a course after the seventh week of the quarter.

The impact of marijuana legalization on withdrawal behavior could occur through two channels. First, as noted above, legalization reduces grades and students, upon realizing they are not earning the grades hoped for, may withdraw from a course rather than receive the lower grade. If this is the case, then the earlier estimates of the

39. Grade observations from summer quarters account for 3.7% of the overall sample.

40. Experience polynomials include quadratic and cubic terms for each of the experience controls: accumulated credits, accumulated department credits, and age.

41. As in Lindo et al. (2013).

TABLE 10

Estimated Effects of Legal Access to Marijuana on Course-Taking and Persistence

	Outcome			
	Course Withdrawal	**Pass/No-Pass Grading**	**Number of Credits Taken**	**Expected Term GPA**
Age ≥ 21 during term	0.0001	−0.0004*	0.179***	0.028***
	(0.0001)	(0.0002)	(0.020)	(0.006)
Marijuana × 21	0.0003	0.0003	−0.105***	0.023*
	(0.0010)	(0.0003)	(0.029)	(0.013)
Fixed effects				
Class	Yes	Yes	No	No
Student	Yes	Yes	Yes	Yes
Term	No	No	Yes	Yes
Observations	1,150,285	1,150,285	344,023	338,367
R^2	.14	.95	.42	.45

Notes: The analysis in the first two columns is based on data measured at the student-by-course level whereas the analysis in the last two columns is based on data measured at the student-by-term level (which is why term fixed effects are included instead of class fixed effects). The outcome variable in the first column, course withdrawal, is a binary indicator for whether the student withdrew from the course between the second and the seventh week of the quarter. The outcome in the second column, pass/no-pass grading, is a binary indicator for whether the student elected to take a course for a pass/no-pass or satisfactory/unsatisfactory grade. The outcome in the third column, number of credits taken, is the number of course credits a student enrolls in during a term (including classes that the student eventually withdraws from). The outcome in the last column, expected term GPA, is calculated based on the average grades in the previous offering of each course a student takes during a term. All regression models contain controls for accumulated credits, accumulated department credits, and age in months. Standard errors (in parentheses) are corrected for clustering at the term level.

$^{*}p<.1$. $^{**}p<.05$. $^{***}p<.01$.

impact of legalization on grades may understate the true impact as we would not observe the full complement of lower grades because of avoidance through the withdrawal mechanism. The second channel involves motivation and ambition. Research has shown that prolonged marijuana exposure reduces the brain's ability to synthesize dopamine which is connected with reduced reward sensitivity and lower levels of motivation.[42] If decreased motivation is connected to lower levels of course engagement, then a plausible result would be students withdrawing from courses before they were completed.

We investigate the role of marijuana legalization on course completion by replacing standardized grades in Equation (2) with a binary variable equal to one if the student withdrew from the course. Results in the first column of Table 10 demonstrate that there is no statistically significant relationship between marijuana legalization and course withdrawals for students over age 21. Moreover, the coefficient on $Marijuana_t \times Age21_{it}$ is estimated quite precisely with the ability to exclude increases in withdrawal rates above 0.23 percentage points at the 95% confidence level.

While marijuana legalization does not appear to impact course completion, it could alter the mix of graded versus nongraded courses in which a student enrolls. Like many universities, WWU provides the opportunity to enroll in courses on a pass/no-pass basis. If marijuana reduces student achievement and students recognize this, then it is possible that students enroll in courses under a pass/no-pass rule in order to avoid lower letter grades. Following the regression approach outlined earlier, we estimate the impact of marijuana legalization on the probability of enrolling in a course pass/no-pass. The results of this exercise are reported in the second column of Table 10. We find no statistical evidence that enrolling in pass/no-pass courses changes after marijuana legalization for those over age 21. Again, this estimate is measured very precisely; we rule out changes in this behavior larger than 0.06 percentage points at the 95% level.

We further investigate marijuana legalization's impact on student behavior by examining the number of credits attempted by students. If marijuana reduces motivation, then one might imagine less-ambitious students enrolling in fewer credits each quarter. Students who enroll in fewer credits would extend their time-to-graduation and, because it takes longer to graduate, possibly increase their risk of not graduating.

42. See Bloomfield et al. (2014) and van Hell et al. (2010).

WWU measures the number of credits a student enrolls in at the beginning of the quarter. We designate this by the variable *AttemptedCredits*. The median class-credit offering at WWU is a four-credit class; fewer than 10% of courses are offered for less than four credits while about one-third of courses are offered for five credits, the maximum amount offered in traditional courses. The median student enrolls in 15 credits per quarter, an amount that would enable students to meet the university's graduation requirement of 180 credits in four academic years (excluding summer quarters).

Our strategy in identifying the impact on *AttemptedCredits* of marijuana legalization is similar to that used in the earlier standardized grade results. However, while the grade findings made use of within-class differences in legal access, there is no corresponding within-class analogy to *AttemptedCredits*. Our model can be written as:

$$(3)\quad AttemptedCredits_{it} = \alpha_i + \beta_2 Age21_{it} + \beta_3 \left(Marijuana_t \times Age21_{it}\right) + \boldsymbol{X}'_{it}\gamma + \epsilon_{it}.$$

The primary difference between Equation (3) and (2) is that we analyze changes in attempted credits at the student-by-term level, rather than the student-by-course-by-term level. In addition, Equation (3) contains explanatory variables that are not in Equation (2). The most important among these are a group of 78 binary variables that measure the number of credits short of 180 a student finds themselves during their last quarter on campus. These binary variables account for students altering their credit load in anticipation of graduating at the end of the quarter. For instance, students who have 172 credits at the beginning of a quarter are much more likely to enroll in 8 credits than a student who has 170 credits. Because nearly all students are over age 21 when this occurs, accounting for it allows us to isolate the impact of marijuana legalization absent end-of-career credit manipulation.[43]

Our estimates of Equation (3) are found in the third column of Table 10. Two results stand out in this column. First, there is a general increase in *AttemptedCredits* by students older than 21. The estimated coefficient of 0.18 suggests that upon turning 21, the average student increases enrollment by about one-sixth of a credit, which is equivalent to an additional four-credit course enrollment for every 24 students. This finding is consistent with a general increase in both course-taking and credit enrollment observed as students advance in their majors and toward graduation. The second result is that the post-21 increase in credit enrollment falls after marijuana legalization by 0.11 credits, the coefficient on $Marijuana_t \times Age21_{it}$. This result suggests that marijuana access reduced credits attempted by the equivalent of about one 4-credit course for every 40 affected students and is consistent with the upward-biased marijuana effect observed when accumulated credits are omitted as a control in the third column of Table 3.

As a final exploration into course enrollment effects, we investigate whether students are more likely to enroll in easier-grading classes. If marijuana reduces grades or motivation, one might expect students to seek out courses that assign higher grades. To determine this, we calculate the average grade given in each course during its most recent offering prior to the quarter in which a student enrolls in it. For instance, a student enrolling in Introduction to Microeconomics in spring 2017 would be assigned the average of the grades given in this course from winter 2017. We then aggregate these course-level average grades for each student in each quarter to construct an expected quarterly grade point average (GPA). We use this expected GPA as the dependent variable in a student-level fixed effects regression that controls for accumulated credits, accumulated department credits, student age, and term-by-year fixed effects. The results from this model are found in the fourth column of Table 10, where we find that upon gaining legal access to alcohol, students enroll in courses that expect to offer 0.03 standard deviations higher grades. The impact of marijuana is about 0.02 standard deviations, though it is only significant at the 10% level. This provides weak evidence that marijuana legalization altered course-taking behavior by encouraging legal-age students to enroll in courses that offer higher grades on average. To the extent that this effect exists, it means that our earlier marijuana-effect estimates understate the actual negative impact of marijuana legalization on grades.

VI. CONCLUSION

In this research, we have investigated how legalizing the possession and use of small quantities of marijuana impacts collegiate achievement,

43. Also included in **X** in Equation (3) are term-by-year fixed effects and a quadratic in individual-level time trends to account for progression of enrollment changes over the course of a student's academic career.

finding that the performance of students who gain access decreases. Using our preferred specification, legal access is associated with a decrease in standardized grades by about 0.016 standard deviations, or roughly one-half of the estimated effect of legal access to alcohol. The decline in grades is driven primarily by an increase in the instance of D and F grades and, consistent with earlier research, the largest grade impacts are found in quantitative courses, among weaker students, and among men. In addition, we document that students attempt fewer credits after marijuana legalization. Taken with the fact that more D and F grades are received, this means that total credits completed declined with legalization as well. Students who complete fewer credits per quarter take longer to graduate and, given their extended length of time in school, potentially increase the likelihood of dropping out as well. The reduction in credits attempted may mean that our estimates of the impact of legalization actually understate its true effect on grades. If legalization reduces the amount of credits attempted and, *ceteris paribus*, students attempting fewer credits can better focus their attention on their remaining classes, then the observed decline in grades is occurring even in the presence of this increased focus.

A second argument can be made that our preferred specification understates the true impact of legalization. While access became legal after 2012 for those over 21, our survey data suggest marijuana was used illegally prior to 2012 and almost certainly remains used by those under 21 postlegalization. This means that our within-student and within-class counterfactuals are unlikely to be perfect counterfactuals and generally will attenuate our estimates of the impact of legalization.

In thinking about our estimated impact of marijuana legalization, it is important to note that not all students consume marijuana and our results are driven only by those who change their behavior. Thus, a useful exercise is to estimate the treatment effect on the treated to inform us about the impact of marijuana access on marijuana users. Our main results indicate that legal access to marijuana decreases students' grades by an average of 0.016 standard deviations, an effect size much lower than the 0.11 standard deviation increase in grades from prohibiting legal marijuana access found by Marie and Zölitz (2017). However, Marie and Zölitz report a very low level of noncompliance with the policy change, citing survey data that suggest the policy was strictly enforced. Survey data from Table 1 suggest that the proportion of students who consumed marijuana at least once in the prior month increased roughly 7% from 2010 (prelegalization) to 2016 (postlegalization). Using this as our estimate for the proportion of students who consumed marijuana in response to the change in policy, the treatment effect on the treated would be about 0.23 standard deviations (0.016/0.07). Importantly, this is similar to the treatment effect on the treated estimated by Marie and Zölitz who use a compliance rate of 38%–100% to estimate effects ranging from 0.19 to 0.49 standard deviations.

A secondary finding of this paper is confirming the alcohol effect established by Lindo et al. (2013). At a different university and with the inclusion of class-level fixed effects, we estimate an alcohol effect of −0.03 standard deviations, nearly identical to that found by Lindo et al. In addition, we document similar changes in the grade distribution following legal access to alcohol: fewer A grades and more Ds and Fs.

While we provide evidence that legal access to marijuana leads to a decline in academic achievement, it is less clear what this means for the ongoing debate over legalization. Observing that student achievement falls after legalization may suggest prohibiting access to marijuana. However, only to the extent that this reduced achievement has external costs to society should this be taken as an argument to prohibit marijuana use. Indeed, the legalization of marijuana may have numerous societal benefits in the form of reduced crime, controlled access, and increased tax revenues. In short, these findings are only part of a complex societal cost–benefit analysis that should inform any policy change.

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