The Minimum Legal Drinking Age and Morbidity in the US

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By CHRISTOPHER CARPENTER and CARLOS DOBKin

We provide the first evaluation of the effect of the US minimum legal drinking age (MLDA) on nonfatal injuries. Using administrative records from several states and a regression discontinuity approach, we document that inpatient hospital admissions and emergency department (ED) visits increase by 8.4 and 71.3 per 10,000 person-years, respectively, at age 21. These effects are due mainly to an increase in the rate at which young men experience accidental injuries, alcohol overdoses, and injuries inflicted by others. Our results indicate that the literature's disproportionate focus on mortality leads to a significant underestimation the benefits of tighter alcohol control.
1. Introduction

A large body of research in economics and public health has examined the causal effect of laws restricting access to alcohol on mortality rates.\(^1\) Evidence from a variety of quasi-experimental research designs has convincingly shown that reducing access to alcohol (and, by implication, reducing alcohol consumption) significantly reduces mortality risk due to motor vehicle and other types of accidents, homicide, suicide, and alcohol overdoses (Cook and Tauchen 1992, Cook et al. 2005, Dee 1999, Biderman et al. 2009, and others). This has been shown to be especially true for young adults (Carpenter and Dobkin 2009, Wagenaar and Toomey 2001, Birckmayer and Hemenway 1999, Carpenter 2004, and others).

There is far less evidence, however, on the extent to which easier access to alcohol affects the rate of nonfatal injuries (i.e., morbidity).\(^2\) This is a serious gap in the literature because injuries – which can be very costly – are far more common than deaths, particularly among young adults. For example, the overall death rate due to injuries for 20 year olds in the United States is 7 per 10,000 person-years. By comparison, the rates of health events severe enough to require an inpatient hospital stay or treatment in an Emergency Department (ED) are on

\(^1\) Arguably the first to do so using modern quasi-experimental methods is Cook and Tauchen (1982), who demonstrate that alcohol tax increases reduce death rates from liver cirrhosis.

\(^2\) Some epidemiologic research has focused on injuries from drunk driving accidents (see, for example, Hingson and Winter 2003), but mortality is by far the more commonly studied outcome related to alcohol consumption in general and drunk driving specifically.
the order of 341 and 3,951 per 10,000 person-years, respectively (i.e., orders of magnitude larger than the age-specific mortality rate). Moreover, public health and medical research suggests that about a third of emergency room visits due to nonfatal injuries are alcohol-related, while nearly half (45%) of drug-related ED visits among young people age 12-20 are alcohol-involved (SAMHSA 2006). This suggests that laws restricting alcohol consumption have the potential to substantially reduce these adverse event rates.

What explains the substantial gap in our understanding of how much regulations targeting alcohol affect morbidity? Rehm et al. (2003) note that “information on alcohol-related morbidity ... is limited because studies with morbidity as the endpoint demand substantial resources to assess individual outcomes in an objective and standardized way.” That is, data constraints have limited the ability of researchers to comprehensively study alcohol access and morbidity. For example, while panel data evaluations of the effects of changes in state alcohol policies (such as alcohol taxes, drinking ages, or drunk driving laws) on mortality are enabled by high quality annual data on deaths at the state level, there are far fewer high quality datasets on population rates of nonfatal injury that support these types of analyses.3

3 For example, although several studies have used state experimentation with lower drinking ages in the 1970s and 1980s to study mortality rates (see, for example, Birckmayer and Hemenway 1999, Carpenter 2004, and others), we are not aware of similar research that has examined nonfatal injury rates in this way.
We are aware of only three economics studies that use quasi-experimental designs to evaluate the effects of stricter alcohol controls on nonfatal injuries (as opposed to mortality); all use variation in alcohol access induced by minimum drinking ages. Conover and Scrimgeour (2013) and Boes and Stillman (2013) study the effect of a policy change in New Zealand in 1999 that lowered its drinking age from 20 to 19. They both find that the policy increased alcohol-related hospitalizations using difference-in-differences approaches. Lindo et al. (2013) use a regression discontinuity design to examine the effects of the MLDA in New South Wales, Australia on hospitalizations (among other outcomes) and find it reduces admissions due to alcohol abuse and assault.

Our study advances this literature in several key ways. First, to our knowledge we are the first study to directly examine the issue of alcohol control and morbidity in the United States using this MLDA-based quasi-experimental approach and high quality administrative data. While it is useful to understand related experiences of other countries such as Australia, New Zealand, and Canada, their youth drinking profiles, alcohol availability, and alcohol control

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4 Note that we do not review here some related work in economics that uses quasi-experimental methods applied to survey data to examine the relationship between state alcohol control policies and domestic violence outcomes such as being slapped or hit by a partner (Markowitz and Grossman 2000, 1998). Similarly, some previous work linking movie violence and professional sports to violent outcomes has suggested alcohol consumption as a possible mechanism (Dahl and DellaVigna 2009, Card and Dahl 2011). These violent outcomes are likely related to the nonfatal injury outcomes we study in this paper using administrative data.

5 A recent study in public health also uses this design to study inpatient hospitalizations in Canada from 1997 to 2007 (Callaghan et al. 2013). They find significant increases in alcohol use disorders and suicide events at the Canadian MLDA, as well as increases in injuries from motor vehicle accidents for males.
policies differ in several important ways from those in the US. Focusing on the US setting is also important given active debates in the US about changing the drinking age (McCardell 2012). Second, we also benefit from the fact that there is extensive evidence on the first stage relationship between the alcohol control policy we consider (MLDA in the US) and alcohol consumption. This allows for more straightforward interpretation of our findings compared to other settings. Third, we examine both emergency department visits as well as hospital admissions; prior work in this area has focused mainly on hospital admissions. As referenced above, ED visits are an order of magnitude more frequent than inpatient admissions among young adults and are quite costly (over $1,500 in list charges per injury-related ED visit on average in our data). Understanding the determinants of ED admissions and what can be done to reduce them is also important in light of concerns over ED overcrowding (IOM 2004, Owens et al. 2010). Fourth, we comprehensively examine all causes of morbidity, not just injuries from motor vehicle accidents and alcohol overdoses—the main focus of the limited prior work on nonfatal injuries. This is important, as it allows us to assess whether the significant increases in alcohol-related causes of morbidity we find at the MLDA are simply outcomes that are being systematically

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6 Previous research shows that alcohol consumption increases sharply at age 21 in the US by 20-30 percent (Carpenter and Dobkin 2009, 2011b, Crost and Guerrero 2012, SAMHSA 2009). That work also demonstrates that other observable characteristics such as employment, education, and demographics do not change discretely at the same threshold.
recategorized at the threshold. Finally, our very large samples of administrative ED and hospitalization data (over 3.7 million records) allow us to estimate how the effects of easier access to alcohol on morbidity vary by both cause and gender.

Our empirical approach follows much recent work in this area and leverages variation in access to alcohol induced by the MLDA (Carpenter and Dobkin 2009). We use a regression discontinuity design (RD) which takes advantage of the fact that access to alcohol and alcohol consumption increase discretely at age 21, the MLDA in the United States. We use administrative records which include a near-census of emergency room visits and inpatient hospital stays from several large states. These records allow us to observe any medical event severe enough to require treatment in an emergency department or on an inpatient basis. The sample sizes are large enough and the records have sufficient medical and demographic information that by combining them with denominators from the census it is possible to precisely estimate age profiles for various types of adverse health events. These age profiles allow us to determine

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7 Lindo et al. (2013) are not able to study overall rates of hospitalizations due to the likelihood that other things change at the MLDA in their setting (New South Wales, Australia). For example, they report that hospital admissions due to ‘diseases of the oral cavity’ also exhibited a discontinuity at the MLDA, which is not plausibly attributable to easier access to alcohol. The fact that in the US almost nothing else changes at age 21 allows us to consider overall rates of ED visits and hospital admissions as well as the usual alcohol-related measures.

8 This design has also been used recently to examine the effects of easier alcohol access on marijuana and tobacco consumption (Crost and Rees 2013, Crost and Guerrero 2012), academic outcomes of students at the United States Military Academy (Carrell, Hoekstra, and West 2011), and academic outcomes of students at the University of Oregon (Lindo, Swenson, and Waddell 2013).
how much illnesses and injury rates increase at exactly age 21 when people are no longer subject to the MLDA.

We find that ED visits and hospital admissions both increase sharply at age 21 by 71.3 and 8.4 per 10,000 person-years, respectively. These increases are primarily due to accidents (including motor vehicle accidents), alcohol overdoses, and injuries inflicted by others. We also find that the effect of the MLDA on nonfatal injuries is larger for males than for females, and in many cases these gender differences are statistically significant. Overall our results are the first to comprehensively document the effects of easier alcohol access on morbidity in the United States using quasi-experimental methods and high quality administrative data and indicate that the costs of alcohol use by young adults are much larger than previously estimated (Bonnie and O'Connell 2004).

The remainder of the paper proceeds as follows. Section 2 describes our data sources and discusses our empirical methods. Section 3 presents the main results, and Section 4 offers a discussion and concludes.

2. Data and Methods

We use administrative data comprising a near-universe of visits to emergency rooms in three states (Arizona 2005-2009, New Jersey 2004-2010, and Wisconsin 2004-2010) and inpatient hospital admissions in four states (Arizona
1990-2010, New York 1993-2008, Texas 1999-2003, and Wisconsin 2004-2010). These records include a detailed description of the cause of the ED visit or hospital stay and the treatment the patient received. In addition the records include month and year of both birth and start of treatment which allows us to estimate the patient’s age in months.

We classify causes of ED visits and hospital admissions into three mutually exclusive categories: alcohol intoxication, injuries, and a residual category we denote as ‘illness’ (which strictly speaking is everything other than alcohol intoxication and injuries). In addition to being an outcome of independent interest, alcohol intoxication rates also proxy for very heavy alcohol consumption. Injuries are also likely to be directly affected by the MLDA given previous work on mortality; we separate injuries into three mutually exclusive categories: self-inflicted injuries (e.g., attempted suicides), injuries inflicted by others, and accidental injuries (including motor vehicle accidents, falls, etc.). A single ED visit or hospitalization can have more than one cause. To create the mutually exclusive categories we give alcohol intoxication, when it is coded as the primary

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9 These records come from the Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) and State Emergency Department Databases (SEDD). Our choice of states derives in part from the fact that there are no discrete changes in insurance coverage at age 21 in these states. Emergency room data exist for other states as well, but in some states young adults “age out” of Medicaid eligibility at age 21, and indeed in these states there are discontinuous changes in the presence and sources of health insurance coverage at age 21. Since previous research has shown a direct causal effect of insurance coverage on medical care use (including emergency room visits and hospital admissions – see, for example, Anderson, Dobkin, and Gross 2012a forthcoming, 2012b), we do not use data from these states since any discrete change at age 21 that might be attributable to changes in alcohol access would be confounded by changes in the presence and source of insurance coverage.
cause of admission, precedence over injuries. We then code injuries with a precedence order of injured by other, self-inflicted injury, and accidental injury.\textsuperscript{10} Any visit/admission that does not fall into one of these groups is categorized as due to illness.\textsuperscript{11}

Throughout our main analyses, we exclude pregnancy-related hospital admissions, as in this age range (19-22) pregnancy represents over half of all female hospital admissions. For symmetry in presenting results, we also exclude the very small number of pregnancy-related ED visits. This has very little effect on our results (especially in the analyses of ED visits), which is not surprising given that alcohol use in the third trimester of pregnancy is rare. Results that include the pregnancy-related ED visits and hospital admissions are very similar and are available upon request.

To create the age profiles we compute a count of the number of people that experience an ED visit or hospital stay at a particular age in months (such as between their 21\textsuperscript{st} birthday and their 21\textsuperscript{st} birthday + 1 month). We convert the counts of ED visits and hospital stays into rates per 10,000 person years by dividing them by age-specific population estimates from the census. We then plot

\textsuperscript{10} There are very few records that have more than one of these three types of injuries coded.
\textsuperscript{11} Each category includes the following ICD codes: Alcohol intoxication: primary ICD-9 first three digits '291' or '303' or first four digits '3050'; Injury inflicted by other: E code first three digits 'E96'; Injury self-inflicted: E code first three digits 'E95'; Accidental injury: any E code not starting with ‘E95’ or ‘E96’. Any admission or visit that does not fit into one of the categories above is coded as due to illness unless there is a mention of alcohol intoxication on one of the secondary ICD codes in which case it is added to the alcohol intoxication category.
these age profiles to assess visually whether there is a discrete change in adverse event rates at age 21.

To determine if an increase in the injury rate visible in a figure is statistically significant we estimate the following model using the estimate of the adverse event rates for the 24 months before and after the 21st birthday (i.e., from age 19 to 22).

\[
Y_a = \alpha_0 + \alpha_1 Z_a + \alpha_2 A_a + \alpha_3 A_a^2 + \alpha_4 Z_a A_a + \alpha_5 Z_a A_a^2 + \alpha_6 B_a + \nu_a
\]

In this model \(Y_a\) is the rate of ED visits or hospital stays per 10,000 person years for the one month age cell \(a\), \(A_a\) is age re-centered at 21, and \(Z_a\) is an indicator variable that takes on a value of 1 for age greater than or equal to 21. The variable \(B_a\) is an indicator variable that takes on a value of 1 for the month in which the 21st birthday falls and 0 otherwise and is intended to absorb the pronounced celebration effects we observe for some adverse events such as ED visits due to alcohol intoxication.\(^{12}\) The parameter of interest is \(\alpha_1\) which captures the discrete increase in the adverse event rate that occurs at age 21. If none of the other determinants of the ED visit and hospitalization rates are changing discretely at 21 and the second order polynomial is sufficiently flexible

\(^{12}\) This also lets us avoid any attenuation bias that results from not knowing if a person with an inpatient stay or ED visit in the month that they turn 21 is over or under 21.
to absorb age-related changes then the discrete increase in adverse events picked up in the model by $\alpha_i$ can be interpreted as the effect of the MLDA.\textsuperscript{13}

3. Results

\textit{a. Representativeness of the Analysis States}

We begin by addressing the issue of representativeness of young adults in the analysis states compared to young adults in the US population. Specifically, we are interested in comparisons of demographic characteristics and alcohol consumption patterns for young adults in our analysis states compared to the US as a whole. We present direct evidence on this question in Table 1, which reports average characteristics from the Centers for Disease Control’s Behavioral Risk Factor Surveillance System (BRFSS) for young adults age 19-22 for the period 2004-2010. The BRFSS is a large telephone survey that is designed to be representative at the state level and that asks questions about alcohol use, other health outcomes, and demographics. We report in Table 1 sample average characteristics for the full sample, young adults in states represented in the ED visits analysis (Arizona, New Jersey, and Wisconsin), and young adults in states represented in the inpatient hospital stays analysis (Arizona, New York, Texas,

\textsuperscript{13} In prior work we have documented that there are no other major discrete changes in factors that are likely to affect injury rates (Carpenter and Dobkin 2014 forthcoming).
and Wisconsin). We also report for each characteristic the p-value of the difference in means between the relevant subsample and the rest of the sample.

The patterns in Table 1 show that although for the most part the young adults in the states included in the analysis are fairly similar to young adults in the US population, some of the differences are statistically significant. The most striking differences are in the percent Hispanic which is much higher in the inpatient sample than in the overall population. This is due largely to the inclusion of Texas in this sample.\(^{14}\) For alcohol consumption, we find no significant difference between young adults in the inpatient hospital stays state sample and the full US population, while the states in the ED sample have significantly higher drinking participation and binge drinking rates than the rest of the US. The differences between the samples and the overall population documented in Table 1 do not result in biased estimates but in estimates that are specific to the subsamples in the study if there is significant treatment heterogeneity.

\(\textbf{b. Descriptive Statistics}\)

We present descriptive statistics from the data on ED visits and inpatient hospital stays in Table 2. Among young adults in our age range (19-22, inclusive), the rate of ED visits and inpatient hospital admissions is 3,951 and 341 per 10,000, respectively. Recall that the total mortality rate per 10,000 in the US

\(^{14}\) The results without the inclusion of Texas are very similar to the results with Texas and are available on request.
among 20 year olds is about 7; thus, the outcomes we study are far more common than mortality which is the main focus of prior work. Table 2 also indicates that ED visits for injuries and alcohol intoxication are disproportionately prevalent among men. The table reveals that the list charges for the ED visits and the hospital stays are substantial: average list charges for inpatient admissions are $15,567 while ED visits for this age group have average list charges of $1,593.\textsuperscript{15} Finally, Table 2 shows that a significant portion of these costs are transferred to others (i.e., not borne privately) through the mechanism of insurance.

c. ED Visits

Figure 1 presents the overall age profile of non pregnancy-related ED visits per 10,000 person-years separately for two groups of causes: alcohol intoxication and injuries (combined) in the bottom series and the residual illness category in the top series. The lines on top of each series are fitted estimates from a regression of the ED visit rate on a second order polynomial in age interacted with a dummy variable for being over 21 and a dummy for the month in which the 21\textsuperscript{st} birthday falls (equation 1). Figure 1 shows a sharp increase in ED visits due to alcohol intoxication and injuries at age 21. This increase is apparent even ignoring the very high rate of ED visits in the month in which people’s 21\textsuperscript{st}

\textsuperscript{15} Insurers have negotiated discounts on the list prices. The median list prices are substantially lower as the distribution of list charges, particularly for hospitalizations, has a very long right tail.
birthday falls. In contrast, Figure 1 shows no visual evidence of an increase in ED visits for illness.

We further separate out the external cause categories in Figure 2. Because ED visits due to accidental injuries are much more common than intentional injuries (both self-inflicted and inflicted by others) and alcohol intoxication visits, we present the age profiles using different scales. The most striking series in Figure 2 is for alcohol intoxication (dark diamonds) which is scaled on the right axis and shows clear evidence of a discontinuity at the MLDA, as well as very strong evidence of celebration effects at all birthdays with particularly large effects on the 21st birthday. The other series that shows strong evidence of an increase at age 21 is for ED visits due to injuries deliberately inflicted by another person. Finally, the series for accidental injury-related ED visits shows some evidence of a small increase at the MLDA. Appendices 1 and 2 present the same age profiles as in Figure 2 separately for males and females, respectively. These appendices show clearly that the increase in ED visits for injuries deliberately inflicted by others at age 21 is driven entirely by males, while the increases in ED visits for accidental injuries and alcohol intoxication are observed for both genders.

16 This increase in the birth month is likely driven mainly by spikes on people’s 21st birthday and the early morning of the day after the 21st birthday. We account for these ‘celebration effects’ by including a dummy variable for the month immediately after the 21st birthday, thus identifying the effects of easier alcohol access from the otherwise smooth differences on either side of the MLDA discontinuity.
We present the regression estimates corresponding to Figures 1 and 2 and Appendices 1 and 2 in Table 3. The dependent variable in the regression is the number of ED visits per 10,000 person-years occurring X months before or after the individual’s 21st birthday, and we estimate equation 1 over the 48 months for people ages 19 to 22, inclusive. A comparison of the fitted values from equation 1 in the figures with the plotted estimate of the corresponding rates suggests that the equation is sufficiently flexible to fit the age profiles of the various outcomes. In the tables to save space we only present our estimate of $\alpha_1$ from model 1 and its standard error along with the estimate of the constant. Because the age variable has been re-centered at 21, $\alpha_1$ provides an estimate of the discrete increase in the adverse event rate at age 21 and the constant provides an estimate of the rate for people just under 21.

The results in the top, middle, and bottom panels of Table 3 correspond to results for the full sample, males, and females, respectively, and provide point estimates of the increases in adverse event rates visible in the age profiles. Specifically, we estimate that ED visits (excluding pregnancy-related visits for females) increase by about 71.3 per 10,000 at age 21 for the full sample in the top panel of column 1 of Table 3, and this estimate is statistically significant. Relative to the ED visit rate for young adults just below the MLDA, this is about a 1.8 percent increase. In column 2 we confirm that the increase in illness-related causes (i.e., not alcohol intoxication or injuries) is small (both absolutely and as a
proportion of the below-MLDA mean – about a 0.5% effect) and statistically insignificant. As seen in Figure 1, we confirm in column 3 of Table 3 that there is a statistically significant increase in ED visits due to injuries or alcohol intoxication at the MLDA of 57.8 visits per 10,000. When we break the result in column 3 out into its component causes, we find statistically significant increases at the MLDA for ED visits due to alcohol intoxication (31.8% effect), accidental injury (2.7% effect), and injuries deliberately inflicted by others (11.3% effect). We find no evidence of statistically significant increases in self-inflicted injuries. As can be seen in Appendices 3 and 4 which present regression estimates and confidence intervals for a range of bandwidths, these estimates are robust to bandwidth choice. Moreover, for most outcomes the bandwidth selection procedure proposed in Imbens and Kalyanaraman (2012) yields optimal bandwidths between 1.5 and 2.5; Appendices 3 and 4 confirm our results are not sensitive to bandwidth choice within this range.

Disaggregating the results by sex in the middle and bottom panels of Table 3 confirm that, as observed in Appendices 1 and 2, the increase in ED visits at the MLDA for accidental injuries and alcohol intoxication is economically and statistically significant for both males and females. In contrast, however, the increase in ED visits at age 21 for injuries deliberately inflicted by others is only significant for males. These patterns are confirmed in the bottom row of Table 3 which reports the p-values of the gender differences in the estimated effects of the
MLDA on ED visits and indicates that the estimated increase in injuries inflicted by others among young men is significantly larger than the associated estimate for deliberately inflicted injuries among young women.

d. *Inpatient Hospital Admissions*

We next examine the increase in adverse events severe enough to result in a hospitalization. We present these age profiles in Figures 3 and 4 which correspond to Figures 1 and 2 for the ED data and have the same layout. Figure 3 shows evidence of an increase in hospital admissions due to alcohol intoxication or injuries (top series, left y-axis) and no change in admissions due to illness (bottom series, right y-axis). Figure 4 shows that the increase in Figure 3 is driven by admissions due to alcohol intoxication, unintentional injuries, and injuries deliberately inflicted by another person. Disaggregating the results by sex in Appendices 5 and 6 for males and females, respectively, shows stronger evidence of discontinuous increases in hospital admissions for alcohol intoxication, injuries inflicted by others and accidental injuries for males and very little evidence of any meaningful changes for females. Overall the patterns for hospital admissions are qualitatively very similar to those for ED visits.

We present the regression estimates corresponding to Figures 3 and 4 and Appendices 5 and 6 in Table 4. The dependent variable in the regression is the number of hospital admissions per 10,000 person-years occurring X months before or after the individual’s 21st birthday, and the format is otherwise identical.
to Table 2. The results in Table 4 confirm the visual patterns in Figures 3 and 4. Specifically in the top panel of Table 4, corresponding to Figure 3, we estimate that hospital admissions for alcohol intoxication or injury increase significantly by 6.4 admissions per 10,000 person-years at the MLDA, and there is no statistically significant increase in admissions coded as due to illness. When we separately consider the causes of injury-related admissions, the rightmost panels of Table 4 reveal that accidental injuries drive the majority of the discontinuous increase in injury-related hospital admissions.\(^{17}\) We also show robustness of the main results on inpatient hospital stays to choice of bandwidth in Appendices 7 and 8. As with emergency department visits, we find that for most outcomes the bandwidth selection procedure proposed in Imbens and Kalyanaraman (2012) yields optimal bandwidths between 1.5 and 2.5; Appendices 7 and 8 confirm our results on inpatient hospital stays are not sensitive within this range.

Disaggregating the results by sex in the middle and bottom rows of Table 4 confirms that as was true with the ED results, the MLDA has a much larger effect on the injury rates of men: estimates for alcohol intoxication, accidental injury, and injuries deliberately inflicted by another person are all sizable and statistically significant. In contrast, we find no significant increases in hospital admissions at the MLDA for women for any cause. The bottom row of Table 4 confirms that the gender differences in the effects of the MLDA on inpatient

\(^{17}\) In Appendices 7 and 8 we present evidence that the estimates for hospital admissions are robust to the choice of bandwidth.
admissions (i.e., larger for men) for alcohol-related causes and accidental injuries are statistically significant.

4. Discussion and Conclusion

Previous research examining the adverse health consequences of alcohol use in a quasi-experimental setting has focused primarily on mortality due in large part to the lack of high quality data on nonfatal injuries. We argue this paints an incomplete picture of the potential benefits of stricter alcohol controls since morbidity – which can be very costly – is much more common than mortality. We fill this gap in the literature by examining a near-census of ED visits and inpatient hospital admissions from several large states. We leverage the discontinuous change in alcohol availability associated with turning 21 in the United States to identify the effect of easier alcohol access on morbidity; our RD approach provides straightforward, intuitive, and visually assessable estimates of the impact of the MLDA.

We find statistically significant increases in ED visits and inpatient hospital admissions at the MLDA of about 71.3 and 8.4 per 10,000 person-years, respectively. To our knowledge these are the only quasi-experimental estimates of the impact of the MLDA on emergency department visits and the only estimates of its effects on nonfatal injuries in the US. These effects are clearly visible in the age profiles and are statistically significant. The increases in
morbidity are most pronounced for males and are driven primarily by alcohol overdoses, injuries inflicted by others, and accidental injuries.

What explains the large gender difference in the effects of alcohol access on ED visits and inpatient hospitalizations? We first note that this broad pattern – that males experience larger increases in adverse outcomes at age 21 – was also observed in other work using this design that studied mortality and crime (Carpenter and Dobkin 2009, Carpenter and Dobkin 2014, forthcoming). Our best guess is that the differential effects by gender are due at least in part to differences in how men and women react to unrestricted access to alcohol. Carpenter et al. (2014) show using extremely detailed alcohol consumption data available for Canadians that when young adults are allowed to purchase and consume alcohol without restriction men show a large increase in very heavy drinking. Drinking by women, in contrast, increases in frequency but at a much lower intensity. Given the relatively extreme nature of the outcomes we study, it is therefore not surprising that the bulk of the effects occur for young males.

How generalizable are our findings to the rest of the United States? Recall that in Table 1 we directly compared demographic characteristics and alcohol consumption profiles of young adults in the states included in our ED visits and inpatient hospital stays samples, respectively, against the associated means for the entire US using data from the CDC BRFSS. We did not find any significant

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18 We are not aware of survey data with large enough samples of young adults that would permit us to perform a similar ‘first stage’ type of analysis for the states we study in this paper.
differences in alcohol consumption patterns between the inpatient hospital stays sample and the full US sample, suggesting that the MLDA effect on inpatient hospital stays is likely to have good representativeness. Moreover, with respect to demographic characteristics, the states in the ED visits sample differed from the overall population in ways dissimilar to the inpatient sample. The fact that we find very similar patterns across gender and causes in the effects of the MLDA on both ED visits and inpatient hospital stays suggests that the significant demographic differences are unlikely to seriously alter conclusions about the effects of the MLDA on nonfatal injuries in the US population.

Of course, our study is not without limitations, and an important one for interpretation is the concern that young adults who are under the drinking age may choose not to go to the hospital when they are sick for fear that people (e.g., parents, police) might find out they were drinking alcohol illegally. However, this phenomenon should be less likely for more severe morbidities such as those we study here: it is unlikely that young adults can avoid seeking treatment for, say, broken bones. We argue that the outcomes we study (going to an emergency department or getting admitted to the hospital) indicate an actual or perceived substantial health problem and represent substantial social costs of youth alcohol use.

Overall, our results are important for several reasons. First, our finding that there is a significant discontinuous increase at age 21 in the likelihood of
needing treatment for an injury inflicted by another person provides one of the literature’s most direct pieces of evidence that allowing individuals to purchase and consume alcohol increases the probability they will become the victim of violence – an idea that has received considerable anecdotal support but relatively little empirical validation using a quasi-experimental approach. Of course, it is possible that the party who ended up in the hospital is also the party who instigated the violent event (such that the perpetrator and the victim could be the same person).

More importantly, these results are the first to comprehensively evaluate the effect of the MLDA on all the major causes of morbidity in the US. We note that prior work found that total deaths increase by about 0.8 per 10,000 person-years (Carpenter and Dobkin 2009). In contrast, we estimate here that at that same threshold non-pregnancy related ED visits increase by 71.3 per 10,000 person years and hospital admissions increase by about 8.4 per 10,000 person-years. That is, these effect sizes are about two and one orders of magnitude larger, respectively, than the associated mortality estimate. Moreover, these events are costly: the average total hospital list charge of an emergency room visit for injuries among young adults in our data is $1,561, and the average cost of a hospitalization in these categories is $21,367.19 These costs also likely significantly understate the total costs because alcohol-related injuries may

19 We find no evidence that the average cost per alcohol or injury related ED visit is changing discretely at age 21.
require expensive rehabilitation and in many cases are also likely to—at least in the short term—reduce productivity. Though the cost of non-fatal health events are much smaller than the values commonly used in policy-related valuations of a death, unlike the cost of a death the majority of the direct health cost of nonfatal injuries is transferred to other people through the mechanism of insurance. Taken together, our results suggest that the literature’s disproportionate focus on mortality misses a significant part of the benefits of stricter alcohol control and thus the case for government intervention in this setting is stronger than previously understood.
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Figure 1: Emergency Department Visit Rates

Not Injury or Intoxication

Injury or Alcohol Intoxication

Note: The points are ED visit rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Figure 2: Emergency Department Visits by Cause

Note: The points are ED visit rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Figure 3: Inpatient Admission Rates

Note: The points are inpatient admission rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Figure 4: Inpatient Admissions by Cause

Note: The points are inpatient admission rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
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<th>P-Value</th>
<th>State in Inpatient Sample</th>
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<td>Drank in Last 30 Days</td>
<td>52.8</td>
<td>56.4</td>
<td>0.0107</td>
<td>52.5</td>
<td>0.8127</td>
</tr>
<tr>
<td>Days Drinking in Last 30</td>
<td>3.35</td>
<td>3.7</td>
<td>0.0334</td>
<td>3.31</td>
<td>0.6711</td>
</tr>
<tr>
<td>Days Drinking in Last 30 if Drank</td>
<td>6.46</td>
<td>6.64</td>
<td>0.4648</td>
<td>6.42</td>
<td>0.8148</td>
</tr>
<tr>
<td>Days Binge Drinking in Last 30</td>
<td>1.19</td>
<td>1.49</td>
<td>0.0038</td>
<td>1.25</td>
<td>0.3534</td>
</tr>
<tr>
<td>Health Excellent</td>
<td>24.2</td>
<td>26.3</td>
<td>0.0729</td>
<td>24.3</td>
<td>0.8461</td>
</tr>
<tr>
<td>Very good or Better</td>
<td>59.7</td>
<td>61.9</td>
<td>0.1283</td>
<td>57.6</td>
<td>0.0294</td>
</tr>
<tr>
<td>Good or Better</td>
<td>90.6</td>
<td>90.4</td>
<td>0.8144</td>
<td>88.2</td>
<td>0.0002</td>
</tr>
<tr>
<td>Fair or Better</td>
<td>98.7</td>
<td>98.9</td>
<td>0.5045</td>
<td>98.6</td>
<td>0.5183</td>
</tr>
<tr>
<td>Some High School</td>
<td>10.0</td>
<td>8.1</td>
<td>0.0752</td>
<td>11.8</td>
<td>0.0066</td>
</tr>
<tr>
<td>High School Graduate or GED</td>
<td>36.9</td>
<td>35.8</td>
<td>0.3870</td>
<td>36.5</td>
<td>0.6409</td>
</tr>
<tr>
<td>Some College</td>
<td>50.6</td>
<td>53.8</td>
<td>0.0249</td>
<td>48.5</td>
<td>0.0344</td>
</tr>
<tr>
<td>Working</td>
<td>50.4</td>
<td>48.7</td>
<td>0.2335</td>
<td>48.2</td>
<td>0.0269</td>
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<tr>
<td>Health Insurance</td>
<td>68.4</td>
<td>72.0</td>
<td>0.0049</td>
<td>64.9</td>
<td>0.0003</td>
</tr>
<tr>
<td>Observations</td>
<td>56,014</td>
<td>2,784</td>
<td>4,195</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: The descriptive Statistics are from the Behavioral Risk Factor Surveillance System 2004 - 2010. The Emergency Department Sample includes Arizona, New Jersey and Wisconsin. The Inpatient Sample includes Arizona, New York, Texas and Wisconsin. The P-values are from a comparison of 19 to 22 year olds in the subsample with those not in the subsample.
Table 2: Descriptive Statistics for Emergency Department and Inpatient Samples

<table>
<thead>
<tr>
<th>Group</th>
<th>Emergency Department Visits</th>
<th>Inpatient Hospital Admissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Visits</td>
<td>Illness</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56.97</td>
<td>63.97</td>
</tr>
<tr>
<td>Total List Charges</td>
<td>1.593</td>
<td>1.597</td>
</tr>
<tr>
<td>Private Insurance</td>
<td>39.82</td>
<td>38.75</td>
</tr>
<tr>
<td>Medicaid</td>
<td>19.58</td>
<td>22.35</td>
</tr>
<tr>
<td>Other Insurance</td>
<td>7.81</td>
<td>5.57</td>
</tr>
<tr>
<td>Self Pay</td>
<td>32.79</td>
<td>33.34</td>
</tr>
<tr>
<td>Rate per 10K</td>
<td>3.951</td>
<td>2.727</td>
</tr>
<tr>
<td>Number of Records</td>
<td>2,729,392</td>
<td>1,883,492</td>
</tr>
</tbody>
</table>

### Table 3: Emergency Department Visits

<table>
<thead>
<tr>
<th></th>
<th>All Visits</th>
<th>Illness</th>
<th>Injury or Alcohol</th>
<th>Alcohol</th>
<th>Accidental Injury</th>
<th>Self Inflicted Injury</th>
<th>Injury Inflicted by Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Over 21</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
</tr>
<tr>
<td>Constant</td>
<td>3,973.8</td>
<td>2,758.2</td>
<td>1,215.6</td>
<td>54.1</td>
<td>1,039.0</td>
<td>19.5</td>
<td>103.1</td>
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<tr>
<td></td>
<td>[16.1]</td>
<td>[13.8]</td>
<td>[6.6]</td>
<td>[1.3]</td>
<td>[7.1]</td>
<td>[1.1]</td>
<td>[2.1]</td>
</tr>
<tr>
<td>Observations</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.927</td>
<td>0.961</td>
<td>0.845</td>
<td>0.914</td>
<td>0.781</td>
<td>0.602</td>
<td>0.697</td>
</tr>
<tr>
<td><strong>Men Over 21</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
</tr>
<tr>
<td>Constant</td>
<td>3,314.8</td>
<td>1,921.1</td>
<td>1,393.7</td>
<td>69.4</td>
<td>1,178.4</td>
<td>17.0</td>
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<td>48</td>
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<td>48</td>
<td>48</td>
<td>48</td>
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<td>48</td>
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<tr>
<td>R-squared</td>
<td>0.917</td>
<td>0.963</td>
<td>0.793</td>
<td>0.891</td>
<td>0.749</td>
<td>0.347</td>
<td>0.642</td>
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<tr>
<td><strong>Women Over 21</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
</tr>
<tr>
<td>Constant</td>
<td>4,670.2</td>
<td>3,642.9</td>
<td>1,027.3</td>
<td>37.8</td>
<td>891.7</td>
<td>22.1</td>
<td>75.7</td>
</tr>
<tr>
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<td>[29.5]</td>
<td>[27.6]</td>
<td>[8.8]</td>
<td>[1.6]</td>
<td>[8.5]</td>
<td>[1.5]</td>
<td>[1.8]</td>
</tr>
<tr>
<td>Observations</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.792</td>
<td>0.864</td>
<td>0.726</td>
<td>0.902</td>
<td>0.578</td>
<td>0.636</td>
<td>0.287</td>
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</table>

P-value of Gender Difference: 0.7105

Notes: See notes from Table 2. Standard Errors in brackets. The dependent variable is Emergency Department visits per 10000 persons. An observation is the admission rate for a 30 day age range. The regressions include a second order polynomial fully interacted with an indicator variable for over 21 and a dummy for the month the 21st birthday falls in. The regressions include people age 19 to 22 inclusive which is equivalent to a bandwidth of two years. For most outcomes the bandwidth selection proposed in Imbens and Kalyanaraman 2012 gives optimal bandwidths between 1.5 and 2.5.
### Table 4: Inpatient Admissions

<table>
<thead>
<tr>
<th></th>
<th>(1) All Visits</th>
<th>(2) Illness</th>
<th>(3) Injury or Alcohol</th>
<th>(4) Alcohol</th>
<th>(5) Accidental Injury</th>
<th>(6) Self Inflicted Injury</th>
<th>(7) Injury Inflicted by Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Over 21</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>338.2</td>
<td>241.6</td>
<td>96.6</td>
<td>19.8</td>
<td>55.6</td>
<td>10.0</td>
<td>11.2</td>
</tr>
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<td>[1.6]</td>
<td>[1.0]</td>
<td>[0.3]</td>
<td>[0.6]</td>
<td>[0.2]</td>
<td>[0.2]</td>
</tr>
<tr>
<td>Observations</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.923</td>
<td>0.865</td>
<td>0.838</td>
<td>0.969</td>
<td>0.260</td>
<td>0.757</td>
<td>0.422</td>
</tr>
<tr>
<td><strong>Men Over 21</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
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<td>211.0</td>
<td>120.0</td>
<td>23.9</td>
<td>69.3</td>
<td>7.5</td>
<td>19.3</td>
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<td></td>
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<td>[1.8]</td>
<td>[1.2]</td>
<td>[0.6]</td>
<td>[0.7]</td>
<td>[0.3]</td>
<td>[0.3]</td>
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<tr>
<td>Observations</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.892</td>
<td>0.723</td>
<td>0.861</td>
<td>0.966</td>
<td>0.331</td>
<td>0.339</td>
<td>0.464</td>
</tr>
<tr>
<td><strong>Women Over 21</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>330.2</td>
<td>265.7</td>
<td>64.5</td>
<td>11.4</td>
<td>39.4</td>
<td>11.5</td>
<td>2.2</td>
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<td>[1.5]</td>
<td>[0.6]</td>
<td>[0.9]</td>
<td>[0.3]</td>
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<tr>
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<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.872</td>
<td>0.868</td>
<td>0.432</td>
<td>0.898</td>
<td>0.206</td>
<td>0.777</td>
<td>0.139</td>
</tr>
</tbody>
</table>

**P-value of Gender Difference**

|                  | 0.0197 | 0.5684 | 0.0033 | 0.0016 | 0.0827 | 0.2734 | 0.1604 |

Notes: See notes from Table 2. Standard Errors in brackets. The dependent variable is hospital admissions per 10000 persons. An observation is the admission rate for a 30 day age range. The regressions include a second order polynomial fully interacted with an indicator variable for over 21 and a dummy for the month the 21st birthday falls in. The regressions include people age 19 to 22 inclusive which is equivalent to a bandwidth of two years. For most outcomes the bandwidth selection proposed in Imbens and Kalyanaraman 2012 gives optimal bandwidths between 1.5 and 2.5.
Appendix 1: Emergency Department Visits by Cause – Male

Note: The points are ED visit rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Appendix 2: Emergency Department Visits by Cause – Female

Note: The points are ED visit rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Appendix 3: Increase in ED Visits

Robustness to Bandwidth Choice

Note: The estimates of the increase at age 21 are from a second order quadratic polynomial fully interacted with an indicator variable for being over 21. The heavy line is the point estimate; the dotted line is the 95% confidence interval.
Appendix 4: Increase in ED Visits

Robustness to Bandwidth Choice

Note: The estimates of the increase at age 21 are from a second order quadratic polynomial fully interacted with an indicator variable for being over 21. The heavy line is the point estimate; the dotted line is the 95% confidence interval.
Appendix 5: Inpatient Admissions by Cause – Male

Note: The points are inpatient admission rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Appendix 6: Inpatient Admissions by Cause – Female

Note: The points are inpatient admission rates per 10,000 and the fitted lines are from a second order quadratic polynomial in age estimated separately on either side of the threshold.
Appendix 7: Increase in Inpatient Admissions

Robustness to Bandwidth Choice

Note: The estimates of the increase at age 21 are from a second order quadratic polynomial fully interacted with an indicator variable for being over 21. The heavy line is the point estimate; the dotted line is the 95% confidence interval.
Appendix 8: Increase in Inpatient Admissions

Robustness to Bandwidth Choice

Note: The estimates of the increase at age 21 are from a second order quadratic polynomial fully interacted with an indicator variable for being over 21. The heavy line is the point estimate; the dotted line is the 95% confidence interval.