May 2016

Three Essays on Public Policy and Health

Darin F. Ullman
University of Wisconsin-Milwaukee

Recommended Citation

Ullman, Darin F., "Three Essays on Public Policy and Health" (2016). *Theses and Dissertations*. 1217.
https://dc.uwm.edu/etd/1217

THREE ESSAYS ON PUBLIC POLICY AND HEALTH

by

Darin Frank Ullman

A Dissertation Submitted in
Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY
in ECONOMICS

at
The University of Wisconsin-Milwaukee
May 2016

ABSTRACT

THREE ESSAYS ON PUBLIC POLICY AND HEALTH

by

Darin Frank Ullman

The University of Wisconsin-Milwaukee, 2016
Under the Supervision of Professor Scott J. Adams

This dissertation consists of three chapters. My first chapter examines the effect of mandatory first time offender ignition interlock laws. Specifically, I use difference in difference techniques to estimate the effect of the laws on alcohol related fatal accidents. I also discuss and link behavioral models of deterrence and incapacitation to the results, so that finding can easily be interpreted. Results of the study provide pivotal policy relevant information that are essential to maximizing public health and reducing dangerous alcohol related crashes. In particular, results show that states which adopt legislation that requires mandatory participation of first time offenders in ignition interlock programs, at low blood alcohol levels, experience significant reductions in alcohol related accidents.

The second chapter of my dissertation uses detailed vehicle specifications to analyze the impact identifiable vehicle characteristics and technological progress has on fleet fuel economy by vehicle type and class. Estimates are generated following a cobb-douglas framework and an identification strategy of a widely cited American Economic Review (AER) paper developed by Christopher Knittel in 2011. Results reveal that vehicle manufactures will have a difficult task complying with the new footprint-based C.A.F.E. standards by changing identifiable vehicle characteristics alone. I also find evidence that more stringent footprint-based standards may create incentives for manufacturers to increase vehicle size to lower the burden of compliance.

My final chapter, uniquely contributes to the literature on medical marijuana laws (MML) by being the first paper to analyze the impact of MML on employee sickness absence. With evolving MML and an increasing number of states with recreational marijuana laws it will be important for economist to understand how these laws impact markets and in particular the labor market. The paper lays the groundwork for future research in this area by Utilizing the Current Population Survey, the study identifies that absences due to sickness decline following the legalization of medical marijuana. The effect is stronger in states with “lax” medical marijuana regulations, for full-time workers, and for middle-aged males, which is the group most likely to hold medical marijuana cards.

This dissertation is dedicated to Mother, Father, Brothers, Sisters, and beautiful Fiancée.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to everyone who supported me throughout my graduate school career. In particular, I would like to thank my advisor Scott J. Adams for knowing when to help me and when not to. I could not have completed my dissertation without your guidance. You are one of the most intelligent, yet down to earth individuals I have met and that says a lot compared to most economist. I would also like to thank John Heywood, for always having an open door and helping me become a well-rounded researcher. Thank you as well to Chad Cotti for providing me direction throughout my under-grad and graduate career. I would also like to convey my appreciation to the additional members of my dissertation committee: Professors Matt McGinty, Owen Thompson, and Scott Drewianka for their thoughtful and helpful criticism, and support. Finally, I cannot forget to thank my family, friends, and beautiful fiancée (Nicole), for putting up with me and providing the mental and emotional support needed to obtain a PhD.

1 Locked and not Loaded: First Time Offenders and State Ignition Interlock Programs

1.1. Introduction

Accidents involving drunk drivers impose enormous social and economic costs on society. The National Highway Traffic and Safety Administration (NHTSA) reports that in 2012, 10,322 people died in drunk driving crashes and an additional 290,000 individuals were injured. Furthermore, they estimate that drunk driving costs the United States $199 billion every year and 90% of these costs occurred in crashes involving a drunk driver with a blood alcohol concentration (BAC) of .08 or higher (Report No. DOT HS 812 013).[1] Given the magnitude of these societal and economic costs, government officials are continuously enacting policies to prevent drunk driving and the all too common fatal motor vehicle crashes that follow.

One such policy designed to prevent drunk driving is the ignition interlock program. The ignition interlock device (IID) is designed to prevent vehicle operation when the driver is impaired from alcohol consumption. Drivers are required to provide a breath specimen to the device before it will allow the operator to start the vehicles' engine. Legislation to support the use of the device began in the late 1980's. Improvements made to the device in the early 1990's led to the adoption of the program by counties and states across the country.[2] Currently, numerous states have also implemented the program to include mandatory participation by first time drunk driving offenders, a group that the Center for Disease Control (CDC) has found to have driven drunk more than 80 times before being caught.

---

[1] The estimated $199 billion costs include societal costs such as "lost quality of life". Pure economic costs are equal to $59 billion in 2010 for alcohol involved accident. Costs are expressed in 2010 dollars

[2] Second generation IID improvements help prevent falsified tests. New features include: hum tone recognition, filtered air detection, blow abort, and random running tests (Collier DW. 1994).

Previous research has highlighted the effectiveness of the IID technology. In particular, a recent meta-analysis has shown that the risk of recidivism for DWIs can be reduced up to 64 percent (Willis et al. 2004). Other research has highlighted the lack of success of comparable drunk driving preventative policies, such as license suspensions. For instance, studies show that 50 to 75 percent of convicted drunk drivers whose license has been suspend continue to drive. (Peck R.C. et al. 1995 and Beck K.H. et al. 1999).

This paper advances the literature on drunk driving laws and ignition interlocks in several important ways. To begin, it is the first to apply difference in difference estimation methods to analyze the effectiveness of current state polices that require mandatory installation of IID's for first time drunk driving offenders. Though this framework has become standard in policy evaluation, the identification strategy controls for unobservable cross state heterogeneity, in alcohol related behaviors, which can lead to biased estimates in traffic fatalities (Dee 1999). Additionally, given what we know from prior research on ignition interlocks and the failures of other drunk driving laws to prevent the behavior, this paper provides critical estimates of the magnitude and effect of mandatory ignition interlock laws, which directly incapacitates offenders from potentially fatal future drunk driving decisions.

Another contribution of the study is that is it provides suggestive evidence that incapacitation is the primary reason for the estimated effect, rather than the deterrence. Finally, the study provides pivotal public policy information for current and future legislation. Specifically, the results from the study uncover that states that adopt "strong" (i.e., applied to drivers convicted of having BAC .08 or greater) mandatory IID installation for first time offenders experience a significant reduction in the number of fatal accidents involving a drunk driver. This result is also negative and significant when considering the number of fatal accidents involving drivers with positive alcohol levels. However, results for states that adopt “weak” (i.e., only for drivers with BAC .15 or greater) mandatory IID installation for first time offenders show no significant effect in decreasing the number of fatal accidents with alcohol involvement.

In detail, the preferred estimates on strong IID adoption indicate that fatal accidents involving a drunk driver decrease by 9% and fatal accidents involving a driver with a positive alcohol level decrease by nearly 7%. In terms of fatal accidents cause by a drunk driver, this is potentially equivalent to 1.4 fewer fatal accidents a month for a typical state. Focusing on the reduction in fatal accidents from drunk drivers alone and considering that the NHTSA estimates that the economic cost of a fatal accident is approximately $1,650,000, the national adoption of strong ignition interlock laws for first time offenders could potentially save $1.39 billion dollars. If we instead consider the Department of Transportation (DOT) guidelines for the value of statistical life (VSL) which is equal to $9,100,000, then the total saving from the saved lives of non-drivers alone is equal to $2.95 billion dollars in a year.

These results are robust to alternative models with varying controls, including state and time fixed effects, state-time trends, population changes, economic climate, demographic characteristics, other drunk driving polices, and taxes related to gasoline and beer. Additionally, California’s pilot program provides an excellent case study at the county-level to analyze the effectiveness of strong mandatory first time offender ignition interlock programs. These within-state results do not suffer from the potential heterogeneity that sometimes plagues cross-state analyses. The results are again robust and support the findings at the state level.

Overall, given the finding in this paper it is prudent for policy makers to take into consideration the effectiveness of strong ignition interlock laws for first time offenders in preventing fatalities as a result of alcohol involved accidents. With 14 states that currently have weak ignition interlock laws for first time offenders and 11 states who still have no mandatory policy for using the IID for first time offenders, this study provides essential information in designing lifesaving public policy related to drunk driving.

The remainder of the paper is organized as follows. Section 2 lays the ground work for the underlying behavioral models and provides a brief background on ignition interlock laws. Section 3 discusses the related literature. Section 4 describes the data and methodology. Section 5 explores the empirical results at the state level, discusses the results, briefly describes cost benefit analysis of the IID, provides robustness tests using an alternative BAC measure, different dependent variables, as well as presents the California case study. Section 6 concludes.

1.2. Conceptual Framework and Background

1.2.1. Behavioral Model

The vast majority of economic studies related to drunk driving explicitly or implicitly adopt the framework of Becker's (1968) expected utility model of criminal behavior. The model and associated literature propose that individuals are deterred from illegal actions when the associated costs outweigh the benefits. Evidence of deterrence in the drunk driving literature is inconclusive. As shown by Benson et al. (1999), deterrence alone has little effect on drunk driving without high probability of police involvement.

In addition to deterrence theory, others such as Shavell (1987) and Polinsky and Shavell (2007), have modeled optimal crime prevention through incapacitation. Overall, when incapacitation is the goal, the length and number of individuals incapacitated increases with time, as long as the cost of incapacitating those individuals is less than the cost of the potential harm they could create. Recent work by Miceli (2010, 2012) has also adapted the standard economic model for crime to include both deterrence and incapacitation theory. The unified model presents an optimal decision that either increases the level of incapacitation if the deterrence level is low or decreases the level of incapacitation if deterrence level is high.

In regards to mandatory ignition interlock laws, there is potential for both deterrence and incapacitation to influence individual behavior that yields the result estimated in this paper. For instance, individuals may be deterred from drinking and driving because they fear potential negative social interactions. Mandatory device installation could bring about unwanted interactions with family, friends, and co-workers that reveal the offender's prior illegal activity. On the other hand, given that the device directly incapacitates individuals from operating their vehicle while under the influence of alcohol, the more participants and greater probability of installment, means lower BAC levels on the roadways and reduced likelihood of drunk driving fatalities.

A reduction in fatal accidents itself is consistent with both the incapacitation and deterrence models. However, I will engage in a number of tests that will be suggest the incapacitation model is more reasonable in the case of IIDs.[3] In short, we would expect incapacitation to be stronger as the number of individuals affected by the law likely increases. So, if the effects grows over time or the effect is stronger in locations where more individuals are expected to be incapacitated, then this supports the behavioral model of incapacitation more than deterrence.

1.2.2. Basic Background

---

[3] An event study, Figure 1.4., also suggests incapacitation, as there is a distinct lagged divergence in the trend of the drunk accident rate for the strong IID states versus the control states. The lack of an immediate divergence in the trend likely results because it takes time for offenders to be convicted and have a device installed. For instance, some states do not require installment until after a 45-90 day suspension of license is served. Additionally, as time increase the number of program participants increases, which magnifies the effect.

In this section I briefly provide additional specifics on state ignition interlock programs and mandatory first time offender IID polices.[4] Currently, all states have ignition interlock laws. However, until recently those laws did not included mandatory participation among first time offenders. Mainly they were used for repeat offenders.

Mandatory first time offender programs have been enacted in states in two forms: 1) interlock requirement starts on conviction with BAC of 0.08 or greater and 2) interlock requirement starts on conviction with BAC of 0.15 or greater.[5] Although there is some small variations in the length of time, generally convicted first time offenders are required to have the device installed in their vehicle for a minimum of five months, but the length can exceed one year.[6] Another difference in state interlock programs is how they are administered, which according to the NHTSA can be grouped into three categories.[7] Specifically, they are "administrative," which is overseen by a department of motor vehicles or similar agency, "judicial," which is mandated by the court system, and "hybrid" programs, which utilizes aspects of both of the prior mentioned groups. Currently, states with first time offender programs are evenly split between each type.

1.3. Related Literature

1.3.1. Literature on Ignition Interlocks

A thorough review of the literature assessing the effectiveness of ignition interlocks was recently conducted by Elder et al. (2011), with a consensus of studies showing drivers with

---

[4] I refrain from dedicating a large portion of the text to IID specifics because detailed documents are easily available. For instance, the NHTSA and MADD are heavy supporters of ignition interlock laws and both provide comprehensive specifics of the laws and programs, which can be found on their websites. See: www.nhtsa.gov/staticfiles/nti/pdf/IgnitionInterlocks_811883.pdf

[5] Three states have higher BAC limits for the weaker first time offender IID program. Minnesota (BAC=.16), Michigan (BAC=.17), and Nevada (BAC=.18). They are included in the "weak" IID policy group.

[6] Summarized details of required installment length can be found here: http://www.ncsl.org/research/transportation/state-ignition-interlock-laws.aspx

[7] See DOT HS 811 8883 for details.

interlocks installed are at substantially less risk for recidivism. Additionally, the review evaluated studies on the effect of ignition interlocks on motor vehicle crashes and driving, but just three studies were available for review and only two were deemed reliable. The results of these studies suggested that in comparison to a group of individuals who were subject to suspended licenses, the ignition interlock group was found to have a higher crash risk. This could be due to the fact that the IID group was also found to drive greater distances. Also noted was that some studies found evidence that interlocks protected against alcohol-related crashes. Additionally, in a study not included in the review by Lahausse et al. (2009), found that installing interlocks in all newly registered vehicles, in Australia, could reduce traffic fatalities up to 24% a year.

Overall, the authors of the review are hesitant to draw any strong conclusions on the effect of ignition interlocks on motor vehicle crashes given the limited number of studies. One major conclusion of the review however, is that the success of ignition interlock programs is determined by who participates and how it is implemented. In particular, the authors' posit that mandatory participation for first time offenders would likely be a major boost to overall public safety, and the program should not be used for just repeat or high BAC offenders.

Finally, the NHTSA has developed several reports related to ignition interlock programs, an example being "Ignition Interlock Institutes: Promoting the Use of Interlocks and Improvements to Interlock Programs" (2013). Much of the reports focus on the IID research developed by Richard Roth.[8] Primarily, Roth's research evaluates the effectiveness of New Mexico's interlock program. The studies find that the program has led to a substantial decrease in interlock users' recidivism rates as well as a 28% decrease in the number of DWI fatalities from 2005 to 2008 after the program moved to include first time offenders.

---

[8] Research available at http://www.rothinterlock.org/welcome.htm.

1.3.2. Literature on Other Policies Related to Drunk Driving

The literature on the effect drunk driving policies have on fatal traffic crashes is vast. Several previous publications, for instance Eisenberg (2003), have detailed literature reviews so I refrain from providing anything but the highlights of the papers most applicable to my approach. In particular, several studies examine the effectiveness of BAC limit laws. Dee (2001) uses an OLS fixed effects model and finds that .08 BAC regulations reduce the fatal traffic crash rate by 7.2%, and the .10 BAC limit laws reduces the rate by 5.3%. Eisenberg (2003) evaluates the effect of states switching from a .10 to .08 BAC limit and finds that the fatal crash rates falls by 3.1%. Conversely, Freeman (2007) and Grant (2010) show that the effect of switching from a .10 to .08 BAC level is limited and that there is a declining effect of BAC limit laws over time.

In addition to BAC limit laws, Eisenberg (2003) also examines several other drunk driving policies, including zero tolerance, administrative license revocation, dram shop, open container, mandatory jail sentence for first conviction, and preliminary breath test laws. The results of the analysis fit into the already mixed and conflicting conclusions of the previous research on these drunk driving polices, with dram shop laws being the only universally agreed upon effective policy. Similarly, Dills (2010) finds that social host laws for minors has a significant negative effect drunk fatal crash rates among young adults between 18-20.

This study contributes to the existing literature in several unique and important facets. Specifically, it is the first to use a regression-identified specification to analyze the impact of mandatory participation of first time offenders in state ignition interlock programs. Using panel data and variations across states, as well as within, the study is able to identify a causal effect of the program. Though endogenity of the policy variable is always a concern in such studies, this study includes controls for other polices enacted during the period and shows that the effect is observed apart from underlying trends in fatalities. This lends support for the exogenity of the policy variable and presents the dynamic effect of the policy on drunk, BAC ≥ .08, and positive alcohol, BAC ≥ .01, fatal accidents. Furthermore, this study provided additional information for policy makers that wish to implement the best possible programs to prevent deadly and costly alcohol related vehicle crashes.

1.4. Data and methods

1.4.1. Fatal accident data and state ignition interlock laws

Data on fatal vehicle crashes are obtained through the Fatality Analysis Reporting System (FARS) of the NHTSA. It serves as the main source of data to generate the primary variables of interest. Two of which are the monthly number of fatal accidents in a state for which a driver's imputed BAC is greater or equal to .08 and the monthly number of fatal accidents in a state for which a driver's imputed BAC is greater or equal to .01. These two dependent variables indicate the number of fatal accidents that occur at the hands of drunk drivers and fatal accidents that occur with drivers that have positive alcohol levels. The imputation of driver BAC is necessary because of rampant misreporting of actual BAC levels at crash scenes. Although federal law requires BAC levels to be obtained for every fatal crash, this is often not done. The NHTSA developed a multiple imputation procedure following suggestions by Rubin et al. (1998) that uses characteristic of individual crashes, such as time of day, time of week, and position of the car, to predict and impute a BAC level for cases in which this data are missing.[9] Confirmation of the procedure's accuracy in predicting driver BAC can be seen in the NHTSA (2002) report, "Transitioning to Multiple

---

[9] The presence of an IID device in a vehicle involved in a crash is not use in the imputation process.

Imputation."[10] In what follows I routinely use the median or mean of the imputed BAC values for each driver.[11]

For this study, I link these counts of monthly state fatal accidents to state-level legislative data on strong and weak mandatory installation of the IID for first time offenders. States that have enacted mandatory installation for first time offenders between 2001 and 2012 are branded as treatment states for one of the two treatment levels and are used to create the policy variables of interest in the form of dummy variables. Information on dates and state coverage of ignition interlock laws was obtained from Mothers Against Drunk Driving (MADD).[12] For clarity, Table 1.1. describes the first time offender ignition interlock laws and enactment dates for both types of treated states.[13]

The preferred estimates exclude Washington DC because of its unique driving conditions, as well as Alaska for its relatively small number of monthly fatal accidents. Additionally, Iowa is considered to be a part of the weak treatment group because of its unique BAC level but is coded properly to represent its lack of within state variation.[14] California's first time offender policy is limited to the participation of four major counties—Los Angeles, Alameda, Sacramento, and Tulare. However, given that these counties include some of California's major metropolitan areas and account for over 13 million of the states' population, it is included in the treatment group.[15]

---

[10] Ten imputed BAC values are reported for each driver in a fatal accident. The mean or median is used to categorize each driver as drunk, positive alcohol, or no alcohol. Results are robust with both methods.

[11] Coupling the fact that previous actual values of driver BAC's have been misreported along with the recent report by the NHTSA, which assures the accuracy of the imputation process, there should be no concern in using imputed values to determine the counts of alcohol involved fatal accidents. Additionally, this practice has become very common in the drunk driving literature (Cumming et al. 2006; Adams et al. 2008; Romano et al. 2008; Williams et al. 2012). In order to ensure that IID laws are not affecting predictors of BAC, I also estimated results using previous techniques of drunk driving related research. Specifically, I regressed my models using only the times when most alcohol related accidents are believed to occur, i.e.: nights and weekends. Results were consistent with those found using imputed BACs.

[12] See - http://www.madd.org/drunk-driving/ignition-interlocks/status-of-state-ignition.html

[13] Table 1.1. notes, lists states that enact first time offender IID policies after 2012.

[14] Iowa's mandatory policy has dictated that first time offenders with a BAC above .10 install the IID since 1995.

[15] Results of various models are robust without the inclusion of California.

The final data consist of 49 states, of which 12 are consider weak treatment states, 17 are strong treatment states, and the remaining 20 state are controls. The data are evaluated over a 144 month period for a total of 7056 observations.

Table 1.2. provides descriptive statistics, including means of the two treatment groups and the control group used in analysis. The statistics show that there has been an overall decrease in the raw number of fatal accidents involving drunk drivers in strong IID states, from 16.72 to 12.09 fatal accidents per month. Considering the changes in average population that occur for the pre- and post-treat strong IID group, I also look at the rate of fatal accidents involving a drunk driver per 100,000 people, which in this case falls from .24 to .20. This reduction does not account for downward trends that may be occurring over time for these types of accidents independent of the IID policies, which necessitates the fixed effects research design described later. Estimates discussed later in the paper provide evidence that the decrease is substantial and significant for states that have adopted strong IID laws for first time offenders. A similar decrease in the number of fatal accidents involving a driver with positive alcohol levels is also visible in the descriptive statistics, of strong IID states from 20.39 to 14.69 per month. The rate per 100,000 people using average population also falls from .29 to .245. This again proves to be a substantial and significant decrease in the estimate results. Given that the number of fatal accidents is highly variable in smaller states, ordinary least squares (OLS) estimates are weighted by the state-year population size obtained from the Census Bureau.

1.4.2. Methodology

Individual numbers of fatal accidents involving a drunk driver and fatal accidents involving drivers with positive alcohol levels are first aggregated into state monthly totals. Those results are then pooled into the strong and weak states that have mandatory IID laws for first time offenders. Remaining states that do not have either of these laws or do not change during 2001-2012 are then pooled into the control group. The basic analysis takes the form of a standard difference-in-difference fixed effects model:

$$(1) \qquad FA_{st} = \alpha + \eta_s + \tau_t + \mu_{st} + \beta_1 StrIID_{st} + \beta_2 WkIID_{st} + \lambda' X_{st} + \varepsilon_{st} ,$$

where subscripts *s* and *t* denote states and months. The terms η_s and τ_t are the state and month fixed effects, respectively. To control for other factors that may impact the number of fatal accidents over time, such as weather and construction, I include a complete set of state-time trends unique to each state in some specifications. The state-time trend is the linear time trend "τ" interacted with individual states "η", that is "τ*η", indicated above as μ_{st}. Even though including comprehensive state-time trends in the model can often limit some identifying power, results prove robust. *StrIID* and *WkIID* are the policy variables and indicate states that have a strong or weak ignition interlock mandatory program for first time offenders. Thus, β_1 and β_2 are the primary coefficients of interest. As a reminder, strong states require participation if drivers are caught under the influence of alcohol with a BAC of .08 or greater and weak states require participation if the individuals BAC is .15 or greater.

FA is defined as the log (number of fatal accidents +1) involving a driver whose BAC is greater or equal to .08. Alternatively, estimates are also performed where the dependent variable FA is defined as the log (number of fatal accidents +1) involving a driver who has a BAC level of .01 or greater, referred to earlier as a positive alcohol level. The log format was chosen to provide an easy interpretation of the effect of policy variables in terms of percentages.[16] Log accident estimates of equation (1) are weighted by state-year population. All estimate standard-errors are corrected for correlation across states by means of clustering (Arellano 1987).

The *X* matrix contains a set of additional controls. I include controls for the log of the population for each state, the proportion of males, the proportion of specific races, the median age in each state, and real income per capita represent in 2012 dollars. The proportion of males is included because males are more likely to be involved in fatal accidents.[17] Other factors for which I control that might be related to fatal accidents include the prevailing gasoline tax, beer tax, and unemployment rate. Beer taxes for each state are included and represented in 2012 cents. State unemployment rates, which were constructed from census data, are included because economic volatility during the time period may have led to fewer drivers on the road (Cotti and Tefft 2011). Finally, estimates also include controls for a selection of other relevant drunk driving policies enacted during the sample period that could be correlated with IID policy variable of interest. For instance, policy variables for .08 BAC limits (BAC08) and open container (OPEN) laws were included, along with two polices directed at reducing underage drinking, which are license suspension or revocation for underage purchase, possession, and consumption (UND21) and liability for hosting underage drinking parties (PARTY). [18],[19] Information and effective dates for the above policy variables was obtained from the Alcohol Policy Information System of the National Institute of Alcohol Abuse and Alcoholism.

---

[16] Given the count nature of these dependent variables, for robustness and to ensure results are not driven by the model choice, estimates were also preformed using an unweighted Poisson model. The results were consistent and had no substantive effect on the conclusion of the analysis. Negative Binomial estimates were not used because this model has been previously criticized as not being a true fixed effects estimator (Allsion et al. 2002)

[17] See Washington State Department of Health (2012) for representative statistics.

[18] An administrative license suspensions policy variable was not included because only one state (New York) in the sample exhibited any variation of policy during the sample period.

[19] Coefficients of these policies are omitted from results tables, as are many other controls, for brevity. Full regression results for the various dependent variables are available in the appendix.

In addition to estimating equation (1), I examine a similar model at the county-level using California's ignition interlock pilot program. The program has the same guidelines of mandatory participation for first time offenders as the strong states described earlier, but there is no longer a weak treatment group. Previous state-level controls such as gasoline tax and beer tax are no longer included, and the state unemployment rate is replaced by county-level unemployment rate. State and month fixed effects are now transformed to county and year fixed effects. Year fixed effects replace months because there are numerous months in which several of California's counties have zero fatal accidents involving a drunk driver. Thus, the dependent variables for the number of accidents involving a drunk driver and the number of accidents involving a driver with positive alcohol levels are aggregated at the county-year level and include years 2007 through 2012. The California case study results are intended to provide a robustness check on the effectiveness of strong IID mandatory first time offender programs.

1.5. Results

1.5.1. State-level Results

I begin by estimating equation (1) at the state-level for both treatment groups and controls. Table 1.3. provides the results for fatal accidents involving a drunk driver.[20] Additionally, results are provided without and with state-time trends and indicate the robustness of the identification strategy. As indicated by the results, strong ignition interlock laws for first time offenders, reduce the number of fatal accidents involving a drunk driver by 9%. The result is significant at the 5 percent level, including state-time trends. The results also indicate the lack of effectiveness of

---

[20] An accident is indicated as a drunk fatal accident if a drivers BAC is greater or equal to .08, using median imputed BAC level of drivers.

weak ignition interlock laws (i.e.: BAC ≥ .15) for first time offenders in reducing the number of fatal accidents involving a drunk driver, as all estimates yield positive but insignificant results.

To consider the effectiveness of both strong and weak IID laws for first time offenders in preventing fatal accidents involving drivers with positive alcohol levels, equation (1) is estimated with the dependent variable now indicated as the number of fatal accidents with drivers who have a BAC greater or equal to .01. The results for these estimates can be seen in Table 1.4. Again, it is apparent that states with strong ignition nterlock laws for first time offenders are able to substantially lower the number of fatal accidents involving a driver with positive alcohol levels. For instance, results without and with controls for state-time trends, indicate that the number of fatal accidents involving a driver with a positive alcohol level decreased by 9% and 7%. These results are significant at the 1 and 5 percent level. With regard to weak IID states, the results once again indicate that the more relaxed policy for drinking and driving for first time offenders does not have a significant impact on lowering the number of fatal accidents involving a driver with positive alcohol levels.

In all models for both drunk drivers (BAC ≥.08) and drivers with positive alcohol (BAC ≥.01) lead and lag effects were tested in regards to the policy variables (i.e.: strongIID and weakIID). These results can be seen in Table 1.5., separated for regression by drunk, column (1), and positive alcohol, column (2), and by weak and strong leads and lags. In all cases, no significant results were found for leads. This supports the exogenity of the policy variables, as opposed to an effect from a previously existing trend. It is also unlikely that the policies would have any effect before enactment due to alcohol influenced drivers anticipating the enforcement of the law. A pretreatment graph, Figure 1.1., displays the trend of the treatment groups and control group. There are no differences in the trends. Additionally, the dynamic framework of Table 1.5., also provides additional insight on the impact of the strong IID policy. Results show that a greater and more statistically significant impact prevails the longer the policy has been in place. This is not surprising. As more offenders are prosecuted and the number of devices installed increases, the more likely and stronger the potential impact of the policy, which further suggests incapacitation as the dominant effect.[21]

It is worthwhile to convert the previously mentioned percentages into an actual number of reduced fatal accidents involving drunk drivers. To do so, I focus my attention on the log accident estimates that includes a full set of controls, along with a complete set of state-time trends. In 2012, the NHTSA reported that there were 9,364 fatal accidents resulting in 10,322 fatalities involving a driver with a BAC .08 or higher (DOT HS 811 870, 2013). Using this information and the estimation results, I find that the reduction in fatal accidents from strong ignition interlock laws for first time offenders would be equal to 1.4 fewer fatal accidents involving a drunk driver for a typical state in a typical month.[22] We can also think about this in terms of saved lives. Using the FARS data and estimation results, the 1.4 fewer fatal accidents involving a drunk driver would approximately save 1.54 lives per state-month. Additionally, of the 10,322 reported fatalities involving a driver with BAC .08 or higher, 6,688 were the drunk driver (DOT HS 812 032, 2013). If we focus our concern to the lost lives of non-driver crash victims, then the 1.4 fewer fatal accidents from strong IID laws for first time offenders would save approximately .54 non-driver lives for a typical state in a typical month.[23] Over an entire year, national adoption of strong ignition interlock laws for first time offenders would save 324 innocent victims lives from drunk

---

[21] When a quadratic state-time trend is added to the estimates of both drunk and positive alcohol models, the effect of the IID policies are soaked up, suggesting a ramping of enforcement and incapacitation.

[22] $1.4 = (9{,}364*.09) / (12*50)$

[23] $.54= (1.54 - (1.54*.648)); (6688/10322)=.648$

drivers.[24] With regard to fatal accidents involving a driver with a BAC .01 or higher, the NHTSA reported that 10,918 such fatal accidents occurred in 2012, resulting in 12,041 fatalities (DOT HS 811 870, 2013). Following a similar process, using the estimated 7% reduction in fatal accidents involving a driver with positive alcohol levels from having strong ignition interlock laws for first time offenders, yields approximately 1.27 fewer fatal accidents involving a driver with positive alcohol levels, for a typical state in a typical month.[25] This reduced number of fatal accidents involving a driver with positive alcohol levels could potentially save 1.41 lives per state-month, of which .50 would be assumed to be the lives of non-drivers.[26]

1.5.2. Discussion of Results

It is useful to first assess the plausibility of results of this magnitude. In other words, is the use of IID sufficiently large enough to account for up to a 9% reduction in fatalities among drunk drivers? To provide support for the plausibility, Figure 1.2. provides two side by side graphs. One shows the estimated (in use) IIDs since 2005, the year in which states began to enact laws requiring mandatory participation for first time offenders, until year 2013.[27] The other shows the number of alcohol impaired driving fatalities, where the drivers BAC level was .08 or higher. Figure 1.3. plots both graphs together and normalizes the number of interlocks in use and number of fatalities by their first year value. From the graphs, there appears to be a distinct correlation between the increase in the number of interlocks and the decrease in the number drunk driving fatalities. Furthermore, since the inclusion of first time offenders in the interlock program, the number of estimated interlocks has increased by over 245%, whereas the number of fatalities has

---

[24] 324=.54*12*50

[25] 1.27 = (10,918)*.07 / (12*50)

[26] .50= 1.41 - (1.41*.642)); (7730/12041)=.642

[27] Data is limited to 2005 and after and was obtained from http://www.rothinterlock.org/welcome.htm.

fallen by 25%. Also, the majority of interlock use can be linked to states that require mandatory first offender participation. Specifically, in 2012 it was estimated that there were 280,000 interlocks in use, of which over 80% were in strong and weak first time offender law states, with nearly 2/3 in strong states alone. Overall, these graphs provide evidence that the use of IIDs is large enough to generate the results uncovered in this study.

Additionally, since California enacted its pilot program in 2010, the number of interlocks installed for first time offenders for the four pilot counties went from about 2,348 to 43,574 by 2013, a nearly 1800% increase in IIDs for first time offenders (Chapman et al. 2015). This, along with the density of the population and driving conditions in counties where the program was installed, could explain why the effect in the case study is larger than the state level analysis. [28]

In addition to understanding plausibility, it is important to policy makers to understand whether it is deterrence or incapacitation that is underlying the results. There are a number of reasons that suggest incapacitation. First, Figure 1.4. presents the average monthly drunk accident rate for strong treated states. The accident rate is aligned by each state's treatment date, where negative values indicate pre-treatment and positive values indicate post-treatment. For comparison, the average weighted rate of drunk driving accidents is also presented for the control states. While pre-treatment trends look similar, there is a distinct divergence in the trend compared to the control states that begins approximately five months after the enactment. Since offenders need to be caught and the devices installed, we would expect such a lagged effect. If deterrence was indeed driving the results, we should see more immediate impacts.[29] It is important to recognize that the values in Figure 1.4. are not regression adjusted, which again necessitates the

---

[28] For density of traffic in California treated areas, see California Department of Public Health website: http://www.ehib.org/page.jsp?page_key=980.

[29] Offenders generally have to serve a 45-90 day license suspension before a device can be installed.

difference in difference methodology. Overall, the figure does provide further support for incapacitation.

Second, one would also expect that strong laws would have a greater incapacitation effect than weak laws because it applies to a broader group of drivers and affects more offenders. Specifically, the BAC limit of .08 is nearly half of the .15 BAC limit weak laws require. As a result, strong laws create a greater probability of participation because a wider span of coverage exists. This is supported by results. In strong states, where participation of offenders is more likely, alcohol related accidents are significantly reduced. However, in weak states, where participation is much less likely, there is no estimated effect on alcohol related accidents. Additionally, dynamic timing of events results in Table 1.5., further exhibit the broader coverage of strong laws. The results show that the magnitude and significance of the law increase as time goes by, which is likely because of greater offender program involvement. All of this evidence provides additional support for incapacitation.

1.5.3. Cost-Benefit Analysis

Vehicle crashes involving a drunk driver impose enormous social and economic cost on society. In order to examine the cost-effectiveness of strong IID laws for first time offenders, I compare the savings generated from preventing alcohol involved crashes and fatalities to the cost of an interlock program. Since 90% of all costs occur in crashes involving a drunk driver with a BAC of .08 or higher, I focus my cost-benefit analysis to this group alone.

In 2010, the NHTSA estimated that an alcohol involved fatal accident generates economic costs of $1,650,000 in 2010 dollars. This total comes from a variety of potential costs, including medical, insurance, legal, property damage, etc. all of which are magnified when the accident is fatal. Given that the prior estimation results, I can predict that the national adoption of this policy could save up to 1.39 billion dollars in economic costs.[30] Similarly, assuming that a lost life is worth $9,100,000, (U.S. Department of Transportation 2013), then the non-driver lives saved by strong IID laws for first time offenders would be approximately $2.95 billion. .[31]

In comparison, the cost of the ignition interlock program is fractional to the potential savings just discussed. According to IgnitionInterlockDevice.org, the costs associated with the device amounts to $50-200 installation fee and an additional monthly fee of $50-100. Overall, this equates to about $2-4 per day over a year period, or roughly the cost of a drink at a bar. If we aggregate these numbers to include the 280,000 reported in use devices by the NHTSA for 2012, for all convicted drunk driving offenders, the total cost of installment is approximately between $204 million to $409 million a year.[32] This is about 7 to 14 percent of the total potential benefits from the saved lives of non-drivers. More importantly, the offender is responsible for the cost of the device, thus the potential benefits are realized by society but the cost is paid by the offender.

Additionally, according to incapacitation theory, a high level of incapacitation is ideal when the cost to society, of the illegal activity, is large and the cost of incapacitation is small. Thus, the approximated cost and benefit of the first time offender IID program discussed above, suggests that incapacitation of offenders should be the goal of the program.

1.5.4. Robustness Checks

Although the previously estimated models are viewed as reasonable and able to identify the impact of ignition interlock laws for first time offenders, it is important to recognize that there

---

[30] $1.39 bill= (9364*.09)*$1,650,000

[31] $2.95 billion = $9,100,000*324

[32] See (Report No. DOT HS 811 815) for ignition interlock use data.

are alternative ways to ways to measure individual BAC levels and different possible definitions of the dependent variables. In order to verify the results are robust to alternative choices additional estimates, of those alternatives are presented in this section. These robustness results are located in Table 1.6. For comparison, the first panel repeats the Tables 1.3. and 1.4. policy variable results from columns (2) and (3).

The first robustness check uses an alternative measure of individuals BAC level. Results are in Panel A and use mean imputed values of driver BAC to identify the drunkest driver in an accident and to categorize drivers as either drunk, BAC ≥ .08, or positive alcohol, BAC ≥ .01. The change is made in order to see if the earlier choice of using median imputed BAC levels had any impact on the results. The alternative mean BAC measure prove to be nearly identical in both magnitude and significance level compared to the previous median BAC estimates. Results are significant for both drunk and positive alcohol accidents at the 1% level without state-time trends and at the 5 and 10 percent level for drunk drivers and positive alcohol when a state-time trend is added. Additionally, the results using the alternative BAC measure consistently indicate that strong IID laws for first time offenders substantially decrease the number of fatal accidents caused by a drunk driver, by approximately 8%. Again, all results indicate weak IID laws have no significant impact.

Next, I test for robustness of the dependent variable by estimating an alternative dependent variable and two other definitions of the number alcohol-related fatal accidents. The first result in Panel B changes the dependent variable to the log of the number of drivers who were drinking and involved in a fatal accident. It is reasonable to believe that if IID laws for first time offenders reduce the number of fatal accidents involving a drunk driver than it should also reduce the number of drunk or positive alcohol drivers who took part in a fatal accident. The results indicate that states with strong IID laws for first time offenders significantly reduce the number of drunk drivers by 11% and 10%, without and with state-time trends respectively. These results are significant at the 1% and 5% level. However, results for states with weak IID laws indicate that the policy had no significant impact on the number of drunk or positive alcohol drivers involved in a fatal accident. Second, to test the sensitivity of the linear results using log accidents (instead of levels), the number of alcohol-related fatal accidents as the measure for my dependent variable. The results do not change the conclusion that states with strong IID laws significantly reduce the number of fatal accidents involving a drunk driver and the number of fatal accidents involving drivers with positive alcohol levels. Whereas states with weak IID laws for first time offenders do not significantly reduce alcohol-related fatal accidents. I also define the dependent variable as the number of alcohol-related fatal accidents per 100,000 state residents, which is a common form of the dependent variable in previous fatal accident analysis literature. Once again, the results are consistent and highly significant at the 1 and 5 percent level without and with state-time trends.[33]

In addition to the robust results discussed above, I also do some work to refine the control group using propensity score analysis. These results are located in the appendix as Table 1a. After matching treated states with the best available control states, results again indicate that policy enactment for strong states led to a statistically significant reduction in both the number of drunk and positive alcohol fatal accidents. Whereas the weak IID policy has not. A dependent variable of the number of accidents involving a driver that is under 21 was also examined. This result can be seen in the appendix in Table 2a. Again, the result of interlock program was negative and

---

[33] The number of non-alcohol related accidents was used as a falsification exercise. Given that this is not the target group of the interlock program it is reasonable to hypothesis that the dependent variable should yield no significant results. With both mean and median BAC levels used to identify a driver as no alcohol, no significant effects of IID polices on fatal accidents were found. Results can be seen in the appendix.

significant at the 5 percent level, even with including state-time trends. Individuals under 21 are also subject to installation of an IID under their first offense for alcohol involved driving. However, part of the result could be driven by preventing those legal age drinkers who would have chosen to drink and drive at night or on the weekends, from crashing into younger under experienced drivers. For instance, the Insurance Institute of Highway safety found that in 2012, 49% of under 21 accidents occurred at night.

Finally, Table 1.8. reports the results of the first time offender IID polices impact on total fatalities. Overall, the enactment of the strong interlock policy had a negative impact of 5% in reducing total fatal accidents, which is significant at 1 percent level without state-time trends. This result helps confirm the impact of the IID polices is likely the result of a reduction in fatal accidents involving drivers under the influence of alcohol. When trends are added the result falls to a 3% reduction in fatal accidents, and significant at the 10 percent level.

1.5.5. California Case Study

California enacted a pilot program on July 1, 2010 that is set to run through December 31, 2015, which requires first time offenders of drunk driving (i.e. BAC greater or equal to .08) to install an IID in their vehicle. The program is limited to the participation of four counties (Alameda, Los Angeles, Sacramento, and Tulare), but the population totals of these counties account for over one third of the states' entire population or approximately 13 million people. Additionally, any offender who is cited and convicted of a DUI in one of these four counties is required to install and IID regardless of the offenders' legal residence. Given the guidelines of California's ignition interlock pilot program, it provides an excellent case study to examine the effectiveness of strong ignition interlock laws for first time offenders at the county level. These within state estimates have the additional benefit of avoiding potential heterogeneity that cross state estimates can sometimes suffer from. The estimation procedure again follows a fixed effects model with a few subtle modifications, which are described in detail in the methodology section. The results for the case study can be seen in Table 1.7., which includes estimates for accidents involving drunk drivers and accidents involving drivers with positive alcohol levels.

These estimates indicate that strong ignition interlock laws for first time offenders significantly reduce the number of fatal accidents involving a drunk driver, as well as the number of fatal accidents involving drivers with positive alcohol levels. Specifically, the log accident model shows that strong ignition interlock laws for first time offenders reduce the number of fatal accidents involving a drunk driver by about 25% in California. This result is significant at the 5 percent level. With regard to drivers who have positive alcohol levels, the results again indicated that strong ignition interlock laws for first time offenders have a significant impact in reducing the number of fatal accidents. The estimates suggest that the policy reduced the number of fatal accidents involving a driver with positive alcohol levels by 20%. This results is significant at the 5 percent level.

We can again think about these results in terms of an anticipated reduction in the actual number of fatal accidents involving a drunk driver and the anticipated reduction in the number of fatal accidents involving a driver with positive alcohol levels if California would have applied the law to all counties. In 2012, California had 719 fatal accidents involving a driver with a BAC greater or equal to .08, thus the strong IID policy for first time offenders would have the potential to prevent 3 fatal accidents for a typical county in a typical year.[34] Additionally, in 2012 California had 842 fatal accidents involving a driver with positive alcohol levels. Using the estimation results

---

[34] 3.09 = (719*.25) / 58; there are 58 counties in California.

for this group would imply that statewide application of the strong ignition interlock pilot program would have had the potential to prevent 2.90 fatal accidents involving a driver with positive alcohol levels for a typical county in a typical year.[35]

A previous report created by the California Department of Motor Vehicles in 2005 also looked at the effects of ignition interlocks on first time offenders in the state. At the time of the report the policy was not mandatory and only impacted first time offenders who were convicted of drunk driving with a BAC of .2 or greater, thus is was a much weaker policy than the pilot program. Using a Cox model, the report compared a treatment group of offenders who were required to install an IID to a comparison group with similar traits who were not. The study differed from mine in that its particular interest was examining whether there were lasting effects of the IID policy that encouraged behavioral modifications of those convicted of drunk driving and were required to use an IID. There were no differences between the treatment and comparison group subsequent crash rates following IID use (DeYoung et al. 2004).

However, one could argue that this may be a result of the treatment and control groups being an extreme group of drunk drivers that are unlikely to modify their behavior and results may prove significant if the groups included first time offenders with BAC greater or equal to .08. For instance, a study by the Insurance Institute for Highway Safety, examined Washington's first time offender IID policy and found that first time offenders were dramatically affected by the policy change as their two-year recidivism rate fell by 12% (McCartt et al. 2013). On another note, the California DMV recently (2015), published a report on the deterrent effect of the pilot program on drunk driving convictions and found no support of deterrence. The report did not examine the

---

[35] $2.90 = (842*.20)/ 58$

pilot programs impact on accidents but its results that show IID laws do not deter drunk driving appear to be consistent with the ones found in this paper.

It is important to note that the California estimates in this paper suffer from a short post treatment period, which questions whether the estimates size could be due to some unobservable transitory effects. Nevertheless, the California result indicate consistency with the state level results presented earlier. Additionally, whether or not strong IID laws for first time offenders modify the behavior of the offender in the long run, it is evident from my California case study and statewide results that the desired effect of reducing and preventing costly alcohol related accidents is possible when strong IID polices for first time offenders are in place.

1.6. Conclusion

This paper uniquely applies difference in difference fixed effects estimation methods to analyze the effectiveness of ignition interlock programs, at the county- and state-level in preventing fatal alcohol involved crashes. Results indicate that the potential for interlock programs to prevent alcohol involved driving and alcohol-related crashes is most significant when the program is applied to a broader cross-section of offenders and a higher proportion of offenders have the interlock device installed. Thus, states and counties that adopt strong IID programs, which require mandatory participation by first time offenders convicted of driving under the influence with a BAC of .08 or higher, see a significant and sizeable decrease in the number of costly fatal accidents involving a drunk driver or a driver with positive alcohol levels. Furthermore, these estimates are consistent across county- and state-level models, robust to an alternative measures of individual BAC, and to several alternative definitions of the dependent variable. Relatedly, results indicate that incapacitation of offenders is driving the estimated effect and individuals are not deterred by the laws alone. However, given the relatively low cost of program implementation and high estimated benefits, theory suggests incapacitation should be the goal of the program.

With current and future legislation activity yet to be determined on the inclusion of first time offenders and level of participation by BAC, this paper provides evidence that allows states to maximize public safety. The interlock program should be applied to first time offenders who are not just high-BAC offenders. Additionally, the interlock program provides a low cost solution, paid for by offenders, to a dangerous and often fatal activity that imposes large social and economic costs on society. To maximize public health, states with weak IID laws or states that currently have no interlock program which require mandatory participation for first time offenders, should adopt strong IID programs to prevent future costly alcohol-related fatal crashes.

References

Adams, S., & Cotti, C. (2008). Drunk driving after the passage of smoking bans in bars. *Journal of Public Economics*, *92*(5), 1288-1305.

Abouk, R., & Adams, S. (2013). Texting band and fatal accidents on roadways: Do they work? Or do driver just react to announcement of bans? *American Economic Journal: Applied Economics,* 5(2), 179-199.

Allison, P.D., & Waterman, R.P., (2002). Fixed-effects negative binomial regression models. *Sociological Methodology,* 32, 247-265.

Arellano, M. (1987). PRACTITIONERS'CORNER: Computing Robust Standard Errors for Within-groups Estimators*. *Oxford bulletin of Economics and Statistics*, *49*(4), 431-434.

Beck, KH, et al. Effects of Ignition Interlock License Restrictions on Drivers with Multiple Alcohol Offenses: A Randomized Trial in Maryland. *American Journal of Public Health*, 89 vol. 11 (1999): 1696-1700

Becker, Gary. (1968). Crime and Punishment: An Economic Approach. 76 *Journal of Political Economy.* 169-217.

Benson, B. L., Rasmussen, D. W., & Mast, B. D. (1999). Deterring drunk driving fatalities: An economics of crime perspective. *International Review of Law and Economics*, *19*(2), 205-225.

Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2014, May). The economic and societal impact of motor vehicle crashes, 2010. (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration.

Chapman E. A., Oulad Daoud S., Masten S. V. (2015). General Deterrent Evaluation of the Ignition Interlock Pilot Program in California. (Report no. CAL-DMV-RSS-14-247). Sacramento: California Department of Motor Vehicls.

Cotti, C. D., & Tefft, N. (2011). Decomposing the Relationship between Macroeconomic Conditions and Fatal Car Crashes during the Great Recession: The Role of Alcohol Consumption. *Available at SSRN 1736703.*

Cummings, P., Rivara, F.P., Olson, C.M., Smith, K.M., (2006). Changes in traffic crash mortality rates attributed to use of alcohol, or lack of a seatbelt, air bag, motorcycle helmet, or bicycle helmet, United States, 1982–2001. *Injury Prevention* 12, 148–154.

Elder, R. W., Voas, R., Beirness, D., Shults, R. A., Sleet, D. A., Nichols, J. L., & Compton, R. (2011). Effectiveness of ignition interlocks for preventing alcohol-impaired driving and alcohol-related crashes: a Community Guide systematic review. *American Journal of Preventive Medicine*, *40*(3), 362-376.

Esienberg, D. (2003). Evaluating effectiveness of policies on drunk driving. *Journal of Policy Analysis and Management,* 22(3), 249-274.

Dee, Thomas S. (1999). State alcohol policies, teen drinking and traffic fatalities. *Journal of public Economics,* 72.2, 289-315.

Dee, T.S. (2001). Does setting limits save lives? The case of 0.08 BAC laws. *Journal of Policy Analysis and Management*, 20(1), 113-130.

DeYoung D.J., Tashima H.N., Masten A.S. (2004). An evaluation of the effectiveness of ignition interlock in California: report to the legislature of the State of California. (CAL-DMV-RSS-04-210/AL0357). Sacramento CA: California Department of Motor Vehicles.

Dills. A.K., (2010). Social host liability for minors and underage drunk-driving accidents. *Journal of Health Economics,* 29(1), 241-249.

Freeman, D.G. (2007) Drunk driving legislation and traffic fatalities: new evidence on BAC .08 laws. *Contemporary Economic Policy*, 25(3), 293-2308.

Grant, D. (2010) Policy analysis and policy adoption: A study of three national drunk driving initiatives. *Manuscript, Sam Houston State University*.

Ignition Interlock Device. (2010). Accessed September 15, 2014. (http://ignitioninterlockdevice.org/index.html)

Insurance Institute for Highway Safety (IIHS). Fatality facts: teenagers 2012. Arlington (VA): The Institute; (2012). http://www.iihs.org/iihs/topics/t/teenagers/fatalityfacts/teenagers

Lahausse, J. A., & Fildes, B. N. (2009). Cost-benefit analysis of an alcohol ignition interlock for installation in all newly registered vehicles. *Traffic injury prevention*, *10*(6), 528-537.

Mayer, R. (2014, February). *Ignition interlocks – A toolkit for program administrators, policymakers, and stakeholders. 2nd Edition.* (Report No. DOT HS 811 883). Washington, DC: National Highway Traffic Safety Administration.

McCartt, A. T., Leaf, W. A., Farmer, C. M., & Eichelberger, A. H.. (2012). Washington State's Alcohol Ignition Interlock Law: Effects on Recidivism Among First-Time DUI Offenders. Arlington, VA: Insurance Institute for Highway Safety.

Miceli, T. J. (2010). A model of criminal sanctions that incorporate both deterrence and incapacitation. *Economics Letters*, *107*(2), 205-207.

Miceli, T. J. (2012). Deterred or Detained? A Unified Model of Criminal Punishment. *Review of Law & Economics*, *8*(1), 1-20.

Mothers Against Drunk Driving. (2013, July). Ignition interlock institutes: Promoting the use of interlocks and improvements to interlock programs. (Report No. DOT HS 811 815). Washington, DC: National Highway Traffic Safety Administration.

Mothers Against Drunk Driving (MADD). (2014). Status of State Ignition Interlock Laws. (http://www.madd.org/drunk-driving/ignition-interlocks/status-of-state-ignition.html)

Peck, R.C., Wilson, R. J., and Sutton, L. (1995). Driver license strategies for controlling the persistent DUI offender, Strategies for Dealing with the intent Drinking Driver. Transportation Research Board, Transportation Research Circular No. 437. Washington, D.C. National Research Council: 48-49

Polinsky, A. M., & Shavell, S. (2007). The theory of public enforcement of law. *Handbook of law and economics*, *1*, 403-454.

Rivkin R., Trottenberg P. (2013, February). Guidance on treatment of the economic value of statistical life (VSL) in U.S. Department of Transportation Analysis. Washington DC: United States Department of Transportation.

Romano, E., Kelley-Baker, T., & Voas, R. B. (2008). Female involvement in fatal crashes: Increasingly riskier or increasingly exposed? *Accident Analysis & Prevention*, *40*(5), 1781-1788.

Rubin, D.B., Shafer, J.L., Subramanian, R., (1998). Multiple Imputation of Missing Blood Alcohol Concentration (BAC) Values in FARS. (Report No. DOT HS 808816). National Highway Traffic Safety Administration, Department of Transportation.

Shavell, S. (1987). A model of optimal incapacitation. *The American Economic Review*, 107-110.

Subramania, R. (2002). Transitioning to multiple imputation – a new method to estimate missing blood alcohol concentration *(BAC) in FARS.* (Report No. DOT HS 809 403) National Highway Traffic Safety Administration, Department of Transportation.

U.S. Department of Transportation. The economic and societal impact of motor vehicle crashes, 2010. 2014. (Report No. DOT HS 812 013). National Highway and Traffic Safety Administration

U.S. Department of Transportation. Traffic Safety Facts 2012: Alcohol Impaired Driving. December, 2013. (Report No. DOT HS 811 870). National Highway and Traffic Safety Administration.

U.S. Department of Transportation. 2013. Traffic Safety Facts 2012: A compilation of motor vehicle crash data from the FARS and the GES. (Report No. DOT HS 812 032). National Highway and Traffic Safety Administration. (www-nrd.nhtsa.dot.gov/CATS/index.aspx.)

U.S. Department of Transportation. 2013. Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses. (http://www.dot.gov/sites/dot.dev/files/docs/VSL%20Guidance%202013.pdf)

U.S. Department of Transportation. 2013. Ignition Interlock Institutes: Promoting the Use of Interlocks and Improvements to Interlock Programs. (Report No. DOT HS 811 815). National Highway and Traffic Safety Administration.

Williams, A. F., Tefft, B. C., & Grabowski, J. G. (2012). Graduated driver licensing research, 2010-present. *Journal of Safety Research*, *43*(3), 195-203.

Willis, C., Lybrand, S., & Bellamy, N. (2004). Alcohol ignition interlock Programs for reducing drink driving recidivism. *Cochrane Database Syst Rev*, *4*.

Table 1.1. States with First Time Offender Ignition Interlock Laws and Effective Dates

State	Effective Date	Enforcement
Alaska	January-2009	Strong
Arizona	September-2007	Strong
Arkansas	April-2009	Strong
California*	July-2010	Strong
Colorado	January-2009	Strong
Connecticut	January-2012	Strong
Florida	October-2010	Weak
Hawaii	January-2011	Strong
Illinois	January-2009	Strong
Iowa	July-1995	Weak
Kansas	July-2011	Strong
Louisiana	July-2007	Strong
Maryland	October-2011	Weak
Michigan	October-2010	Weak
Minnesota	July-2011	Weak
Nebraska	January-2009	Strong
Nevada	July-2005	Weak
New Jersey	January-2010	Weak
New Mexico	June-2005	Strong
New York	August-2010	Strong
North Carolina	December-2007	Weak
Oklahoma	November-2011	Weak
Oregon	January-2008	Strong
Texas	September-2005	Weak
Utah	July-2009	Strong
Virginia	July-2012	Strong
Washington	January-2009	Strong
West Virginia	July-2008	Strong
Wisconsin	July-2010	Weak
Wyoming	July-2009	Weak

Notes: States Alabama, Delaware, Maine, Mississippi, Missouri, New Hampshire, and Tennessee enacted Strong ignition interlock laws after 2012. States Rhode Island and Sound Carolina enacted Weak ignition interlock laws after 2012. *Pilot Program: Los Angeles, Alameda, Sacramento, and Tulare (Counties)

Table 1.2. Summary Statistics (means)

	Pre-Treat (Strong)	Post-Treat (Strong)	Pre-Treat (Weak)	Post-Treat (Weak)	Control
Number of Fatal Accidents BAC ≥ .08	16.72	12.09	22.49	29.45	15.75
Number of Fatal Accidents BAC ≥.01	20.39	14.64	27.29	35.97	18.99
Population	7,025,690	5,983,977	7,477,607	10,533,561	5,519,973
Beer Tax (2012 Cents)	.35	.33	.24	.28	.30
Real Gas Tax	.001	.001	.001	.001	.001
Unemployment Rate (monthly)	5.36	7.62	5.39	8.14	5.65
Percent Male	.495	.496	.495	.497	.492
Real Inc. Per. Cap.	41,978	40,337	42,652	42,048	41,166
Median age	35.8	36.4	36.9	36.9	36.9
Percent White	.786	.802	.806	.797	.809
Percent Black	.088	.081	.124	.123	.116
Percent Asian	.063	.046	.032	.041	.034
Other	.063	.071	.038	.039	.041

Note: Accident means are reported using median BAC counts. All estimates are weighted by state-year population.

Table 1.3. Results for Drunk Drivers Median BAC

	(1)	*(2)*	*(3)*
Strong	-.084**	-.104***	-.090**
	(.0363)	(.0258)	(.0399)
Weak	.019	.033	.040
	(.0404)	(.0328)	(.0376)
Population		.742**	3.910***
		(.2842)	(1.034)
Unemployment		-.078	-.061
		(.0540)	(.0686)
Real Gas Tax		.019	-.004
		(.0187)	(.0247)
Percent Male		.045	.106***
		(.0296)	(.0315)
Real Income Per. Cap.		1.030***	.873***
		(.2677)	(.3631)
Median Age		.374	.313
		(.7414)	(1.099)
Percent Black		-.025	-.217***
		(.0283)	(.0730)
Percent Asian		-.011	-.001
		(.0186)	(.2191)
Percent Other		.085**	-.003
		(.0360)	(.2307)
Beer Tax		-.002	-.055
		(.0248)	(.0337)
Other DD Policies	No	Yes	Yes
State, Time F.E.	Yes	Yes	Yes
State-Time Trend	Yes	No	Yes
Observations	7056	7056	7056

Notes: Reported results are from weighted least squares regressions, weighted by state-level population for 49 states over 144 months. The dependent variable is the natural log of fatal accidents + 1 involving a drunk driver, i.e. BAC≥ .08. Standard errors are in parentheses and are clustered to allow for nonindependence of observations from the same state.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 1.4. Results for Positive Alcohol Drivers Median BAC

	(1)	*(2)*	*(3)*
Strong	-.060*	-087***	-.068**
	(.0320)	(.0252)	(.0333)
Weak	.0167	.036	.039
	(.0380)	(.0321)	(.0360)
Population		.848***	4.115***
		(.2750)	(.9859)
Unemployment		-.067	-.065
		(.0490)	(.0628)
Real Gas Tax		.022	.004
		(.0235)	(.0256)
Percent Male		.421	.101***
		(.0284)	(.0282)
Real Income Per. Cap.		1.210***	.776**
		(.2947)	(.3506)
Median Age		.495	.075
		(.7741)	(1.034)
Percent Black		-.040	-.210***
		(.0282)	(.0665)
Percent Asian		-.010	-.010
		(.0232)	(.2357)
Percent Other		.045	-.033
		(.0434)	(.1823)
Beer Tax		-.017	-.069
		(.0278)	(.0442)
Other DD Policies	No	Yes	Yes
State, Time F.E.	Yes	Yes	Yes
State-Time Trend	Yes	No	Yes
Observations	7056	7056	7056

Notes: Reported results are from weighted least squares regressions, weighted by state-level population for 49 states over 144 months. The dependent variable is the natural log of fatal accidents + 1 involving a driver with positive alcohol levels, i.e. BAC$\geq$ .01. Standard errors are in parentheses and are clustered to allow for nonindependence of observations from the same state.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

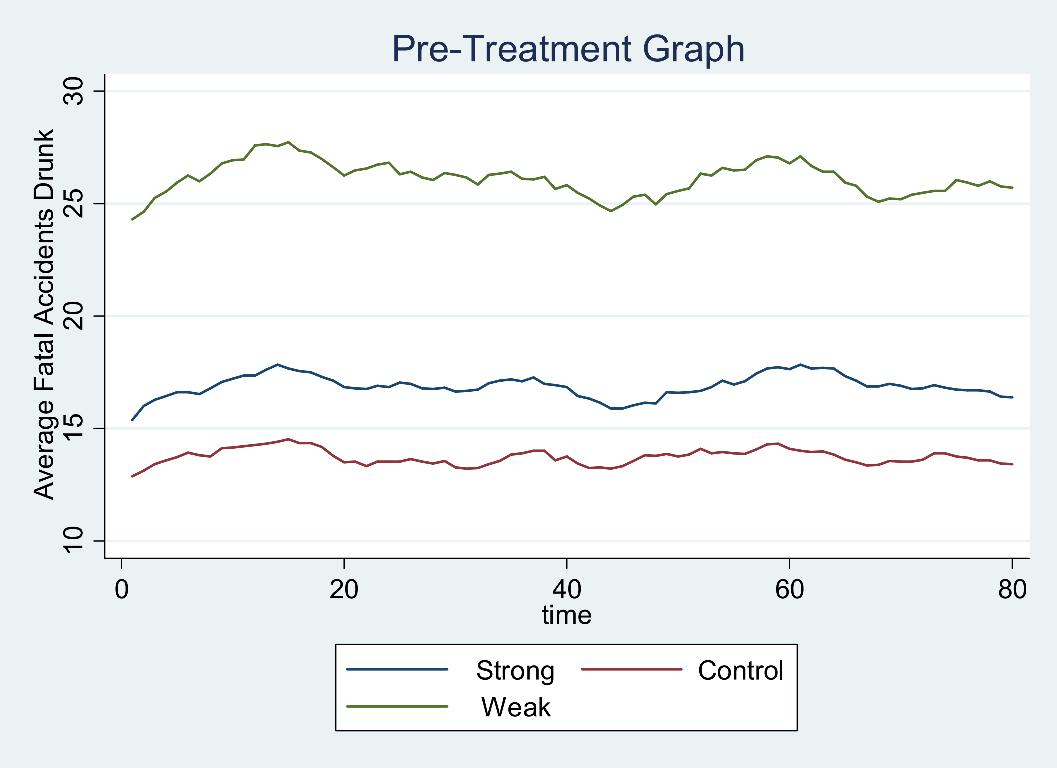
Table 1.5. Timing of Effects (Median BAC)

	(1) Drunk Drivers BAC ≥.08		*(2)* Positive Alcohol BAC ≥.01	
	Strong	***Weak***	***Strong***	***Weak***
3 Months	-.015	-.022	.007	-.007
Before	(.0513)	(.0908)	(.0384)	(.0843)
6 Months	-.001	.005	-.015	-.012
Before	(.0590)	(.0838)	(.0428)	(.0766)
9 Months	.055	.048	.053	.010
Before	(.0582)	(.0581)	(.0401)	(.0505)
0-3 Months	-.062	.063	-.056	.086
After	(.0425)	(.0533)	(.0432)	(.0640)
3-9 Months	-.050	-033	-.030	-.032
After	(.0497)	(.0378)	(.0472)	(.0332)
9-15 Months	-.078*	.035	-.072*	.037
After	(.0426)	(.0564)	(.0415)	(.0504)
15 + Months	-.084**	.021	-.070**	.019
After	(.0351)	(.0308)	(.0347)	(.0299)
Other DD Policies	Yes		Yes	
Full Set of Controls	Yes		Yes	
State, Time F.E.	Yes		Yes	
State-Time Trend	Yes		Yes	
p-value: joint test leads *(strong)*	.71		.60	
p-value: joint test leads *(weak)*	.81		.98	

Notes: (1) and (2) represent a separate weighted least squares regressions. The dependent variable is the number of fatal accidents involving a drunk driver +1, i.e. BAC≥ .08 and the number of fatal accidents involving a driver with positive alcohol +1, i.e. BAC≥ .01. Standard errors are in parentheses and are clustered to allow for nonindependence of observations from the same state.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Figure 1.1. Pre-Treatment Graph



Notes: The graph is a moving average of the number of fatal drunk driving accidents in a month, where time period 80 corresponds to July, 2007. The graphs shows that the pre-treatment trends for all groups are nearly identical. New Mexico and Nevada are not included in the averages because they become treated in 2005. However, I chose the following because the pre-treatment window falls right in the middle of my data (2001-2012) and most states, besides NM an NV, do not begin to treat until after July, 2007. The shorter window with NM and NV included, also exhibits the same pre-treatment trend between all of the groups.

Table 1.6. Additional Estimates with Robustness Checks

	Drunk Driver BAC ≥ .08		Positive Alcohol Driver BAC ≥ .01	
Strong	-.104***	-.090**	-087***	-.068**
	(.0258)	(.0399)	(.0252)	(.0333)
Weak	.033	.040	.036	.039
	(.0328)	(.0376)	(.0321)	(.0360)
Panel A. Alternative BAC Measure:				
Mean				
Strong	-.094***	-.066**	-.079***	-.048*
	(.0278)	(.0332)	(.0300)	(.0280)
Weak	.039	.034	.021	.041
	(.0331)	(.0332)	(.0294)	(.0260)
***Panel B. Alternative Dependent. Variables**:*				
Log Number of Drinking Drivers Involved in Fatal Accident, (median BAC)				
Strong	-.110***	-.098**	-.094***	-.079**
	(.0264)	(.0411)	(.0263)	(.0350)
Weak	.034	.034	.036	.034
	(.0352)	(.0412)	(.0341)	(.0387)
Number of Fatal accidents i.e., levels not logs, (median BAC)				
Strong	-2.590**	-2.951**	-2.262*	-2.653*
	(1.068)	(1.440)	(1.214)	(1.520)
Weak	1.401	-.619	2.582	-.317
	(1.318)	(1.244)	(1.601)	(1.294)
Log Alcohol-related Accident Rate per 100,000 people, (median BAC)				
Strong	-.115***	-.098**	-.094***	-.077**
	(.0279)	(.0421)	(.0261)	(.0338)
Weak	.031	.039	.041	.043
	(.0318)	(.0381)	(.0333)	(.0392)
Other DD Policies	Yes	Yes	Yes	Yes
Full Set of Controls	Yes	Yes	Yes	Yes
State, Time F.E.	Yes	Yes	Yes	Yes
State-Time Trend	No	Yes	No	Yes

Notes: Standard errors are in parentheses and are clustered to allow for nonindependence of observations from the same state.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 1.7. Results for California Case Study, Accidents involving a Drunk Drivers and Positive Alcohol Drivers

	Log Accidents	
	BAC ≥ .08	BAC ≥ .01
Strong	-.257**	-.204**
	(.1039)	(.1016)
Population	10.946	7.555
	(8.888)	(9.507)
Unemployment	.246	.2503
	(.4649)	(.3918)
Percent Black	.855	.709
	(.6049)	(.6126)
Percent Asian	.065	.361
	(.6113)	(.5994)
Percent Other	-.218	-.075
	(.3002)	(.2590)
Percent Male	.184	.201
	(.1856)	(.1698)
County- time F.E.	Yes	Yes
County-Time Trend	Yes	Yes
Observations	348	348

Notes: Reported results are from regression for 58 total counties over 6 years. The dependent variable(s) are the number of fatal accidents involving a drunk driver, i.e. BAC≥ .08 and the number of fatal accidents involving a driver with positive alcohol levels, i.e. BAC≥ .01. Standard errors are in parentheses and are clustered to allow for nonindependence of observations from the same county.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 1.8. Total Traffic Fatalities and Ignition Inter-lock Laws

	(1)	*(2)*	*(3)*
Strong	-.056**	-.057***	-.032*
	(.0231)	(.0153)	(.0184)
Weak	.015	.006	.017
	(.0139)	(.0215)	(.0243)
Other DD Polices	No	Yes	Yes
State-, Time- F.E.	Yes	Yes	Yes
Controls	No	Yes	Yes
State-Time Trend	No	No	Yes
Observations	7056	7056	7056

Notes: Dependent variable is equal to the number of total fatalities. Standard errors, corrected for correlation by means of clustering at the state level, are in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Figure 1.2. Estimated Installed Interlocks and Alcohol-Impaired Driving Fatalities

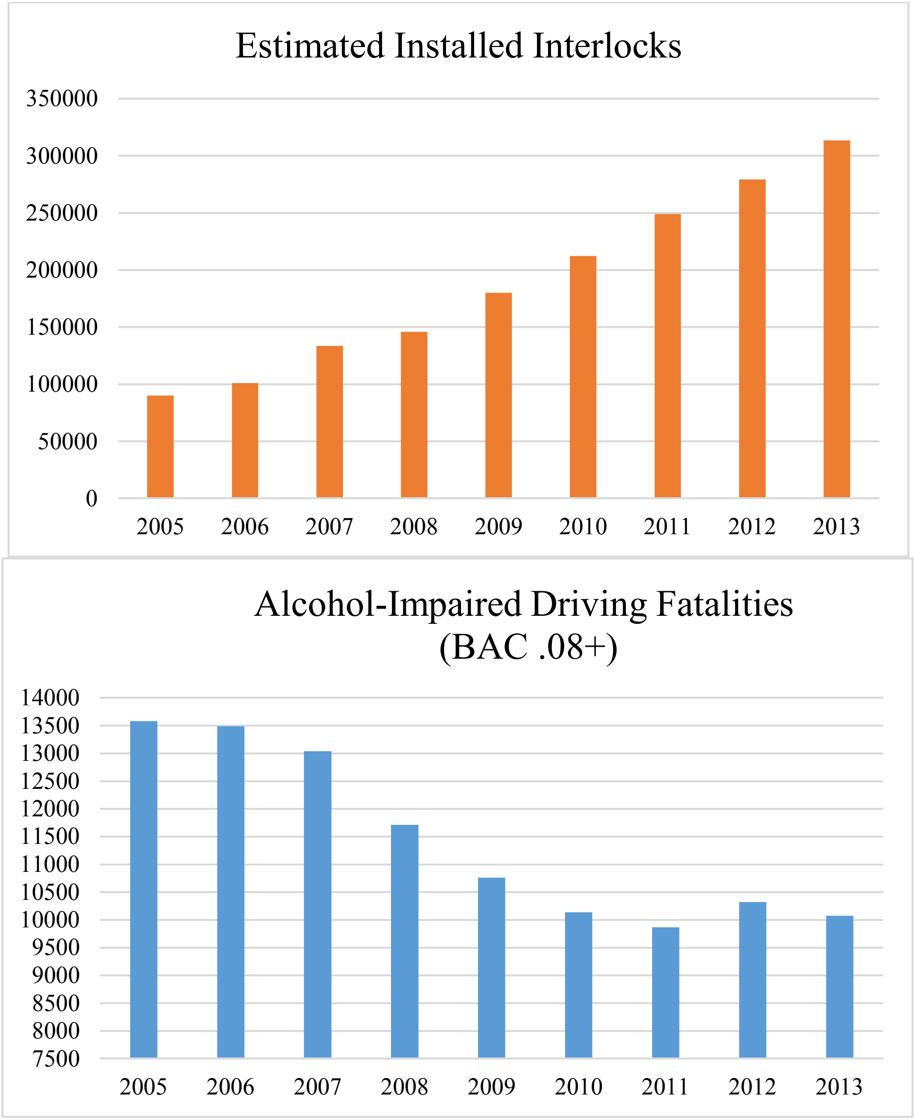


Figure 1.3. Normalized Estimated Interlocks and Traffice Fatalities

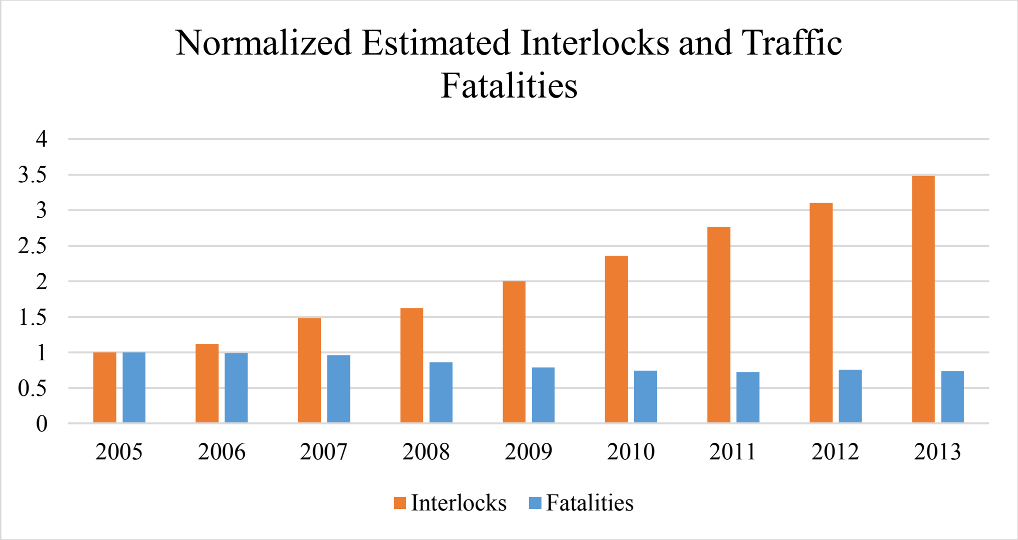
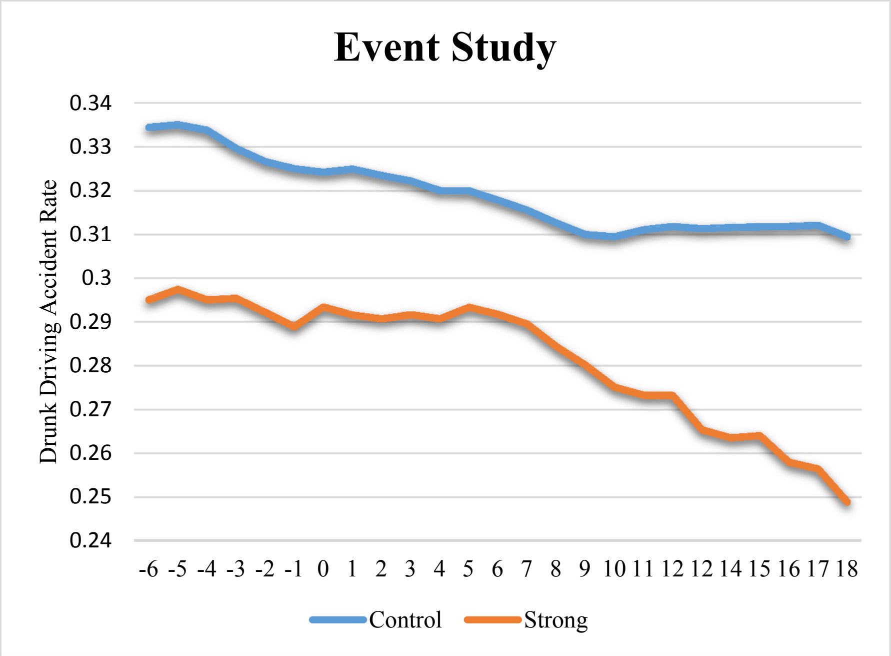


Figure 1.4. Event Study



2 A Difficult Road Ahead: Fleet Fuel Economy, Footprint Based CAFE Compliance, and Manufacturer Incentives

2.1. Introduction

The future of the vehicle fleet and its characteristics is in flux. Recent federal guidelines, finalized by the Obama Administration and U.S. automakers, have been issued by the Department of Transportation (DOT) and Environmental Protection Agency (EPA), to raise Corporate Average Fuel Economy standards, (CAFE), from the 35.5 mpg for 2016 model year vehicles, to 54.5 mpg for 2025 model year vehicles. The increase has many wondering how vehicle manufacturers will comply with the new standards and the impact it may have on vehicle characteristics.

CAFE standards, enacted in 1975 as a part of the Energy Policy and Conservation Act, have been used to encourage progress in fleet vehicle fuel economy, but the recent mandate is the largest change in the standards' relatively short history. Estimates by the EPA, predict that the new standards will reduce oil consumption in the United States by 4 billion barrels and reduce greenhouse gases (GHG) by 2 billion metric tons over the lifetime of vehicles sold in model years 2017-2025 (EPA 2012). Additional benefits of fuel standards include consumer savings from reduced fuel expenditures and the creation of an estimated 570,000 new jobs throughout the U.S. economy (The Blue Green Alliance 2012). However, all of these expected estimated benefits would be overstated if manufacturers were to comply with standards through an alternative plan, such as increasing vehicle sizes. Such a plan was not originally conceived, by policy makers, as a possible compliance strategy for automakers, however it has the potential to undermine the benefits and goals of the new footprint based CAFE program.

Since the first fuel economy target of 18 mpg for passenger cars by 1978, the fleet of vehicles in the United States has been ever evolving in power, size, and weight. A rich and diverse collection of research has been dedicated to CAFE standards and changing fleet characteristics, including their impact on safety (Anderson and Auffhammer 2011; Jacobsen 2011, 2012), energy policy (Greene 1998), technology (Knittel 2011), and sales (Thorpe 1997; Klier and Linn 2010), as well as whether CAFE polices are effective (Clerides and Zachariadis 2006).

For this paper, two prior publications are most relevant for discussion. Knittel (2011) serves as the starting point for this paper's approach. He uses model-level data for vehicles in the U.S. from 1980 to 2006 to determine compliance strategies for both Bush Administration model year 2020 CAFE standards and the more rigid Obama Administration 2016 model year CAFE standards. Congruent with results found in this paper, his results suggest that above average technological advances are needed for standard compliance. Additionally, for manufacturers to reach fuel economy levels near or above 50 mpg, for passenger cars and light trucks, vehicle characteristics would have to be unrealistically downsized to the vehicle power and curb weight characteristics observed in 1980. The mix of vehicles in the fleet would also have to be primarily passenger cars. Unlike Knittel, I estimate results by vehicle classes, as well as passenger cars and light-duty trucks, which provides a more comprehensive story for compliance strategies to the new footprint based standards.

Incorporating how vehicle footprint calculations might impact manufacturer compliance strategies brings us to the second relevant publication of discussion. Whitefoot and Skerlos (2012) look at whether manufacturers have any design incentive to increase the footprint of their vehicles in production as opposed to changing vehicle characteristics and performance that may be more in-line with consumer preferences. Using an oligopolistic-equilibrium model, they simulate the change in the sales-weighted average of overall vehicle size with varying consumer preferences to vehicle fuel economy, performance, and technology features. The results from simulations with different levels of price-elasticity of demand, suggest that manufacturers have an incentive to increase vehicle size in all simulations except when consumer preference for vehicle size are at its lowest bound. The authors conclude that the hypothesis that footprint-based CAFE standards do not create incentives for manufacturers to increase vehicle size is rejected across a wide-range of consumer preferences. In light of the results by Whitefoot and Skerlos (2012), I revisit the model developed by Knittel to see whether manufacturers have an incentive to increase vehicle size to lower the burden of compliance.

Specifically, I test how changes in vehicle weight, power, other vehicle specifications, and annual technological progress impact fuel economy. This study illustrates the difficulties manufacturers will face if compliance is only obtainable through these identifiable vehicle characteristics. In comparison to Knittel, I use more recent data and extend the analysis beyond just passenger cars and light-duty trucks. This is an important consideration because the new standards are footprint based, where smaller vehicles have relatively more stringent standards, and larger vehicles have less stringent standards. Specifically, footprint calculations measure the relative size of a vehicle and are derived by averaging the front and rear track width and multiplying by the wheelbase of the vehicle.[36] To incorporate footprint calculations, I stratify estimates by vehicle class using vehicle classifications set by the National Highway Traffic Safety Administration (NHTSA) and use average class footprints to determine designated compliance levels.[37]

Over the 13 year span of data (2001 to 2013), I find that vehicle weight and technological progress are major factors in determining fuel economy among all vehicle classes. Specifically, a

---

[36] Footprint calculations: $ftpt_{it} = (((ftrk_{it} + rtrk_{it})/2)*whbs_{it})/144)$, which yields square feet

[37] Table 2.1. provides a description of the ten vehicle classes. Full-size trucks do not include 2500 or 3500 models. See http://www-nrd.nhtsa.dot.gov/Pubs/809979.pdf.

reduction in weight is most impactful in sub-compact and minivan classes, with a 10 percent reduction in weight within these classes associated with a 7 percent increase in fuel economy.[38] Remaining gains in fuel efficiency are the result of residual technological progress that comes about apart from the most identifiable vehicle characteristics. My model identifies this residual technological growth at 1.9 and 1.4 percent for passenger cars and light-duty trucks per year, whereas average class results range from .5 to 2.1 percent.

The results suggest that manufacturers will face difficulties in complying with standards if advances in technology continue at an average level and the only other compliance measures are attempted through changing basic vehicle characteristics such as weight and power. Significant additional technological progress beyond current rates of progress are needed for each class of vehicles to reach compliance. Only two classes of vehicles (minivans and compact SUV) are able to comply with the 2025 standards without experiencing the maximum estimated technological growth.[39]

Despite the NHTSA belief, that the new footprint based standards are designed in such a way that the standards do not encourage manufactures to increase vehicle footprints (NHTSA 2009), my estimates suggest manufactures have an incentive to increase vehicle footprints in order to fall to a more conservative fuel economy level that is achievable with smaller changes to vehicle weight, power, and is less dependent on technological advances. This incentive undermines the standards potential to reduced oil consumption and reduced emission levels that would come from the fuel efficient vehicles the program is designed to create.

---

[38] A 10 percent reduction in weight increases fuel economy for passenger cars and light-duty trucks by 3 percent. These results are slightly less than those found by Knittel (2011) of approx. 4 percent for vehicle data 1980 to 2006, and may suggest manufacturers are finding less need to reduce weight in order to improve fuel economy

[39] Maximum estimated technological progress is obtained from the difference between years of technological progress estimates. By ordering these technology growths from smallest to largest I am also able to select the 75th percentile.

Alternatively, manufacturers may also have the incentive to take advantage of the CAFE programs built in flexibilities which introduce credits and compliance multipliers that lower the burden of compliance. For this paper, I do not model CAFE program flexibilities but incorporate them into discussion as relevant manufacturer alternatives for potential compliance.

The remainder of the paper is organized as follows. Section 2 describes the data and methodology used for estimation. Section 3 explores the empirical results at the passenger car and light-duty truck level, class-level, and results for compliance strategies incorporating footprint measures. Section 4 concludes the paper.

2.2. Data and Methodology

2.2.1. Data Source

Data for all new vehicles sold in the United States from 2001 to 2013 are obtained from Edmunds. A rich set of specifications is described within the data including curb weight, transmission-type, aspiration method, engine specifications, and size measurements. Vehicle dimensions are used to compute each vehicles footprint for post estimation compliance strategies. The smallest average footprint, for model year 2013 vehicles, belongs to class 1, sub-compact passenger cars, at 40.2 square feet and the largest belongs to class 10, full-size trucks, at 66.4 square feet.

Several specifications are not used in estimation but are used to provide useful graphical analysis with regard to vehicle trends. For example, Figure 2.1. provides graphical evidence of the share of vehicles using available fuel saving technologies. The figure shows some of the technologies that are captured by the residual technological progress estimates and the increased use of these technologies by manufacturers. In particular, the figure shows a decline in four or five speed transmissions and an increase in advanced transmissions technologies such as six speeds or more as well as, continuously variable transmissions. Tests on the impact the number of transmission speeds has on fuel economy, by the EPA, have shown that an additional gear can improve fuel efficiency by as much as two percent, compared to four speed transmissions.[40] Additionally, the figure shows the existence and increased penetration of other new technologies such as stop-start systems which automatically turn off the vehicle's engine when the vehicle is idling. Overall, the figure provides information on how the newer vehicles in this study differ from those in Knittel (2011) and also provides evidence for the persistent technological progress estimates found in both studies.

Table 2.2. provides the summary statistics of the data used in analysis. Specifically, the minimum horsepower for any vehicle is 70 and the maximum is 570.[41] The min and max of fuel economy, for all passenger vehicles used in estimation, is 10.7 and 53.4 mpg, which is in terms of window sticker mpg. For light-duty trucks, it is 9.35 and 32.65 mpg.[42] A total of 21,379 observations are used to estimate the models and observations with missing values are not included in the estimations.

2.2.2. Methodology

As described by Knittel (2011), the goal of this empirical work is to estimate the technical relationship between vehicle weight, engine power and fuel economy. The production possibilities frontier (PPF) illustrates the trade-off between these characteristics. Relative to the base year of 2001, shifts in the PPF represent advances in vehicle technology. These advances have many

---

[40] See https://www.fueleconomy.gov/feg/tech_transmission.shtml for more details on advanced transmission technologies.

[41] To eliminate extreme values of horsepower and fuel economy, I created a class 11, or 2-door sport, but I do not estimate this class. Similarly, no electric vehicle observations are included in the estimation models.

[42] CAFE compliance is not determined by window sticker fuel economy but by the unadjusted fuel economy level. I convert average window sticker fuel economy levels, to the approximate CAFE equivalent value during the compliance strategy section, the conversion process is briefly explained in this section as well.

forms from engine, transmission, aerodynamic, etc. improvements to the vehicle. Technology expenditures are omitted from regressions but any potential bias is assumed to small. I use the estimates to analyze how future vehicles with look if I reduce vehicle attributes and assume various rates of technological progress. This follows the work of Knittel (2011).[43]

Overall, I can use estimates to focus on a direct approach to compliance, where I assume compliance would require manufacturers to improve average class fuel economy to the designated compliance levels determined by the average class footprint. I consider the physical and structural options that manufactures have the ability to change, within reason, to increase fuel economy. For instance, as pointed out by Cheah et. al (2009) vehicle weight, size, and power are major factors in determining vehicle fuel economy and they believe a relative downsizing may be necessary to achieve a fuel use reduction. Combining the impact of the vehicle's curb weight and power with fuel efficiency improvements attributed to technological progress, I model the changes necessary to reach standards set for model year 2025 vehicles. Following Cobb-Douglass assumptions the analysis takes the subsequent functional form and is described below.[44]

Using a basic linear regression model, I estimate:

$$\textbf{(1)}\ ln(mpg_{it}) = \beta_0 + \beta_1 ln(curbwt_{it}) + \beta_2 ln(hp_{it}) + \beta_3 ln(tor_{it}) + \tau_t + \mu_i + \beta j`Xit + \varepsilon_{it}$$

The dependent variable is the natural log of average window sticker fuel economy, where subscripts describe individual vehicles in each class for a given year.[45] Vehicle curb weight (*curbwt)* is the vehicle's standing weight in complete operating condition including fluids.

---

[43] For detailed descriptions of the identification strategy please see Knittel (2011).

[44] Translog functional form estimates are included in the appendix.

[45] Average fuel economy (mpg) is calculated through a weighted average of city and highway vehicle and year specific fuel economy i.e.: $mpg_{it} = .55\ (Citympg_{it}) + .45\ (Hwympg_{it})$

Horsepower and torque are (*hp*) and (*tor*), respectively. Multiple measures of vehicle power are included in the regression because horsepower and torque are highly correlated and interpreting the impact on fuel economy in only one of these variables is challenging.[46] (X_{it}) includes, transmission type, and engine type. μ_i represents manufacturer fixed effects.[47] The error term is assumed to be uncorrelated with controls and mean-zero.

Year fixed effects (τ_t) are assumed to capture residual technological progress in improved fuel efficiency for that year. I am not interested in the impact of specific technologies.[48] Instead, the fixed effects allow for estimates of overall technological growth among the fleet and vehicle classes, holding measurable vehicle characteristics constant.[49]

I estimate various versions of equation (1), each including various combinations of determinants of fuel economy. The results obtained from the model later described as Model 3 is used to infer compliance strategies and to project fuel economy levels for model year 2025 vehicles. This model allows for the most flexibility in estimating technological progress by limiting X to include only controls for manual, diesel, and manufacturer fixed effects. The impact of any of the other specific technologies, which are controlled for in other versions, are assumed to be absorbed by the year fixed effects.

I use the coefficient results from this model, along with the baseline average class fuel economy for model year 2013, to project fuel economy improvement over various scenarios for

---

[46] For passenger cars pairwise correlations for horsepower and torque is 0.95 and for light-duty trucks it is 0.91.

[47] I do not make special considerations for vehicle manufacturers that merge companies. All manufacturers are considered separate across the sample period.

[48] For example, one might be interested in the impact of variable valve timing (VVT), a technology that determines the optimal rate of air flow for the vehicle depending on the engine speed and power needed. The EPA estimates that VVT has the potential to improve efficiency by 5 percent. Another is cylinder deactivation, which is a technology that shuts down cylinders once the vehicles has reached a cruising speed and less power is needed to maintain the vehicles rate of motion.

[49] I do allow of some model variations to incorporate popular technologies of interest such as turbo-charged, hybrid, and super-charged technologies.

changes in vehicle weight, power, and rates of technological progress. The implied changes to basic vehicles specifications allow me to see whether manufacturers will be able to comply with the recently mandated CAFE standards.[50]

2.3. Results

2.3.1. Passenger Car and Light-Duty Truck

The estimation results for passenger cars and light-duty trucks are summarized in Table 2.3. Model 1 includes vehicle weight, performance and transmission controls, as well as a set of controls for specific technologies of interest (i.e., diesel fuel, turbocharger, supercharger and hybrid). Model 2 adds manufacturer fixed-effects to Model 1 and Model 3 drops the turbocharger, supercharger, and hybrid controls in order for these technologies to be absorbed by the year fixed effects, described earlier as the residual technological progress estimates.[51]

Analyzing the results for specific technology indicators of Model 2, we can see that both passenger cars and light-duty trucks benefit from turbochargers, which lead to efficiency gains of 5.4 percent and 6.5 percent respectively. Passenger cars also see fuel improvements of 3.6 percent from superchargers, whereas, the results for light-duty trucks are inconclusive. Cars and trucks that utilize hybrid technology see fuel improvements of 29.6 and 28.2 percent.[52]

---

[50] I cluster vehicle manufacturers for passenger car and light-duty truck models, since modeling errors are assumed to be correlated within clusters but uncorrelated across clusters (Cameron and Miller 2013). This helps to ensure that the model is obtaining accurate standard-errors and that t-statistics are not misleadingly large. Class level estimates are reported with robust standard errors as clustered groups are few and even with bias-correction result using clusters can lead to over-rejection (Cameron and Miller 2013). For this paper, I do not provide robustness checks for this model and ask the reader to look towards Knittel (2011) for other estimation methodologies.

[51] Model 3 is assumed to provide the best estimate of technological progress, thus this model specification is the only model estimated at the class level. Results of identifiable characteristic controls that are discussed throughout the paper come from Model 3. Model 2 is used to highlight the effect of current popular technologies of interest.

[52] Hybrids utilize large battery packs which improve fuel economy for several reasons including 1) regenerative braking capture energy and charge battery, 2) two sources of power allow engine to operate at maximum efficiency, 3) the engine can be shut off at idle. Along with monitoring the use of Hybrid technology the EPA is also following manufacturer plans to "turbo-downsize" engines. Turbo-downsizing allows for efficiency gains from having smaller

Interpreting the results of Model 3, we can discuss the impact identifiable vehicle characteristics have on fuel economy. For instance, with regard to passenger cars, the results imply, *ceteris paribus*, a 10 percent reduction in the vehicles' curb weight would yield an increase in fuel economy by 3 percent. Given the average weight for all passenger cars, this would imply a 333 pound reduction in weight. Additionally, a 10 percent increase in horsepower has a negative impact on fuel economy of 2.93 percent. Passenger cars powered by diesel combustion engines are 23.4 percent more fuel efficient than those that are not, which is consistent with results found in Knittel. Furthermore, in comparison with Knittels' results the gains in fuel economy due to having a manual transmission have disappeared with modern vehicles.[53] This could reflect technological improvements that have been made to automatic transmissions including the number of speeds, continuously variable speeds, and new transmissions such as automated manual.

Likewise, Model 3 results for light-duty trucks imply a 10 percent reduction in vehicle curb weight would improve fuel economy by 3 percent. Vehicle torque becomes highly impactful on fuel economy, in that a 10 percent increase would decrease fuel economy by nearly 6 percent, whereas an increase in horsepower would yield fuel savings of 3.2 percent.[54] Finally, manual transmissions reduce fuel economy by 2.6% and diesel powered engines are 48.4 percent more efficient than gasoline powered engines. The impact of diesel combustion engines is substantially larger than the results found in Knittel, 24 to 27 percent, and could represent dramatic improvements in diesel combustion engines thermal efficiency.[55] However, the result could suffer

---

engines but yet still providing and potentially satisfying consumers' desire for vehicle performance. The EPA is also currently researching the benefits and impact of Hydraulic Hybrids on the vehicle fleet. This vehicle specification was not indicated in the data for my analysis. (EPA, Trends Report 2013 pg.53)

[53] Knittel finds that manual transmissions improve fuel economy by nearly 5 percent for passenger cars.

[54] As pointed out be Knittel (2011), torque and horsepower are highly correlated in that $horsepower = torque*RPM/5250$.

[55] The result is consistent with previous evidence that larger more powerful diesel engines see more efficiency gains http://www.eia.doe.gov/kids/energyfacts/.

from having a small sample of diesel trucks, as only 0.005 percent of light-duty trucks in the sample are diesel engines as opposed to the 0.05 that exist in Knittels' sample.

With regard to average technological progress estimates, the annual fuel efficiency gains from residual technological progress average 1.77 and 1.53 percent for passenger cars and light-duty trucks, respectively. These results are nearly identical to those reported in Knittel, which found average technological progress to be 1.76 and 1.78. The lower average technological progress for trucks could be because the rate of technological progress slows for light-duty trucks after 2008. This is likely due to falling gasoline prices in the U.S, which is consistent with previous literature such as Newell et al. (1999) and Popp (2002). Specifically, these studies find that the rate of energy innovation depends on both regulatory standards as well as energy prices.

2.3.2. Class-Level

Estimation results for the 10 vehicle classes, using the Model 3 specification, are summarized in Table 2.4. From the results, we can see that both Sub-Compact and Mini-van classes of vehicles have the greatest gains in fuel economy with a reduction in vehicle weight. Specifically, a 10 percent reduction in weight would generate over a 7 percent increase in fuel economy, for both classes. All other classes range from 2 percent to 5.2 percent improvement in fuel economy with a 10 percent reduction in weight. Comparing the impact of vehicle horsepower for the 10 classes, the results indicate that classes 1 through 4 see negative effects; in that, a 10 percent increase would yield a decrease in fuel economy ranging from 1.6 to 4.7 percent. For classes 5 through 10, also known as light-duty trucks, the class would either benefit from an increase in horsepower (classes 5,7,9, 10), are inclusive (class 8), or see a loss in fuel economy (class 6). However, as mentioned earlier horsepower and torque are highly correlated and can have a different impact on fuel efficiency depending on the use of the vehicle. Specifically, in classes 6 through 10, which makes up the majority of the previously described group of light-duty trucks, torque is more highly correlated with reduced fuel economy.[56] Most of the vehicles in these classes have towing capabilities where power in the form of torque is needed for the vehicle to engage in the initial stage of work. This also sheds more light on why diesel engines are more efficient as they are cable of generating more low-end torque at lower rpm's which generates efficiency. Not all models at the class level are able to provide insight on desired controls, such as manual transmission and diesel engines, due to missing data.

Figure 2.2. plots technological progress estimates for each of the 10 classes. Comparing results of average annual technological progress, we see that class 3 (Mid-size passenger cars), exhibited the highest at 2.1 percent and class 6 (Large Van) the lowest at half of a percent.[57] Largest technological growth between years range from 3 to 7 percent for all classes, in which 4 of the 10 classes exhibit a period of growth, at some point between 2001 and 2013 model year vehicles, of 4 percent or greater.

2.3.3. Footprint Based Compliance Strategies

To complete the compliance section of this paper, average class window sticker fuel economy for model year 2013 vehicles are converted into CAFE-equivalent fuel economy values. In reality, actual fuel economy of a vehicle is determined largely by how the consumer drives the vehicle. For example speed, acceleration, braking, weather conditions, and air conditioning use are all important factors. The EPA considers these factors when determining the sticker MPG. This is

---

[56] This result is consistent with Knittel (2011) and Klier and Linn (2014) in which the latter only includes one measure of power, horsepower for passenger car and torque for light trucks, in their estimates with fuel consumption as the dependent variable.

[57] Class 6 suffers from a small sample size of 254 observations

why the sticker MPG is much lower than the CAFE standards. The EPA uses a 5-cycle method to adjust tested vehicle fuel economy to the window sticker fuel economy, which is the measure of fuel efficiency consumers see when purchasing a vehicle. This value is also the fuel economy reported by Edmunds. To determine CAFE compliance by vehicle class, I need unadjusted fuel economy values. To obtain an approximate conversion factor, I use a conversion file provided by the EPA to determine that the 54.5 mpg CAFE fleet standard is equal to roughly 39.5 mpg adjusted fleet fuel economy (i.e., window sticker fuel economy), which is approximately a 38 percent difference. The conversion varies for specific vehicles at high and low levels of fuel economy. However after comparing several vehicle models in different classes and for simplicity, I assume the adjusted fuel economy to CAFE equivalent is approximately a 34 percent increase. I use this value to adjust vehicle fuel economy throughout the remainder of the paper in order to discuss compliance and results.

The second phase (2017 to 2025) of the EPA designed CAFE program allows for several flexibilities, in which manufacturers can use to comply with standards. Flexibilities include building credits from A/C (air conditioning) improvements that lower CO_2 emissions and credits for implementing off-cycle technologies, such as solar panels, hybrids, and engine stop start. Additionally, manufacturers will be allowed to bank and trade these credits, which the EPA hopes will ease the transition into the stringent phase two standards. There are also incentives built into the program that encourage manufacturers to incorporate advanced technologies and more electric (EV), Plug in hybrid electric (PHEV), fuel-cell (FCV), and compressed natural gas (CNG) vehicles into production, which will act as a multiplier towards compliance.[58] All of the described program flexibilities are designed to lower the burden of compliance.[59]

As stated earlier however, the goal of this paper was not to present all possible ways vehicle manufacturers could comply with the more stringent CAFE standards but instead is to showcase the challenges manufacturers will face if they attempt to comply using a direct approach of changing only identifiable vehicle characteristics. Thus, I do not attempt to model the CAFE programs flexibilities but reiterate that manufacturers must experience significant technological growth, take advantage of program flexibilities, or lower the burden of compliance through vehicle footprint size in order to reach compliance. This is why program provisions were created by the EPA, so that manufacturers would have time to make the technological improvements required to reach the final stage fuel economies set for year 2025. However, as pointed on this paper alternatively manufacturers may choose to increase vehicle sizes instead of pursuing technological advances thus undermining the goals of the program. In order to pursue the previously describe direct approach method of compliance, Table 2.5. summarizes the vehicle characteristics for all classes in year 2013, including average adjusted fuel economy, the CAFE- equivalent value, curb weight, horsepower, torque and calculated average class footprint. Table 2.6., labeled class compliance and footprint increase incentive, illustrates each classes 2025 model year projected compliance target with the predicted fuel economy of the class.[60]

---

[58] It is important to note that manufacturer compliance is also determined by production levels of each vehicle and not just model or class level fuel economy. Thus, fleet fuel economy is calculated using a harmonic mean. For this paper, neither sales nor production data were available.

[59] For more information on program flexibilities see http://www3.epa.gov/otaq/climate/documents/420f12051.pdf.

[60] Compliance targets are determined by the average class footprint in this paper. See http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf for information regarding vehicle footprint size and CAFE compliance levels.

Predicted CAFE fuel economy(s) are generated by adjusting 2013 average mpg for each class by the Model 3 results for weight, power, and technological progress.[61] I assume three rates of technological progress: average progress, 75th percentile, and maximum estimated progress.[62] Additionally, I consider weight reductions of 10 and 20 percent. The weight reductions are reasonable when considering the possible introduction of high-strength aluminum steel frames. Ford has already introduced this technology with their 2015 model year F-150's, which weigh as much as 700 lbs. less than previous models (Ford Manufacturer website). This 700 lb. reduction is approximately 14 percent of the class 10, full-size truck average curb weight. Additionally, the weight changes are consistent with history for plausible reductions as weight has increased 6.5 and 17.5 percent for cars and trucks respectively, over the 2001 to 2013 time period. In comparison to the Knittel's (2011) study and the 1980 average weight, values have increased 11 and 20 percent. Finally, to incorporate a possible change to performance characteristics, a 10 and 20 percent increase or decrease to each vehicle class most influential power measure was also factored into possible compliance strategies.[63] Again, these are reasonable adjustments given that the average passenger car in 2013 has about 27 percent more horsepower and the average light-duty truck has 27 percent more torque, than the vehicle models available in 2001.

From the projection results, it is apparent that manufacturers will have a difficult time complying with the standards set for model year 2025 vehicles through changing vehicle characteristics alone. This result is conducive with those found by Bastani et al. (2012), in that,

---

[61] I change the power measure that is most highly correlate with fuel consumption in each class. Thus, classes 1-4, 6 have implied reductions in horsepower, class's 7-10 reductions in torque, and class 5 in class 5 horsepower is increased. It is important to briefly reiterate that class 5 and 6 have small sample sizes and are likely not precisely estimated.

[62] Technological progress rates come from the difference of technological progress estimates that can be seen in Table 2.5. Ranking the rates from smallest to largest allows me to identify the 75th percentile and maximum estimated growth rate.

[63] See footnote 23.

they find the likelihood of combined compliance of passenger cars and light-duty trucks meeting or exceeding the 2025 standards is less than 1 percent. In fact my results indicate, only two classes of vehicles, compact SUV and Minivans, were able to reach the compliance level without substantial technological progress in fuel economy, i.e.: maximum estimated technological progress. All vehicle classes were able to comply when vehicle weight was decreased by 10 or 20 percent, power was changed by 10 percent and fuel improvements attributed to technological progress was assumed to continue at each classes estimated maximum.[64] This also illustrates how important continued application of existing technologies and technological progress will be in maintaining a vehicle fleet that is similar to those consumers have grown accustom too. As pointed out by Klier and Linn (2011), consumers value an increase in power more than a proportional increase in fuel economy. Thus, drastic changes to vehicle characteristics, due to manufacturers' attempts to comply with CAFE standards, may impact demand in the market for new vehicles.

Considering these results, it would be practical for manufacturers to take advantage of the CAFE programs flexibilities and incentives, including, obtaining credits through either emission reducing technologies or from trading with other manufacturers. Increasing production and sales of EV, PHEV, CNG, and FCV vehicles would also help since these vehicles would count as more than one vehicle in the manufacturers' compliance calculation for 2017 to 2021 model year vehicles. From the Model 2 estimation results, we also know that the increase in fuel efficiency from hybrid technology is 30 percent and 28 percent for passenger cars and light-duty trucks. Turbo-downsizing is another avenue manufacturers may wish to pursue since prior research indicates vehicle power is a significant factor in consumer vehicle choice. Estimates also show that the existence of turbochargers improves fuel efficiency by 5.4 and 6.5 percent for passenger

---

[64] Maximum technological progress estimates range from 3 to 7.3 percent for the various classes of vehicles.

cars and light-duty trucks, thus improving fuel economy but still keeping the power consumers desire.

Further investigation shows that manufacturers may also have an incentive to increase the size (“footprint”) of their vehicles in order to fall to a lower required CAFE compliance standard. Previous research by Whitefoot and Skerlos (2012) supports the idea that footprint-based CAFE standards do create incentives to increase vehicle size, dependent on assumptions made about consumer preferences. Table 2.6. also represents the increased attainability of compliance from an increase of 10 percent to average class footprint. On average this 10 percent change results in a 4.6 sq. ft. increase in the vehicles footprint. This is a relatively small change in the vehicles size and for most classes this value could be obtained with an increase in the track-width and wheelbase by four inches or less. Additionally, this increase in size is still modest compared to the estimated results in Whitefoot and Skerlos (2012) which suggest that the incentive to increase vehicle size is 5.7 and 9.9 sq. ft. for passenger cars and light-duty trucks, respectively.

Highlighted values in the table indicate acceptable compliance levels of fuel economy. The results illustrate that after average class footprint is increased, eight out of the ten classes no longer require maximum technological progress in order to reach compliance. Three of those eight only require average technological progress to comply with standards. Additionally, if technological progress is assumed to continue at the 75th percentile, 4 classes meet compliance standards with only a 10 percent weight reduction, along with a 10 percent change to power. Even more interesting is that the 10 percent increase in footprint allows six out of ten classes to comply without any change to power measures at all. This is a desirable option given that Whitefoot and Skerlos (2012) find that consumers are willing to pay $160-$5500 more from an additional 0.1 hp/lb in acceleration performance. Given prior results presented about the difficulty manufacturers will face when attempting to comply with the stringent CAFE standards. It is clear from the results, that increasing the footprint of their vehicles in production will make them less dependent on technological progress and require smaller changes to the existing characteristics of the fleet.[65]

2.4. Conclusion

This paper estimates the impact of identifiable vehicle characteristics have on fuel economy, as well as estimating technological advances that have occurred over the model year 2001 to 2013 vehicle fleet. Estimates were used with average footprint calculations, for each vehicle class, to discuss possible compliance strategies for the CAFE standards set for 2025 model year vehicles.

The results suggest that a difficult road is ahead for manufacturers who attempt to comply with standards by changing identifiable vehicle characteristics, such as curb weight and power alone. It is also evident that significant technological progress will be needed to improve fuel economy to the compliance levels. This plays into the flexible incentive based design of the program and encourages manufacturers to improve and use existing fuel technologies to earn credits and multipliers that could be used in final compliance calculations. However, under the current CAFE policy the burden of compliance may also incentivize manufacturers to increase vehicle size in order to fall to a lower footprint based compliance level. This issue of incentivizing alternative means of compliance may not have been considered as a potential problem by those in charge of designing the new CAFE standards. The potential incentive to increase vehicle size to attain compliance is counterproductive to the fuel improvements CAFE standards are designed to

---

[65] The increase in vehicle size may also require unwanted changes to vehicle weight, which lowers fuel efficiency, but this could be countered by the use of lighter high-strength aluminum frames.

generate among the fleet. It also creates vehicle safety concerns when considering the possibility of an increasing gap between the size of small and large vehicle classes.

Continued research on the impact of the stringent standards, on vehicle safety, fuel efficiency, the market for new vehicles, environmental issues, and vehicle insurance will be crucial for policy analysis of the current footprint based CAFE standards. This paper adds to the prior literature and continued research on CAFE policy and highlights the difficulties manufacturers will face as they set out to comply with the footprint based 2025 model year vehicle standards.

References

Anderson, Michael L., and Maximilian Auffhammer. "Pounds that kill: the external costs of vehicle weight." *The Review of Economic Studies* 81.2 (2014): 535-571.

Bastani, Parisa, John B. Heywood, and Chris Hope. "U.S. Cafe Standards." MIT.edu, (2012).

Cameron, A. Colin, and Douglas L. Miller. "A Practitioner’s Guide to Cluster-Robust Inference." *Forthcoming in Journal of Human Resources* (2013).

Chris Busch, John Laitner, Rob McCulloch, and Ivana Stosic “Smart Standards Create Good Jobs Building Cleaner Cars.” *The Blue Green Alliance* (2012).

Clerides, Sofronis, and Theodoros Zachariadis. “Are standards effective in improving automobile fuel economy”. No. 6-2006. University of Cyprus Department of Economics, 2006.

Edmunds, Dan. "FAQ: New Corporate Average Fuel Economy Standards." *Edmunds*. N.p., 9 Sept. 2013.

Ford Manufacturer Website ‘http://www.ford.com/trucks/f150/2015/”

Greene, David L. "Why CAFE worked." *Energy Policy* 26.8 (1998): 595-613.

Jacobsen, Mark R. "Fuel economy, car class mix, and safety." *The American Economic Review* 101.3 (2011): 105-109.

Jacobsen, Mark R. “Fuel Economy and Safety: The Influences of Vehicle Class and Driver Behavior.” No. w18012. *National Bureau of Economic Research*, (2012).

Klier, Thomas, and Joshua Linn. "New-vehicle characteristics and the cost of the Corporate Average Fuel Economy standard." *The RAND Journal of Economics* 43.1 (2012): 186-213.

Klier, Thomas, and Joshua Linn. "The Effect of Vehicle Fuel Economy Standards on Technology Adoption." Resources for the Future working paper. (2014).

Knittel, Christopher R. "Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector." *American Economic Review*, 101.7 (2011): 3368-99.

Newell, J. Richard, Jaffe, B. Adam, and Robert N. Stavins. “The induced innovation hypothesis and energy saving technological change.” *Quarterly Journal of Economics*, (1999). 114 (3): 941-975.

Popp, David. "Induced Innovation and Energy Prices." *American Economic Review*, 92(1): (2002): 160-180.

Thorpe, Steven G. "Fuel economy standards, new vehicle sales, and average fuel efficiency." *Journal of Regulatory Economics* 11.3 (1997): 311-326.

U.S. Energy Information Administration, Annual Energy Review 2013, DOE/EIA 0383(2013) Washington, DC: September (2013), website www.eia.gov/aer

U.S. Environmental Protection Agency. “Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975-2013,” U.S. ***EPA***-420-R-13-011, Office of Transportation and Air Quality, December 2013.

U.S. Environmental Protection Agency. “EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks,” U.S. EPA-420-F-12-051, Office of Transportaion and Air Quality, August 2012.

U.S. National Highway and Traffic Safety Administration. “Proposed rulemaking to establish light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standard,” Federal Register 74, no. 186, September 2009.

Whitefoot, Kate S., and Steven J. Skerlos. "Design incentives to increase vehicle size created from the US footprint-based fuel economy standards." *Energy Policy* 41 (2012): 402-411.

Figure 2.1. Penetration of Fuel Improving Technologies

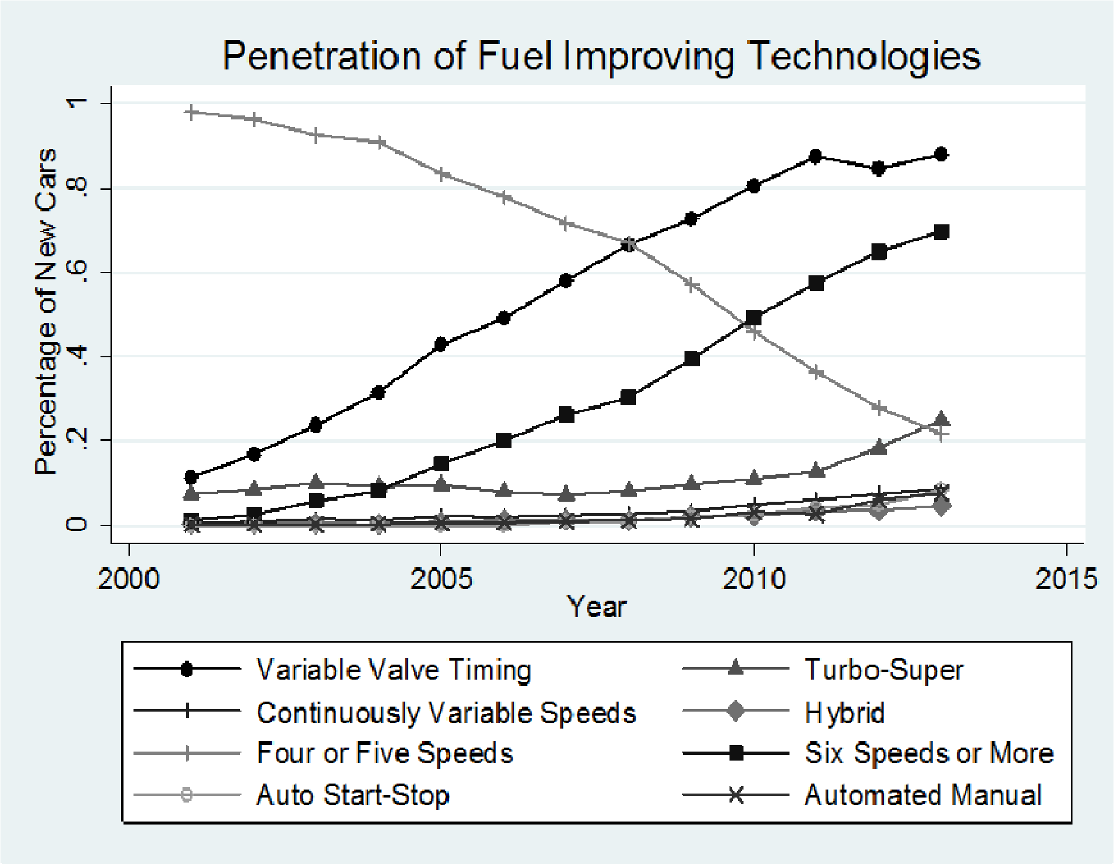


Figure 2.2. Technological Progress by Vehicle Class

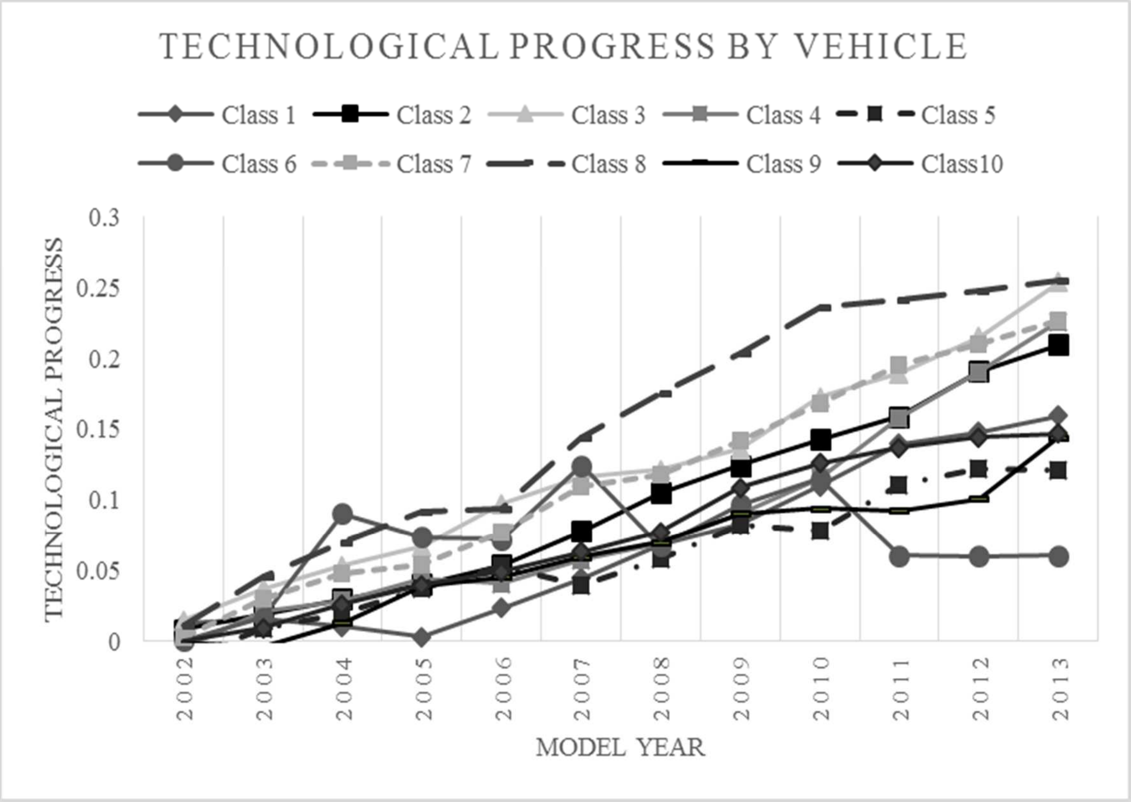


Table 2.1. Vehicle Classes

Vehicle Classes			
Vehicle Type	Description	Name	Example
Passenger Cars	Class 1: Wheelbase under 100 in.	Subcompact	Toyota “Yaris”
	Class 2: Wheelbase 100-104 in	Compact	Honda “Civic”
	Class 3: Wheelbase 105-109 in	Midsize	Chevy “Malibu”
	Class 4: Wheelbase > 109 in.	Full-Size	Volkswagen “Passat”
Light-Duty Trucks	Class 5: Unibody	Minivans	Dodge “Caravan”
	Class 6: Frame Based	Large Van	GMC “Savana”
	Class 7: FARS classification	Compact SUV	Ford “Escape”
	Class 8: FARS classification	Large SUV	Acura “MDX”
	Class 9: Under 4500 lbs	Compact Truck	Chevy “Colorado”
	Class 10: Over 4500 lbs	Full-Size Truck	Ram “1500”

Table 2.2. Summary Statistics Passenger Cars and Light-Duty Trucks

Passenger Cars						
Variable	Mean	SD	Min	Max	2001 Mean	2013 Mean
Fuel Economy	23.68	5.12	10.70	53.40	22.85	26.65
Curb Weight	3329.42	582.43	1808	6814	3157.49	3363.54
Horsepower	217.64	95.62	70	570	180.78	230.48
Torque	215.16	92.75	68	774	188.80	225.63
Diesel	0.019	0.138	0	1	0.016	.040
Manual	0.381	0.486	0	1	0.405	0.320
Supercharged	0.021	0.142	0	1	0.018	0.025
Turbocharged	0.171	0.377	0	1	0.105	0.319
Hybrid	0.020	0.140	0	1	0.006	0.056
Sample Size	10,851				669	1186
Light-Duty Trucks						
Variable	Mean	SD	Min	Max	2001 Mean	2013 Mean
Fuel Economy	17.80	2.96	9.35	32.65	17.28	19.56
Curb Weight	4438.89	775.07	2624	7154	3932.62	4619.94
Horsepower	245.91	66.38	97	555	191.16	274.94
Torque	266.72	73.41	103	575	222.50	282.59
Diesel	0.005	0.067	0	1	0.005	0.012
Manual	0.181	0.385	0	1	0.355	0.063
Supercharged	0.009	0.094	0	1	0.015	0.009
Turbocharged	0.026	0.159	0	1	0.005	0.091
Hybrid	0.015	0.123	0	1	Omitted	0.028
Sample Size	10,528				592	759

Table 2.3. Estimates of Passenger Cars and Light-Duty Trucks

	Passenger Cars			*Light-Duty Trucks*		
	Model 1	*Model 2*	*Model 3*	*Model 1*	*Model 2*	*Model 3*
ln(curbwt)	-0.254***	-0.300***	-0.299***	-0.314***	-0.328***	-0.297***
	(0.070)	(0.042)	(0.065)	(0.037)	(0.040)	(0.046)
ln(hp)	-0.250***	-0.220***	-0.293**	0.281***	0.290***	0.312***
	(0.092)	(0.067)	(0.130)	(0.039)	(0.042)	(0.073)
ln(torque)	-0.102	-0.088	-0.024	-0.541***	-0.545***	-0.581***
	(0.092)	(0.061)	(0.147)	(0.042)	(0.044)	(0.073)
Manual	-0.006	-0.005	-0.009	-0.026***	-0.025***	-0.026***
	(0.006)	(0.005)	(0.007)	(0.007)	(0.007)	(0.007)
Diesel	0.221***	0.240***	0.234***	0.413***	0.429***	0.484***
	(0.049)	(0.033)	(0.069)	(0.029)	(0.030)	(0.049)
Turbo	0.042***	0.054***		0.060***	0.065***	
	(0.013)	(0.014)		(0.012)	(0.018)	
Super	0.054**	0.036*		-0.051**	-0.031	
	(0.027)	(0.020)		(0.023)	(0.033)	
Hybrid	0.328***	0.296***		0.288***	0.282***	
	(0.037)	(0.039		(0.022)	(0.282)	
Year Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes
Manufacturer Fixed-Effects	No	Yes	Yes	No	Yes	Yes
Observations	10851	10851	10851	10528	10528	10528
Adjusted R2	0.850	0.902	0.860	0.815	0.828	0.779

Average Annual Technological Progress	*Passenger Cars*	*Light-Duty Trucks*
2002	0.007	-0.003
2003	0.019	0.016
2004	0.027	0.032
2005	0.034	0.044
2006	0.054	0.056
2007	0.072	0.074
2008	0.085	0.085
2009	0.104	0.109
2010	0.132	0.129
2011	0.155	0.141
2012	0.182	0.152
2013	0.202	0.165

Notes: Standard errors are clustered at the manufacturer level. *** $p<0.01$, **$p<0.05$, * $p<0.1$. Individual model technological progress estimates are significant at the 0.05 and 0.01 level.

Table 2.4. **Model 3 Estimates by Vehicle Class**

	Model 3 Estimates by Vehicle Class									
	Sub-Compact	**Compact**	**Mid-size**	**Full-size**	**Mini-vans**	**Large Van**	**Compact SUV**	**Large SUV**	**Compact Truck**	**Standard Truck**
ln(curbwt)	-0.739***	-0.287***	-0.410***	-0.456***	-0.713***	-0.334***	-0.362***	-0.523***	-0.356***	-0.202***
ln(hp)	-0.471***	-0.383***	-0.272***	-0.157***	0.259***	-0.207***	0.315***	-0.009	0.521***	0.138***
ln(torque)	0.325***	0.040*	-0.066***	-0.160***	-0.247***	0.033	-0.611***	-0.189***	-0.836***	-0.276***
Manual	0.011***	0.003	-0.017***	-0.030***	0.021		-0.025***	-0.104***	0.012***	0.015***
Diesel	0.194***	0.182***	0.215***	0.241***			0.486***	0.294***		
Technological Progress Estimates										
2002	0.013*	0.008	0.014**	-0.005	-0.013	0.000	0.003	0.011	-0.001	-0.000
2003	0.016**	0.019**	0.037***	0.022**	0.009	0.017	0.030***	0.046***	-0.004	0.010
2004	0.010	0.030***	0.053***	0.029***	0.019**	0.090***	0.048***	0.070***	0.013**	0.026***
2005	0.003	0.040***	0.067***	0.044***	0.037***	0.074***	0.054***	0.091***	0.039***	0.040***
2006	0.023***	0.054***	0.097***	0.041***	0.053***	0.072***	0.077***	0.094***	0.045***	0.049***
2007	0.045***	0.078***	0.116***	0.057***	0.039***	0.124***	0.110***	0.144***	0.060***	0.063***
2008	0.068***	0.105***	0.121***	0.069***	0.058***	0.067***	0.118***	0.175***	0.070***	0.078***
2009	0.083***	0.124***	0.136***	0.090***	0.082***	0.097***	0.142***	0.204***	0.090***	0.109***
2010	0.110***	0.143***	0.172***	0.115***	0.079***	0.115***	0.168***	0.236***	0.094***	0.126***
2011	0.140***	0.159***	0.189***	0.158***	0.110***	0.060***	0.195***	0.242***	0.092***	0.137***
2012	0.148***	0.191***	0.215***	0.190***	0.122***	0.060***	0.209***	0.248***	0.101***	0.144***
2013	0.160***	0.210***	0.254***	0.226***	0.121***	0.060***	0.226***	0.255***	0.145***	0.147***
Year Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Manufacturer Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1635	2512	3976	2747	738	254	3661	1463	1653	2759
Adjusted R2	0.891	0.887	0.838	0.861	0.738	0.613	0.833	0.703	0.804	0.468

Notes: *** p<0.01, ** p<0.05, * p<0.1. Reported results are from robust standard errors which are omitted for brevity.

Table 2.5. **Summary Statistics by Vehicle Class**

Summary Statistics by Vehicle Class										
Class	Sub-Compact	Compact	Mid-Size	Full-Size	Mini-Van	Large Van	Compact SUV	Large SUV	Compact Truck	Full-Size Truck
Variable										
Fuel Economy	28.93	28.14	27.89	23.455	22.048	14.2	22.353	17.78	18.894	16.71
CAFE MPG	38.77	37.71	37.37	31.42	29.54	19.03	29.95	23.83	25.32	22.39
Curb Weight	2799.52	3038.31	3258.49	3935.17	4157.87	5694.38	3949.05	5314.54	4134.15	5216.41
Horsepower	152.63	196.94	208.17	309.01	228.11	265.31	236.45	327.85	226.32	322.32
Torque	155.63	192.72	204.22	299.4	216.17	308.75	228.06	346.86	245.98	342.51
Footprint	40.2	42.59	44.84	49.76	53.02	65.71	47.51	55.05	54.96	66.37

Table 2.6. Class Compliance and Footprint Increase Incentive

Vehicle Class	1	2	3	4	5	6	7	8	9	10
Average FT (Square Feet)	**40.2**	**42.59**	**44.84**	**49.76**	**53.02**	**65.71**	**47.51**	**55.05**	**54.96**	**66.37**
Average Tech. Progress	45.42	46.41	48.03	39.31	33.34	20.21	37.5	30.66	29.23	25.91
10% weight & Avg. Tech.	48.78	47.75	49.73	41.09	35.71	20.88	38.84	32.26	30.27	26.43
20% weight & Avg. Tech.	52.14	49.08	51.43	42.87	38.09	21.56	40.2	33.86	31.31	26.95
10% & 75% tile	53.62	48.7	51.88	44.75	39.58	24.52	41.88	36.46	32.01	27.13
20% & 75% tile	57.31	50.06	53.65	46.73	42.22	25.31	43.35	38.27	33.11	27.66
10% weight, power, Avg. Tech	51.08	49.58	51.08	41.73	36.64	21.32	41.21	32.87	32.81	27.17
20%,10%, Avg. Tech	54.60	50.96	52.83	43.54	39.08	22.00	42.65	34.51	33.94	27.70
20, 20, Avg. Tech	57.04	52.86	54.20	44.20	40.07	22.44	40.68	35.15	36.54	28.43
10, 10, 75% tile	56.14	50.57	53.29	45.49	40.61	25.03	44.44	37.15	34.70	27.89
20, 10, 75% tile	60.01	51.98	55.11	47.46	43.31	25.84	44.71	38.31	34.84	28.04
20, 20, 75% tile	62.70	53.92	56.55	48.18	44.41	26.35	43.87	39.73	38.64	29.18
10, 10, Max	61.88	58.41	62.98	54.94	47.08	47.02	48.30	45.64	47.57	33.94
20, 10, Max	66.14	60.04	65.12	57.33	50.21	48.54	48.59	47.06	47.76	34.13
20, 20, Max	69.10	62.28	66.82	58.19	51.49	49.50	47.68	48.80	52.97	35.52
Compliance Fuel Economy (2025)	61.07	58.43	56.01	50.75	40.5	33.4	44.1	39.2	39.2	33.4

Vehicle Class	1	2	3	4	5	6	7	8	9	10
10% increase in Footprint	**44.22**	**46.85**	**49.32**	**54.74**	**58.32**	**72.28**	**52.26**	**60.56**	**60.46**	**73.01**
Average Tech. Progress	45.42	46.41	48.03	39.31	33.34	20.21	37.5	30.66	29.23	25.91
10% weight & Avg. Tech.	48.78	47.75	49.73	41.09	35.71	20.88	38.84	32.26	30.27	26.43
20% weight & Avg. Tech.	52.14	49.08	51.43	42.87	38.09	21.56	40.2	33.86	31.31	26.95
10% & 75% tile	53.62	48.7	51.88	44.75	39.58	24.52	41.88	36.46	32.01	27.13
20% & 75% tile	57.31	50.06	53.65	46.73	42.22	25.31	43.35	38.27	33.11	27.66
10% weight, power, Avg. Tech	51.08	49.58	51.08	41.73	36.64	21.32	41.21	32.87	32.81	27.17
20%,10%, Avg. Tech	54.60	50.96	52.83	43.54	39.08	22.00	42.65	34.51	33.94	27.70
20, 20, Avg. Tech	57.04	52.86	54.20	44.20	40.07	22.44	40.68	35.15	36.54	28.43
10, 10, 75% tile	56.14	50.57	53.29	45.49	40.61	25.03	44.44	37.15	34.70	27.89
20, 10, 75% tile	60.01	51.98	55.11	47.46	43.31	25.84	44.71	38.31	34.84	28.04
20, 20, 75% tile	62.70	53.92	56.55	48.18	44.41	26.35	43.87	39.73	38.64	29.18
10, 10, Max	61.88	58.41	62.98	54.94	47.08	47.02	48.30	45.64	47.57	33.94
20, 10, Max	66.14	60.04	65.12	57.33	50.21	48.54	48.59	47.06	47.76	34.13
20, 20, Max	69.10	62.28	66.82	58.19	51.49	49.50	47.68	48.80	52.97	35.52
Compliance Fuel Economy (2025)	57.19	53.78	51.72	46.39	37.5	30.9	41.2	35.8	35.8	30.6

Notes: *Left-hand descriptions are as follows: When numbers are listed, first number represent change to vehicle weight, second number represents change to power. Final description represents assumptions made about technological progress, except row (1) where no characteristic changes are made to the vehicles in each class. Non-bold numbers within the tables are 2025 projected fuel economy values. The compliance level is shown for the various footprint size classes in the last row of each table. Specifically, the last row of the lower table shows compliance levels if manufacturers increased the footprint size of each class by 10 percent. Shaded Values indicated compliance to CAFE standards.*

Chapter 3: The Effect of Medical Marijuana on Sickness

3.1. Introduction

The merits of legalizing marijuana for medical purposes are touted by interest groups like High Times, MedicalMarijuanaprocon.org, and the Marijuana Policy Project.[66] Claims of the medical benefits of marijuana are hardly unfounded. The Institute of Medicine posit that nausea, appetite loss, pain, and anxiety are all afflictions that can be mitigated by marijuana (Joy et al. 1999). Economists have recently begun examining the effects of medical marijuana legalization (MML) from a variety of policy relevant angles, including traffic fatalities (Anderson et al. 2013), suicide rates (Anderson et al. 2014), and even seat belt use (Adams et al. 2014). Although there has been some work on the labor market impact of illicit marijuana use, the same is not true of the effect of MML.[67]

To fill this void, I analyze work absences after MML. If individuals experience relief from disabling symptoms, absence from work could decline. For example, migraines result in an estimated annual 270 lost work days for every 1000 persons (Rasmussen 1992). Alternatively, medical marijuana is likely a better means to self-medicate a variety of symptoms instead of alcohol. Anderson et al. (2013) found that alcohol consumption declined after MML, and Marmot et al. (1993) found that heavy drinkers are more often absent from work. Green et al. (2015) found that extending bar hours increased work absence. There is also the possibility that MML could lead to an increase in work absences. This suggests a complementary relationship

---

[66] Cost and benefit debates, links below are those referred to above.
http://www.hightimes.com/read/new-study-cannabis-may-help-cure-cancer
http://medicalmarijuana.procon.org/view.answers.php?questionID=1325
http://www.mpp.org/assets/pdfs/library/Effective-Arguments-for-Medical-Marijuana.pdf

[67] See Ours and Williams (2014) for a thorough review.

between alcohol and marijuana. Previous research supporting complementarity is described in Anderson et al. (2014).

Currently, 24 states allow people to use marijuana for medical purposes. My results show that absences due to sickness have decline after enactment of MML, and the effect is concentrated on worker groups more expected to hold cards. Overall, this paper advances the literature on MML by providing insight on the effect these laws have on the labor market, while also providing unique evidence that may encourage others to pursue research on this relatively untapped topic.

3.2. Data and Methods

The data were obtained from the Integrated Public Use Microdata Series (IPUMS**),** March Current Population Survey (CPS), which contain self-reported work absence data from the individuals' week of work prior to the survey. I construct an indicator of absence from work due to illness/medical issues as well as demographic indicators for, gender, age cohorts, race, marital status, and education level. I then link absence data to state-level legislation on medical marijuana. States that legalized medical marijuana from 1992-2012 are treatment states (indicated by the MML dummy). All MML state data on effective dates, were obtained from MedicalMarijuana.procon.org. A table of this detailed information was omitted for brevity of the paper but will be released to readers upon request.

The estimation method follows a linear probability model (LPM), which tests for effects at the individual-level, as well as effects on subgroups most likely affected by MML.[68] Although

---

[68] For robustness, I also estimate a Poisson count model, which tests for overall declines in the number of individuals reporting absence due to illness/medical issues at the state-level. The results found an 8 percent and 11 percent reduction for the full sample and full-time workers, respectively. Results are significant at the 5 and 1 percent level.

there are limitations of the LPM, it provides estimates with easily interpretable coefficients and avoids the incidental parameters problem.

The basic analysis takes the following form:

$$(1)\ SA_{ist} = \alpha + \eta_s + \tau_t + \mu_{st} + \beta MML_{st} + \lambda' X_{ist} + \varepsilon_{ist,}$$

where subscripts i, s and t denote individual, state and year. SA is a dichotomous variable indicating that the individual reported being absent from work due to illness, injury, or medical issues.[69] MML is an indicator variable that captures whether the state allowed individuals to use marijuana for medical purposes. Thus, β is our primary coefficient of interest in both models.[70] In some specifications, I indicate states with "lax" MML (i.e. large number of card-holders, ease of access to marijuana, and large potential spillovers) and "strict" MML (i.e. small number of card holders and tougher supply-side restrictions). Specially, "lax" states include California, Colorado, Michigan, Oregon, and Washington whereas, "strict" states include Alaska, Delaware, Maine, New Jersey, Rhode Island, and Vermont.[71] One would expect a stronger result in "lax" versus "strict" states.[72]

Additionally, dummies for gender and age cohorts are interacted with the policy variable to identify an effect specific to that group. This isolates the effect of MML on the group of individuals most likely to hold licenses. The group that reports the heaviest use of marijuana for medicinal purposes are ages 25-44 (Nunberg et al. 2013). Additionally, Reiman (2007) found in a sample of cardholders, an average age of 39.9. In Colorado, it is 42.[73] Additionally, all

---

[69] The CPS is self-reported data. Given this element, it is important to acknowledge the possibility of classical measurement error which could impact the interpretation of the estimates in this paper. However, the CPS is commonly used in studies to represent the US labor force.

[70] Lead policy variables are insignificant.

[71] See http://medicalmarijuana.procon.org/view.resource.php?resourceID=005889 for cardholder numbers.

[72] Other treated states are dropped from regression.

[73] See https://www.colorado.gov/pacific/sites/default/files/CHED_MMJ_07_2014_%20MMR_report.pdf for statistics

sources report that the proportion of applicants and card-holders who are male is approximately 70%. The terms η_s and τ_t are the state and time fixed effects, which capture differences in sickness absence across states and differences unique to every time period in the sample. The state-time trend is the linear time trend "τ" interacted with individual states "η", that is "τ*η", indicated above as μ_{st}. The X vector includes controls for gender, age, race, marital status and education.

Self-employed individuals are dropped because the meaning of absence from work is less clear (Lechmann et al. 2013). Individuals who reported absence from work for reasons that are not health related were dropped. However, the inclusion of either groups do not substantively change the results. I also limit the sample to full-time employees because of their greater attachment to the labor market and value placed on the job (Bulow and Summers 1986). Thus, full-time employees may be more motivated to pursue options that allow them to return to work sooner and as a result we would expect to see a stronger effect from MML.

3.3. Results

The LPM estimate results for the full sample are presented in columns (1)-(4). In column (1) the estimate is negative, significant at the 10 percent level and suggests that relative to the mean of the sample, respondents were 8 percent less likely to report being absent from work due to health issues after MML. Column (2), presents results for "lax" and "strict" MML states and show "lax" states sickness absence decreased by 13 percent, relative to the mean and is significant at the 5 percent level. Furthermore, to isolate the groups that are most likely to use medical marijuana for health issues, columns (3) and (4) report results with policy dummy interactions. Relative to the mean sickness absence of the isolated group, men are nearly 9 percent and individuals ages 30-39 and 40-49 are 15 and 11 percent less likely to report sickness absence after MML. These results are significant at the 5, 1, and 5 percent level.

Results for full-time workers can be seen in columns (5)-(7). Specifically, age groups 30-39, 40-49, and 50-59 are 16, 11, and 13 percent less likely report absences due to illness/medical issues after MML. These results are significant at the 1, 10, and 1 percent level, respectively.

3.4. Conclusion

Dunn and Youngblood (1986) estimate that costs of absenteeism in the U.S. are around 24 billion dollars a year. Coles et al. (2007) estimate that the wage offset of a 1 percent increase in the absence rate is 56 cents. The results of this paper therefore suggest that MML would decrease costs for employers as it has reduced self-reported absence from work due to illness/medical issues. Although there is not a direct identification of those who use marijuana for medical purposes in the data, overall sickness absence is reduced for those in age and gender groups most likely to be cardholders.

With momentum in the favor of legalized medical marijuana, it will be important to understand how this legislation will impact the labor market. Given the lack of prior studies, more research is warranted in this area.

References

Adams, S., et al. 2014. Seatbelt use as a police avoidance strategy: A test using the legality of medical marijuana. *mimeo UW-Milwaukee*.

Anderson, D. M., et al. 2013. Medical marijuana laws, traffic fatalities, and alcohol consumption. *Journal of Law and Economics* 56.2: 333-369.

Anderson, D. M., et al. 2014. Medical marijuana laws and suicides by gender and age. *American Journal of Public Health*: e1-e8.

Anderson, D. M., et al. 2014 The Legalization of Recreational Marijuana: How Likely Is the Worst-Case Scenario?. *Journal of Policy Analysis and Management* 33.1: 221-232.

Burlow, J., et al. 1986. A Theory of Dual Labor Markets with Application to Industrial Policy, Discrimination, and Keynesian Unemployment, *Journal of Labor Economics,* 4: 376-414.

Coles, M., et al. 2007. Pay, technology, and the cost of worker absence. *Economic Inquiry*, *45*(2): 268-285.

Dunn, L.F., et al. 1986. Absenteeism as a mechanism for approaching an optimal labor market equilibrium. *Review of Economics and Statistics*, 68: 668–674.

Green, C. P., et al. 2015. Play Hard, Shirk Hard? The Effect of Bar Hours Regulation on Worker Absence. *Oxford Bulletin of Economics and Statistics.* Forthcoming.

Joy, J. E., et al. 1999. Marijuana and Medicine: Assessing the Science Base. *National Academies Press*.

Lechmann, D. S., et al. 2013. Absence from work of the self-employed: A comparison with paid employees (No. 09/2013). *IWQW Discussion Paper Series*.

Marmot, M.G., et al. 1993. Alcohol consumption and sickness absence: From the Whitehall II study. *Addiction* 88:369–382.

Nunberg, H., et al. 2011. An analysis of applicants presenting to a medical marijuana specialty practice in California." *Journal of Drug Policy Analysis* 4.1.

Rasmussen, B. K., et al. 1992. Impact of headache on sickness absence and utilization of medical services: a Danish population study. *Journal of Epidemiology and Community Health*, *46*(4): 443-446.

Reiman, A. 2007. Medical cannabis patients: Patient profiles and health care utilization patterns. *Complementary Health Practice Review*, 12(1): 31-50.

Ours, J. C., et al. 2014. Cannabis use and its effects on health, education and labor market. *Journal of Economic Surveys.* doi:10.1111/joes.12070

Table 3.1. Effect of MML on Sickness Absence

	(1)	*(2)*	*(3)*	*(4)*	Mean Sickness LPM Groups	*(5)*	*(6)*	*(7)*	Mean Sickness LPM Groups
	LPM	*LPM*	*LPM*	*LPM*		*LPM*	*LPM*	*LPM*	
	Full Sample					*Full-Time Workers*			
Policy Variable:									
MML	-.0013*				.0155	-.0067**			.0770
	(.0007)					(.0033)			
Lax*MML		-.0020**			.0140		-.0091*		.0683
		(.0010)					(.0048)		
Strict*MML		-.0007			.0185		-.0018		.0795
		(.0018)					(.0054)		
Male*MML			-.0017**		.0174				
			(.0008)						
Female*MML			-.0011		.0143				
			(.0008)						
15-19*MML				.0007	.0023			.0008	.0065
				(.0007)				(.0053)	
20-29*MML				-.0010	.0126			-.0021	.0337
				(.0010)				(.0050)	
30-39*MML				-.0038***	.0244			-.0140***	.0853
				(.0008)				(.0033)	
40-49*MML				-.0034**	.0316			-.0135*	.1253
				(.0016)				(.0074)	
50-59*MML				-.0016	.0250			-.0165***	.1300
				(.0012)				(.0060)	
60-65*MML				.0005	.0104			.0014	.0783
				(.0010)				(.0044)	
Controls	Yes	Yes	Yes	Yes		Yes	Yes	Yes	
State, Time F.E.	Yes	Yes	Yes	Yes		Yes	Yes	Yes	
State-Time Trend	Yes	Yes	Yes	Yes		Yes	Yes	Yes	
Observations	757,677	697,476	757,677	757,677		121,710	111,829	121,710	

Notes: Each column indicates an individual regression. All models include controls for race, marital status, age cohort, and educational attainment. Standard errors are in parentheses and are clustered by state. All estimates are weighted using CPS sampling weights. Mean sickness levels are included to interpret coefficient results. ***, **, * significant at .01, .05, .10.

Curriculum Vitae

Darin F. Ullman

University of Wisconsin-Milwaukee | Department of Economics

E-mail: dfullman@uwm.edu Website: https://sites.google.com/site/darinfullman/

Fields of Interest

Primary: Applied Microeconomics, Health, Public Policy, Labor, Environmental
Secondary: Applied Econometrics, Behavioral

Education

University of Wisconsin – Milwaukee
Ph.D. Economics, May, 2016
"Three Essays on Public Policy and Health"
Advisor: Scott J. Adams

University of Wisconsin – Oshkosh
B.S. Economics with Mathematics Minor, 2010

Research

Peer-reviewed Publications

"Locked and Not Loaded: First Time Offenders and State Ignition Interlock Programs"
*International Review of Law and Economics, (*2016), vol. 45, issue C, pages 1-13

"A Difficult Road Ahead: Fleet Fuel Economy, Footprint Based CAFE Compliance, and Manufacturer Incentives" (2016) *Forthcoming, Energy Economics*

Working Papers

"The Effect of Medical Marijuana on Sickness Absence" (2015).
Revise and Resubmit, Health Economics

"Seatbelt use as a police avoidance strategy? Behavioral responses to changes in the legality of marijuana possession" (2014). (with Scott J. Adams and Chad Cotti) *Under Review, Transportation Research Part F: Traffic Psychology and Behavior*

Work in Progress

"Social Drinking, Social Capital, and Wages" (with Scott J. Adams and John Heywood)

"Moral Hazard and the Affordable Care Act"

"School Choice Programs, Community Development, and Juvenile Crimes (with Bryan Weber)

Teaching Interests

Microeconomics, Labor, Health, Environmental, Public Policy

Teaching Experience

Lecturer, University of Wisconsin - Whitewater, College of Business and Economics
Principles of Macroeconomics, 2 sections, 2015-Current
Business Statistics, 2 sections, 2015-Current

Adjunct Instructor, Waukesha County Technical College
Introductory Economics, 3 sections, 2013-2015

Graduate Teaching Assistant, University of Wisconsin – Milwaukee, Economics Dept.
Instructor
Labor Economics and Employment Relations, 3 sections, 2012, 2014-2015
Environmental Economics, 1 section, 2013
Principles of Microeconomics, 7 sections, 2011-2014

Teaching Assistant
Principles of Microeconomics, 1 section, 2010
Prof. William L. Holahan
Principles of Macroeconomics, Head TA, 5 sections, 2012-2015
Emeritus Prof. G. Richard Meadows

Economics Tutor, University of Wisconsin – Oshkosh, 2008-2010

Honors and Awards

Chancellor Graduate Student Award, 2011-2012
Graduate Student Teaching Assistantship, 2010-2015
Outstanding Student in Economics, Oshkosh Economics Department, 2010
Summa Cum Laude, University of Wisconsin – Oshkosh, 2010

Academic Services

UW-Milwaukee Open House, Economics Booth Representative 2011, 2012

Computer Skills

STATA, MS-Office, E-Views, SAS, Guass, Maple

Presentations

"Seatbelt use as a police avoidance strategy? Behavioral responses to changes in the legality of marijuana possession" University of Wisconsin – Milwaukee, 2014

References

Prof. Scott J. Adams* *(Advisor)* sjadams@uwm.edu (414) 229-4212	***Prof. John S. Heywood**** heywood@uwm.edu (414) 229-4437
Prof. Chad Cotti ° cottic@uwosh.edu (920) 424-3013	***Prof. Owen Thompson**** thompsoo@uwm.edu (414) 229-4429

Address for:

* University of Wisconsin-Milwaukee, Department of Economics
P.O. Box 413, Milwaukee, WI 53201

° University of Wisconsin-Oshkosh, Department of Economics
College of Business 800 Algoma Blvd. Oshkosh, WI 54901