THE RELATIONSHIP BETWEEN LAWS REGULATING USE OF MOBILE COMMUNICATION DEVICES BY YOUNG DRIVERS AND CRASH FATALITIES

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By

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ABSTRACT

The use of mobile communication devices (MCDs) by drivers is a significant public health problem. Research suggests that MCD use plays a role in almost 400,000 traffic crashes each year, resulting in over 3,000 deaths (NHTSA, 2013). Drivers using an MCD are as much as four times more likely to crash as other motorists (Redelmeier & Tibshirani, 1997). Since 2001 forty-eight states have adopted one or more laws aimed at reducing the use of MCDs by drivers, many of which have been strengthened through subsequent amendments. Evaluations have yielded a mixed picture of their effectiveness (Braitman & McCartt, 2010; Highway Loss Data Institute, 2010; McCartt & Geary, 2004; McCartt, Hellinga, Strouse, & Farmer, 2010). Existing studies, however, have been limited by various design features. This study employs time-series methods to explore whether laws prohibiting use of MCDs by young drivers effectively reduce crash fatalities. The quasi-experimental design relies on an identification strategy that is common in empirical legal studies but has not yet been applied to laws regulating driver MCD use. The implementation of the identification strategy leverages the developing concept of legal epidemiology. Four state laws are ultimately evaluated. The primary analytic approach is difference-in-difference. In two of the four instances, there is some evidence suggesting a protective effect could be attributed to the law. However, this evidence was limited and differed in relation to specification choices. These findings cast doubt on some fifty state panel analyses that have suggested that laws are effectively decreasing MCD use and associated harms.

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CHAPTER 1: INTRODUCTION

The use of mobile communication devices ("MCDs") by drivers is a significant public health problem. Epidemiological studies implicate distraction from MCD use in thousands of deaths and tens of thousands of injuries each year (NHTSA, 2013). Although estimates vary and are subject to debate (Kolko, 2009), drivers using an MCD are as much as four times more likely to crash as other motorists (Redelmeier & Tibshirani, 1997). Research has documented substantial negative effects of MCD use on reaction time, attention and overall driving performance (Beede & Kass, 2006; Charlton, 2009; Drews, Pasupathi, & Strayer, 2008). Since 2001 forty-eight states have adopted one or more laws aimed at reducing the use of MCDs by drivers ("MCD-laws"), many of which have been strengthened through subsequent amendments. These laws differ significantly across a number of dimensions including the classes of drivers and activities regulated, the penalties associated with violations, and the methods of enforcement. Evaluations of these laws have yielded a mixed picture of their effectiveness (Highway Loss Data Institute, 2010; McCartt, Braver, & Geary, 2003; McCartt & Geary, 2004; McCartt, Hellinga, & Geary, 2006; McCartt, Hellinga, et al., 2010; McCartt, Kidd, & Teoh, 2014). Given the apparent harmfulness of the MCD use behind the wheel, identifying whether current legal interventions are effective is an essential step in preventing avoidable injury and death.

Purpose of the Study

Legal intervention has been essential to the reduction of many sources of morbidity and mortality on the roads including, among others, alcohol-impaired driving and driver inexperience (CDC, 1999). The prominence of law in these previous campaigns highlights the relative dearth of evidence supporting current legislation targeting driver MCD use. That MCD-laws spread rapidly among the states in the face of questionable evidence of effectiveness raises important questions about their appropriateness and opportunity costs, as well as the correct approach to ongoing reform.

Continuing uncertainty about the effects of MCD-laws a decade after they emerged also reflects the challenges of evaluating legal interventions. Unlike with clinical interventions, which are tested in a multistep process culminating in studies that randomly assign subjects a uniform treatment or placement in a control group, randomization of legal interventions is generally impracticable, and when laws do emerge they often differ in form. These challenges are substantial but not intractable. By using theory about how law influences health and "deep substantive knowledge of the law itself"(Ho & Rubin, 2011), it is possible to design legal evaluations using comparisons that approximate randomization while avoiding problems associated with heterogeneous laws. Such theory-driven selection of comparisons is what distinguishes quasi-experiments, which can generate credible causal inferences about treatment effects, from purely observational studies, which cannot (Heinsman & Shadish, 1996; Rosenbaum, 1999). The "manner in which a researcher uses observational data (i.e., data not generated by a randomized trial) to approximate a real experiment" is often described as an identification strategy (Angrist & Krueger, 1999).

The purpose of this study is to increase understanding about the relationship between MCD-laws and motor vehicle fatalities by deploying a specific identification strategy. This identification strategy is common in evaluations of traffic safety interventions but has not yet been applied to the study of MCD-laws. It relies on comparisons between trends in fatal crash rates for drivers subject to the law and trends for similar age groups in the same or proximal states. This design is intended to control for exogenous regional and state influences that might confound inferences about changes observed in crash trends after the adoption of an MCD-law for a "treated" subgroup. The MCD-laws evaluated in this study pertain exclusively to young drivers because the identification strategy relies on the availability of an age-defined threshold between drivers covered by the law and not. To implement the identification strategy substantial legal research was needed to identify instances when such comparisons were feasible. Starting with all fifty states and a period of twelve years, all state laws were evaluated for their suitability in a quasi-experiment. Out of the thousands of possible comparison permutations, only three states and four laws fit the criteria. The criteria are described in Chapter Three as are the theories that guided the conceptualization and implementation of the study.

The specific aim for this study is:

Specific Aim 1: To evaluate the effect of laws regulating MCD use by young drivers in three states.

The specific research questions associated with this aim include:

RQ1: Did Arkansas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

RQ2: Did Arkansas' law prohibiting all handheld use of MCDs for drivers age 18 to 20 reduce motor vehicle fatalities involving drivers of that group?

RQ3: Did North Carolina's law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

RQ4: Did Texas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

Background on MCD Use and Crash Morbidity and Mortality

Epidemiology of MCD Use Behind the Wheel

Incidence

The use of mobile communication devices (MCDs) is but one of a number of distracting activities that drivers engage in behind the wheel. As defined by the Centers for Disease Control and Prevention, distracted driving encompasses any activity that draws attention away from the operation of a motor vehicle (CDC, 2014). Studies have linked numerous behaviors to crash risk, including adjusting inboard music players (Stutts et al., 2005), interacting with navigation systems (Makishita & Matsunaga, 2008), and a range of more quotidian activities like eating, shaving, and putting on makeup. These activities, however, are relatively uncommon according to surveys (Royal, 2003) and observational studies (Stutts et al., 2005). Moreover, these non-communication activities generally occur episodically in slow moving traffic (Stutts et al., 2005). Driver use of MCDs is different in kind and degree.

Research confirms what everyday experience suggests: driver use of MCDs is extensive and growing. Observational studies have found that anywhere between 3% and 11% of drivers are using an MCD at any given moment (Eby & Vivoda, 2003; Johnson, Voas, Lacey, McKnight, & Lange, 2004; NHTSA, 2010). One large scale four year observational study of Michigan drivers found that hand-held use of devices by drivers increased from 2.7% to 5.8% between 2001 and 2005 (Eby, Vivoda, & St Louis, 2006). Survey research conveys similarly high rates of use. A CDC study using 2011 survey data revealed that almost 70% of drivers in the U.S. reported using an MCD while operating a vehicle in the 30 days before they were surveyed; over 30% reported reading or sending typed messages (CDC, 2013). According to the 2011 Youth Behavior Survey, 45% of high school drivers reported recently having sent or read a text message from behind the wheel (Olsen, Shults, & Eaton, 2013).

Proximal Effects on Driving Performance

The effect of MCD use on driving performance has been explored in over eighty studies conducted in driving simulators or road courses (Caird, Willness, Steel, & Scialfa, 2008). These studies suggest that using an MCD impairs an individual's operation of a motor vehicle by reducing ability to perceive and process information, essentially a sort of cognitive overload (Beede & Kass, 2006). The effect is slightly amplified by physical manipulation of devices with one or more hands, but occurs with hands-free devices as well belying the idea that such devices constitute a safe alternative (McEvoy et al., 2005). Conversations with passengers also negatively influence driving performance, but the effect is relatively small because passengers can calibrate conversation intensity to the changes in the driver's attention demands resulting from challenging driving conditions (Charlton, 2009; Drews et al., 2008). Impairment from MCD use manifests as reduced reaction time, weaker attention and poorer overall decision-making (Caird et al., 2008). The riskiness of these performance decrements is compounded by how poorly drivers recognize them occurring (Hancock, Lesch, & Simmons, 2003; Horrey, Lesch, & Garabet, 2008, 2009). Some researchers have likened the magnitude of the impairment to intoxication (Strayer, Drews, & Crouch, 2006).

Experimental studies provide a great deal of evidence about how MCD use influences driving performance in a simulated or highly controlled driving environment. The nature of the risk process in everyday life is a little murkier. Not all drivers are equally affected by MCD use (Horberry, Anderson, Regan, Triggs, & Brown, 2006); indeed, some “supertaskers” appear totally unaffected (Watson & Strayer, 2010). There is also some evidence that the relationship between MCD use and crash risk is partly if not largely spurious, with aggressive and high risk tendencies predictive of both (Hahn & Prieger, 2006). This is consistent with research suggesting that MCD use only increases crash risk in difficult driving conditions like on dark and wet roads (Kolko, 2009). Researchers have noted a pattern in distracted driving studies: evidence of impairment is far more severe in simulator studies compared to naturalistic studies (Abouk & Adams, 2013).

Distal Effects on Crash Incidence and Associated Harms

Epidemiological studies of various designs have explored how these risk processes play out on the road in terms of otherwise preventable injury. The simplest studies are surveillance reports tracking the number of crashes in which MCD use is reported as a contributing factor. According to one such study, driver distraction from all types of activities was identified as a factor in 16% of all fatal crashes in 2009, of which 20% involved MCD use (NHTSA, 2010). In absolute terms, the most recent surveillance data point to a role for MCD use in thousands of crash deaths and tens of thousands of injuries each year (NHTSA, 2013). Findings like these likely under account for the role of MCD distraction in crashes because drivers have obvious incentives not to report MCD use because of possible civil, criminal or social sanctions. Isolating the effect of MCD use is also complicated by the fact that it is associated with other risky driving behaviors (Beck, Yan, & Wang, 2007; Zhao, Reimer, D'Ambrosio, & Coughlin, 2012).

There are a handful of naturalistic studies measuring the relationship between

MCD use and crash outcomes. The best known is a case-crossover study in which researchers relied on an extensive analysis of phone use and crash records in finding that MCD use increases crash risk by a factor of four (Redelmeier & Tibshirani, 1997). The Virginia Tech Transportation Institute has also conducted a handful of large scale studies using in-vehicle cameras and sensory technology to measure the effects of MCD use. One such study based on data from over six million miles of travel found that nearly 80% of crashes and 65% of near-crashes were connected in some way to driver inattention within three seconds of the event and that the most common distraction was MCD use (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). There are also simulation studies that estimate the effect of increasing MCD access and use on crash outcomes (Cohen, 2003; Farmer, Braitman, & Lund, 2010). Using data about text message volume, one team of researchers estimate that texting alone resulted in 16,000 otherwise avoidable road fatalities between 2001 and 2007 (Wilson & Stimpson, 2010).

Despite the apparent risk of MCD use behind the wheel, an increase in crash mortality has not accompanied increases in MCD ownership and use. Between 2000 and 2010, the proportion of Americans with mobile service plans doubled to effective saturation at over 90% while the number and the rate of crash fatalities per million vehicle-miles-travelled declined 27% and 37% respectively. Crash mortality has been decreasing consistently since the 1970s, and it is plausible that this secular trend is obscuring a slight or even sizable increase in crash risk from driver MCD use. It is notable, however, that the most rigorous attempt to isolate the population effect of MCD use on crash fatalities, which compared driver MCD use and crash rates around the 9:00 PM “free minutes” threshold, found no evidence that increased MCD use increases fatal crash rates (Bhargava & Pathania, 2013). Fatalities, of course, represent just one crash outcome and do not necessarily provide a good measure of crash risk. It is also possible, as some researchers have speculated (Fowles, Loeb, & Clarke, 2010; Redelmeier & Tibshirani, 1997), that MCD use increases crash risk while decreasing crash mortality by shortening emergency response time. Such orthogonal effects would explain why early laws – adopted while MCD access was widening – appeared to have a protective effect on fatalities while non-fatal crash rates, measured for example by insurance claims, were increasing (HLDI, 2009, 2010). Difficulty specifying the contribution of MCD use to fatal crash rates does not undermine the case for working to reduce MCD use behind the wheel; almost all Americans think the activity is dangerous and each day brings another anecdote of lost life and limb from a telecommunicating driver. It does, however, suggest that the relationship between legal intervention and fatal crash rates may be difficult to detect.

Social and Economic Costs

Distracted driving is a complicated social and economic issue. Mobile communication by drivers carries benefits as well as risks. This complexity is reflected in national polling in which almost 70% of licensed drivers admitted recently talking on an MCD while driving, yet 88% indicated that driver use of MCDs is a somewhat or a very serious threat to safety on the roads (AAA, 2014). The societal costs of distracted driving appear substantial, especially because motor vehicle injury strikes so many early in life. In terms of economic measures of life like Years of Potential Life Lost (YPLL) and Quality Adjusted Life Years (QALY), motor vehicle crashes, like many other injuries, carry a much larger burden of premature death than many chronic conditions that account for more total deaths. Distracted driving also presents considerable problems of distributional fairness because drivers using an MCD endanger others too. A more prosaic externality of MCD use behind the wheel is increased community car insurance premiums.

The Role of Law in Road Safety

Law as an Effective Health Intervention

Law is an important tool for promoting population health. Across a wide variety of public health domains ranging from infectious and chronic disease to injury prevention, legal intervention has been essential to reducing morbidity and mortality (Burris & Anderson, 2013; CDC, 1999, 2011). Law has been especially effective in improving road safety. The absolute number of annual crash fatalities has almost halved in the United States since the 1970s despite large increases in the number of people driving and annual miles driven (CDC, 1999). Law has contributed to this trend by setting out simple but essential coordination rules (e.g., drive on the right side of the road (Dworkin, 1981)) and regulating the design of roads and vehicles (CDC, 1999). Perhaps the most impactful and well-researched legal interventions have regulated drivers and passengers; of the sixty-five systematic reviews of legal interventions conducted by the Community Guide for Preventive Services and the Cochrane Collaborative, fourteen have focused on driver and passenger behavior (Moulton et al., 2009; PHLR, 2013).

Law is by no means the only intervention targeting MCD use by drivers and its associated harms. There have also been a number of social marketing campaigns aimed at reducing risky MCD use by drivers. These private (e.g., Oprah) and government endeavors (NHTSA, 2014) have not been systematically evaluated, but some localized interventions - like admonishing signs - have revealed small improvements in behavior at least over short periods of time in small populations (e.g., among users of parking lot)(Clayton, Helms, & Simpson, 2006). Nevertheless, laws banning MCD use by drivers remain the primary strategy for reasons both of necessity and of ethics. These laws are necessary because health education alone is seldom effective at changing behavior, especially when the behavior is enjoyable and socially-ingrained. Humans are, after all, notoriously poor at identifying and managing risk (Kahneman, Slovic, & Tversky, 1982). To change behavior typically requires changing environments, and law is one of the most effective and readily available tools for such structural change (Burris et al., 2010).

The ethical necessity of addressing MCD use behind the wheel derives from the same source as the legal justification for MCD-laws. Whether stated as the Harm Principle or Social Contract Theory, both law and public health ethics support government intervention to protect citizens from the unreasonably risky behavior of others, be it distracted- or alcohol-impaired driving (Gostin, 2008; Mill, 1859). Without this imperative and the traffic safety laws it sustains roads would be a strikingly *Hobbesian* incarnation of modern life. The authority to regulate driver behavior falls primarily to states and localities in the United States, an arrangement that simultaneously complicates and benefits public health research.

Federalism and Policy Learning

Federalism refers to the distribution of policy-making authority between federal, state and local governments. This decentralization is an important feature of the regulatory system in the United States. It enables states and localities to experiment, which creates the variation necessary for evaluating the costs and benefits of different policy options. Findings from such research guide ongoing reform both within and outside the jurisdiction. Under ideal conditions, jurisdictions iterate towards effective policy through this “policy learning” process of identifying new interventions, revising (and sometimes removing) existing ones and continuous evaluation and dissemination (Shipan & Volden, 2012).

States responded to the problem of distracted driving with a rapid onslaught of legislation. Such policy cascades are common early in the policy learning process when concern about the threat is most intense (Downs, 1972). But initial legislative approaches are typically hampered by empirical and popular uncertainty about the nature of the problem (Kuran & Sunstein, 1999) and associated political constraints (Kingdon, 2003; Weiss, 1989). Policy innovation therefore often precedes a period of regulatory refinement (Anderson & Burris, 2014). For example, in the five years following adoption of the first law mandating safety restraints for child passengers in 1978, all states created laws requiring at least some children to be placed in some form of restraint system, but the actual requirements in terms of the children covered and the devices mandated varied considerably (Teret, Jones, Williams, & Wells, 1986). As evidence about the biomechanics of child crash injury and the relative benefits of different legal requirements accumulated, the laws became more specific and more restrictive (Bae, Anderson, Silver, & Macinko, 2014).

The response to distracted driving has followed the same pattern with states experimenting with different legislative approaches and with research exploring the relative effects of different policy choices on the risk behavior and different crash outcomes. As with previous campaigns, the process has generated lots of research so far, but few definitive answers about the ideal MCD-law and what it might accomplish. Laws will inevitably continue to evolve for the foreseeable future pending the widespread arrival of self-driving vehicles or some other unforeseen technological development. This is neither surprising nor is it a sign of that the policy learning process has failed. Although child restraint laws still differ across the fifty states more than forty years after their emergence (Bae et al., 2014), even in their slowly evolving form these laws have saved tens of thousands of children from avoidable harm. The child restraint story and others like it illustrate that even small and incremental improvements in the identification and evaluation of legal interventions are directly measurable in prevented harm. Of course, this means that any delay in identifying and disseminating effective policy can be measured in preventable harm.

The policy learning process unfolds slowly for multiple reasons. Lack of creativity and systematic thinking in policy innovation (Anderson & Burris, 2014) and failure to actively translate evidence into action are perennial challenges, which recent investments in training, institutional capacity, and advocacy aim to address (Brownson, Colditz, & Proctor, 2012). The evaluation component of the policy learning process is perhaps the strongest and most well-supported of the three, but it too can lag. Without the ability to systematically vary and randomly assign legal interventions, rigorous policy evaluation is inevitably a game of opportunity. Some legal interventions are simply easier to evaluate than others because of the availability of data and the feasibility of quasi-experiments; research on safety belt laws benefitted from reliable data about restraint use in fatal crashes and the opportunity to compare trends in fatal crash rates for front and back seat passengers because only the former where typically covered by early laws

(Burris & Anderson, 2013). In addition to the problem of too little variation, there is also a problem of too much variation. Identifying workable comparisons over time and across jurisdictions for complicated and rapidly evolving areas of law can seem prohibitively difficult. Unlike the problem of too little variation, however, this latter problem is tractable. Modern computing technology and a more systematic approach to measuring law have the potential to accelerate the earliest stages of policy evaluation in which description provides the foundation for inference. In recent years, there has been a systematic and multi-pronged effort to support the policy evaluation life cycle (Burris, et al., 2010). One prong with special relevance to the deployment of quasi-experimental designs is the concept of legal epidemiology.

Legal Epidemiology

Road safety represents just one out of many health domains that have been profoundly reshaped by law over the last hundred years (Burris & Anderson, 2013; CDC, 1999, 2011). The transformative effect of law on health is apparent in the reduction of some harms (e.g., smallpox eradication through vaccination mandates (Gostin, 2008)) and the spread of others (e.g., HIV/AIDS transmission through the criminalization of drug paraphernalia (Burris et al., 2011)). The links between Law and Health – with capitalization here indicating their broadest embodiments as fields of study, advocacy and practice - are diverse and numerous. Those links are also dynamic: while Law has been shaping Health, Health has also been shaping Law. Perhaps the most obvious influences of Health on Law have been on legal doctrine. The advent of modern disease control and the associated epidemiologic transition have surely altered conceptions of the possible and rightful role of government (Parmet, 1996). It is hard to ignore recent changes in

Federalism and First Amendment jurisprudence wrought, in part, by evolving challenges and opportunities in healthcare delivery.

The influence of Health on Law has not been limited to doctrine. Just as Law has changed the practice of Health (e.g., allowing nuisance abatement, contact tracing (Gostin 2008)), Health has been changing the practice of Law. The ability to measure and explain disease and disability has contributed to important shifts in how responsibility for harm is conceptualized as matter of legal theory, argued as a matter of legal advocacy, and determined as a matter of legal procedure. Class action lawsuits surged in popularity with the growth of the environmental health movement in the mid-1970s (Yeazell, 1987). Epidemiological evidence about the health effects of asbestos launched millions of claims, more than a few Supreme Court decisions, state legislation, and hundreds of law review articles (O'Malley, 2008). Recent litigation surrounding the painkiller Vioxx portends dramatic shifts in employment practices at large law firms and in fiduciary duties between attorneys and clients (Erichson, 2010).

The importance of Health as subject of litigation and epidemiology as a source of illuminating but contestable evidence has focused attention on the use of Health evidence in the courtroom and in the legislative chamber. Notable treatments of the two, like those by Goodman and colleagues ("Epidemiology and the Law" (2007)) have tended to provide primers on Law for Health, and Health for Law. These represent important resources for those working in areas where Health and Law routinely collide, but hardly exhaust the types of interaction between the two fields. One area of Law that has gone largely untouched by Health is legal research. The identification and analysis of legal texts has changed relatively little in the last century. While Health and its associated fields have been focusing on the promise of big data, the importance of replication, and a general imperative for rigor, law has stayed remarkably true to its traditional and largely unstructured pencil-and-paper approach. In the Health toolkit, qualitative coding methods have advanced along with supportive technology like NVIVO and ATLAS TI, while quantitative methods benefit from increasingly powerful and user friendly analysis packages like SPSS and SAS. There have been only limited flirtations with the use of such technology in legal research.

There are plenty of reasons why legal research has been slow to adopt some of the more systematic methods and associated tools of Health specifically and science more generally. Lawyers and scientists are socialized in different paradigms. Lawyers are conditioned to think and reason persuasively (i.e., "this is how things should be"); scientists are conditioned to think and reason objectively (i.e., "this is how things are"). Scientists publish not just findings but the methods that yielded them; lawyers often keep their methods hidden as valuable and confidential "work product." Lawyers are trained to represent the unique and narrow interests of their future clients; scientists, and particularly those working in the field of public health, aim to create generalizable knowledge necessary to develop and deploy strategies that improve life at the population level. While the epidemiologist eschews individual cases, the lawyer would be sanctioned for privileging the interests of a broader population over the interests of the client.

Some of the cultural and social obstacles to integration of research methods across Law and Health are dissipating. Empirical legal studies has emerged as a popular field of legal scholarship in recent decades displacing long term ambivalence in the law with scientific discourse. With each passing year the percentage of faculty at top law schools with doctorates in fields other than law increases blurring disciplinary boundaries. Meanwhile law has become widely recognized as an essential tool of public health (Burris et al., 2010; Institute of Medicine, 2011) at a time when the emergence of causally complex problems embedded in social and economic processes is intensifying the ethical and empirical challenges of developing and evaluating interventions. Consider, for example, obesity, for which plausible legal interventions range widely across domains (e.g., food, exercise) and their multiple intervention points (e.g., menu label laws, mandated gym class). New and diverse legal interventions are necessary but not sufficient to halt the obesity epidemic; systematic evaluation and vigorous dissemination are also essential to ensuring that evidence about the costs and benefits of different policies guide ongoing reform.

But evaluation and dissemination are difficult when laws are many and diverse. Just identifying the laws related to childhood obesity is itself an enormous undertaking (Abiola & Mello, 2011). Organizing and making sense of that variation in ways that enable evaluation is difficult if not impossible with traditional methods of legal research. And evaluation requires not just an understanding of the incidence of laws being studied but also the incidence of other confounding laws. A growing movement has recognized these challenges in recent years and has called for a more systematic and scientific approach to legal research. At the heart of this movement is the recognition that law is, like other health-related phenomena, measurable. This idea has taken explicit form with the concept of policy surveillance: the scientific measurement of the law as distributed over space and time. Policy surveillance brings law inside the epidemiological tent. Like the twinning of epidemiology with sociology (i.e., social epidemiology), there is growing momentum for what might be called legal epidemiology. Whereas social epidemiology explicitly frames social dynamics as an important determinant of population health, legal epidemiology casts law as an important feature of the risk environment, which can be understood and studied like other population exposures.

Just like with social epidemiology whose roots extend a hundred years before it became an acknowledged field (Durkheim, 1895), legal epidemiology has been around for decades if not longer though not branded or necessarily understood as such (Burris 2010). Epidemiological concepts have been increasingly filtering into legal scholarship as framing devices (e.g., "Legislative Epidemics" in (Carpenter, 2010) and into empirical legal studies as way conceptualize law as an exposure (e.g., "incidence of soda tax" in (Kifer, 2015)). But few studies explicitly apply an epidemiologic perspective to the measurement of law, although a number are undoubtedly on the way (Presley, Reinstein, & Burris, 2015). This study adds to an emerging wave of legal epidemiology. It employs theory about plausible relationships between MCD laws and health behavior to explore the multiple dimensions of MCD-laws as population exposure including start, duration, form, and intensity. This conceptualization of MCD-laws as an exposure then guides the selection and implementation of comparisons aimed at identifying whether some MCD-laws influence fatal crash rates.

Summary

The use of MCDs is a socially important and rewarding behavior. When MCD use occurs behind the wheel of a moving vehicle, however, it increases the risk of crashes and related harms. Law is an established and often necessary tool for addressing such high risk driving behavior. Almost every state has adopted one or more laws prohibiting driver MCD use for at least some drivers. But despite over ten years of experience with these laws, there remains uncertainty about whether they effectively reduce the underlying behavior and its associated harms. The challenges of evaluating such laws have tractable and intractable elements. The impossibility of randomization and the diversity of legal interventions are largely intractable; their distorting effects on the strength of inferences in evaluation research can be minimized but never eradicated. The difficulty identifying comparisons for quasi-experiments is, on the other hand, tractable. Legal epidemiology provides a conceptual framework for systematically measuring and making sense of variation in legal interventions like MCD laws over time and across jurisdictions. This more systematic approach to legal research facilitates the identification of opportunities to design rigorous quasi-experiments.

CHAPTER 2: REVIEW OF THE LITERATURE

Researchers have been studying the use of MCDs by drivers since the late 1960s (Brown, Tickner, & Simmonds, 1969). Over the intervening decades, MCD use has changed both in kind and frequency. Mobile communication devices were a novelty consumer item fifteen years ago; today they are a pervasive feature of everyday life. The use of a mounted rotary car telephone from an early study (Kames, 1978) is a quaint reminder of how much the technology of mobile communication has changed since it began to draw the attention of safety researchers. Not only has the risk behavior changed, but so have available data sources and empirical methods. Administrative data on crash fatalities had not yet taken its modern form as the Fatal Accident Reporting System (FARS) when Brown and colleagues conducted their seminal study in 1969. Driving simulators, which play an important role in the current evidence base, have become vastly more sophisticated over recent decades. This section serves two functions. The first part describes the relevant evidence base with particular attention to the distribution of evidence over research type (e.g., peer-reviewed, report), study aim, methods, publication source (i.e., journal type and topical focus), location and time. The second part reviews the main findings of the evidence base.

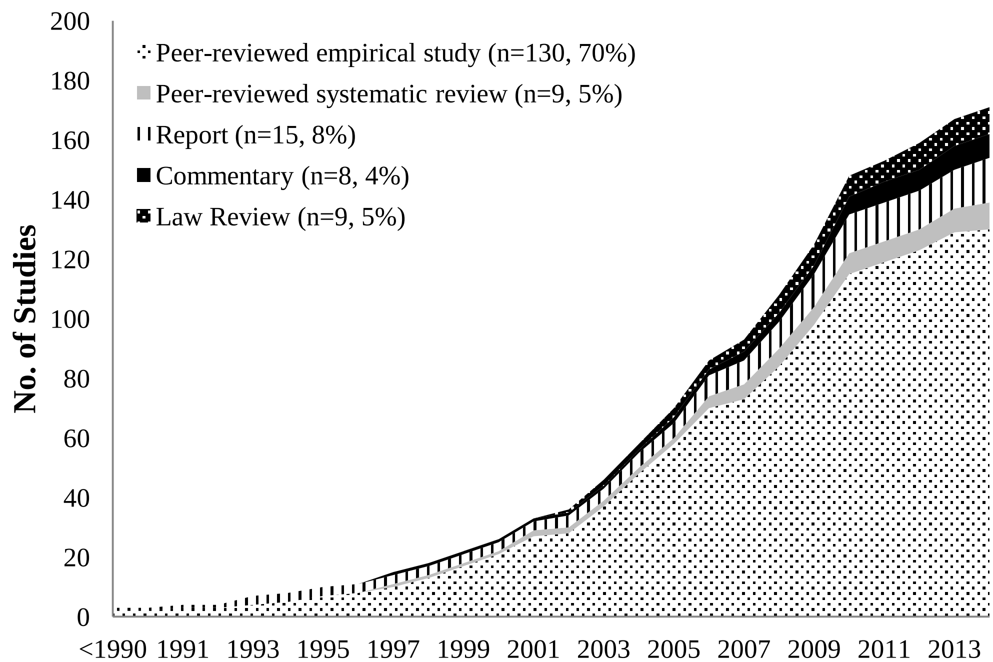
The Epidemiology of MCD Use Behind the Wheel

The Evolution of the Evidence Base

Distribution of Evidence by Type

Since 1969, there have been 130 peer-reviewed empirical studies exploring the frequency, determinants, and effects of MCD use by drivers. These peer-reviewed empirical studies comprise the majority of the evidence base (Figure 1). Given the number of empirical studies, it is not surprising to find nine peer-reviewed systematic reviews, two of which include meta-analysis (Caird et al., 2008; Horrey & Wickens, 2006). The second most numerous type of literature includes government-issued reports, which play two roles in the evidence base. Some reports detail government-sponsored empirical studies like a large naturalistic study using in-vehicle cameras conducted under the auspices of the National Highway Transportation Safety Administration (Klauer et al., 2006; NHTSA, 2006); others synthesize evidence and/or review trends in administrative data (e.g., HLDI, 2010, NHTSA, 2009, 2012).

Figure 1. Evidence Base by Evidence Type



Note: A full table is provided in Appendix A. Numbers and percentages are current as of June 2014

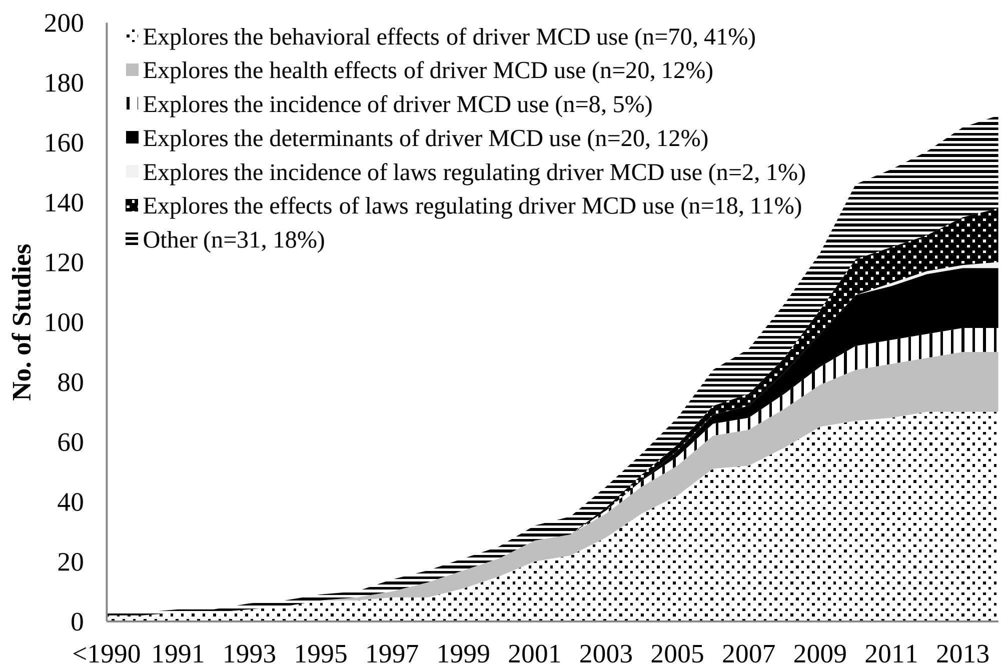
A handful of commentaries - particularly in high profile publications like the New England Journal of Medicine (NEJM) and Journal of the American Medical Association (JAMA) - have further distilled the evidence while pointing out research priorities, methodological challenges, and general changes in the social and ethical dimensions of the problem. For example, commentaries in JAMA have called for more attention to the driver MCD use (Coben & Zhu, 2013) and encouraged physicians to counsel their patients about the dangers of distracted driving (Ship, 2010); another in NEJM reflects on the similarities between distracted driving and impaired driving (Lerner, 2011). Commentaries in JAMA have also conveyed general trends in regulation and education (Jacobson & Gostin, 2010) and offered methodological criticism about prominent studies (Maclure & Mittleman, 1997).

Law review articles comprise a fifth component of the evidence base. Although not peer-reviewed and sometimes written by law students, these publications fill an important gap by exploring the legality and likely effectiveness of laws regulating MCD use behind the wheel. Some law review articles, for example, have provided analysis of the constitutionality of specific laws regulating driver MCD use (Franklin, 2012) while others have examined issues around the constitutionality of searching telephone records for evidence of MCD involvement in crashes (Gershowitz, 2012). Most law review articles are normative in their framing in that they discuss not what the law is or does but what it should be (Amedola, 2008); even these articles, however, typically devote a considerable amount of space to discussion of the relevant literature.

Distribution of Evidence by Study Aim

As with other complicated public health phenomena, researchers have focused on pieces of the puzzle of telecommunicating drivers from their various disciplinary (e.g., epidemiology, psychology, econometrics) and topical perspectives (e.g., transportation safety, health behavior, addiction). This has yielded research with diverse study aims, which can be classified as exploring six dimensions of the problem: the (1) determinants and (2) incidence of the risk behavior, the (3) proximal and (4) distal effects of the risk behavior, and the (5) incidence and (6) effects of interventions. Of the six categories, the most highly represented is the third (Figure 2). Seventy studies explore the proximal effects of MCD use on driving performance as measured by reaction time, reduced attention, and similar indicators. The second most populous category (n=43) includes studies that explore the distal effects of driver MCD use on outcomes like crash incidence and crash injury. Studies exploring the incidence (n=19) and determinants (n=11) of driver MCD use are relatively common as are studies evaluating the effect of legal interventions (n=19). However, only four studies systematically review the distribution of interventions. Important remaining literature ("other") includes reviews and commentaries (n=41).

Figure 2. Evidence Base by Research Focus



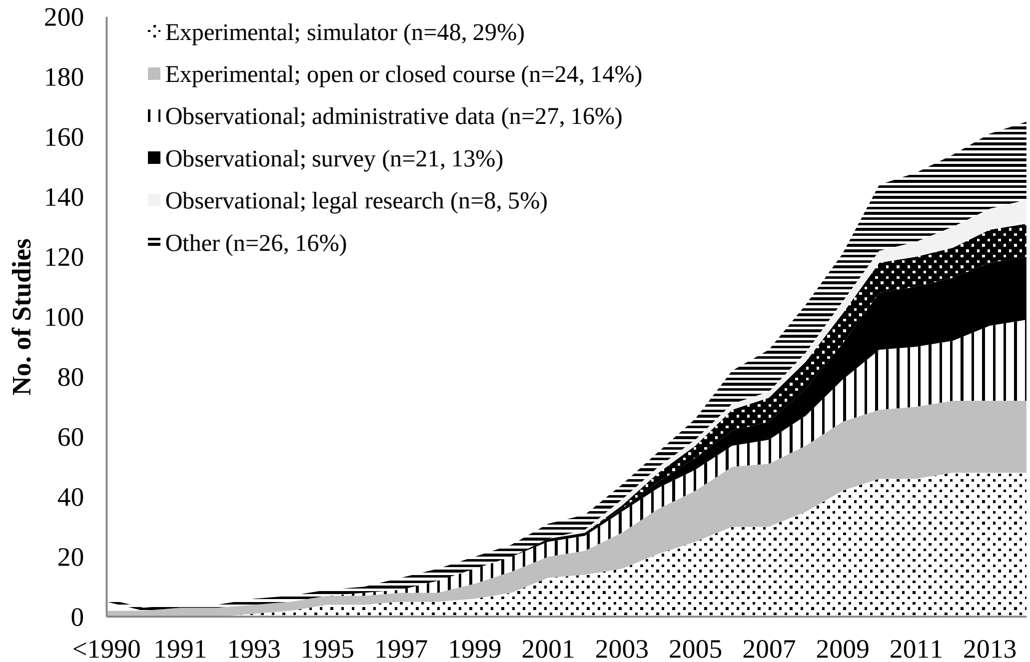
Note: A full table is provided in Appendix A. Numbers and percentages are current as of June 2014

As depicted in Figure 2, research on the incidence and determinants of MCD use behind the wheel did not emerge until a few years into the 21st century when mobile communication devices had just started to proliferate. Studies evaluating the effects of legal interventions did not emerge until around the same time for obvious reasons: there were no laws to evaluate until 2001 in the U.S. That there have been many legal evaluations but only a few studies tracking the incidence of laws reflects the fact that most early legal evaluations examine policy experiments of only one or few states, a pattern common in policy innovation and learning (Burris & Anderson 2013). It is also consistent with the historical tendency in public health to undervalue rigorous descriptive research on policy as a feature of the risk environment.

Distribution of Evidence by Methods Employed

Given the heavy representation of research on the mechanistic properties of MCD use behind the wheel, it is not surprising that almost half of the literature has been experimental (Figure 3), which is defined for purposes here as research involving some intentional manipulation of the relevant exposure. Experiments have enabled researchers to test not just the difference between driving while using an MCD and not, but the relative differences between different types of use (e.g., handheld vs. hands-free use, (Consiglio, Driscoll, Witte, & Berg, 2003), conversation intensity (high vs. low emotionality of dialogue, (Dula, Martin, Fox, & Leonard, 2010; Irwin, Fitzgerald, & Berg, 2000), conversation difficulty (Briem & Hedman, 1995) and context of use (e.g., high vs. low difficulty driving situations, (Rudin-Brown, Young, Patten, Lenne, & Ceci, 2012). A particularly important line of experimental studies has focused on the relative risk of conversing with a passenger versus MCD communication with individuals remote to the vehicle (Amado & Ulupinar, 2005; Charlton, 2009; Gugerty, Rakauskas, & Brooks, 2004; Laberge, Scialfa, White, & Caird., 2004).

Figure 3. Evidence Base by Method(s) Employed

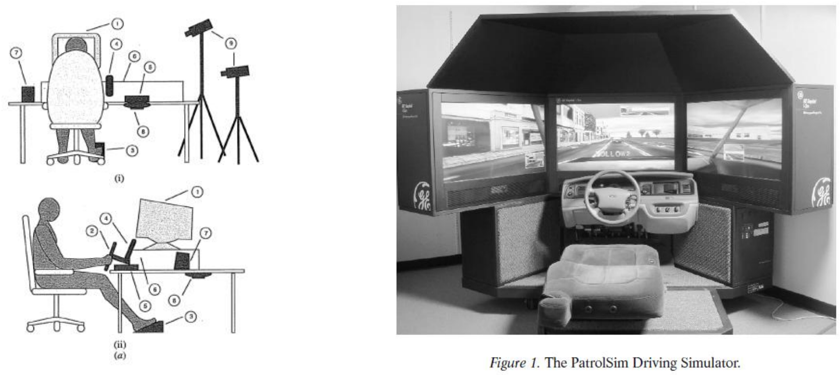


Note: A full table is provided in Appendix A. Numbers and percentages are current as of June 2014

Experimental studies have been conducted in two settings. The more common setting is driving simulators. These devices take a wide variety of forms and have changed significantly over time. They range from simple desk simulators to immersive driving stations (Figure 4). Simulators allow researchers to make subtle differences in the exposure (MCD use) and contextual factors. For example, research teams have explored the effect of texting in tunnels (Rudin-Brown et al. 2012) and handheld MCD use in dense urban environments (Liu & Lee, 2006). Simulators have also enabled researchers to explore a wide array of dependent variables, including, among others braking time (Brookhuis, de Vries, & de Waard, 1991; Strayer et al., 2006), lane positioning (Alm & Nilsson, 1995), speed (Alm & Nilsson, 1994; Gugerty et al., 2004; Horberry et al., 2006; Tornros & Bolling, 2005), and eye movement (Harbluk, Noy, Trbovich, & Eizenman, 2007; Maples, DeRosier, Hoenes, Bendure, & Moore, 2008).

Figure 4. Examples of Driving Simulators

(a) 1995 (b) 2004



Sources: (a) Briem and Hedman (1995); (b) Strayer and Drews (2004).

Roads provide a second setting for experimental studies. These include both closed- and open-courses, the latter occurring in moving traffic on public roads. Closed course studies have often focused on the effects of MCD use during physically challenging driving maneuvers like navigating between narrow spaces (Brown et al., 1969), weaving (Cooper et al., 2003) and sudden braking (Hancock, Hashemi, Howarth, & Ranney, 1999; Hancock, et al., 2003). The risks associated with such testing conditions preclude trials in real traffic alongside other drivers and pedestrians. Studies conducted on open-courses tend to focus on more subtle aspects of MCD use behind the wheel. However, many of these still utilize a car in which a researcher has a redundant set of controls (Lamble, Kauranen, Laakso, & Summala, 1999) or in which the test vehicle is designated with bright signs to warn other drivers about the possibility of reduced safety (Liu & Lee, 2006). In one open-course study, McGarva and colleagues (2006) tested whether drivers react aggressively to seeing MCD use in other vehicles by surreptitiously videotaping 135 drivers traveling through a small city in North Dakota behind a slow driving confederate who sometimes visibly talked on a hand-held MCD. Not surprisingly, drivers appeared considerably more frustrated when the slow driver was using a telephone than not suggesting that MCD use may be contributing “to the growing crisis of roadway aggression.” (McGarva, Ramsey, & Shear, 2006)

One final notable experimental study is a vignette study by Atchley and colleagues (2012) exploring perceptions and social norms surrounding MCD use by young drivers. The researchers had college students read stories about crashes and assign responsibility, fines and jail time. The key experimental variation was whether the driver in the vignette was attentive, had been drinking, or was distracted by MCD use. The researchers also varied the scenario with respect to whether state law prohibited drunk and distracted driving. Alcohol impaired drivers received the highest fines and the longest jail time but distracted drivers were found to be the most responsible. The researchers interpreted the finding as evidence that that norms have not yet changed for distracted driving as they have for alcohol-impaired driving, despite evidence that the subjects know the associated risks of MCD use (Atchley, Hadlock, & Lane, 2012).

There are obvious ethical and practical limitations with experimental research on road safety. It is not surprising therefore that there is a considerable amount of observational research in the evidence base, which can be broadly classified into four categories. The first category is observational research on administratively collected data. Crash incidence and harms are routinely reported and compiled in government databases. The federally-supported Fatal Accident Reporting System (FARS) includes information on over 100 characteristics of fatal crashes. States compile data on a broader but variously defined segment of crashes not involving fatalities. Insurance companies also collect data on crashes related to insurance claims. These administrative data sources are essential to descriptive and inferential studies about patterns and effects of MCD use.

Perhaps the most prominent study in the literature links crash and telephone records (Redelmeier & Tibshirani, 1997). Administrative data has allowed researchers to employ a variety of strategies for isolating the effect of MCD use including, for example, comparing crash trends in single and multiple occupant vehicles (Wilson & Stimpson, 2010).

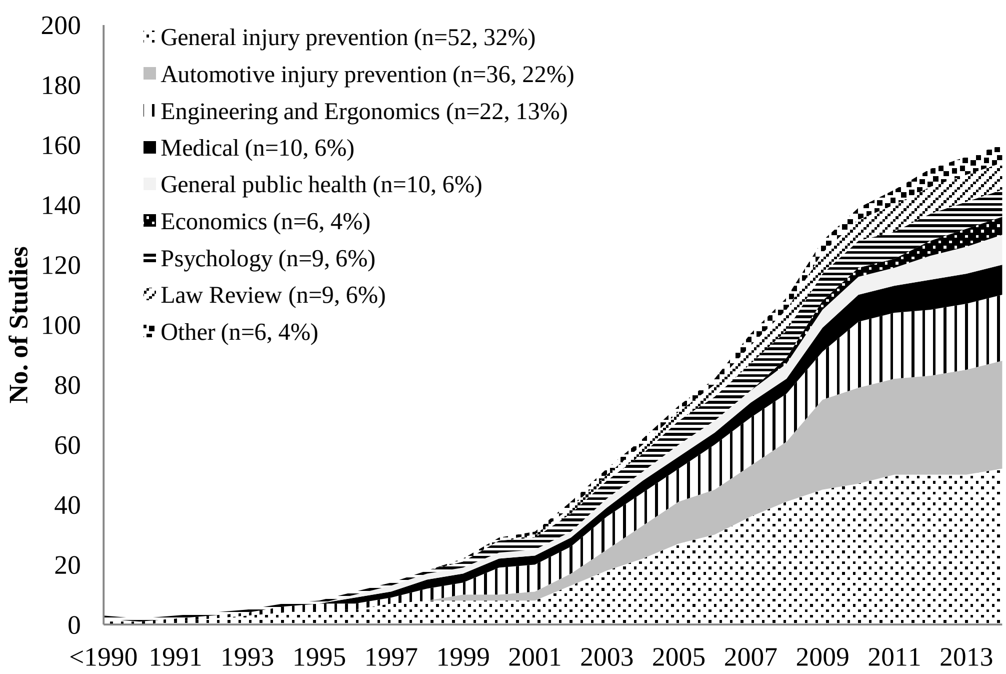
A second type of observational study involves surveying individuals about their behavior, experiences or perceptions concerning MCD use while driving (n=23). Given the logistical difficulty and cost of directly measuring incidence of MCD use behind the wheel surveys represent an important source of information on behavior. Surveys explore patterns of MCD use behind the wheel (Braitman & McCartt, 2010) as well as reported outcomes (Cook & Jones, 2011). Some surveys have measured knowledge and compliance with laws banning MCD use (Foss, Goodwin, McCartt, & Hellinga, 2009; Goodwin, O'Brien, & Foss, 2012). Others have explored how perceived importance of communication content influences behavior (Nelson, Atchley, & Little, 2009). Survey data has allowed researchers to test theories of health behavior like the Theory of Planned Behavior (Nemme & White, 2010). Naturalistic studies represent a third type of observational research and include studies conducted by watching or photographing drivers (Eby et al., 2003, 2006; Vivoda et al, 2008) as well as studies utilizing in-vehicle cameras (Klauer et al., 2006).

A fourth type of observational research is legal research. This can be traditional legal research (Amedola, 2008; Chase, 2014) or more systematic legal epidemiology (Ibrahim, Anderson, Burris, & Wagenaar, 2011). The former is often a snapshot of the law at a specific moment or place, typically with no or very little description of how the legal research was conducted. Ibrahim and colleagues (2011) exemplify a more scientific exploration of MCD-laws by describing how laws were identified and measured.

Distribution of Evidence by Publication Source

The complexity of distracted driving as a health concern is reflected in the diversity of journals in which relevant evidence has appeared (Figure 5). The most common topical focus of such journals is general injury prevention, followed closely by injury prevention journals dedicated to road safety. Notable and important segments of the evidence base have also appeared in ergonomic and engineering journals. Psychological journals housed early studies of MCD use on performance (Brown, et al., 1969; Recarte & Nunes, 2000, 2003). Later psychology research explores the effect of MCD-use on driver aggression (McGarva et al. 2006) and mental workload (Strayer & Johnston, 2001). The late entrance of economists is consistent with the increasing quantity and quality of data measuring variation in MCD laws.

Figure 5. Evidence Base by Publication Field

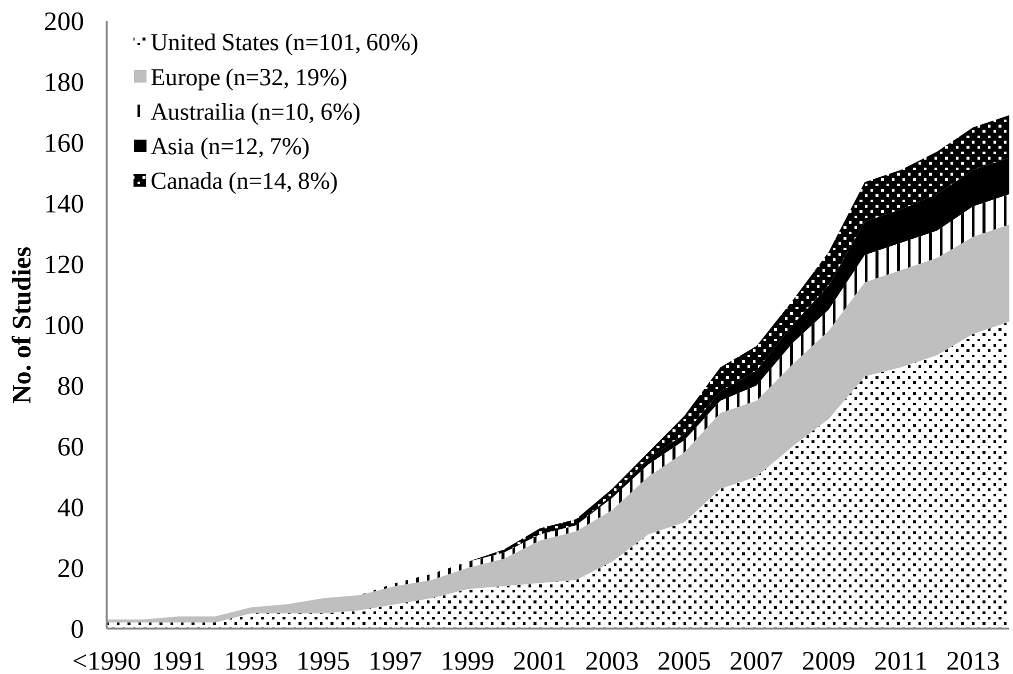


Note: A full table is provided in Appendix A. Numbers and percentages are current as of June 2014

Distribution of Evidence by Geography

Distracted driving is a problem everywhere there are MCDs and roads. It is not surprising therefore that research on driver use of MCDs has been conducted in a diverse array of countries. The design of studies is pretty consistent across regions with one exception: open course studies are much more common outside the U.S. (n=15) than within (n=1)(McGarva, Ramsey, & Shear, 2006) (Figure 6). The same pattern does not exist for closed course studies; only three closed course studies have been conducted outside of the U.S. versus three within. It is unclear whether these patterns reflect relatively more stringent ethics requirements or more accessible driving simulators.

Figure 6. Evidence Base by Country of First Author



Note: A full table with the exact countries is provided in Appendix A. Absolute Number and percentages as of June 2014

Research on MCD use behind the wheel is likely to continue along current trends in terms of diversity and popularity. Since June 2014, there have been more than fifteen additional studies including evaluations of MCD-laws, incidence and outcomes reports, a variety of psycho-social studies.

Review of Key Findings from the Evidence Base

Determinants of MCD Use

Drivers use mobile communication devices for a variety of reasons (Wei, 2008). Over twenty studies have explored the factors that encourage MCD use behind the wheel. These studies examine the determinants of answering or initiating a telephone call or engaging in other uses with devices like text messaging and internet activity. These behaviors have been explored as dichotomous decisions (i.e., to answer a call or not (Nelson, et al., 2009)) and as more nuanced decision-making processes (i.e., whether and how to compensate for MCD use through slower or more attentive driving or shorter and simpler device use (O'brien, Goodwin, & Foss, 2010)). The factors that influence MCD use behind the wheel differ by group and context. Collectively, determinants of driver MCD use can be classified as demographic, perceptual and social factors.

The demographic determinants of MCD use are fairly intuitive. The strongest predictor of MCD use is a pattern of other risky driving behavior. Drivers with a more extensive history of crashes or traffic violations, for example, are more likely to report MCD use and MCD-involved crashes (Cook & Jones, 2011; Prieger & Hahn, 2007). Not surprisingly, male drivers tend to engage in more MCD use and particularly more high risk MCD use (Brusque & Alauzet, 2008). Driving experience, perceived driving skill, and frequency of MCD use in everyday life are also all positively associated with higher rates of MCD use behind the wheel (Brusque & Alauze, 2008). Poystii and colleagues observed this pattern in a large study of licensed drivers and interpreted it as evidence that the risks of MCD use are recognized and “controlled at many levels, by strategic as well as tactical decisions” thereby explaining the why MCD-involved crashes are not more common (Poysti, Rajalin, & Summala, 2005). The evidence supporting this proposition is mixed. On the one hand, large proportions of adults and teens do report engaging in strategies to compensate for the dangers of MCD use while operating vehicles (O'brien et al., 2010). On the other hand, there is plenty of evidence that young and older drivers value MCD use too much to adequately alter behavior (Hafetz, Jacobsohn, Garcia-Espana, Curry, & Winston, 2010; Nelson et al., 2009). This has motivated calls "to minimize the perceived benefits" of MCD use by drivers (White, Hyde, Walsh, & Watson, 2010).

It may also be the case that while drivers recognize that MCD use is generally dangerous, they overestimate their own ability to safely manage risk. Drivers routinely view other drivers' use of MCDs as problematically dangerous, but not their own (Wogalter & Mayhorn, 2005). A set of randomized controlled trials explored an intervention in which subjects drive in a simulator while using a device and then are provided feedback on decreased driving performance. Adults who received the feedback were far less likely to report MCD use in the future; there was a noticeably smaller effect for young drivers (Wang et al., 2009, 2010).

With the exception of surfing the internet or playing games, MCD use is typically a social activity. Social norms influence MCD use directly in the sense that many electronic communications have multiple interlocutors, each with the opportunity to encourage or discourage MCD use behind the wheel. Social norms also play indirect roles in structuring how individuals think about the risk and moral implications of the behavior. In series of experiments, college students read different vignettes and assigned responsibility and penalties for drivers impaired by alcohol and MCD-use; for students in both experiments, drivers using an MCD were viewed as more responsible for crashes than alcohol impaired drivers, but alcohol impaired drivers were assigned higher penalties. The researchers interpreted these results as evidence that public health efforts have shifted social norms around driving under the influence of alcohol, but that norms have not yet changed for distracted driving, even though the risks of MCD use are well known and widely acknowledged (Atchley et al., 2012).

Like many public health issues, risk perception is complicated by the prevention paradox: while MCD use almost certainly increases crash risk, the absolute risk of crashing remains small, whether using an MCD or not. For those who chronically use their MCD behind the wheel, principles of cognitive dissonance support a downward shift in perceived risk. Indeed, Atchley and colleagues suggest that MCD behavior may be driving norms, perceptions, and attitudes surrounding MCD use (Atchley, Atwood, & Boulton, 2010). Pretty intuitive evidence supports this theory: those who use MCDs are far more likely to view MCD use behind the wheel as safe, and vice versa (Wogalter & Mayhorn, 2005).

Incidence of MCD Use

The use of mobile communication devices (MCDs) is a common activity for drivers. Twenty studies have measured the incidence of MCD use behind the wheel. These studies have been conducted using surveys and naturalistic observations. Observational studies have found that anywhere between 3% and 11% of drivers are using an MCD at any given moment (Eby & Vivoda, 2003; NHTSA 2010; Johnson et al., 2004). One large scale four year observational study of Michigan drivers found that hand-held use of devices by drivers increased from 2.7% to 5.8% between 2001 and 2005

(Eby, Vivoda, & St Louis, 2006).

Survey research conveys similarly high rates of use. A CDC study using 2011 survey data revealed that almost 70% of drivers in the U.S. reported using an MCD while operating a vehicle in the 30 days before they were surveyed; over 30% reported reading or sending typed messages (CDC 2013). According to the 2011 Youth Behavior Survey, 45% of high school drivers reported recently having sent or read a text message from behind the wheel (Olsen et al., 2013).

Effects of MCD Use on Driving Performance and Health Outcomes

The most common focus of research on driver use of MCDs has been the relationship between MCD use and driving performance. Over eighty studies conducted in driving simulators or road courses have examined this relationship (Caird, et al., 2008). Early research focused on handheld and visual distraction as the key mechanisms of effect in performance decrements. In 2003, Strayer and colleagues coined the term “inattention blindness” consolidating evidence from increasingly sophisticated studies that the underlying risk process involves information processing more than information perception. These studies suggest that using an MCD impairs an individual's operation of a motor vehicle by reducing ability to perceive and process information, essentially a sort of cognitive overload (Beede & Kass, 2006). The effect is slightly amplified by physical manipulation of devices with one or more hands, but occurs with hands-free devices as well belying the idea that such devices constitute a safe alternative (McEvoy et al., 2005). Conversations with passengers also impair drivers, but the effect is not as great because passengers moderate dialogue in response to changing driving conditions (Drews, Pasupathi, & Strayer, 2008; Charlton, 2009).

Impairment from MCD use manifests as reduced reaction time, weaker attention and poorer overall decision-making (Caird et al., 2008). The riskiness of these performance decrements is compounded by how poorly drivers recognize them occurring (Horrey, Lesch, & Garabet, 2009, 2008; Lesch & Hancock, 2004). In direct comparisons in driving simulators, researchers have found that alcohol intoxication and MCD use produce a similarly high magnitude of impairment (Strayer, Drews, & Crouch, 2006). For obvious reasons, it is hard to test how MCD use affects driving performance outside of laboratory or closed course settings. Use of MCDs is believed to occur in at least 20% of crashes (NHTSA, 2010). But crashes are often complicated events. Many factors influence crash risk. These factors operate and exist independently and collectively. Disentangling the role of MCD use in crash that also involves an alcohol intoxicated drivers is difficult. The strong correlation between MCD use and other risky driving behavior complicates research aiming to isolate the effect of MCD use behind the wheel (Beck, Yan, & Wang, 2007; Zhao et al., 2012). There is also evidence suggesting that MCD use only increases crash risk in difficult driving conditions like on dark and wet roads (Kolko, 2009).

There are a handful of naturalistic studies measuring the relationship between MCD use and crash outcomes. The best known is a case-crossover study in which researchers relied on an extensive analysis of phone use and crash records in finding that MCD use increases crash risk by a factor of four (Redelmeier & Tibshiriani, 1997). The Virginia Tech Transportation Institute has also conducted a handful of large scale studies using in-vehicle cameras and sensory technology to measure the effects of MCD use. One such study based on data from over six million miles of travel found that nearly 80% of crashes and 65% of near-crashes were connected in some way to driver inattention within three seconds of the event and that the most common distraction was MCD use (Klauer et al., 2009). There are also simulation studies that estimate the effect of increasing MCD access and use on crash outcomes (Sperber et al., 2010; Cohen & Graham, 2003; Farmer, et al., 2010). Using data about text message volume, one team of researchers estimate that texting alone resulted in 16,000 otherwise avoidable road fatalities between 2001 and 2007 (Wilson & Stimpson, 2010). Such figures are hard to reconcile with research that finds a smaller or no population effect of MCD use. It is notable, however, that the most rigorous attempt to isolate the population effect of MCD use on crash fatalities, which compared driver MCD use and crash rates around the 9:00 PM "free minutes" threshold, found no evidence that increased MCD use increases fatal crash rates (Bhargava & Pathania, 2013). Fatalities, of course, represent just one crash outcome and do not necessarily provide a good measure of crash risk. It is also possible, as some researchers have speculated (Redelmeier & Tibshirani, 1997; Fowles et al., 2010), that MCD use increases crash risk while decreasing crash mortality by shortening emergency response time. Such orthogonal effects would explain why early laws – adopted while MCD access was widening – appeared to have a protective effect on fatalities while non-fatal crash rates, measured for example by insurance claims, were increasing (HDLI, 2009, 2010).

The Legal Epidemiology of MCD Laws

This section applies an epidemiological lens to MCD-laws. This section does not report on how to systematically define and retrieve MCD-laws. That process has been described elsewhere both in terms of general best practices (Presley et al., 2015) and for the specific issue of MCD-laws (Anderson, Tremper, Thomas, & Wagenaar, 2012); PHLR 2012). This section focuses instead on the form and use of data that quantifies variation in laws. Specifically, it illustrates how systematic measurement of law can guide the identification of opportunities for quasi-experiments.

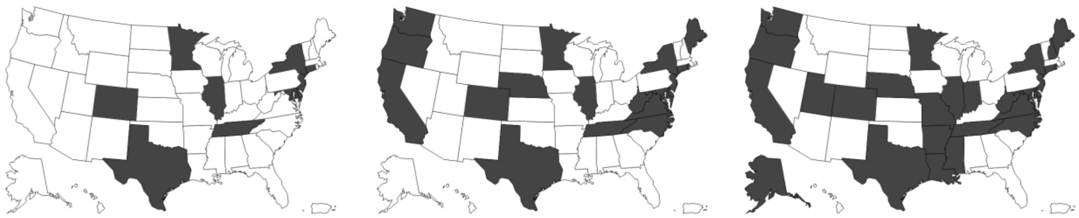
Incidence

Driver use of MCDs has attracted considerable attention from policy-makers since it emerged as a public health concern. There are multiple ways to measure and describe the resulting legislative activity. The simplest is to identify whether a state has adopted an MCD-law in any form. This can be conducted as a snapshot at one point in time or as a series of sequential observations. The former is often depicted in maps, such as Figure 7. The latter can be expressed cumulatively or as a probability function as in Figure 8.

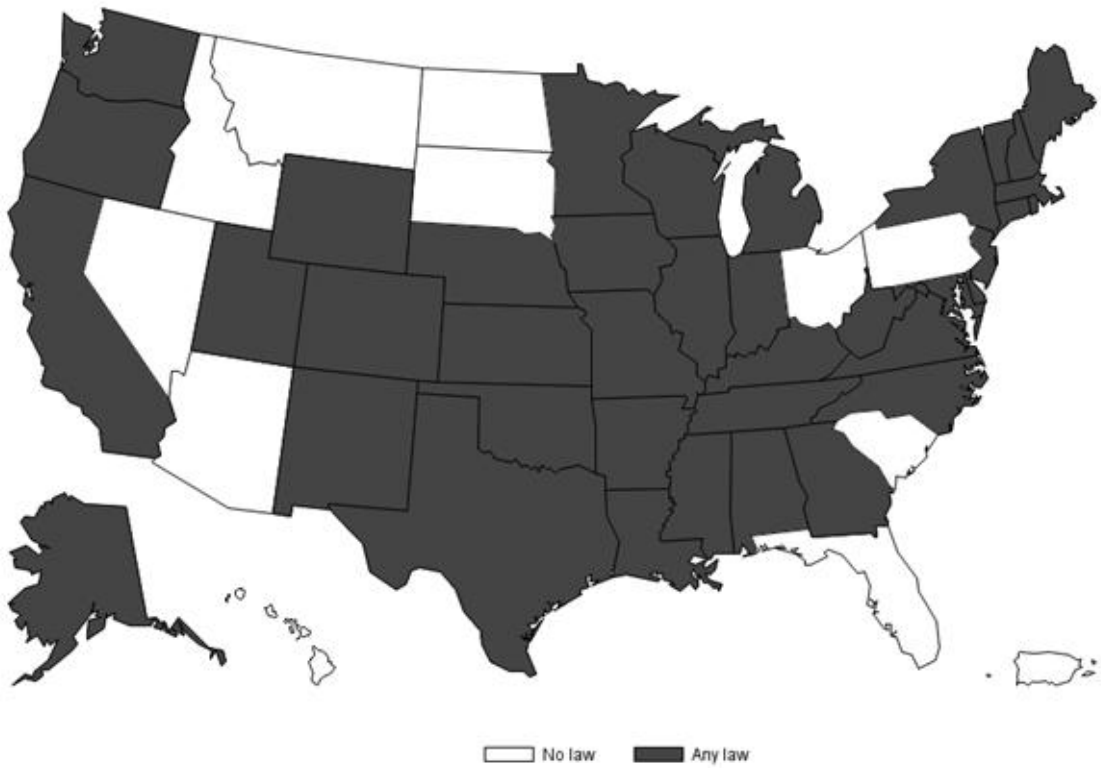
Figure 7. The Spread of MCD-laws Visualized in Maps
States with Any Type and Form of a Law Regulating MCD-Use*

2000 | 2002 | 2004

2006 | 2008 | 2010



2012

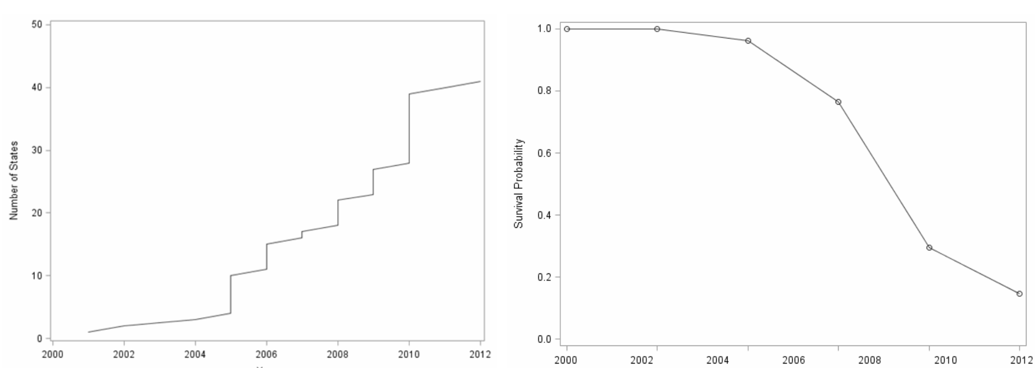


* Note: This reflects all MCD-laws with one exception: this map does not depict the adoption of laws exclusively regulating MCD use by commercial and public sector drivers.

Figure 8. The Spread of MCD-law Visualized Cumulatively and Probabilistically

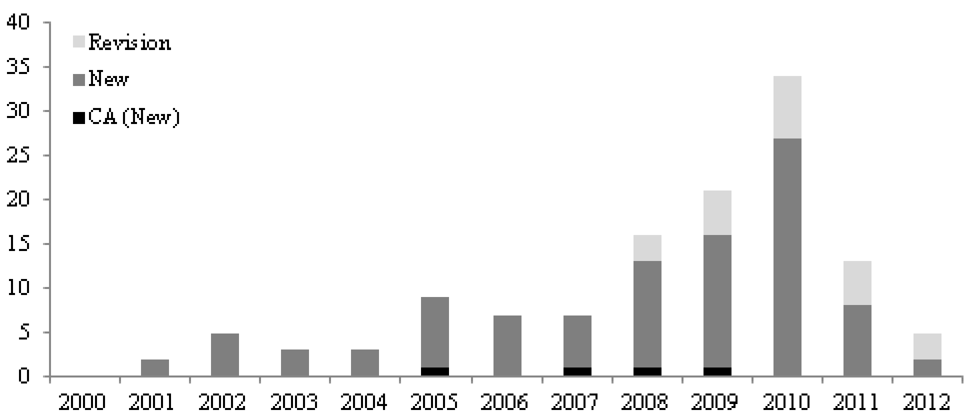
(a) Cumulative Plot

(b) Survival Probability Plot



Representations like Figures 7 and 8 are helpful as general illustrations of the spread of MCD-laws as a dichotomous phenomenon. A slightly more detailed approach is to measure how many times states have adopted a new MCD-law or revised an existing MCD-law. As depicted in Figure 9, states began adding new MCD-laws in 2001 and started to revise existing MCD-laws in 2008. Figure 9 depicts the adoption of 76 new laws and 31 revisions. That 76 laws have been adopted in 50 states underscores that MCD-laws have evolved not only through revision and repeal but also through accretion.

Figure 9. MCD- Law Legislative Activity 2000-2012
Adoption of New Laws or Amendment to Existing Laws



Some states, in other words, have adopted multiple MCD-laws. The black bars in Figure 9, for example, represent the passage of four different MCD-laws in California. One of these laws banned handheld use of MCDs for all drivers (California Statute 23123) in 2007; another banned the use of MCDs by drivers under 18 (California Statute 23124) in 2008. The four California MCD-laws in Figure 9 each became effective at a different time and none were repealed. The laws therefore exist concurrently to a varying degree over four time periods, as described in Table 1.

Table 1. MCD-Laws in California, 2000-2012

State	Start	End	Iteration	Legal Text	Narrative Description of Change
CA	1/1/05	12/31/06	1	CA Statute 23125	On 1/1/05, California Statute 23125 prohibits hand-held use of MCDs for bus drivers. The fine for a first offense is $20; the fine for subsequent offenses is $50. Enforcement is primary.
CA	1/1/07	6/30/08	2	CA Statute 23125 CA Statute 23123	On 1/1/07, California Statute 23123 prohibits hand-held use of MCDs for all drivers. The fine for a first offense is $20; the fine for subsequent offenses is $50. Enforcement is primary. CA Statutes 23125 is unchanged, and therefore hand-held use of MCDs is still prohibited for bus drivers, with the same fines and primary enforcement.
CA	7/1/08	12/31/09	3	CA Statute 23125 CA Statute 23123 CA Statute 23124	On 7/1/08, California Statute 23124 prohibits drivers under age 18 from all use of MCDs, handheld and hands-free, except for emergency calls. The fine for a first offense is $20; the fine for all subsequent offenses $50. Enforcement is secondary. CA Statutes 23125 and 23123 are unchanged, and therefore hand-held use of MCDs is still prohibited for all drivers, with the same fines and primary enforcement.
CA	1/1/09	12/31/12	4	CA Statute 23125 CA Statute 23123 CA Statute 23124 CA Statute 23123.5	On 1/1/09, California Statute 23123.5 prohibits all drivers from using an MCD to send or read text-based communication. There is an exception for starting or stopping a call. The fine for a first offense is $20; the fine for all subsequent offenses $50. Enforcement is primary. CA Statutes 23125 and 23123 are unchanged, and therefore hand-held use of MCDs is still prohibited for all drivers, with the same fines and primary enforcement. CA Statute 23124 is unchanged and therefore drivers under age 18 are still prohibited from all use of MCDs, handheld and hands-free, except for emergency calls, with the same fines and secondary enforcement.

Notes: This is a simplified representation for illustrative purposes only.
*The final end month for the last iteration is always December 31, 2012, the end of the study period. Changes are considered to be effective if they are effective at any time in the month.

Table 1 essentially aggregates the California laws into the same observation periods, which is necessary to convey the full scope of regulation in the state at any time. But this leaves the empirical researcher in the position of having multiple exposures in the same time period, which only works if the legal exposures are additive and can operationalized as incremental units within an interval variable. But this is not the case* and therefore a measurement process predicated on counting MCD-laws would falter in attributing a greater dose to states like California.

To measure variation across time and states, a lower common denominator than the number of state laws is needed. This requires taking the aggregated states laws and disaggregating them into the constituent parts. Unlike many qualitative studies of written texts - thematic analysis of transcripts for example - the study of interventional laws may be grounded in a simple ontology, which can guide the disaggregation of the laws into their constituent parts. Each MCD-law is composed of four elements: a regulated class of drivers, a regulated activity, a method of enforcement, and a fine for violation(s). The class of drivers is defined in terms of age and experience. The activity prohibited is defined in terms of proscribed behavior - talking and texting - and permissible exceptions - hands-free use and starting and stopping a call. The method of enforcement is defined by whether law enforcement officers are allowed to stop drivers for violating the rule even if no other infractions are observable (i.e., primary enforcement), or if enforcement can only occur in the presence of some other infraction (i.e., secondary enforcement). The fines for violations have multiple dimensions because states set graduated penalties for first, second and third offenses. Figure 10 displays the ontology for MCD-laws.

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* The presentation of the law typically does not matter; what matters is the common understanding of the law among drivers and what the law enforcers implement. In a study that contemplates a stronger role of law in shaping social norms - perhaps mediated through public attention to debate about law-making - the passage of multiple MCD-laws might merit a different measurement approach. It is at least theoretically plausible that placement of the law - for example, within a criminal reckless driving statute - might resonate with the anchoring theories about law offered by Dan Kahan (Kahan 1998) or that repeated revision and piecemeal legislation might keep MCD-laws in the public consciousness augmenting normative effects.

Figure 10. MCD-law Ontology

MCD Law	=	Regulated drivers	+	Regulated activities	+	Enforcement method	+	Fine Amount
		• Age 16 on provisional license • All age 16 • Age 17 on provisional license • All age 17 • Age 18 on provisional license • All age 18 • All • All on provisional license		• Hand-held talking • Hands-free talking • Texting, no SS exception • Texting, SS exception		• Primary • Secondary		• First/second/third

Notes: The classes of drivers are nested rather than mutually exclusive. In no instance does a state regulate, for example, 18 year old drivers, but not 17 year old drivers; all laws regulating 18 year old drivers encompass age 17 and younger drivers.

Excluding fines because of their continuous nature, there are 64 (8*4*2) possible permutations of the first three elements of the ontology. Each of these permutations represents one manifestation of what an MCD-law could conceivably require, or what might be called, for narrative simplicity, an MCD-rule.

In Table 2, each of the 64 possible MCD-rules are numbered. The sixth column notes whether the rule is in-effect in California at the end of 2012 purely for illustrative purposes. The final three columns convey how many rules exist at the end of 2004, 2008 and 2012 among all the states. A state can have multiple rules but at most 32 because the stipulated enforcement cannot differ for the same activity and regulated class.

Table 2. The Incidence of MCD Rules in December of 2004, 2008 and 2012

MCD Law	= Regulated drivers	+ Regulated activities	+ Enforcement method	I.D. No.	Effective in CA in 2012	Number of states with the rule at end of: 2004	2008	2012
	Age 16 drivers on provisional license	Hand-held talking	Primary	1	√	3	13	28
			Secondary	2		0	7	3
		Hands-free talking	Primary	3	√	1	9	22
			Secondary	4		0	5	3
		Texting, with SS exception	Primary	5	√	1	12	36
			Secondary	6		1	7	3
		Texting, no SS exception	Primary	7		1	11	29
			Secondary	8		1	6	3
	All age 16 drivers	Hand-held talking	Primary	9	√	3	13	28
			Secondary	10		0	7	3
		Hands-free talking	Primary	11	√	1	9	22
			Secondary	12		0	5	3
		Texting, with SS exception	Primary	13	√	0	12	36
			Secondary	14		1	7	3
		Texting, no SS exception	Primary	15		0	11	29
			Secondary	16		1	6	3

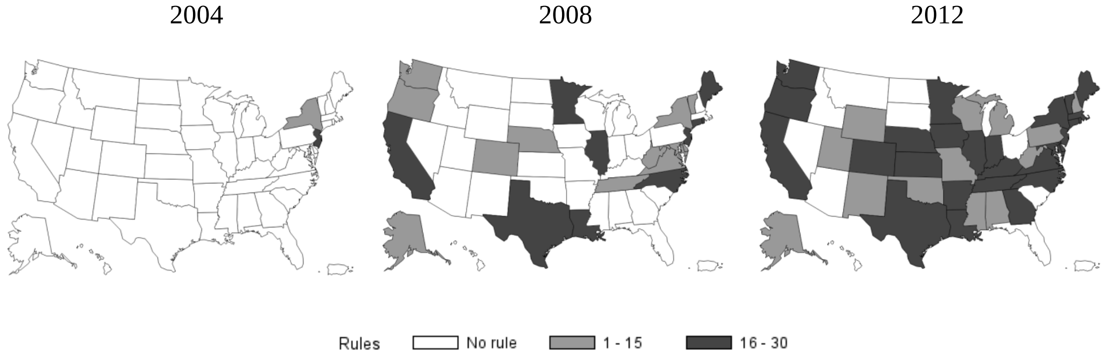
Table 2, continued

Age 17 drivers on provisional license	Hand-held talking	Primary	17	√	3	12	28
		Secondary	18		0	7	3
	Hands-free talking	Primary	19	√	1	8	21
		Secondary	20		0	5	3
	Texting, with SS exception	Primary	21	√	0	11	36
		Secondary	22		1	7	3
	Texting, no SS exception	Primary	23		0	10	28
		Secondary	24		1	6	3
All age 17 drivers	Hand-held talking	Primary	25	√	2	8	18
		Secondary	26		1	4	3
	Hands-free talking	Primary	27	√	0	5	12
		Secondary	28		0	3	3
	Texting, with SS exception	Primary	29	√	0	7	30
		Secondary	30		1	5	5
	Texting, no SS exception	Primary	31		0	6	20
		Secondary	32		2	4	5
Age 18 drivers on provisional license	Hand-held talking	Primary	33	√	2	6	10
		Secondary	34		1	0	3
	Hands-free talking	Primary	35		0	1	2
		Secondary	36		0	0	0
	Texting, with SS exception	Primary	37	√	0	5	31
		Secondary	38		1	1	3
	Texting, no SS exception	Primary	39		0	1	1
		Secondary	40		0	0	0
All age 18 drivers	Hand-held talking	Primary	41	√	2	5	9
		Secondary	42		1	0	2
	Hands-free talking	Primary	43		0	0	1
		Secondary	44		0	0	0
	Texting, with SS exception	Primary	45	√	0	5	31
		Secondary	46		1	1	3
	Texting, no SS exception	Primary	47		0	1	7
		Secondary	48		1	0	2
All drivers	Hand-held talking	Primary	49	√	3	4	8
		Secondary	50		0	0	0
	Hands-free talking	Primary	51		**0**	**0**	**0**
		Secondary	52		**0**	**0**	**0**
	Texting, with SS exception	Primary	53	√	1	3	29
		Secondary	54		0	3	4
	Texting, no SS exception	Primary	55		0	1	14
		Secondary	56		0	1	3
All drivers on provisional license	Hand-held talking	Primary	57	√	3	8	12
		Secondary	58		0	4	4
	Hands-free talking	Primary	59		2	4	6
		Secondary	60		0	3	3
	Texting, with SS exception	Primary	61	√	1	6	30
		Secondary	62		0	4	8
	Texting, no SS exception	Primary	63		1	5	20
		Secondary	64		0	3	5
		Total	**64**	**20**	**46**	**323**	**726**

As depicted in the last three columns of the last row in Table 2, the number of rules has steadily increased indicating that state laws are becoming more complex and more restrictive, although it is notable that no state currently bans hands-free use of MCDs for all drivers, subject to either primary or secondary enforcement (Rules 51 and 52).

Figure 11 depicts the distribution of rules across the U.S. states and over time.

Figure 11. Number of Rules by State for 2004, 2008 and 2012



Here again, these maps illustrate that rules regulating MCD use by drivers are plentiful and have spread rapidly. But they omit or obscure information about the differences between rules. Each element in the ontology has a valence; a stronger law regulates more drivers, prohibits more activity with fewer exceptions, and authorizes primary enforcement. This idea of strength could be operationalized in a scale which measures variation in MCD-laws across the elements in the ontology. And such a scale could guide the design of quasi-experiments, providing the opportunity to incorporate dose-response analysis.

Implementing such a scale raises some difficult questions. Is a law that restricts more activity for fewer drivers stronger than one that bans less activity for more drivers? There is evidence about risk of driver MCD use to inform this type of question. However risk can be expressed multiple ways, and each makes as much sense as the other unless the concept of strength is further defined. A relative risk paradigm, for example, might assign more importance to laws regulating drivers under age 19 who are involved 3.3 times as many crashes as older drivers on a per mile basis. Attributable and absolute risk paradigms, however, would assign more importance to laws regulating adult drivers who account for 97% of all licensed drivers and 95% of fatal crashes.

Table 3. Potential Weighting Options by Age

Drivers Groups	Percentage of Licensed Drivers	Absolute Percentage of Involvement in Fatal Crashes	Percentage of Involvement by VMT
Risk Expression	Potential Risk*	Attributable Risk*	Relative Risk***
Age 16	0.6%	1.0%	
Age 17	1.0%	1.5%	3.3
Age 18	1.3%	2.5%	
Age 19 and above	96.6%	94.6%	Reference

Sources: * NHTSA, 2011; ** Massie & Campbell, 1993

Decisions about scale construction and weighting can only be made with a clear purpose and theory in mind. In Table 4 below, a scale is provided for illustrative purposes. The highest possible score in the stringency scale is 100, which reflects a total ban on all driver activity with MCDs. Each row represents the combination of a population subgroup and a prohibited activity. For example, the first row represents age 16 drivers on a provisional license and the activity of talking on an MCD. If a state law bans this group from engaging in this activity, the stringency score in the state is increased by 3. If that restriction is enforced primarily, an additional one point is added for a total of 4. If an exception is provided for hands-free use, one point is subtracted. For texting restrictions, one point is also subtracted for an exception for starting and stopping a call.

Table 4. Illustrative MCD-law Stringency Scale

Group Covered	Activity	Prohibited Weight	Hands-free exception Weight	Start-Stop exception Weight	Primary enforcement Weight	Total possible for each group/ activity combination
Age 16 drivers on provisional license	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
All age 16 drivers	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
Age 17 drivers on provisional license	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
All age 17 drivers	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
Age 18 drivers on provisional license	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
All age 18 drivers	Talking	4	-1	NA	1	5
	Texting	4	NA	-1	1	5
All drivers	Talking	16	-5	NA	1	17
	Texting	16	NA	-5	1	17
All provisional drivers	Talking	2	-1	NA	1	3
	Texting	2	NA	-1	1	3
Total						**100**

When applied to the MCD-law data, this stringency scale reflects the considerable variation in the laws over states and time. In Figure 12(a) the mean state stringency increases from 2006 to 2010 before leveling off. The median stringency score follows the same general path, although the mean and median reverse position reflecting the higher frequency of less stringent laws before 2008 versus the greater frequency of higher scores (and extreme low scores) from 2009 to 2012. The maximum stringency score – depicted by the upper whisker and listed below each boxplot – has increased relatively little.

Figure 12. Distribution of MCD-law Stringency, 2000-2012

(a) Boxplot of MCD-Law Stringency (b) MCD-Law Stringency Scores by Effective Date

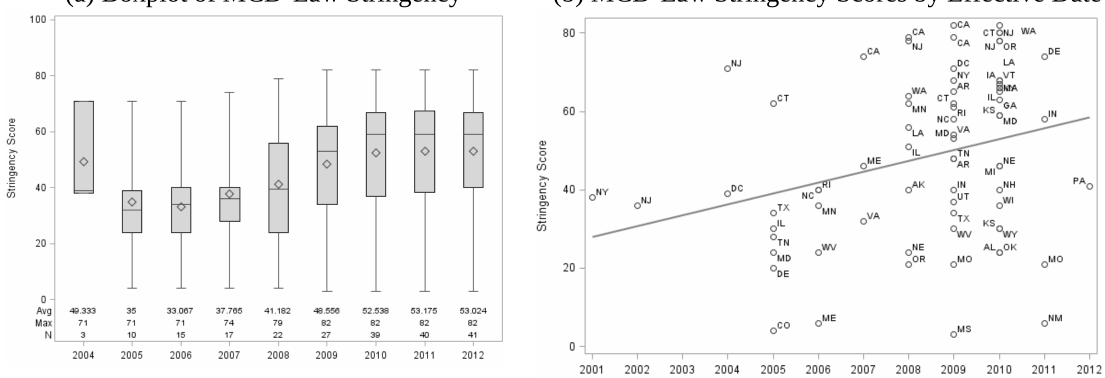
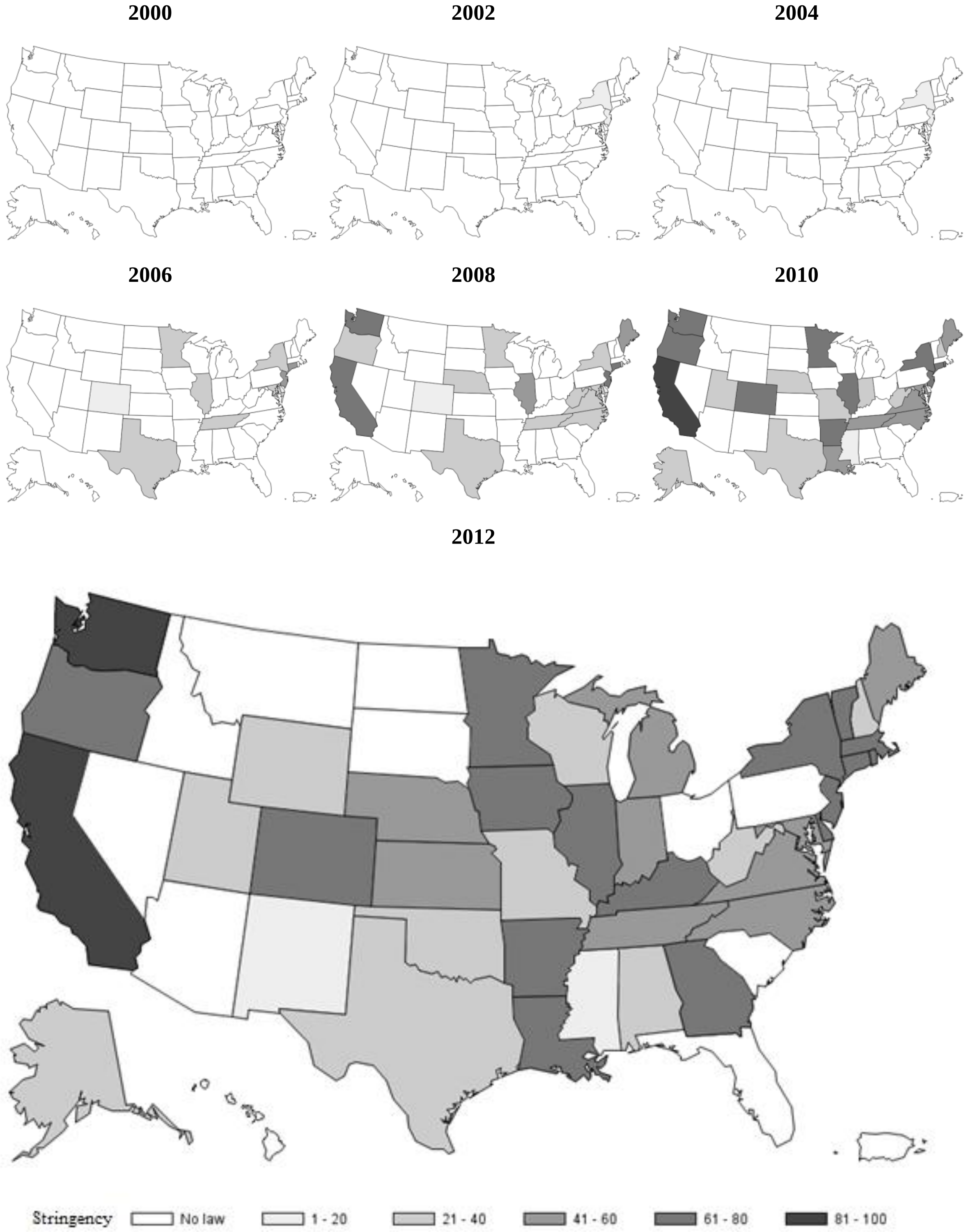


Figure 12(b) conveys that states have tended to adopt stronger laws over time but that relatively weak laws continue to emerge. When plotted over time and by state, as in Figure 13 below, these stringency scores display considerable variation.

Figure 13. The Distribution of MCD-law Stringency Visualized in Maps



With the right data and enough theory, a scale could provide the basis for comparisons between fatal crash trends involving all drivers in states with MCD-laws of varying strength. A simpler approach that relies on fewer assumptions is to use understanding about variation in MCD-laws to select for evaluation MCD-laws which only regulate a portion of a state population and for which there is a readily available comparison group. Perhaps the best example of such laws in this context are state MCD-laws that only regulate drivers under a specific age. These laws, which almost always use age 18 as the relevant threshold, have several attractive features for use in quasi-experiments. First, and most importantly, by defining coverage for the law in terms of age, these laws provide sharply ascertainable treated and untreated groups in the form of those drivers just below and above the threshold. Second, these age-defined laws are typically among the strongest MCD-laws in their other features, banning all or most activity with MCDs and enabling primary enforcement.

While these age-restricted laws present good evaluation opportunities, they can be difficult to identify in a legal landscape in which laws continue to rapidly emerge and evolve. The difficulty is not just finding such laws and their various incarnations as amended over months and years. It also requires research to determine if other potentially confounding laws also exist in the state around the same time. And finally, for the strongest possible inferences, it is preferable that age-restricted laws exist in states near states without any such laws. This final step enables comparisons between the same age group across treated and untreated states. Altogether, this process of identifying groups exposed to a strong MCD-law and similar un-exposed comparison groups is surprisingly complex. Guided by the ontology, however, this process is readily solved by a simple search algorithm across the numeric data measuring variation in the law. Algorithms can be designed to retrieve different comparisons based on other theories about how the law influences behavior or to privilege other design considerations such as the state size or demographic traits. In the primary analysis in this study, discussed in the Chapter Three, the algorithm identifies a procession of state-months in which MCD use is banned for drivers under a specific age but not prohibited for drivers of the same or similar age groups in one or more proximal states. For illustrative purposes, the results for a few different search strategies are presented in Table 5.

Table 5. Number of State-Months Meeting Different Criteria, 2000-2012

Year	State Has "Any Law" and at least 1 Adjacent State Does Not	State Has "Any Law" and at least 3 Adjacent States Do Not	State Has Stringency Score Twice As Large the Lowest Adjacent State	State Has a Stringency Score 1.5 Times As Large The Lowest Adjacent State
2000	0	0	0	0
2001	1	1	1	1
2002	24	12	24	24
2003	24	12	24	24
2004	34	12	34	34
2005	72	36	72	64
2006	156	85	156	116
2007	192	102	192	142
2008	234	102	234	164
2009	265	110	271	187
2010	300	80	323	240
2011	257	24	331	246
2012	222	24	306	242
Total	1,781	594	1968	1484

Notes: The total amount of all state-months in 7344, which corresponds to 144 months (2000-2012) for each of the 50 states and the District of Columbia.

The salience of these comparisons depends on identifying assumptions and aims. In general, however, it is interesting although not surprising to observe that opportunity differs by the nature of the comparison and sometimes follows a parabolic distribution over time with increasing and then diminishing opportunity.

Effectiveness of Current MCD Laws

Studies evaluating the effects of MCD-laws began to appear shortly after the first laws emerged. In 2001, New York adopted the first MCD-law when it prohibited handheld MCD use for all drivers. McCartt and colleagues evaluated the effect of the law on observed MCD use at intersections. They found a substantial reduction in MCD-use from the few months before the law became effective (2.3%) compared with the few months after (1.1%). Across the same two periods, the rate of observed use in Connecticut, which lacked an MCD-law, was unchanged (McCartt, Braver, and Geary 2003). In a follow-up study the next year assessing the durability of the reduction, McCartt and colleagues found that the reduction had dissipated, and that rates of observed use had risen 2.1% (McCartt & Geary, 2004). In a trend analysis using Connecticut drivers as a control group, there was some evidence suggesting that there was less of an increase in New York than expected although the finding did not reach statistical significance.

In July of 2004, Washington D.C. adopted an MCD-law banning adult drivers from inattentive driving including handheld MCD use. The law also banned bus drivers and drivers on learner’s permits from all MCD use (i.e., handheld and hands-free). McCartt and colleagues compared observed driver use of MCDs in the three months before and the three months after the law became enforceable. Observed use once again declined, this time from 6.1% to 3.5% across the pre-law and post-law periods. And once again, the reduction was larger than reductions in nearby states (Maryland and Virginia) without MCD-laws (McCartt et al., 2006). In a similar follow-up study to that in New York, McCartt and colleagues evaluated the effect of the D.C. law fifteen months after implementation. They observed a small reduction in the initial effect of the law (from 3.5% to 4.0%). However, the change from the pre-law period to the period one year after remained practically important and statistically significant (6.1% to 4.0%). This follow-up study on the Washington D.C. MCD-law remains one of the strongest in the evidence base given the size of the effect and its sustainability. It is important to note, however, and as the authors do, that drivers may have simply switched to hands-free use which is not appreciably safer (McCartt & Hellinga, 2007). It is also noteworthy that these four preceding studies measured observed use at traffic lights, which might not generalize very well to highway driving, which is associated with higher crash morbidity and mortality.

In 2006 North Carolina prohibited all drivers under age 18 from all use of MCDs. Foss and colleagues evaluated the effect of the law by observing MCD-use among students leaving high school parking lots in the two months before and five months after the law took effect. Observed use actually increased slightly across the two periods from 11.0% to 11.8% in North Carolina; in a comparison state, South Carolina, observed use remained the same (13%) over the two periods. In the same study, Foss and colleagues also surveyed students about their knowledge of the law and beliefs with respect to how stringently it was being enforced. Most students reported knowledge of the law (64%), but few (22%) believed that the law was being vigorously enforced (Foss et al. 2009).

McCartt and colleagues replicated their observations across the preceding studies in 2009. In all of the states - both with and without MCD-laws - observed use increased significantly. However, the absolute levels and proportional increases were significantly smaller in the states with MCD-laws. According to their analyses, observed use was 43%, 65% and 24% lower than expected in D.C., Connecticut and New York respectively at this longer interval, which ranged from seven years for New York to four years for

Connecticut. They observed that enforcement was generally low in all three states and that the issue had lost of its popular urgency (McCartt, Hellinga et al., 2010).

While research relating MCD-laws to MCD use behind the wheel emerged shortly after the first laws, research examining the relationship between MCD-laws and crash outcomes did not appear for five years after the first law appeared in New York. This changed abruptly starting in 2009 with the emergence of multi-state panel analyses. One of the first compared state-level data on mobile phone ownership, MCD-laws, and traffic fatalities (Kolko, 2009). It found a positive relationship between MCD ownership and crash fatalities, and a protective effect of MCD-laws but only for driving in rainy conditions. In 2010, a team in New York compared trends in fatal and non-fatal crashes in New York counties before and after the 2001 law took effect (Nikolaev, Robbins, & Jacobson, 2010). They found significant protective effect associated with the law. However, this paper was criticized on methodological grounds and a re-analysis found no effect (Sampaio, 2010).

Around this time, the Highway Data Loss Institute (HLDI) conducted two studies on the relationship between MCD-laws and crashes measured by insurance claims, which HLDI systematically collects and analyzes. In the first study, HLDI examined whether the reductions in handheld use observed by McCartt and colleagues in New York, Washington D.C. and Connecticut, as well as California, which enacted a strong MCD law in 2008, resulted in fewer crash claims in comparisons with adjacent control states. HLDI found no evidence linking the MCD-laws to lower crash rates (HLDI 2009). The next year HLDI examined the relationship between MCD-laws exclusively banning texting, of which there were thirty at this point, and crash claims. The results were surprising: crash claims increased significantly in states that banned the use of MCDs for texting compared to states with no MCD-laws or which had not altered the state MCD-law over the study period. This study included an especially rich set of covariates to reduce regional and demographic confounding (HLDI, 2010).

In 2010, Abouk and Adams conducted a set of panel analyses exploring the relationship between MCD-laws exclusively banning texting and fatal crashes. Using multi-period difference-in-differences techniques,[†] they found that MCD-laws banning texting were associated with fewer single-vehicle, single-occupant crashes. The effect was only observed for primarily enforced laws and was short-lived, with crash rates returning to their pre-law trend within a few months (Abouk & Adams, 2013). Cheng conducted similar panel analysis in 2010 once again focusing on MCD-laws exclusively banning text by employing the same covariates while also attempting to control for enforcement proxied by state spending on highway safety, and general driver safety behavior proxied by observed seat belt use. Similar to Abouk and Adams, Cheng found a small evanescent reduction for primarily enforced texting bans (Cheng, 2013).

Until recently, no studies have evaluated the effect of laws aimed exclusively at younger drivers on crash outcomes. One study, just out, yields the strange finding that laws specifically restricting MCD use by young drivers do not decrease MCD use by young drivers, but laws aimed at the general population do reduce MCD use among

[†] A recent literature has explored the problems of serial correlation with the use of difference-in-difference regression across multiple periods (Angrist 2010). In this literature, there are replication studies that test such multi-period difference-in-difference analyses with fake placebo interventions; some find up to 45% of the placebo laws effective at a 95% confidence level (Bertrand, Duflo, & Mullainathan, 2004). One validated correction is to collapse the numerous periods into pre- and post-periods, the strategy I employ below.

youths and only youths (Lim & Chi, 2013). In a second related paper the authors explore the relationship between MCD-laws and fatal crash rates while segmenting alcohol-involved crashes and controlling for GDL laws. This yields the same finding as in the first paper, namely that MCD-laws banning handheld MCD-use for all drivers reduce fatal crashes involving young drivers. In a parallel analysis, they also find no effect of GDL laws on crash fatality over the last ten year period, which is inconsistent with the literature (McCartt et al., 2009).

In 2014, Eshani and colleagues evaluated a Michigan MCD-law exclusively banning text messaging utilizing data on all crashes in Michigan. In set of time series analyses, they conducted trend analyses before and after the MCD-law for crashes involving serious and fatal injuries, non-serious injuries, and no-injury. Although the number of no-injury crashes declined after the MCD-law took effect, the rates of the other more serious crashes significantly increased even after controlling for a multitude of confounding factors (Ehsani, Bingham, Ionides, & Childers, 2014).

Research on MCD-laws has followed a pattern common in the evaluation of state public health law legal intervention (Burris & Anderson, 2013). Early studies tend to explore the relationship between one MCD-law and observed use; later studies exploit variation in MCD-laws across all fifty states in panels utilizing national data sources like FARS and NOPUS. All seventeen peer-reviewed studies are displayed in Table 6.

Table 6. Studies Evaluating MCD-Laws

Author(s) and Year	Evaluated Laws	Outcome and Source	Identification Strategy	Finding(s)
McCartt et al. (2003)	NY MCD-law banning all HH-use	Observed handheld use	Pre-post with adjacent state control (CT)	NY observed handheld MCD use declined from 2.3% to 1.1%; one year later, use was 2.1%, higher than immediately post-law

Table 6, continued

McCartt & Geary (2004)	NY MCD-law banning all HH-use	Observed handheld Use	Pre-post with adjacent state control (CT)	One year later, NY use back to pre-law rates; trend analysis using CT (without an MCD-law) as control suggest NY rates lower than expected
McCartt et al. (2006)	DC MCD-law banning all HH-use	Observed handheld use	Pre-post with adjacent state control (MD, VA)	DC observed handheld MCD use declined from 6.1% before the law to 3.5% after. Rates in MD and VA, control states, increased over same period
McCartt & Hellinga (2007)	DC MCD-law banning all HH-use	Observed handheld use	Pre-post with adjacent state control (MD, VA)	Small dissipation in the initial effect of DC law (from 3.5% to 4.0%), but change from period before the law remained significant (6.1% to 4.0%).
Foss et al. (2009)	NC MCD-law banning all use for age>18	Observed handheld use	Pre-post with adjacent state control (SC)	No reduction in handheld use; wide knowledge of the law among youths but little confidence in enforceability
Kolko (2009)	All state MCD-laws	Fatal Crashes (FARS)	Multiple period D-in-D, fifty states	High mobile phone ownership associated with high traffic fatalities in bad weather; no effect for MCD-laws
HDLI (2009)	All state MCD-laws banning HH-use	Insurance claims	Two period D-in-D, fifty states	No observed relationship between MCD laws and insurance crash claims rates
HLDI (2010)	All state MCD-laws banning texting	Insurance claims	Multiple period D-in-D, fifty states	MCD-laws banning texting associated with higher insurance crash claims
Nikolaev et al. (2010)	NY MCD-law banning all HH-use	NY state data on fatal, disabling, and minor crashes	Multiple period D-in-D, NY counties	NY MCD law associated with reduction in fatal crash rates in 46 NY counties; 62 counties experienced lower injury crash rates
Sampaio (2010)	NY MCD-law banning all HH-use	NY state data on fatal, disabling, and minor crashes	Multiple period D-in-D, NY counties	Criticism and re-analysis of Nikolaev et al. finds no effect and poor identification strategy
Abouk & Adams (2013)	All state MCD-laws banning texting only	Fatal Crashes (FARS)	Multiple period D-in-D, fifty states	Only primary-enforceable laws effective; only short-term effect

Table 6, continued

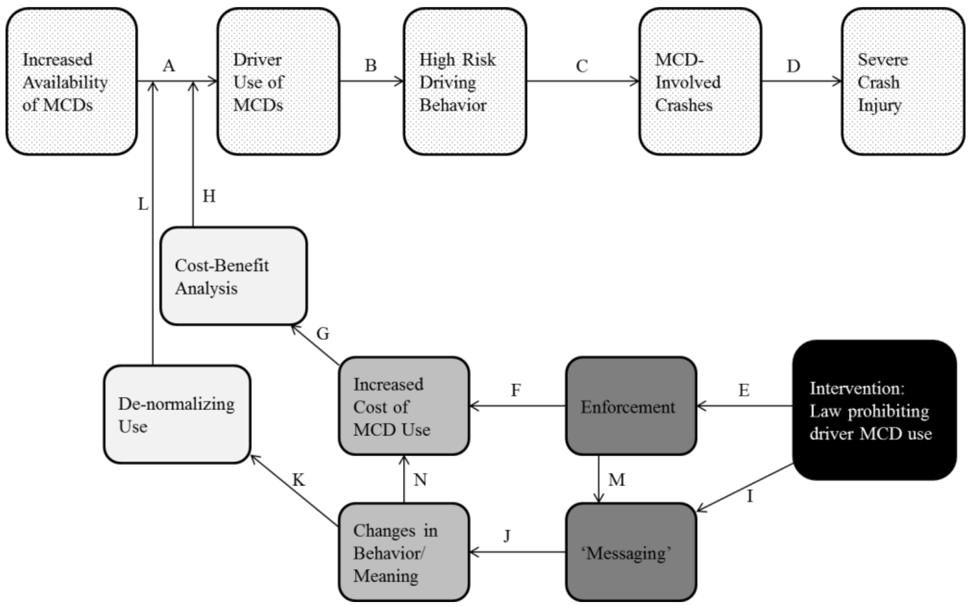
Lim & Chi (2013)	All state MCD-laws	Fatal Crashes (FARS)	Multiple period D-in-D, fifty states	MCD-laws banning all use reduce young driver crashes, no effect for laws targeting only young drivers
Lim & Chi (2013)	All state MCD-laws	Fatal Crashes (FARS)	Multiple period D-in-D, fifty states	MCD-laws banning all use reduce young driver crashes, no effect for laws targeting only young drivers
Ehsani et al. (2014)	MI MCD-law	MI state data on fatal, disabling, and minor crashes	ARIMA, regression discontinuity	MCD law banning texting associated with significant increase in crash rates and monthly crash trends
Cheng (2014)	All state MCD-laws	Observed use (NOPUS) Fatal Crashes (FARS)	Multiple period D-in-D	40-60% less handheld MCD use; but only for adult drivers; no effect crashes and crash deaths

Studies reviewing these evaluations suggest that current evidence does not support the effectiveness of existing MCD-laws in improving road safety (McCartt, Kidd, & Teoh, 2014; NHTSA, 2013).

The Role of Theory in Empirical Legal Research

Distracted driving is a complicated phenomenon. Mere access to MCDs does not guarantee their use by drivers. The decision by drivers to answer or initiate a call or to send or check for electronic messages is influenced by a range of factors. These include social norms, internal motivations, personal attributes, and environmental influences. Some of these factors are immutable, but many are not. To the extent factors can be altered they constitute possible intervention points. In this respect, interventions aimed at decreasing MCD use represent a potential distal determinant of use. Figure 14 depicts the general relationship between MCD-laws and motor vehicle crashes. The causal pathway A-B-C-D is the risk process that public health efforts aim to disrupt.

Figure 14. Logic Model of Driver MCD-Use as a Public Health Problem



There is some disagreement about the magnitude of decreased driving performance and increased crash risk associated with MCD use behind the wheel (Kolko, 2009, Prieger & Hahn, 2007). But few question the basic link or direction of effect. In contrast, there is wide disagreement about whether MCD-laws influence behavior. To explore the effects of MCD-laws on relevant outcomes and antecedent behaviors requires an identification strategy based on one or more explicit theories about how different variables interact. The two pathways that flow from right to left represent two theories about how MCD-laws operate as legal interventions. Deterrence theory suggests that individuals will obey these laws to avoid some cost which, in this instance, might include fines and time-consuming traffic stops. The deterrent effect of MCD-laws is represented by pathway E-G-F-H. As depicted in Figure 14, the analyses also contemplate a role for socio-normative change. The pathway I-J-K-L recognizes that laws embody a government sanctioned message about the propriety of the regulated behavior. Both pathways explain why the explicit text of the law is important and plausibly influences behavior.

Deterrence Theory

Law is typically understood as an instrument of deterrence. Laws requiring or prohibiting specified actions encourage compliance by increasing and internalizing the costs of noncompliance. The driver chooses not to answer her MCD, the theory goes, because she fears being ticketed by the police in a jurisdiction that prohibits that activity. Or, phrased in less colloquial terms, she will not accept the call if the expected costs of her action – the product of the likelihood of being ticketed and the amount of the associated fine – outweigh the expected benefit from answering. Deterrence is an intuitive theory and a powerful tool in the public health toolkit, but it has obvious limitations. Creating a likely- or large-enough deterrent can be difficult. The challenges of enforcing MCD-laws are well covered in the literature and the popular press (Erwinger, 2009; Lazero, 2010), the latter particularly important because it probably amplifies perceptions of weak enforcement among drivers.

Despite enforcement problems, deterrence remains a viable and popular theory in empirical research on legal intervention. Some researchers have attempted to explicitly model deterrence in MCD-law evaluations using traffic safety resources like state highway budgets (Cheng, 2010). Almost all studies lament poor enforcement and attribute it as the cause of ineffective or waning effectiveness of MCD-laws (McCartt et al., 2004, 2010). In recent years law enforcement has tried new strategies to increase actual and perceived enforcement. For example, in 2015 North Carolina began assigning state troopers to ride in state department of transportation trucks on the highway so that they could identify drivers using MCDs in passing motor vehicles, who are then stopped by alerted colleagues (Keys, 2014). While this particular strategy seems novel, enhanced enforcement strategies are common in road safety and have played important roles in alcohol impaired driving and safety belt use through “crackdowns” and “checkpoints” (Dinh-Zarr et al., 2001), and are likely feature prominently with MCD-laws in the future.

Social Norms Theory

One problem with an exclusive reliance on deterrence is that it assumes that the values that humans assign to various decisions are static. Our preferences, however, are never durable. They evolve alongside changing social phenomena and within changing contexts. Law is one of these changing social phenomena. To the extent that law is modifiable it is sometimes viewed as a tool for changing social constructions that motivate harmful attitudes, perceptions and intentions (Lessig, 1995). Criminalization of risky or immoral conduct has been identified as an area of law in which behavior is especially likely to be influenced through normative rather than deterrent processes (Edwards, 2006; Hetcher, 2003; Robinson, 2000).

The relationship between law and social norms is a popular topic for scholarly speculation and theory building in the legal academy. But little research empirically tests these theories and none validates a cohesive and generalizable account about the instrumental use of law in reshaping social norms to promote health. There is evidence from the public health literature that laws can change norms (Albers, Siegel, Cheng, Biener, & Rigotti, 2004; Albers, Siegel, Cheng, Rigotti, & Biener, 2004; Hamilton, Biener, & Brennan, 2008), but the mechanisms mediating those changes remain unclear.

Most research on the socio-normative effects of law offers one of two explanations for how law sometimes influences social norms.[‡]

According to the first explanation, law changes norms and behavior through the internalization of ideas. In this view, the driver does not answer her mobile communication device because prohibitionary laws have changed her views about the meaning of the activity, including its moral and safety implications. With the first explanation, the social norm is internalized in a psycho-social process. With the second explanation, the social norm remains external mediating behavior change not through shame or guilt per se, but through actual or perceived social pressure. The driver does not answer her MCD, according to second explanation, not because she views the activity differently, but because the law has made social disapproval for the behavior more explicit (Scott, 2000). This sort of social transformation only occurs in repeat scenarios or so-called negotiation-through-practice (Edwards, 2006). This mechanism is only salient when there is an important role for repeated social interaction as in, for example, divorce proceedings (Mnookin & Kornhauser, 1979) or youth sports concussion laws (Anderson & Burris, 2014). Both mechanisms may be at play with MCD-laws. Each is revisited in Chapter Five discussion.

[‡] The qualifying term *sometimes* is important here because the relationship between laws and social norms strongly depends on the text (i.e., what the law says) and the context (i.e., the prevailing social environment)(Lessig, 1995). The harsh criminalization of drug activity in the United States is often cited as example of a legal regime whose text ("Just Say No") and context (the psycho-social and neuro-biological phenomena of addiction) inevitably failed to produce the desired normative changes.

Summary

Driver use of MCDs is a complex public health problem. Both the technology and behavior associated with MCDs have changed drastically over recent decades. There is a large and diverse evidence base exploring the determinants, incidence, and effects of MCD use behind the wheel. There is much less and much less certain evidence about the effect of existing legal interventions. Legal epidemiology provides a set of theories for measuring the law and facilitates rigorous quasi-experiments. For such quasi-experiments to be credible, however, they must be based on plausible theories about the relationship between the law and the outcome of interest. Deterrence is one of two prominent theoretical explanations for how law influences behavior. Despite problems with the underlying rational-actor account of decision-making, deterrence remains a plausible and popular basis for legal intervention and evaluative research. Law also has a recognized influence on social norms. The mechanisms mediating this influence remain contested and differ by context. Notwithstanding these conceptual uncertainties, however, like deterrence, social normative theories provide a reasonable basis to conclude that the actual requirements of MCD-laws may alter driver behavior and therefore crash risk.

CHAPTER 3: METHODS

This chapter presents the research design, methods and analyses used to evaluate selected MCD-laws. It discusses the development of an identification strategy. That identification strategy governs the selection of evaluated laws, which is implemented algorithmically. This chapter also discusses the limitations and benefits of the research design and the analytic approach. Following best practices in quasi-experiments, the design of the study preceded all model specification and sensitivity analyses (Ho and Rubin 2013).

Research Design

This study explored the relationship between MCD-laws and motor vehicle fatalities by addressing the following research questions:

> **RQ1:** Did Arkansas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?
>
> **RQ2:** Did Arkansas' law prohibiting all handheld use of MCDs for drivers age 18-20 reduce motor vehicle fatalities involving drivers of that group.
>
> **RQ3:** Did North Carolina's law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?
>
> **RQ4:** Did Texas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

These questions were studied with a quasi-experimental design. The two-phase study design detailed below incorporates systematic legal research and quantitative methods.

Phase I: Developing an Identification Strategy

This phase included: Phase Ia) selecting MCD-laws to evaluate; and Phase Ib) selecting out-of-state control groups, Phase 1c) assessing fatal crash and covariate data, and Phase 1d) preparing analytic datasets.

Phase Ia: Select MCD-Laws to Evaluate

The selection of MCD-laws to evaluate was conducted by searching through a dataset that measures variation in MCD-laws over time and across states. The dataset has 7,344 rows, corresponding to 144 months (January 2000 through December 2012) for each of the fifty states and the District of Columbia. The columns are variables measuring the different features of state MCD-laws, expressed dichotomously as the presence ("1") or absence ("0") of a specific attribute. In the resulting matrix, each cell therefore reflects the presence of a characteristic of an MCD-law (e.g., does the law regulate 18 year old drivers) for a specific state during a specific month and year (hereafter "state-months"). To select MCD-laws to evaluate, an algorithm was designed to identify state-months adhering to three specific criteria. The algorithm was implemented incrementally by testing each criterion singularly. After spot-checking for programming and research errors, the full algorithm was applied. The criteria are as follows:

1. the state prohibits different MCD activity for 17, 18, and 19 year old drivers;
2. the state does not prohibit MCD activity for provisional drivers; and
3. the state does not prohibit MCD activity for all drivers before or within the 3 years after the age-restricted law became effective.

The purpose of Criterion 1 is to identify MCD-laws that define coverage by a clear and discrete age threshold. Age 17 was chosen as the lower threshold because drivers under this age are too few and too often subject to strict and likely confounding regulation of other kinds such as GDL-laws, as discussed below. In 835 state-months, MCD-laws created different requirements for drivers of the three ages. In all instances, the law banned all MCD use for those under age 18. The 835 state-months, which represent potential "treatment" periods, are spread across 15 states.

The purpose of Criteria 2 and 3 is to eliminate potentially competing and confounding MCD-laws. Criterion 2 eliminates state-months in which a state bans use of MCDs for provisional drivers. Laws that apply to provisional drivers are difficult to evaluate because they encompass young drivers of different ages. For example, Louisiana bans drivers from using an MCD in the first year of driving on a provisional license. It is unclear at what age drivers begin this one year period, and it is likely to include some age 16, 17, 18 and older drivers. Many laws that limit driving on provisional licenses operate similarly with driving privileges, including use of MCDs, increasing by virtue of participation in a specific driver education programs, and not just age. Criterion 2 therefore eliminates from consideration laws in which it is unclear whether drivers of a specific younger age are treated by the law or not.[4]

Criterion 3 requires that no other MCD-law in the state bans other activity for a broader group of drivers. This criterion addresses the possibility that the effect of age-restricted laws may be confounded by other MCD-laws of general application in the same state during the same time period. California, for example, banned handheld use of MCDs for all drivers the year before it banned all use of MCDs for drivers under age 18. Isolating the effect of the latter in the presence of the former is a fraught exercise. To address potential confounding through such "competitive" MCD-laws, Criterion 3 identifies the presence of other MCD-laws in the same state during the same periods. Arkansas presents a unique case because it bans different activity for a narrow and

---

[4] It is worth noting that these laws can be evaluated with data that captures the license status of drivers involved in crashes, as do some state crash records. Curry and colleagues have examined the relationship between New Jersey's GDL decal law and crash outcomes using New Jersey records on the license status of all drivers (Curry, Elliott, Pfeiffer, Kim, & Durbin, 2014; Curry, Pfeiffer, Localio, & Durbin, 2012). FARS does not reliably provide such information.

proximate age group, but no other broader MCD-law was adopted within 36 months before or after. Specifically, Arkansas banned *all* use of MCDs for drivers under 18 and *handheld use* for drivers age 18 to 20 in laws that took effect on the same day. While this arrangement makes it impossible to evaluate the under 18 law with a proximal age group in Arkansas, it does not disqualify comparisons with the same age groups in neighboring states. Arkansas is therefore retained in the analyses below and both laws are evaluated using appropriate comparison groups.

Applying all three criteria concurrently yields 178 state-months across four states: Arkansas, North Carolina, Rhode Island and Texas. As one of the smallest states, and with a high proportion of urban and suburban roads, Rhode Island has too few motor vehicle fatalities per month to sustain comparative analyses and was therefore excluded from further analyses.

Phase 1b: Select Out-of-State Comparison Groups

Researchers have been utilizing proximate untreated populations as controls in quasi-experiments at least as far back as John Snow, who famously determined that it was pathogens in the water, and not the air, at fault in the spread of cholera in London in the 1850s (Angrist & Pischke, 2009). The process in Phase 1a yielded four laws in three states. By definition, each has a treated "focal" group (i.e., those just under the age threshold and therefore covered by the law) and an untreated "control" group (i.e., those just above the age threshold and therefore untreated by the law), with the exception of the Arkansas law regulating drivers under age 18, as discussed above. To the extent that these age groups are influenced by the same regional factors, discussed below, the older age group reasonably approximates the counterfactual of interest: the focal group if untreated. However, trends in these age groups might differ for a variety of reasons related to age that could mask or mimic an effect of the MCD-law on the focal group. There could be some factor, for example, that influences crash rates for drivers age 16 and 17 but not drivers age 18 and 19 in North Carolina or vice versa. To address this possibility, control groups composed of drivers of the same age as the focal group were identified in proximal states to motivate a second comparative analysis. When differences in trends across the pre-law and post-law periods are apparent in both comparisons (same-age-proximal-state and same-state-proximal-age), they can modeled jointly for an even more sensitive identification approach (Angrist & Pischke, 2009; Gruber, 1994).

Using algorithms that search adjacent and proximal states, all potential control groups were identified for the respective focal groups. These potential control groups were then assessed for competing laws (Criteria 2 and 3 above) to select only states that were untreated (i.e., not subject to an MCD-law) over the comparison period. As indicated in Table 7, most control states were disqualified.

Table 7. Qualified States and Potential Control Groups

State and Focal Group	Potential In-State Control Group	In-State Disqualified?	Potential Out-of-State Control Group	Out-of-State Disqualified?
Arkansas: age 16-17	Arkansas: age 18-19	Yes	-	-
7/06-7/09;	-	-	Alabama: age 16-17	No
8/09-8/12	-	-	Kansas: age 16-17	Yes
	-	-	Kentucky: age 16-17	Yes
	-	-	Louisiana: age 16-17	Yes
	-	-	Mississippi: age 16-17	Yes
	-	-	Missouri: age 16-17	Yes
	-	-	Oklahoma: age 16-17	Yes
	-	-	Tennessee: age 16-17	Yes
	-	-	Texas: age 16-17	Yes
Arkansas: age 18-20	Arkansas: age 21-23	No	-	-
7/06-7/09;	-	-	Alabama: age 18-20	No
8/09-8/12	-	-	Kansas: age 18-20	Yes
	-	-	Kentucky: age 18-20	Yes
	-	-	Louisiana: age 18-20	Yes
	-	-	Mississippi: age 18-20	No
	-	-	Missouri: age 18-20	Yes
	-	-	Oklahoma: age 18-20	Yes

Table 7, continued

		-	Tennessee: age 18-20	Yes
		-	Texas: age 18-20	Yes
North Carolina: age 16-17	North Carolina age 18-19	No	-	-
11/02-11/06; 12/06-12/10	-	-	Florida: age 16-17	No
	-	-	Georgia: age 16-17	No
	-	-	Pennsylvania: age 16-17	Yes
	-	-	South Carolina: age 16-	No
	-	-	Virginia: age 16-17	Yes
Texas: age 16-17	Texas: age 18-19	No	-	-
8/02-8/05; 9/05-9/08	-	-	New Mexico: age 16-17	No
	-	-	Colorado: age 16-17	Yes
	-	-	Kansas: age 16-17	Yes
	-	-	Oklahoma: age 16-17	No
	-	-	Arkansas: age 16-17	No
	-	-	Louisiana: age 16-17	Yes
	-	-	Mississippi: age 16-17	No
Total	4	Yes=1 No=3	30	Yes=20; No=10

After removing the disqualified states in Table 7, the remaining comparisons were subject to one final legal analysis. In addition to other “competitive" MCD-laws, the existence of different graduate driver licensing law ("GDL-laws") may also confound observations about the relationship between crash fatalities and age-based MCD-laws. GDL-laws define the ages at which driving is allowed and the limitations on drivers with provisional licenses. To address the possibility of confounding GDL-laws, the GDL-laws in each state over the four study periods were assessed across four criteria: (1) the minimum driving age, (2) the restricted hours of nighttime driving for young drivers, (3) the age at which nighttime driving restrictions no longer apply, and (4) the age of minimum unrestricted driving. These components are recognized as the most influential in reducing crash rates for young drivers (McCartt, Teoh, Fields, Braitman, & Hellinga, 2010). The requirements for each state were plotted by year to identify relative differences and changes in GDL policy across the relevant comparison periods

(Appendix B). Florida set a much higher minimum unrestricted driving age (18) than North Carolina over the study period (16.5). On this basis, Florida was dropped as the source of a potential comparison group.

Table 8. Graduated Driver Licensing Requirements

Focal Group	Minimum Driving Age	Night-time Restriction	Night-time Restriction	Minimum Unrestricted Driving	Changes in Study Period
Study Period: 7/2006 to 8/2012					
Arkansas	14	None/ 11PM-4AM	17	18	Yes*
Alabama	15	12AM-6AM	16	17	No
Study Period: 11/2002 to 12/2010					
North Carolina	15	9PM-5AM	16.5	16.5	No
Florida	15	1AM-5AM	18	18	No
South Carolina	15	8PM-6AM	16.5	16.5	No
Pennsylvania	16	11PM-5AM	16.5	17	No
Study Period: 8/2002 to 9/2008					
Texas	15	12AM-5AM	16	16.5	No
Alabama	15	12AM-6AM	16	17	No
Arkansas	14	None	-	18	No
New Mexico	15	12AM-5AM	15.5	16.5	No
Oklahoma	15.5	None /11PM-5AM	16	16.5	Yes**

As depicted in Figure 8, there were two changes across the study periods, namely, Arkansas and Oklahoma added nighttime driving restrictions. While these changes are important and can definitely confound observed trends vis-a-vis MCD-laws, their impact can be assessed by checking for differential changes in crashes by hour of the day as a sensitivity analysis. Arkansas was therefore retained as the source of a focal group, and Oklahoma was retained as the source of a control group in the evaluation of the Texas MCD-law. The final selection of comparisons is provided in Table 9.

Table 9. Final Focal and Control Group Comparisons

Focal Group	Actual control	Restricted Use	Sub-Analysis*
Arkansas age 16-17		All	
	Alabama: age 16-17	None	1a
Arkansas age: 18-20		Hand-Held	
	Alabama: age18-20	None	2a, 2c
	Mississippi: age 18-20	None	2a, 2c
	Arkansas: age 21-23	None	2b, 2c
North Carolina age: 16-17		All	
	South Carolina: age 16-17	None	3a, 3c
	Pennsylvania: age 16-17	None	3a, 3c
	North Carolina: age 18-19	None	3b, 3c
Texas age: 16-17		All	
	Alabama: age 16-17	None	4a, 4c
	Arkansas: age 16-17	None	4a, 4c
	New Mexico: age 16-17	None	4a, 4c
	Oklahoma: age 16-17	None	4a, 4c
	Texas: age 18-19	None	4b, 4c
Total	13	-	12

*Notes: At this point, these are contemplated analyses. The first is the double difference; the second is a potential triple difference pending an interpretable double difference.

Phase 1c: Procure Crash and Covariate Data

The dependent variable in these analyses is the number of crashes resulting in one or more fatalities involving drivers of different ages. These data were obtained from the Fatality Analysis Reporting System (FARS), which is administered by the Department of Transportation, and includes information on all fatal crashes in the US in which at least one fatality occurred within 30 days of the crash (NHTSA, 2013). All FARS data were obtained in raw micro-data form and were transformed into aggregate monthly counts. For each crash in the focal and control states between 2000 and 2012, the age of the drivers and the number of fatalities were also obtained. To adjust for the level of population exposure to crashes across states and time, the number of vehicle-miles-traveled (VMT) in each state was also extracted from the Federal Highway Administration's Highway Statistics series (Kumapley & Fricker, 1996). Data on precipitation and temperature, which are known to influence crash risk, were retrieved for all the states from the National Oceanic and Atmospheric Administration's National Climatic Data Center (NOAS, 2013). Annual mid-year population figures were obtained for each state from the US Census bureau (U.S. Census Bureau, 2013).

Phase 1d: Prepare Final Analytic Datasets

Four analytical datasets were created for each of the contemplated sets of sub-analyses. Each dataset included the monthly crash rate for the focal group and for the respective control groups. Each dataset included thirteen years of monthly data. Ten years of monthly data were provided for the period before the law went into effect and three years were provided inclusive of and after the month the law went into effect. To assist in the graphical inspection and comparison of trends, five step moving averages were calculated for each monthly and quarterly crash rate. Covariate data measuring precipitation, temperature, vehicle-miles-traveled were linked by state and month. The natural log of vehicle-miles-traveled was calculated as an exposure measure (i.e., the regression offset). Indicator variables were assigned to designate season (summer or winter), quarter and month to enable testing for auto correlated errors. Indicator variables were also assigned to designate the focal and control group rates and to designate the pre-law and post-law months. All data manipulations were conducted in SAS 9.3 (SAS Institute Inc., Cary, NC).

Phase II: Analysis

This phase included: Phase Ia) conducting descriptive trend analysis; Phase Ib) identifying the distributional properties of the outcome variables, and Phase 1c) fitting the difference-in-difference regression analyses.

Phase IIa: Descriptive Trend Analysis

For each of the four sets of qualifying comparisons, graphical and univariate analyses were conducted on the respective crash trends. Each trend was plotted in raw numeric form, as a rate adjusted by the million vehicle-miles-traveled, and as a five-step moving average. All graphical analyses were conducted at a monthly resolution for the periods three and ten years before the law in the focal state took effect. To test for the presence of a secular trend, the crash rate was regressed over a continuous variable marking each sequential month. To test for seasonal and autoregressive patterning, Durbin Watson statistics were calculated for each ten year trend using the AUTOREG procedure in SAS 9.3. These plots and figures - which are all exclusively restricted to the pre-law period - are presented below as a predicate step to model specification and testing. The seven sub-analyses and their contemplated driver comparison groups are:

1(a) Focal: Arkansas age 16 and 17
Control: Alabama age 16 and 17

2(a) Focal: Arkansas age 18 to 20
Control: Alabama and Mississippi age 18 to 20

2(b) Focal: Arkansas age 18 to 20
Control: Arkansas age 21 to 23

3(a) Focal: North Carolina age 16 and 17
Control: South Carolina and Pennsylvania age 16 and 17

3(b) Focal: North Carolina age 16 and 17
Control: North Carolina age 18 and 19

4(a) Focal: Texas age 16 and 17
Control: Alabama, Arkansas, New Mexico, and Oklahoma age 16 and 17

4(b) Focal: Texas age 16 and 17
Control: Texas age 18 and 19

1(a): AR Drivers Age 16-17; AL Drivers Age 16-17

Figure 15 displays the trend in fatal crashes involving Arkansas drivers ages 16 to 17 ten years before the MCD-law became effective. Over this period the monthly rate of crashes decreased (β_{time}= -0.003; p=0.190), exhibiting weak evidence of positive autocorrelation (DW= 1.890; p<DW: 0.203).

Figure 15. Fatal Crashes Involving AR Drivers Age 16-17, 10 Years Pre-MCD-Law

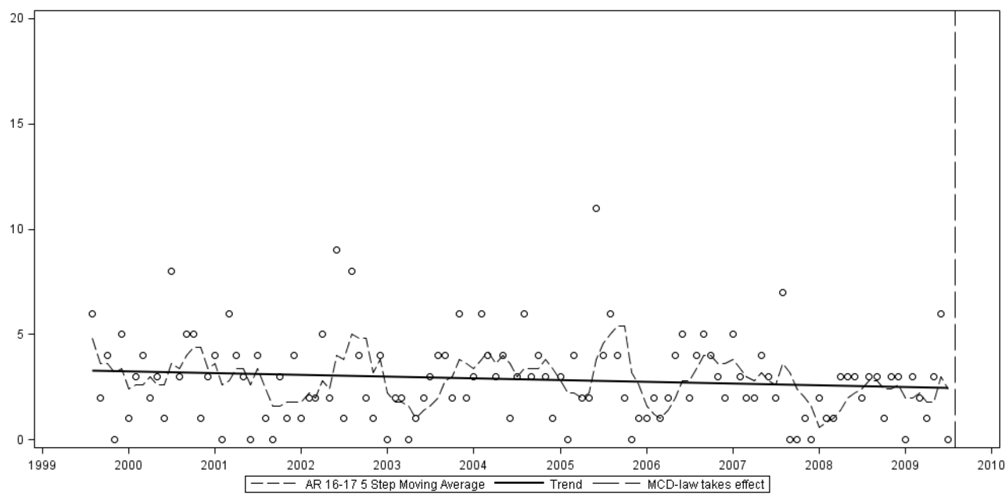


Figure 16 displays the trend for fatal crashes involving Alabama drivers of the same age over the same period. The monthly crash rate decreases (β_{time}=-0.002 p=0.167), exhibiting a similar pattern of autocorrelation (DW= 1.919; p<DW: 0.269).

Figure 16. Fatal Crashes Involving AL Drivers Age 16-17, 10 Years Pre-MCD-Law

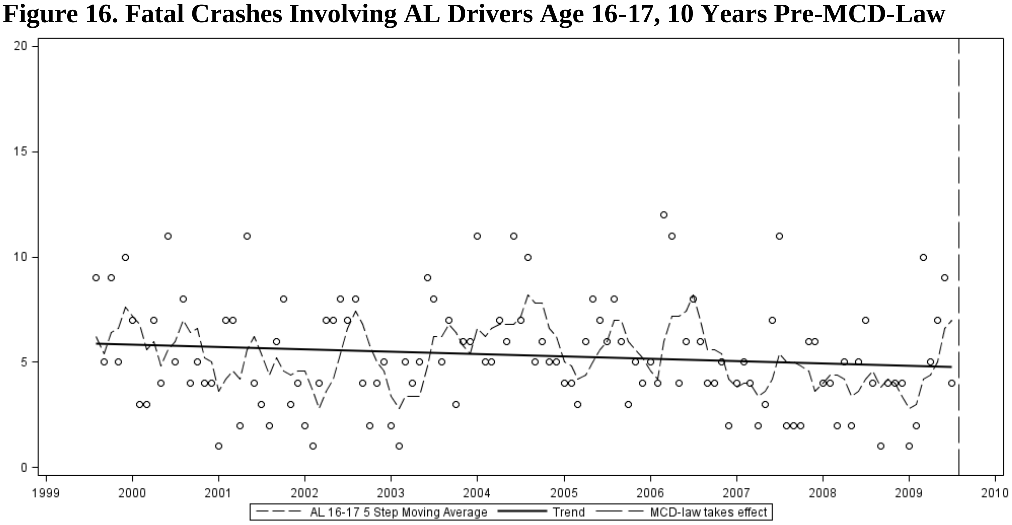


Figure 17 displays the trend for fatal crashes involving Arkansas drivers age 16 and 17 three years before the MCD-law became effective. The three year period exhibited a flat trend (β_{time} = -0.016; p=0.125).

Figure 17. Fatal Crashes Involving AR Drivers Age 16-17, 3 years pre-MCD-law

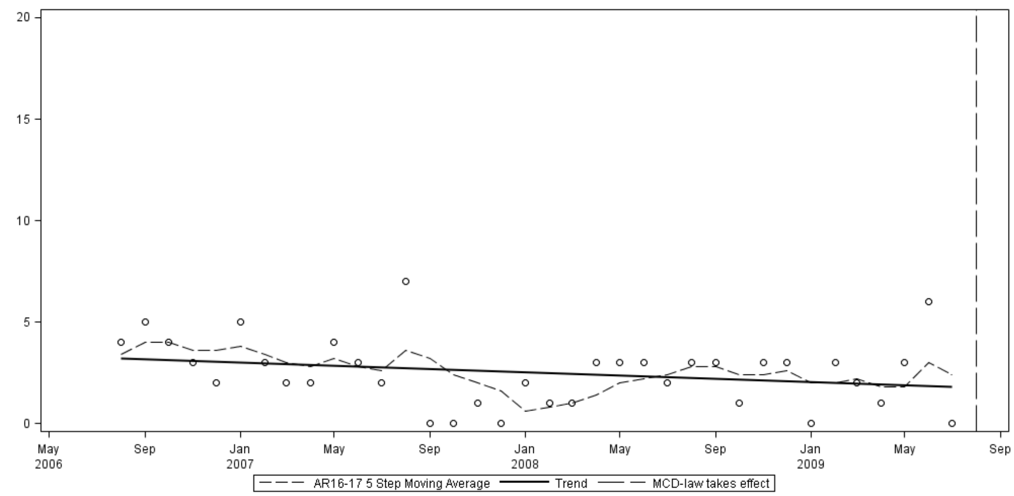


Figure 18 displays the trend for fatal crashes involving Alabama drivers of the same age over the same three year period. The trend of the rate over the three year period was also flat (β_{time} =0.006; p=0.489).

Figure 18. Fatal Crashes Involving AL Drivers Age 16-17, 3 years pre-MCD-law

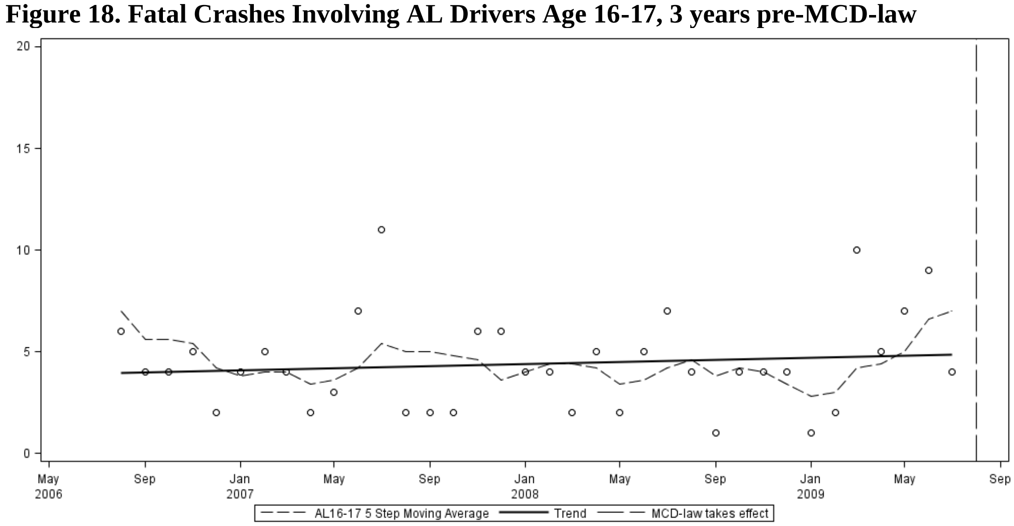


Figure 19 depicts moving averages for the monthly rate of crashes for drivers age 16 and 17 in Arkansas and Alabama over the ten year period preceding the MCD-law.

Figure 19. Moving Averages for Fatal Crashes Involving AR and AL Drivers Age 16-17, 10 years pre-MCD-law

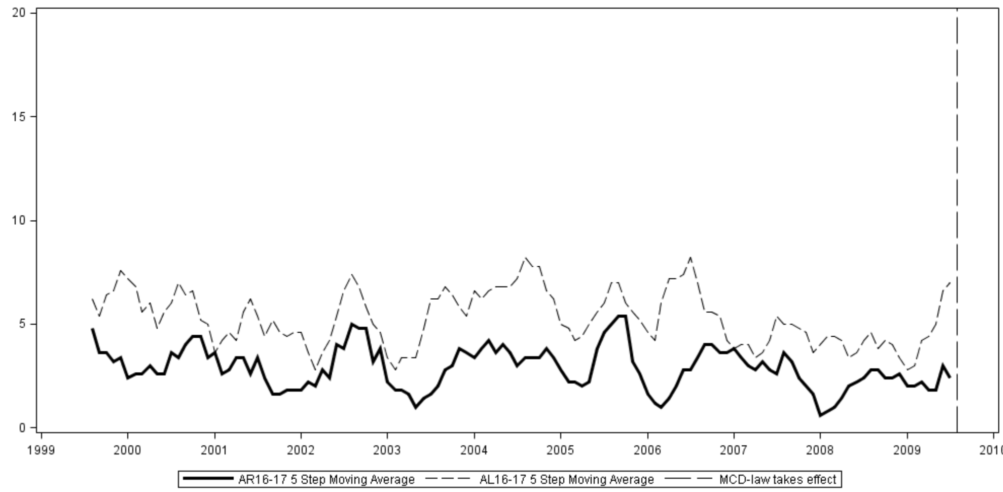
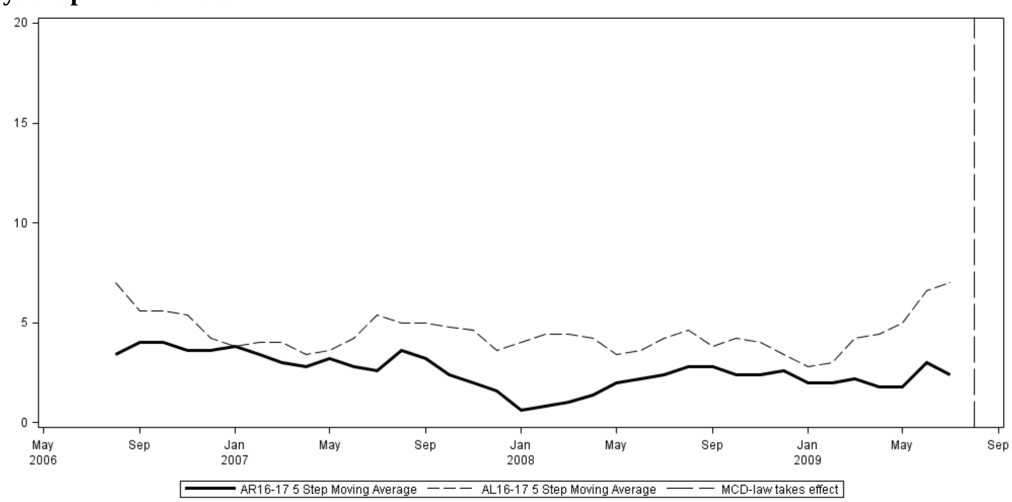


Figure 20 overlays the 5-step moving average for the monthly rate of crashes for drivers age 16 and 17 in Arkansas and Alabama over the three year period preceding the MCD-law. Over this interval, there are some departures, but the trends have similar peaks and the same flat trend.

Figure 20. Moving Averages for Fatal Crashes Involving AR and AL Drivers Age 16-17, 3 years pre-MCD-law



These graphical analyses suggest that Alabama drivers age 16 and 17 provide a reasonable comparison group for Arkansas drivers of the same age.

2(a): AR Drivers Age 18-20; AL-MS Drivers Age 18-20

Figure 21 displays the trend for fatal crashes involving Arkansas drivers age 18 to 20 ten years before the state banned their handheld use of MCDs. Over this period the average rate of crashes was flat (β_{time}= -0.0002; p=0.857), exhibiting weak evidence of positive autocorrelation (DW= 1.833; p<DW: 0.103).

Figure 21. Fatal Crashes Involving Drivers AR Age 18-20, 10 years pre-MCD-law

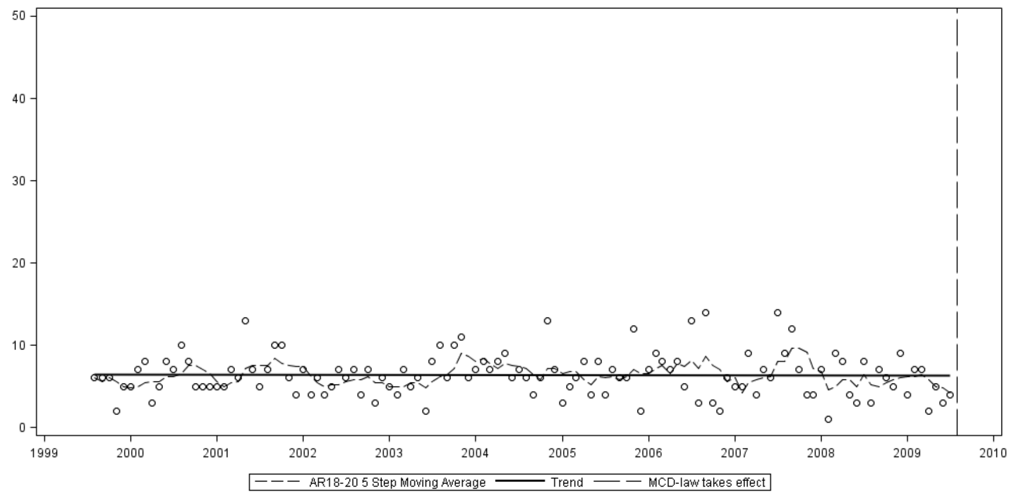


Figure 22 displays the trend for fatal crashes involving Alabama and Mississippi drivers age 18 to 20 over the same period. This trend decreases (β_{time}=-0.001; p=0.071), exhibiting positive autocorrelation (DW= 1.516; p=DW: 0.001).

Figure 22. Fatal Crashes in AL-MS Involving Drivers Age 18-20, 10 years pre-MCD-law

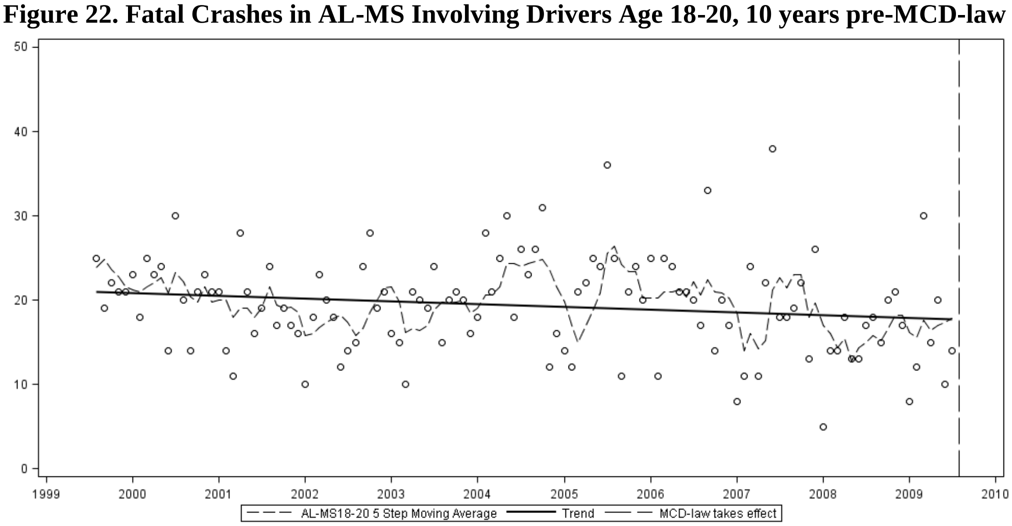


Figure 23 displays the trend for fatal crashes involving Arkansas drivers age 18 to 20 three years before their handheld use of MCDs was banned. Over this period the average crash rate followed a flat trend (β_{time}=-0.009; p=0.252).

Figure 23. Fatal Crashes Involving AR Drivers Age 18-20, 3 years pre-MCD-law

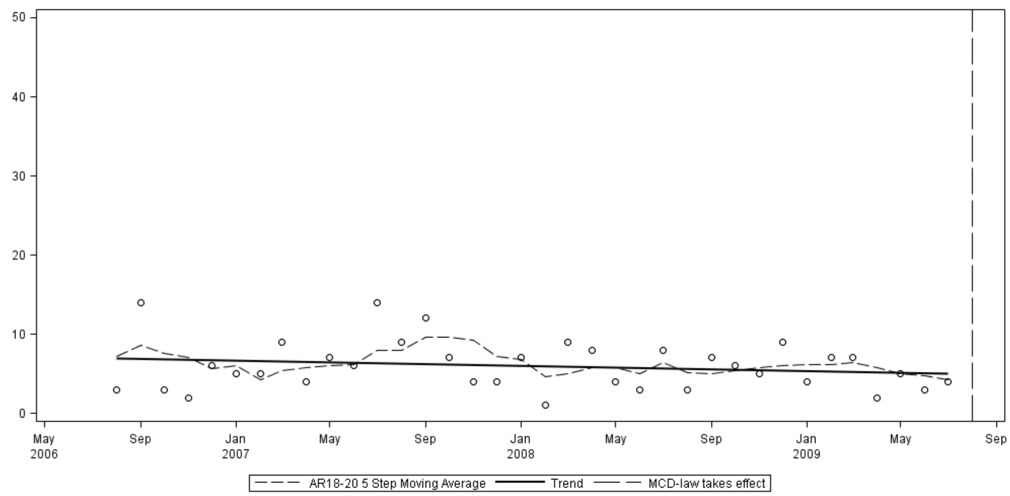


Figure 24 displays the trend for fatal crashes involving Alabama and Mississippi drivers age 18 to 20 over the same three years. Over this period the trend in the average monthly number of crashes was also flat (β_{time}= -0.0077; p=0.262).

Figure 24. Fatal Crashes Involving AL-MS Drivers Age 18-20, 3 years pre-MCD-law

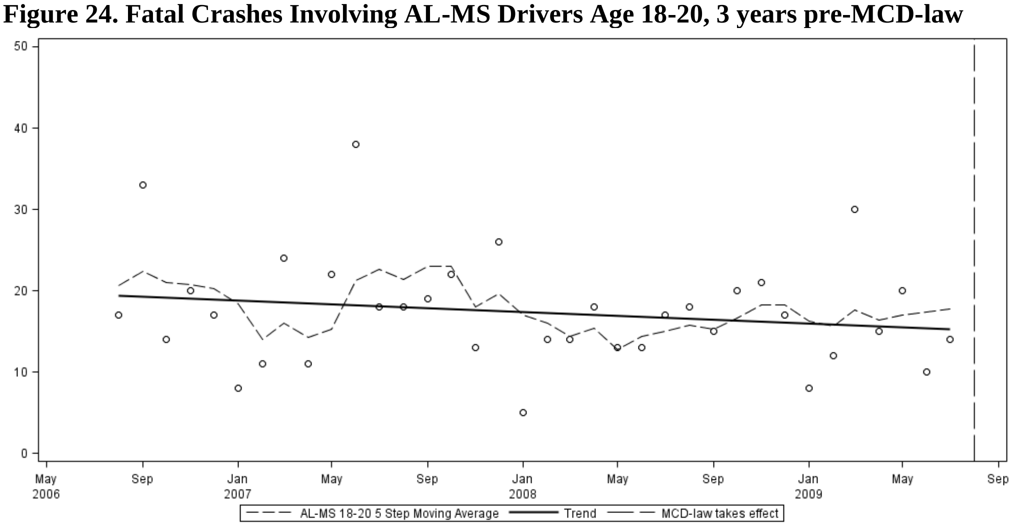


Figure 25 overlays the 5-step moving average for the monthly rate of crashes for Arkansas drivers age 18 to 20, and Alabama and Mississippi drivers of the same age, over the ten year period preceding the MCD-law. The trends follow a similar trajectory despite some notable departures including the early part of 2005.

Figure 25. Moving Averages for Fatal Crashes Involving AR and AL-MS Drivers Age 18-20, 10 years pre-MCD-law

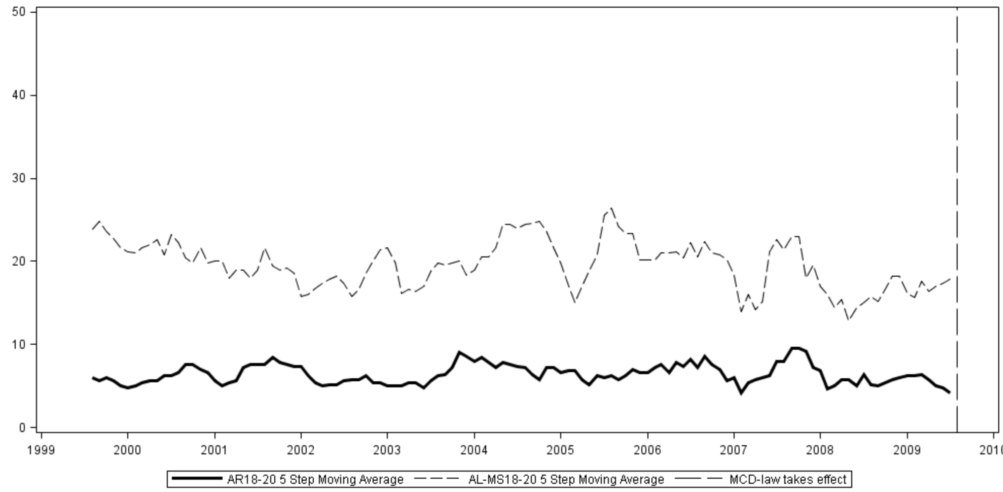
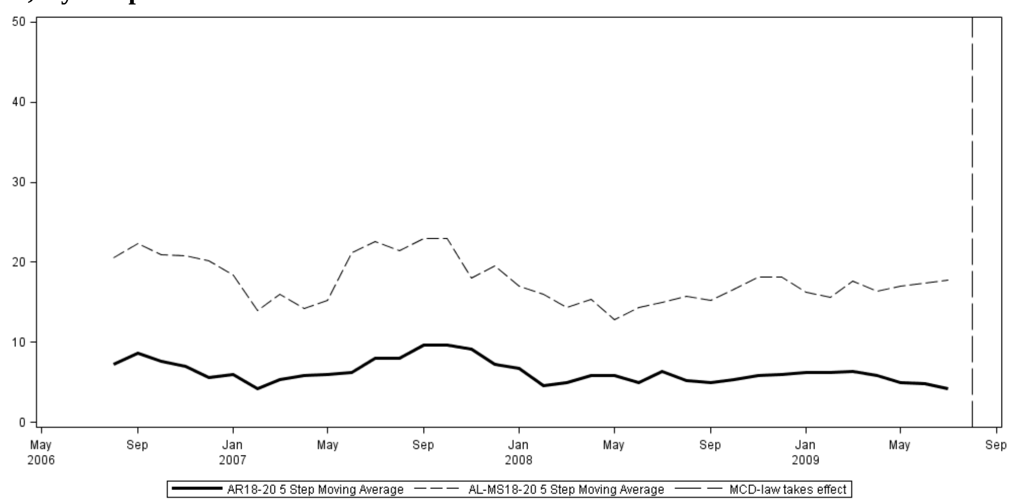


Figure 26 overlays the 5-step moving average for crash rates for the two groups over the three year period preceding the MCD-law. The trends follow an especially close trajectory over this shorter period.

Figure 26. Moving Averages for Fatal Crashes Involving AR and AL-MS Drivers Age 18-20, 3 years pre-MCD-law



These graphical analyses suggest that Alabama and Mississippi drivers age 18 to 20 provide a reasonable comparison group for Arkansas drivers age 18 to 20 based on the parallel movement of each trend in the years preceding the MCD-law.

2(b): AR Drivers Age 18-20; AR Drivers Age 21-23

Figure 27 displays the trend for fatal crashes involving drivers age 21 to 23 in Arkansas ten years before the MCD-law. Over this period, this trend is also flat (β_{time}= -0.001; p=0.272), with evidence of autocorrelation (DW= 1.670; p<DW: 0.101) similar to that of the focal group.

Figure 27. Fatal Crashes Involving AR Drivers Age 21-23, 10 years pre-MCD-law

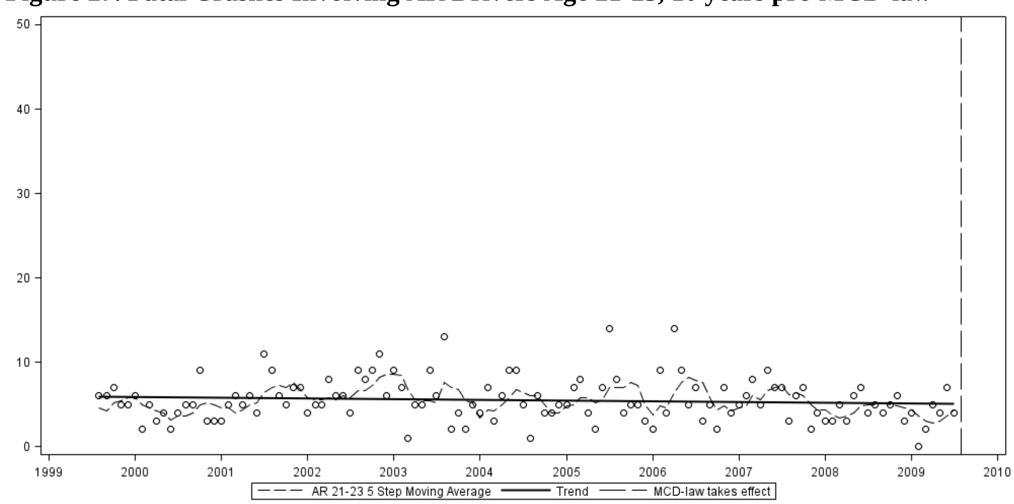


Figure 28 displays the trend for fatal crashes involving Arkansas drivers age 21 to 23 in the three years before the MCD-law became effective. Across the three year period, the average monthly rate was flat (β_{time} = -0.009; p=0.232).

Figure 28. Fatal Crashes Involving AR Drivers Age 21-23, 3 years pre-MCD-law

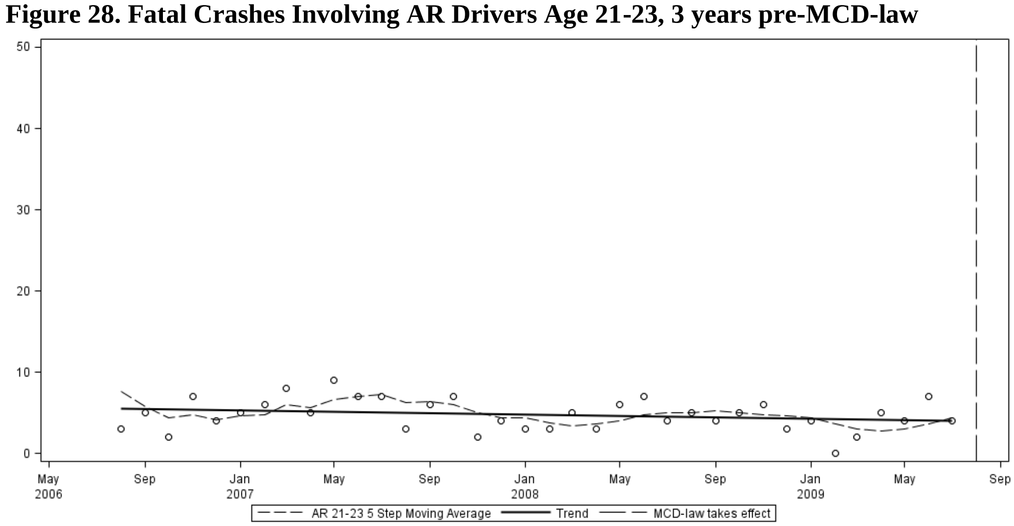


Figure 29 overlays the 5-step moving average for the monthly rate of crashes for Arkansas drivers age 18 to 20 and 21 to 23 over the ten year period preceding the MCD-law. The trends have similar peaks and appear to follow the same general trend.

Figure 29. Moving Averages for Crashes Involving AR Drivers Age 18-20 and 21-23, 10 years pre-MCD-law

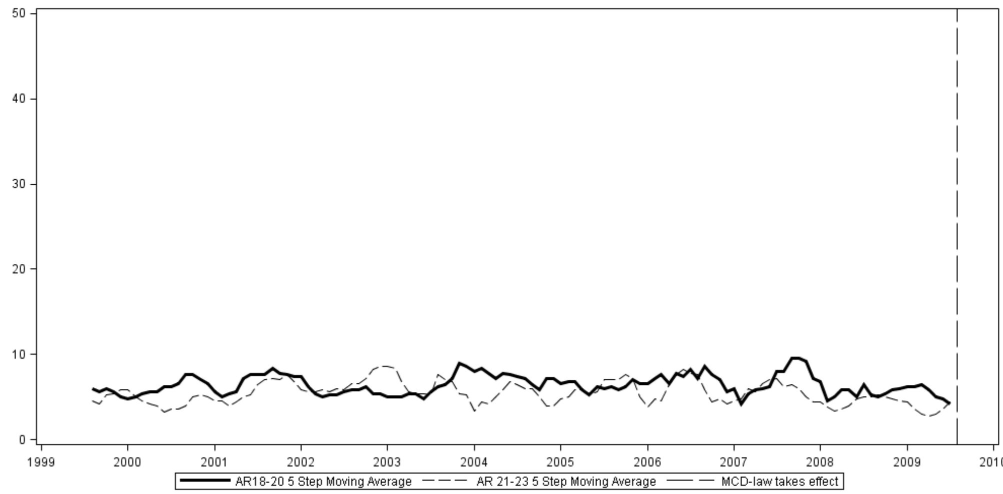
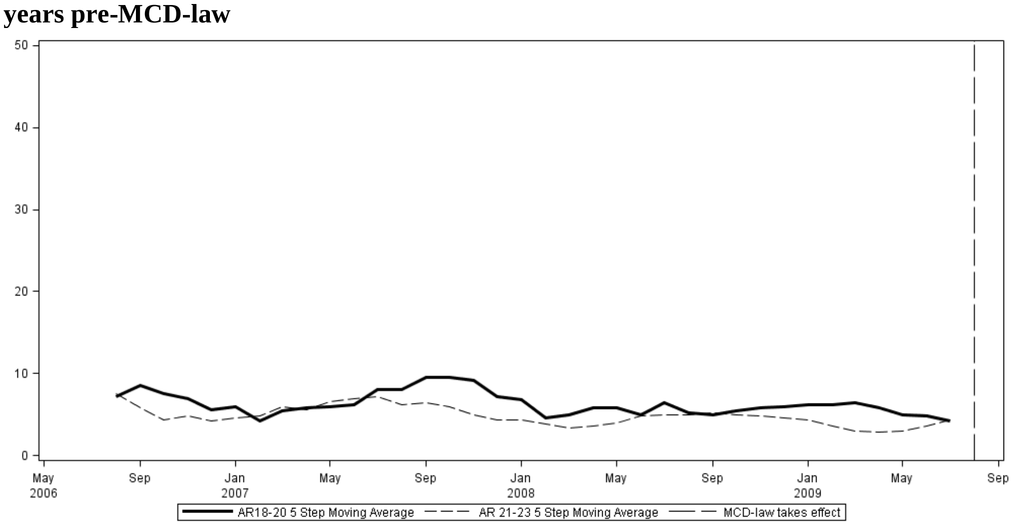


Figure 30 overlays the 5-step moving average for the monthly rate of crashes for the same two Arkansas age groups over the three year period preceding the MCD-law. Once again, the trends appear to follow a similar trajectory.

Figure 30. Moving Averages for Crashes Involving AR Drivers Age 18-20 and 21-23, 3 years pre-MCD-law



These graphical analyses suggest that Arkansas drivers age 21 to 23 provide a reasonable comparison group for Arkansas drivers age 18 and 20.

3(a): NC Drivers Age 16-17; SC-PA Drivers Age 16-17

Figure 31 displays the trend for fatal crashes involving drivers age 16 and 17 in North Carolina ten years before the state banned their use of MCDs. The monthly crash rate decreased (β_{time}=-0.003; p=0.002), exhibiting positive autocorrelation (DW= 1.314; p<DW: 0.001).

Figure 31. Fatal Crashes Involving NC Drivers Age 16-17, 10 years pre-MCD-law

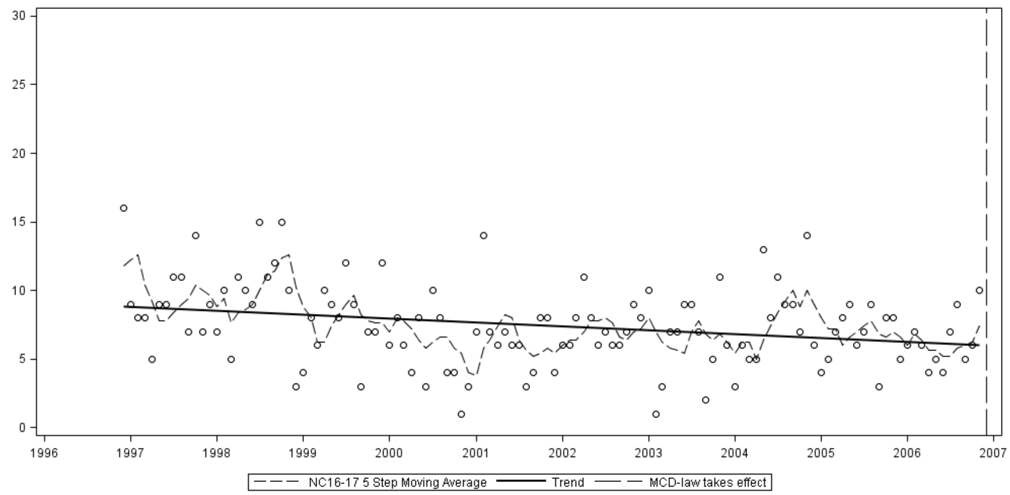


Figure 32 displays the fatal crash rate for drivers age 16 and 17 in Pennsylvania and South Carolina over the same period. This crash rate also decreased (β_{time}=-0.003; p=0.0009), exhibiting positive autocorrelation (DW= 1.314; p<DW: 0.0001).

Figure 32. Fatal Crashes Involving PA-SC Drivers Age 16-17, 10 years pre-MCD-law

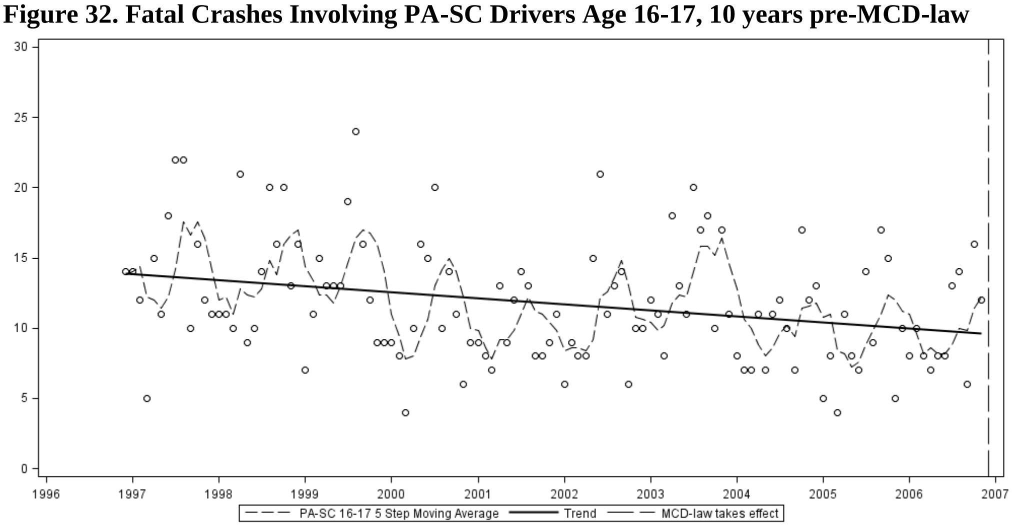


Figure 33 displays the trend for fatal crashes involving drivers age 16 and 17 in North Carolina three years before the MCD-law became effective. Over this period the average monthly number of crashes was flat (β_{time}=-0.004; p=0.469).

Figure 33. Fatal Crashes Involving NC Drivers Age 16-17, 3 years pre-MCD-law

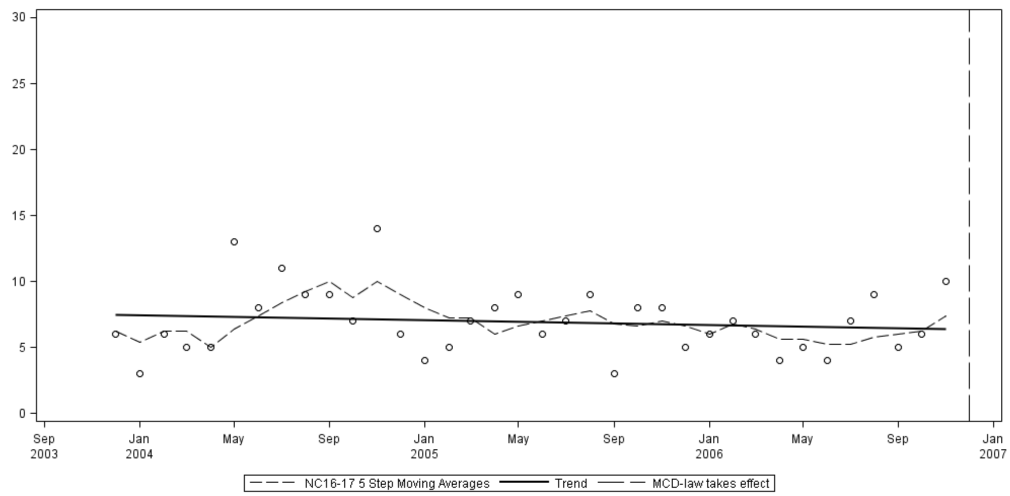


Figure 34 displays the trend for fatal crashes involving Pennsylvania and South Carolina drivers age 16 and 17 over the same three years. Over this period the average monthly number of crashes was also flat (β_{time} =0.004; p=0.434).

Figure 34. Fatal Crashes Involving PA-SC Drivers Age 16-17, 3 years pre-MCD-law

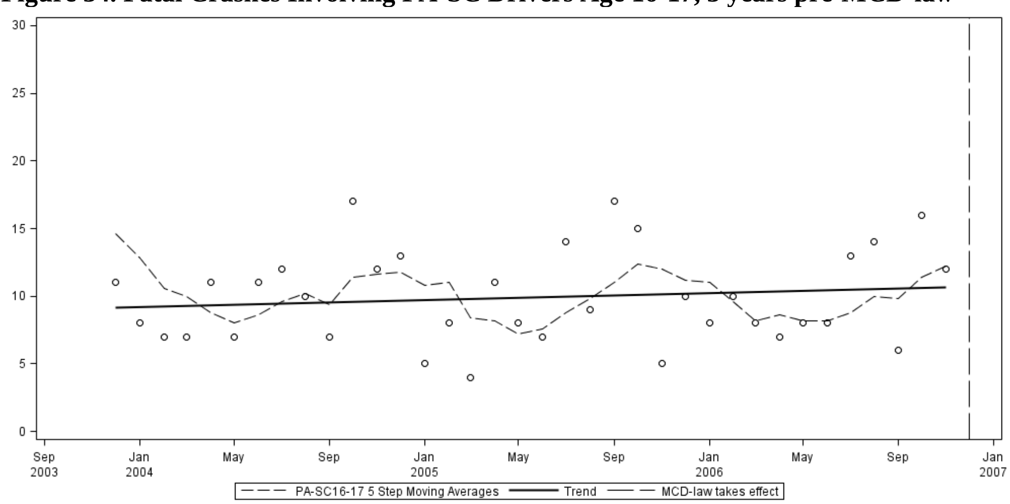


Figure 35 overlays the 5-step moving average for the monthly rate of crashes for North Carolina drivers age 16 and 17 and Pennsylvania and South Carolina drivers age 16 and

17 ten years before the MCD-law. The trends appear to follow a similar trajectory although the trend for the control group is more variable.

Figure 35. Moving Averages for Crashes Involving NC and PA-SC Drivers Age 16-17, 10 years pre-MCD-law

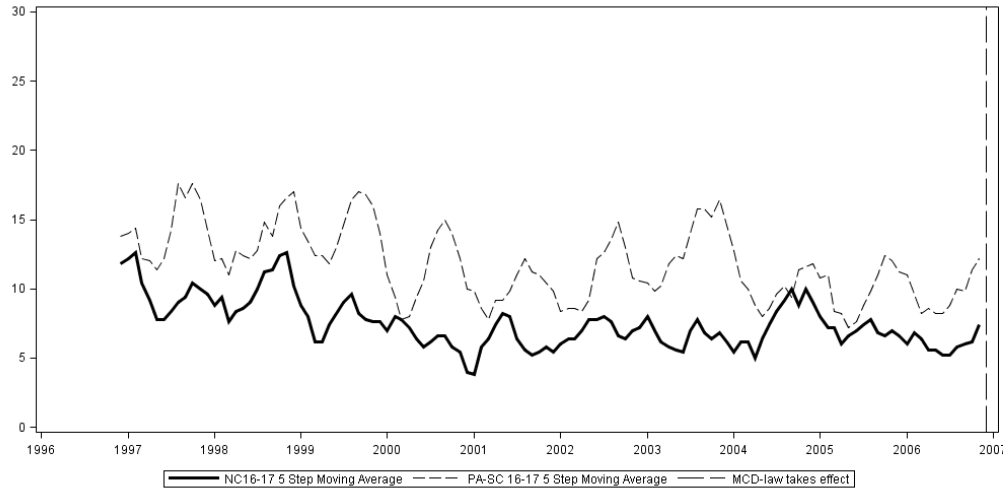
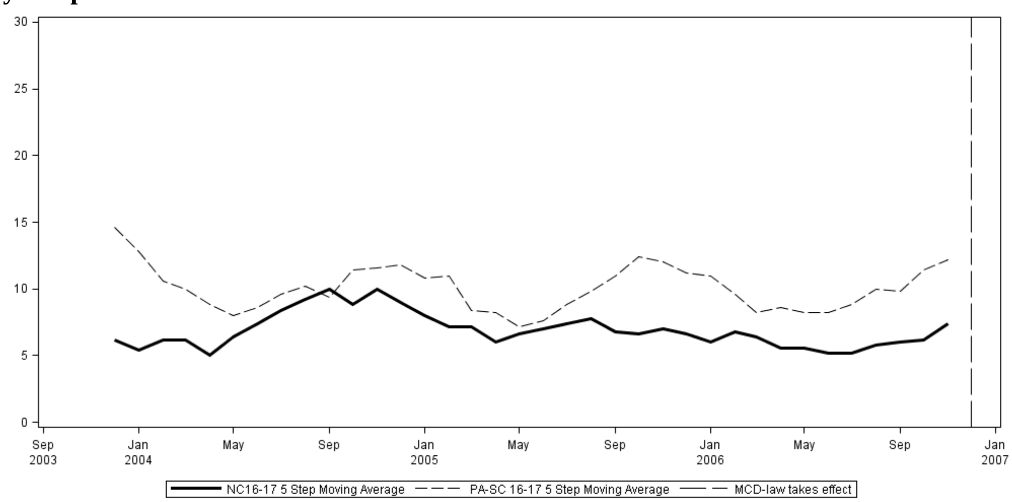


Figure 36 overlays the 5-step moving average for the monthly rate of crashes for both groups over the three year period preceding the MCD-law. The trends follow a similar trajectory over this shorter period.

Figure 36. Moving Averages for Crashes Involving NC and PA-SC Drivers Age 16-17, 3 years pre-MCD-law



These analyses suggest that Pennsylvania and South Carolina drivers age 16 and 17 provide a reasonable comparison group for North Carolina drivers of the same age.

3(b): NC Drivers Age 16-17; NC Drivers Age 18-19

Figure 37 displays the trend for fatal crashes involving drivers age 18 and 19 in North Carolina in the 10 years before age 16 and 17 were banned from all MCD use. This rate has a slight but statistically insignificant upward trend (β_{time}=0.001; p=0.114), exhibiting positive autocorrelation (DW= 1.590; p<DW: 0.001).

Figure 37. Fatal Crashes Involving NC Drivers Age 18-19, 10 years pre-MCD-law

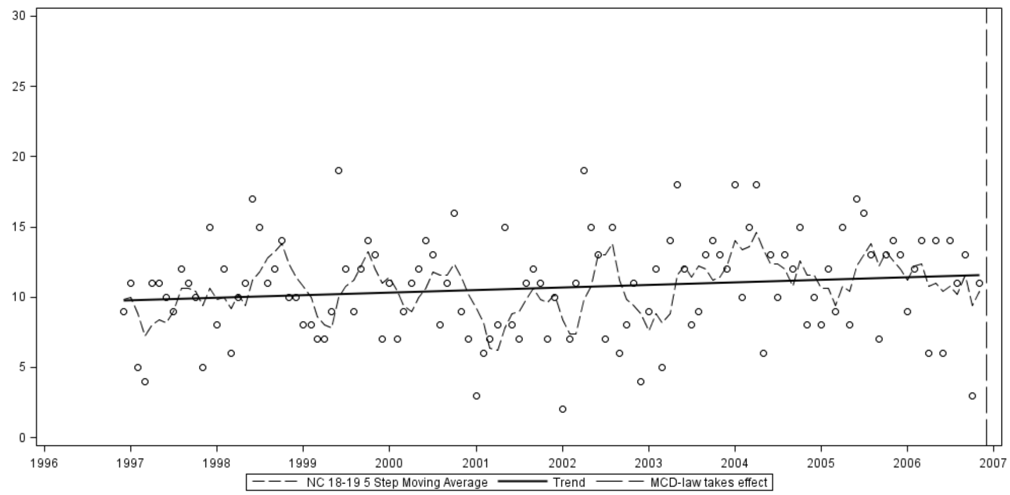


Figure 38 displays the trend for fatal crashes involving North Carolina drivers age 18 and 19 three years before the MCD-law. Over this period the average monthly number of crashes slightly decreased (β_{time} = -0.007; p=0.119).

Figure 38. Fatal Crashes Involving NC Drivers Age 18-19, 3 years pre-MCD-law

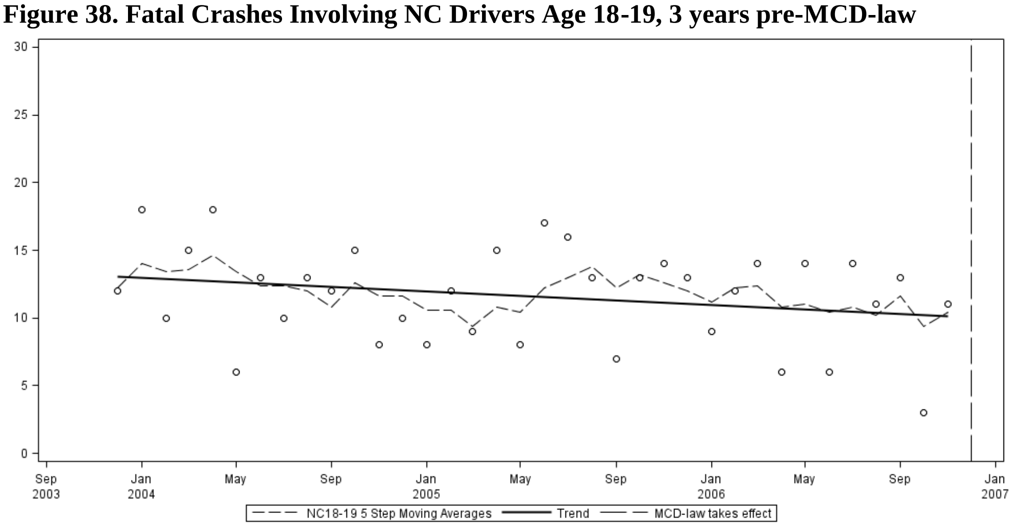


Figure 39 overlays the 5-step moving average for the monthly rate of crashes for the focal and control groups (North Carolina drivers age 16 and 17, and 18 and 19) over the ten year period preceding the MCD-law. The trends follow a similar trajectory.

Figure 39. Moving Average for Crashes Involving Drivers Ages 16-17 and 18-19, 10 years pre-MCD-law

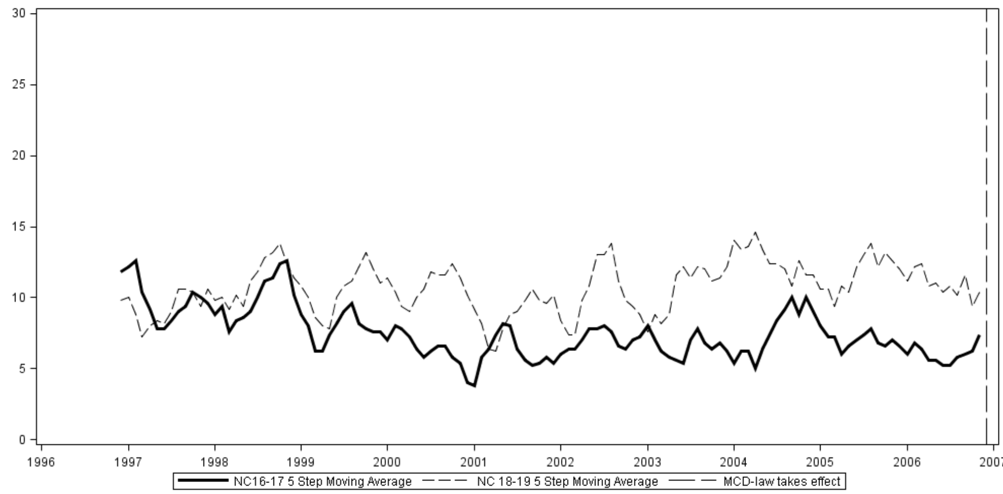
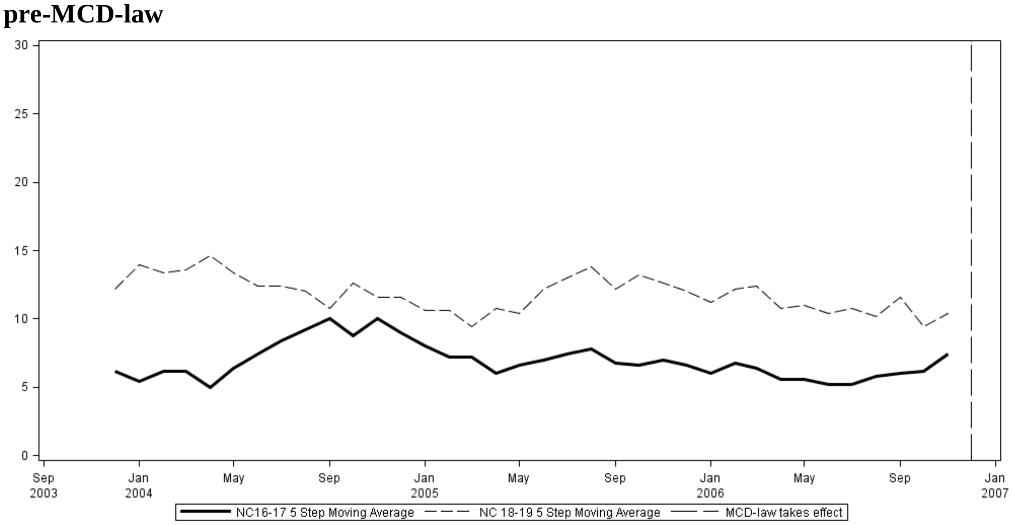


Figure 40 overlays the 5-step moving average for the monthly rate of crashes for the focal and control groups (North Carolina drivers age 16 and 17, and 18 and 19) over the three year period preceding the MCD-law. The trends follow a similar trajectory.

Figure 40. Moving Average for Crashes Involving Drivers Ages 16-17 and 18-19, 3 years pre-MCD-law



Once again, these graphical analyses suggest that North Carolina drivers age 18 and 19 provide a reasonable comparison group for North Carolina drivers age 16 and 17.

4(a): TX Drivers Age 16-17; AL-AR-OK-NM Drivers Age 16-17

Figure 41 displays the fatal crash rate involving Texas drivers age 16 and 17 ten years before the state banned their use of MCDs. Over this period the monthly rate significantly decreased (β_{time} =-0.002; p=0.001). There was strong evidence of positive autocorrelation (DW= 0.888; p<DW: 0.0001).

Figure 41. Fatal Crashes Involving TX Drivers Age 16-17, 10 years pre-MCD-law

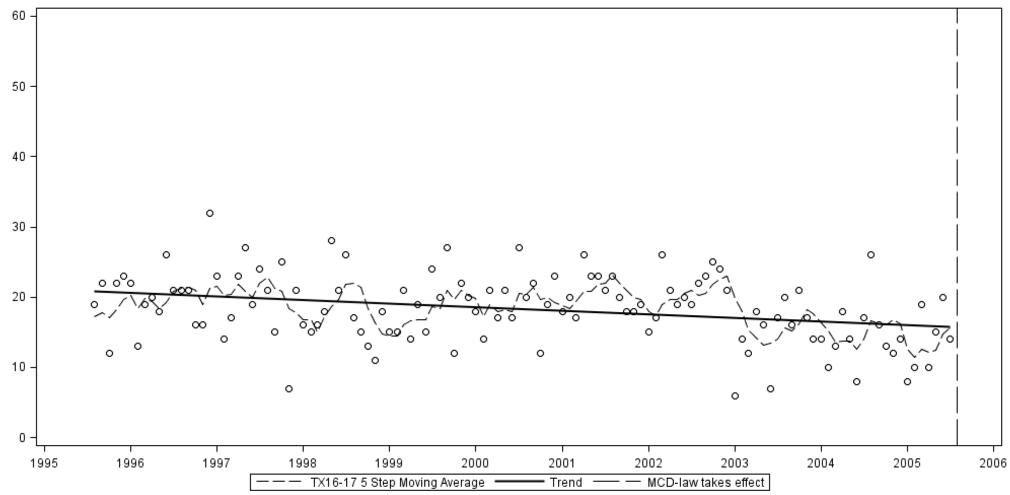


Figure 42 displays the fatal crash rate involving drivers age 16 and 17 in four control states (AL, AR, NM, OK) over the same period. This trend also decreased (β_{time}=-0.003 p=0.001), with similar autocorrelation (DW= 1.110 p<DW: 0.0001).

Figure 42. Fatal Crashes Involving AL-AR-NM-OK Drivers Age 16-17, 10 years pre-MCD-law

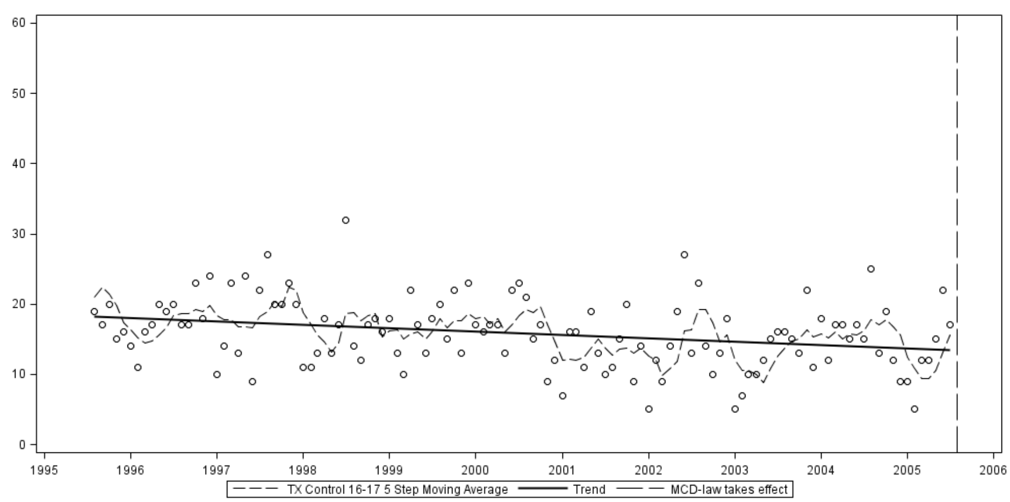


Figure 43 displays the trend for fatal crashes involving Texas drivers age 16 and 17 drivers in the three years before the MCD-law. Over the three year period the average monthly number of crashes decreased (β_{time} =-0.010; p=0.036).

Figure 43. Fatal Crashes Involving TX Drivers Age 16-17, 3 years pre-MCD-law

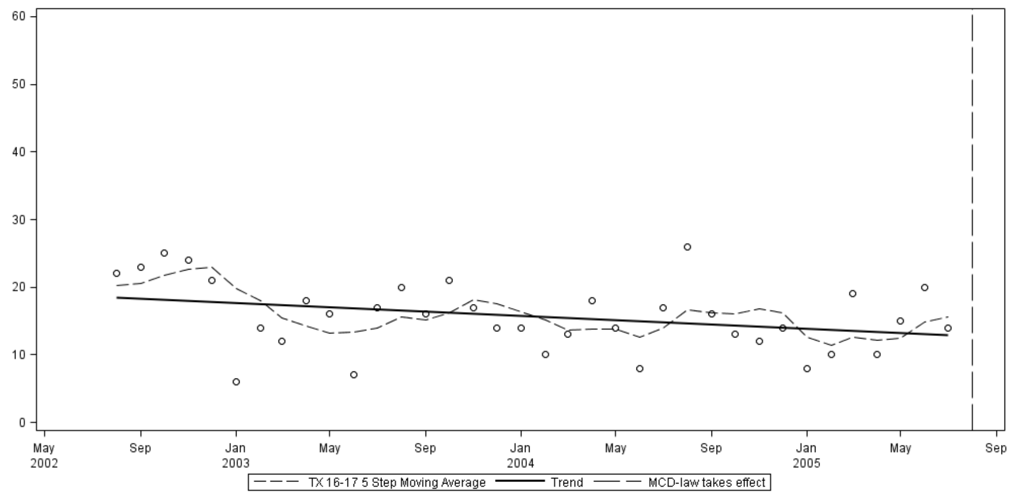


Figure 44 displays the trend for fatal crashes involving drivers age 16 and 17 drivers in the Control States (AL, AR, NM, OK) in the three years before the Texas MCD-law. Over this period the average monthly number of crashes was flat (β_{time}=-0.004; p=0.473).

Figure 44. Fatal Crashes Involving AL-AR-NM-OK Drivers Age 16-17, 3 years pre-MCD-law

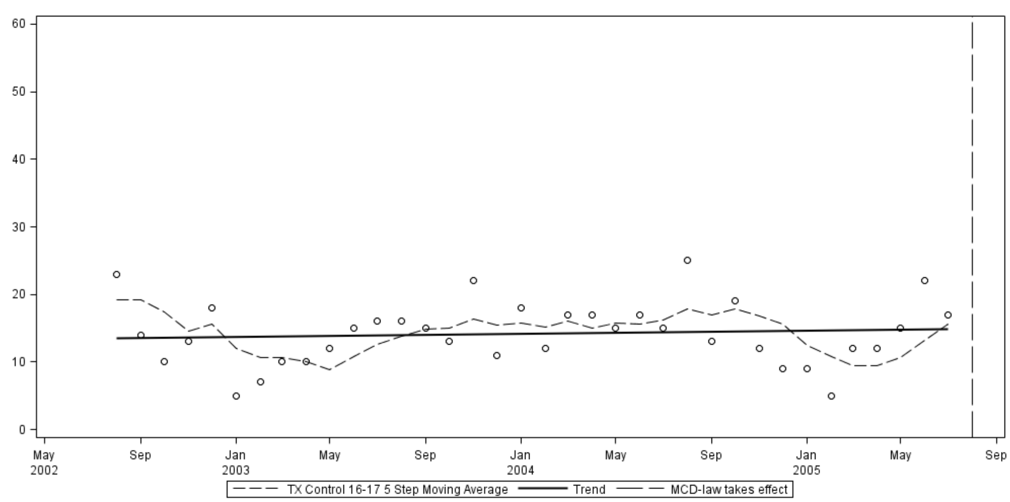
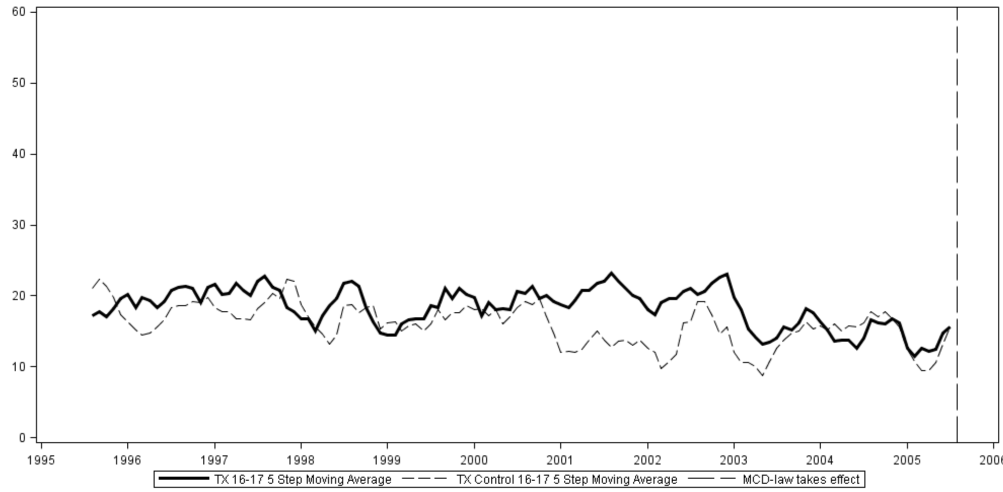


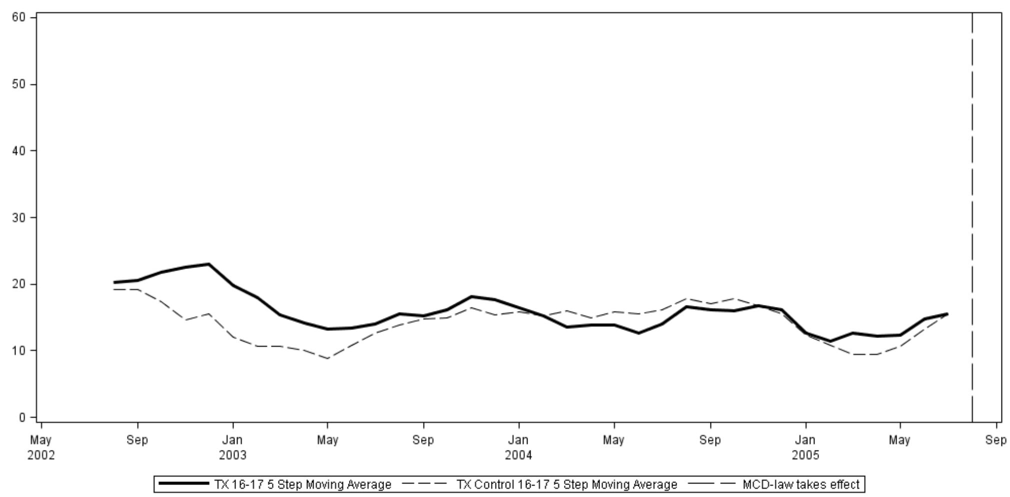
Figure 45 overlays the 5-step moving average for the monthly rate of crashes for Texas drivers age 16 and 17 and the control group over the ten year period preceding the MCD-law. There are some notable departures - for example, between 2001 and 2002. But the trends have similar peaks and the same general decreasing trend.

Figure 45. Moving Averages Ten Years before law for TX Drivers Age 16-17 and Drivers Age 16-17



In Figure 46, the 5-step moving average for the monthly crash rates follow a similar trajectory over the shorter period immediately preceding the MCD-law.

Figure 46. Moving Averages Three Years before law for TX Drivers Age 16-17 and Drivers Age 16-17



These graphical analyses suggest that drivers age 16 and 17 from the four control states provide a reasonable comparison group for Texas age 16 and 17 drivers based on the parallel movement of each trend in the years preceding the MCD-law.

4(b): TX Drivers Age 16-17; TX Drivers Age 18-19

Figure 47 displays the trend for fatal crashes involving drivers age 18 and 19 drivers in Texas in the three years before the MCD-law banned drivers age 16 and 17 from all use of MCDs. The monthly crash rate increased (β_{time}= 0.002; p=0.018) with evidence of positive autocorrelation (DW= 1.110; p<DW: 0.0001).

Figure 47. Fatal Crashes Involving TX Drivers Age 18-19, 10 years pre-MCD-law

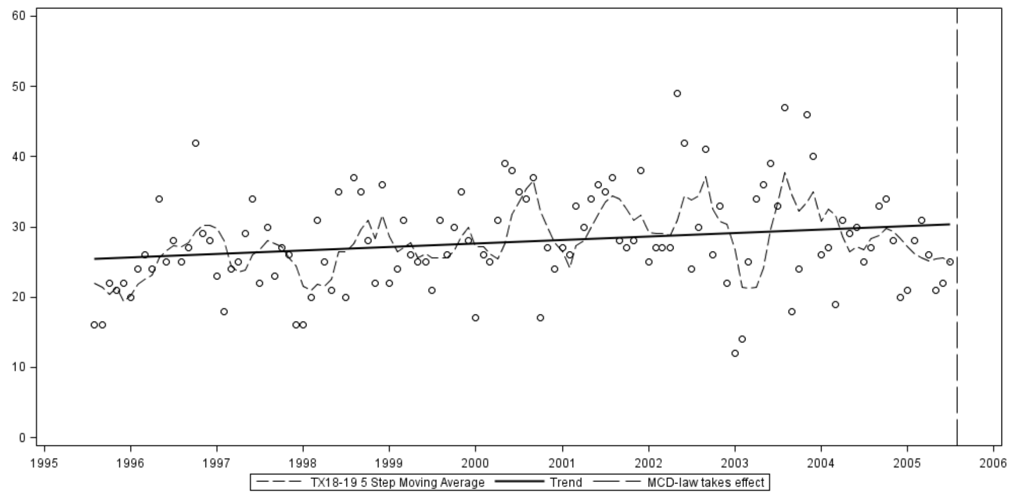


Figure 48 displays the trend for fatal crashes involving age 18 and 19 drivers in Texas three years before the MCD law. The trend slopes down but not to a significant degree (β_{time}=-0.004; p=0.473).

Figure 48. Fatal Crashes Involving TX Drivers Age 18-19, 3 years pre-MCD-law

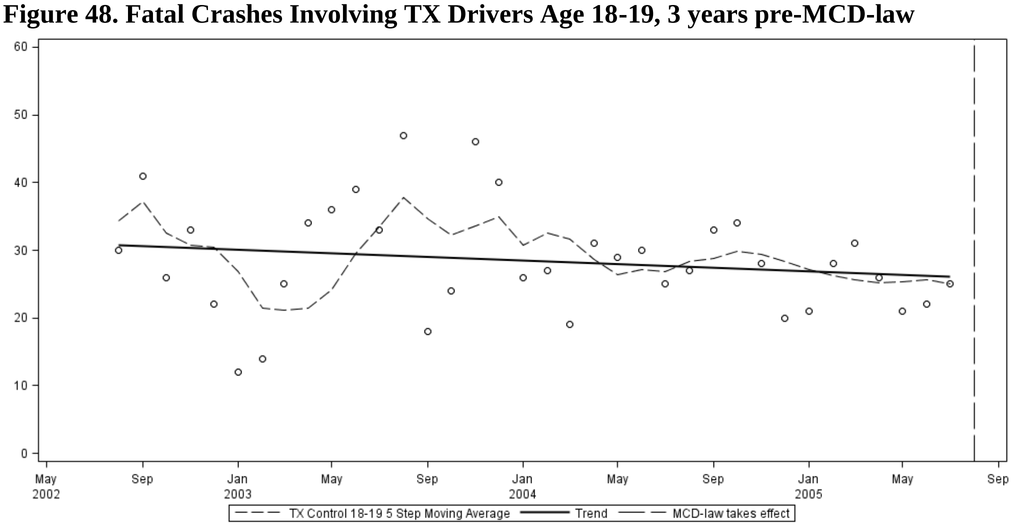


Figure 49 overlays the 5-step moving average for the monthly rate of crashes for the focal group (Texas drivers age 16 and 17) and the control group (Texas drivers age 18 and 19) over the ten year period preceding the MCD-law. The trends follow a similar trajectory although they also appear to drift apart over the ten year span.

Figure 49. Moving Averages Ten years before law for TX Drivers Age 16-17 and Drivers Age 18-19

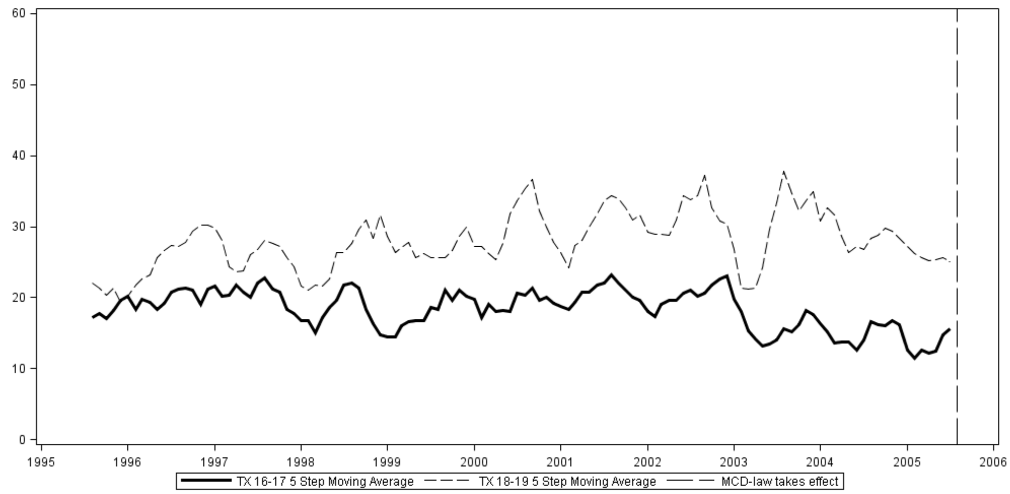
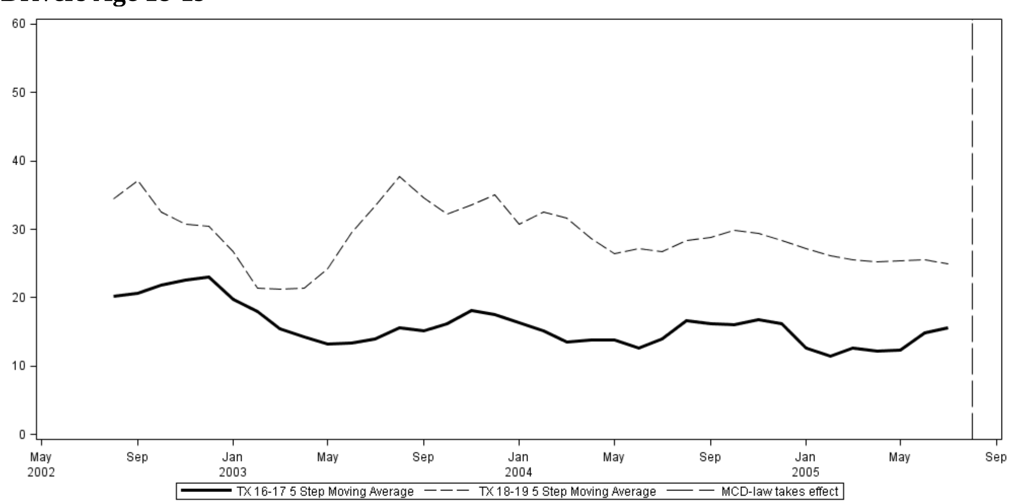


Figure 50 overlays the 5-step moving average for the monthly rate of crashes for the two age groups over the three year period preceding the MCD-law. The trends appear to follow a similar trajectory.

Figure 50. Moving Averages Three years before law for TX Drivers Age 16-17 and Drivers Age 18-19



These graphical analyses suggest that age 18 and 19 drivers in Texas provide a reasonable comparison group for age 16 and 17 drivers in Texas.

Table 10 provides a summary of the respective trends.

Table 10. Mean and Trend Analysis for 3 and 10 Years Before Law

State-Group (F): focal group (C): control group	Mean (pre-law) 10 yr	Mean (pre-law) 3 yr	Trend (β_{time}) 10 yr	Trend (β_{time}) 3 yr	10 yr pre-law Durbin Watson DW<P	10 yr pre-law Durbin Watson DW>P
AR 16-17 (F)	2.85	2.50	-0.0025 (0.1901)	-0.0159 (0.1248)	0.7250	0.2750
AL 16-17 (C)	5.31	4.42	-0.0017 (0.1672)	0.0058 (0.4892)	0.0210	0.9790
AR 18-20 (F)	6.37	6.00	-0.0002 (0.8571)	-0.0094 (0.2520)	0.6245	0.3755
AR 21-23 (C)	5.48	4.72	-0.0013 (0.2723)	-0.0088 (0.2321)	0.0232	0.9768
Control 18-20 (AL, MS)(C)	19.39	17.36	-0.0014 (0.0713)	-0.0067 (0.2623)	0.1587	0.8413
AL 18-20 (C)	11.16	10.08	-0.0014 (0.1075)	-0.0109 (0.0520)	0.2836	0.7164
MS 18-20 (C)	8.23	7.28	-0.0015 (0.2196)	-0.0010 (0.9024)	0.0571	0.9429
NC 16-17 (F)	7.42	6.94	-0.0032 (0.0016)	-0.0044 (0.4689)	0.0048	0.9952
NC 18-19 (C)	10.67	11.61	0.0014 (0.1137)	-0.0071 (0.1342)	0.1912	0.8088
Control 16-17 (PA,SC)(C)	11.74	9.89	-0.0030 (0.0009)	0.0042 (0.4341)	0.0019	0.9981
PA 16-17 (C)	7.43	6.19	-0.0032 (0.0052)	0.0000 (0.9975)	0.0370	0.9630
SC 16-17 (C)	4.32	3.69	-0.0028 (0.0346)	0.0107 (0.2872)	0.0291	0.9709
TX 16-17 (F)	18.29	15.67	-0.0024 (0.0005)	-0.0098 (0.0465)	0.0930	0.9070
TX 18-19 (C)	27.91	28.42	0.0016 (0.0178)	-0.0047 (0.2949)	0.0006	0.9994
Control 16-17 (C) (AL,AR,NM,OK)	15.78	14.19	-0.0025 (0.0013)	0.0027 (0.6112)	0.1141	0.8859
AL 16-17 (C)	6.03	5.69	-0.0024 (0.0363)	0.0094 (0.1634)	0.2339	0.7661
AR 16-17 (C)	3.17	3.17	-0.0004 (0.8400)	0.0101 (0.3452)	0.9626	0.0374
NM 16-17 (C)	2.02	1.86	-0.0013 (0.4983)	-0.0217 (0.0853)	0.0008	0.9992

Table 10, continued

OK 16-17 (C)	4.58	3.48	-0.0049 (0.0001)	-0.0023 (0.7862)	0.4429	0.5571

Notes: Figures in parentheses are p-values for the Durbin Watson statistic.

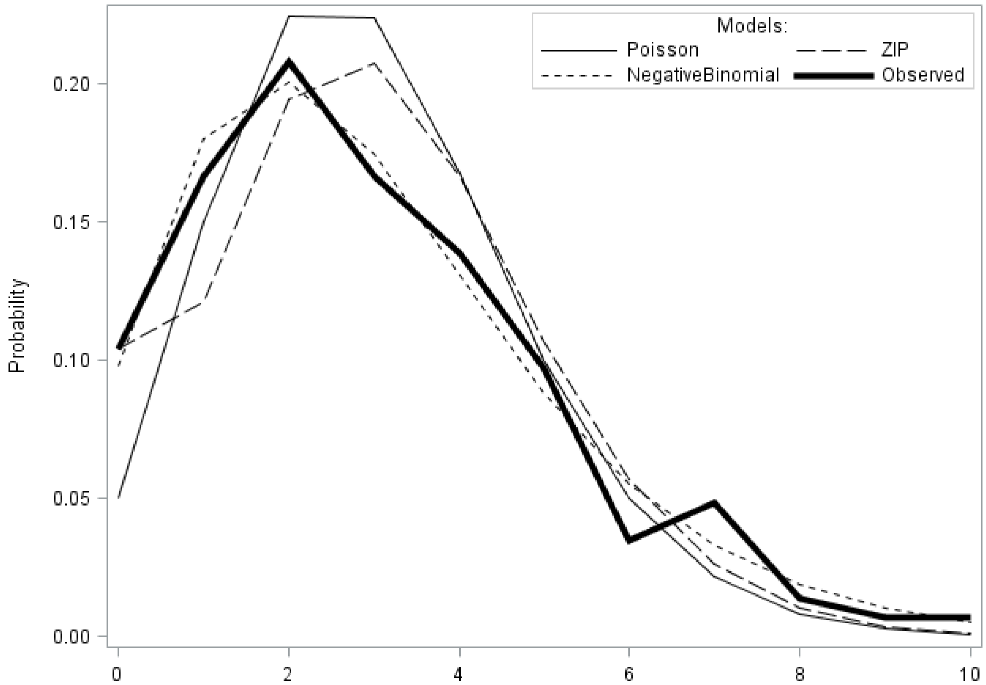
Over the ten year intervals before the respective MCD-laws took effect, most of the subgroups exhibited a downward trend that reached or approached significance. The trends over the three year interval were much less consistent in direction and significance, which is not surprising. There was some evidence of positive autocorrelation, which is consistent with seasonal patterning and weather trends that vary at increments of four or more months.

Phase IIa: Model Specification

This section describes the model specification tasks of identifying the distributional properties of the dependent variable. Crash data are numeric and positive. Descriptive analyses revealed that the crash rates had few zeroes and a heavy right-skew at a monthly resolution, which is consistent with the literature. These monthly crash rates do not follow a normal distribution, but clump below the mean with periods of high mortality. Distributional plots (provided in Appendix C) suggest that motor vehicle crashes follow a Poisson or negative binomial distribution at the monthly resolution. To confirm, predicted values were generated employing Poisson, Poisson zero-inflated, and negative binomial functions, and were then plotted against the raw trend. As depicted in Figures 51-54, the negative binomial distribution provided the closest fit to the raw data.[5] The dispersion estimates in the four negative binomial models support this determination.

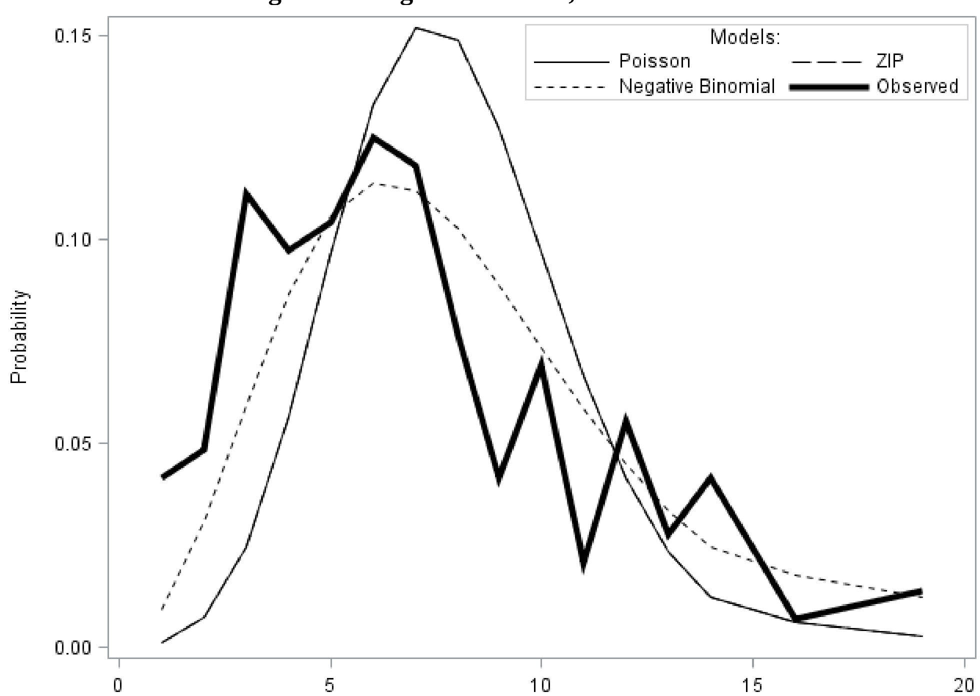
[5] These analyses relied on set of COUNTREG procedures and open source SAS Macro language. The COUNTREG procedures rely on the PROBCOUNTS macro, which SAS provides at http://support.sas.com. Additional code and support materials are available at: http://support.sas.com/documentation/cdl/en/etsug/60372/HTML/default/viewer.htm#etsug_countreg_sect029.htm.

Figure 51. Crashes Involving Drivers Age 16-17 in AR and AL



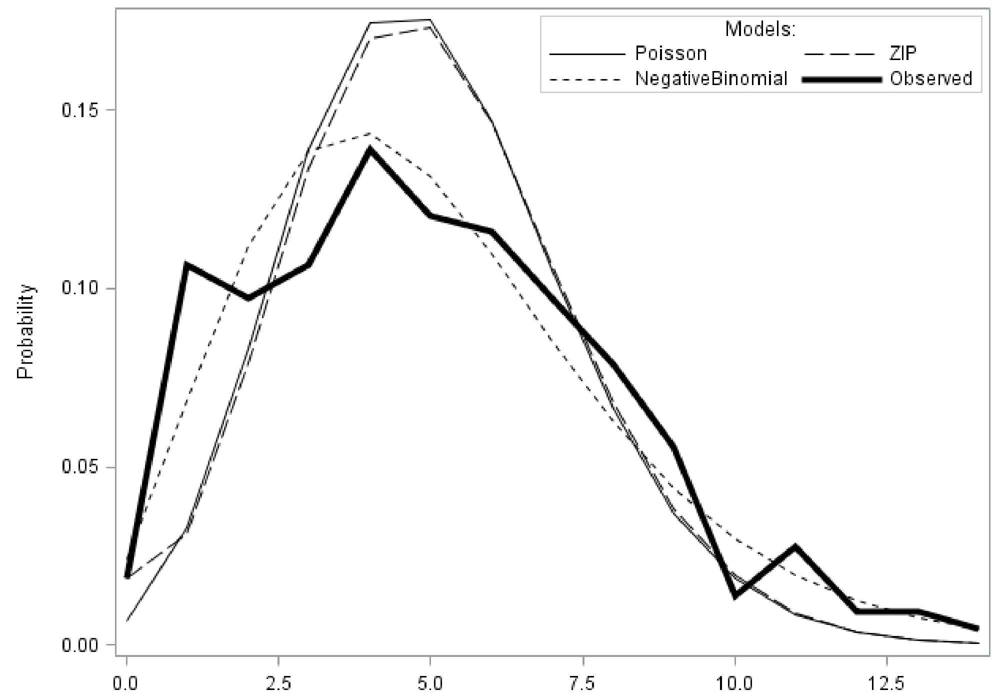
Negative binomial dispersion parameter: β=0.0322

Figure 52. Crashes Involving Drivers Age 18-20 in AR, AL and MS



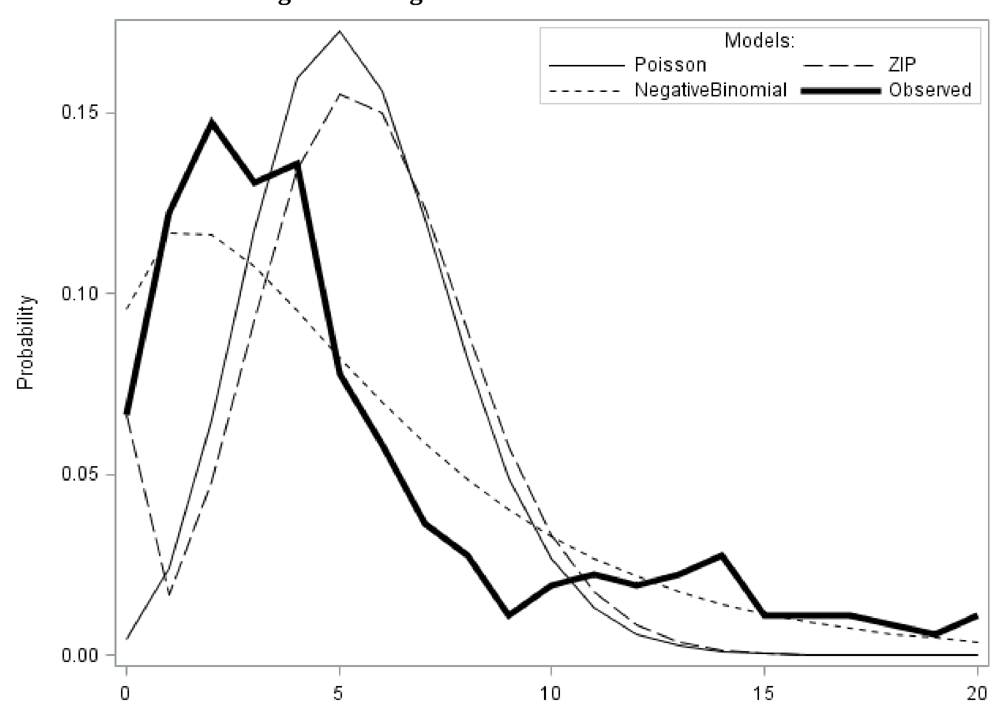
Negative binomial dispersion parameter: β<0.0001

Figure 53. Crashes Involving Drivers Age 16-17 in NC, PA, and SC



Negative binomial dispersion parameter: β<0.0001

Figure 54. Crashes Involving Drivers Age 16-17 in TX and the Control States



Negative binomial dispersion parameter: β<0.0001

Phase IIb: Addition of Covariates

Crash risk is influenced by multiple factors. Precipitation and temperature are known to increase crash risk, although they do not have the same effect across the country (Pisano, Goodwin, & Rossetti, 2004), which is one source of regional confounding. In the state-comparisons below, however, temperature and precipitation have similar effects because the comparisons are all within the same region. Temperature is typically a stronger predictor of fatal crash rates. Although crash risk increases in snow and rain, reductions in speed have a countervailing effect on mortality. Season also sometimes influences crash rates independent of climate. To assess the predictive value of state population, season, precipitation and temperature on monthly crash rates, Type 3 tests were conducted on each trend for all three variables. Table 11 reports the Type 3 test for each covariate.

Table 11. Type 3 Covariate Analysis

Outcomes (F): focal group (C): control group	Type 3 Chi-Square (Pr>ChiSq)			
	Population	Temperature	Precipitation	Summer
AR 16-17 (F) AL 16-17	36.29 (<.0001)	2.97 (0.0847)	3.30 (0.0694)	0.00 (0.9826)
AR 18-20 (F) AR 21-23	31.95 (<.0001)	5.47 (0.0194)	0.00 (0.9487)	0.93 (0.3357)
AR 18-20 (F) AL-MS 18-20	14.53 (0.0001)	8.79 (0.0030)	1.32 (0.2504)	1.62 (0.2025)
NC 16-17 (F) NC 18-19	16.59 (<.0001)	1.81 (0.1784)	0.10 (0.7524)	0.08 (0.7747)
NC 16-17 (F) PA-SC 16-17	37.62 (<.0001)	18.44 (<.0001)	0.26 (0.6133)	9.86 (0.0017)
TX 16-17 (F) TX 18-19	11.01 (0.0009)	1.43 (0.2322)	0.00 (0.9535)	0.01 (0.9043)

Table 11, continued

TX 16-17 (F)	305.74	22.99	11.63	8.27
Control 16-17	(<.0001)	(<.0001)	(0.0006)	(0.0040)

Notes: Figures in parentheses in the trend column are p-values.

Consistent with Table 11, population, temperature and precipitation are included in models below. The seasonal indicator was dropped from further analyses.

Phase IIc: Difference-in-Difference Model

The rate of crashes resulting in a fatality involving a driver in the focal group in the three years after the law went into effect decreased consistently compared with the three years prior. The analytic challenge is identifying whether the law contributed to these reductions or whether they can be explained by generally diminishing rates of crash fatalities observed across most states over the last few decades. To evaluate the effect of the MCD-laws, this study employs difference-in-difference regression, a technique common in the evaluation of health policies (Cho, 2011; Gruber, 1994; Kreft & Epling, 2007). This approach enables estimation of the effect of the policy change accounting for the influence of unobserved exogenous factors or secular trends. The inclusion of comparisons between changes in crash rates in the focal state before and after the law went into effect for drivers in adjacent age groups not covered by the law is intended to account for unobserved state specific shocks (i.e., other state traffic safety interventions of wide applicability). The inclusion of comparisons between changes in crash rates before and after the law for drivers of the same age in proximal states is intended to account for unobserved regional factors related to that specific age group (e.g., changes in fuel prices).

To motivate the estimation an indicator variable was used to identify crashes that occurred in the focal and control states in the three years after the MCD-law went into effect. To determine whether the reduction in the rate of fatal crashes after the law went into effect in the focal state differs significantly from the anticipated rate had there been no law, this study relies on two models. The first model, which compares trends between the same age group in different states is:

$$(1) \qquad \ln(Y_i) = \beta_0 + \ln(V) + \beta_1(T) + \beta_2(L) + \beta_3(T * L) + \beta_z(X_z) + \varepsilon$$

In model (1), the outcome Y_i is the monthly rate of crashes involving drivers of the same ages indexed by state and month. Given the log-link function, the natural log of vehicle-miles-travelled appears as an additive term on the right side of the equation, represented above as ln(V), and functions as an offset variable adjusting the crash rate by state risk-exposure. The variable T is a dummy indicator for fatalities occurring in the focal state. The variable L is an indicator for fatalities occurring after the law went into effect, in both the treatment and control groups. To account for time and state variant contributions of climate and population, a matrix of covariates X_z are included as measures of average monthly temperature, precipitation and population. The coefficient on the interaction term β_3 provides the difference-in-difference estimate that represents the difference between the rates of crashes before the law was implemented in focal state and after compared with the same trend in the control group for both sets of age groups.

The second model, which compares trends between the adjacent age groups in the same state (one covered by the law and one not) is:

$$(2) \qquad \ln(Y_i) = \beta_0 + \ln(V) + \beta_1(C) + \beta_2(L) + \beta_3(C * L) + \beta_z(X_z) + \varepsilon \ (2)$$

In model (2), the outcome Y is the monthly rate of crashes involving drivers of different ages indexed by month and state. The natural log of vehicle-miles-travelled (ln(V)) enters the model as the underlying risk-exposure offset as above. The variable C is a dummy indicator for fatalities involving a driver covered by the law in the focal state. The variable L is an indicator for fatalities occurring after the law went into effect, in both the treatment and control groups. The same matrix of covariates X_z are included to account for time and state variant contributions of climate and population. The coefficient on the interaction term β_3 provides the difference-in-difference estimate that represents the difference between the rates of crashes before the law was implemented in focal state and after compared with the same trend in the control group for both sets of age groups. All analyses are run in SAS 9.3 (SAS Institute Inc., Cary, NC) using GENMOD and AUTOREG procedures.

CHAPTER 4: RESULTS

Restatement of the Study Purpose and Research Questions

The main purpose of this study is to explore the relationship between MCD-laws and crash fatalities using a specific strategy. The strategy relies on comparisons of crash trends for before and after the MCD-laws went into effect for treated and untreated subgroups. Such comparisons were only feasible in four instances. These four instances motivate the following research questions:

RQ1: Did Arkansas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

RQ2: Did Arkansas' law prohibiting all handheld use of MCDs for drivers age 18-20 reduce motor vehicle fatalities involving drivers of that group.

RQ3: Did North Carolina's law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

RQ4: Did Texas' law prohibiting all use of MCDs for drivers under age 18 reduce motor vehicle fatalities involving drivers of that group?

This chapter describes the procedures and outcomes of the analyses conducted to answer each research question. It begins by reviewing some descriptive statistics.

Descriptive Statistics

The rate of fatal crashes decreased from the pre-law period to the post-law period for every subgroup. These reductions are apparent as absolute numbers, as rates per million VMT and as adjusted Rate Ratios (aRRs)(Table 12). This last measure is simply the ratio of the average monthly rate in the post-law period to the average monthly rate in the pre-law period, adjusted by covariates. An aRR significantly less than one suggests a substantial decrease, potentially due a protective factor.

Table 12. Average Monthly Number of Fatal Crashes Three Years Before and After the MCD-Law for Focal and Control Groups

State-Group (F): focal group	No. Pre-Law	No. Post-Law	% Δ	Rate /VMT Pre-Law	Rate /VMT Post-Law	% Δ	aRR (95% CI) * p<0.05 ** p<0.001
AR 16-17 (F)	2.55	1.33	-48%	0.77	0.40	-45%	0.49 (0.32-0.73) **
AL 16-17	4.53	3.56	-21%	0.76	0.56	-20%	0.67 (0.43-1.04)
AR 18-20 (F)	6.25	3.94	-37%	1.89	1.19	-37%	0.62 (0.49-0.78) **
AR 21-23	4.81	4.67	-3%	1.50	1.41	-3%	0.96 (0.77-1.20)
ALMS 18-20	8.76	5.81	-34%	1.71	1.14	-33%	0.66 (0.57-0.76) **
NC 16-17 (F)	6.94	5.33	-23%	0.70	0.52	-26%	0.73 (0.58-0.91) *
NC 18-19	11.61	9.53	-18%	1.17	0.92	-21%	0.80 (0.69-0.93) *
PASC 16-17	4.94	3.99	-19%	0.66	0.54	-18%	0.80 (0.67-0.95) *
TX 16-17 (F)	15.42	12.53	-19%	0.68	0.52	-23%	0.79 (0.69-0.91) **
TX 18-19	28.44	24.53	-14%	1.25	1.03	-18%	0.84 (0.75-0.94) *
Control 16-17 (AL, AR, OK, NM)	14.06	12.17	-13%	0.88	0.73	-17%	0.83 (0.73-0.95) *

As depicted in Table 12, the average monthly number of fatal crashes decreased in every subgroup. Most of these reductions were statistically significant. The analytical question presented is whether significantly larger decreases occurred in the treated subgroups as compared with the control subgroups, while adjusting for covariates.

Results

Research Questions 1: Effect of AR MCD-Law Regulating Drivers Age 16-17

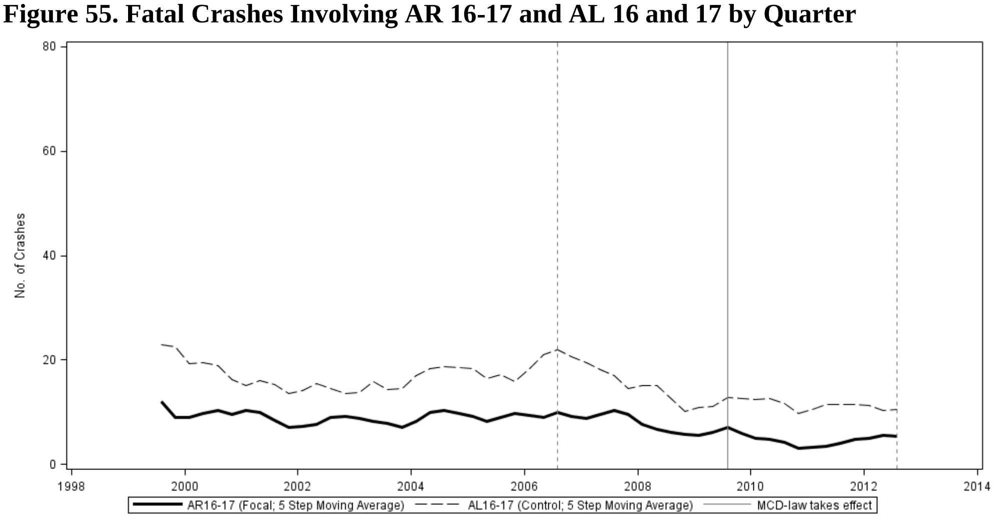
The average monthly number and rate per million VMT of fatal crashes involving drivers age 16 and 17 decreased 48% and 45% per month in Arkansas in the three years after the MCD-law. Adjusting for population, precipitation and temperature, this represented an enormous 51% decrease (aRR=0.486; 95% CI: 0.323-0.731; p=0.001). A smaller but still substantial decrease was observed in the number (21%), rate (20%), and adjusted rate ratio of crashes for age 16 and 17 drivers in Alabama over the same pre-law and post-law periods (aRR=0.668; 95% CI: 0.430-1.037; p=0.072).

Table 13. Change in AR and AL Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
AR 16-17	-48%	-45%	0.486 (0.323-0.731)**
AL 16-17	-21%	-20%	0.668 (0.430-1.037)
Difference	-27%	-25%	-18%

As depicted in Figure 55, at a quarterly resolution, the trends in the crash rates tracked each other closely over the period preceding the MCD-law. There is a small but noticeable divergence between the two trends after the MCD-law.

Figure 55. Fatal Crashes Involving AR 16-17 and AL 16 and 17 by Quarter



Despite the relatively larger magnitude and significance of the effect for the focal group, the ratio of adjusted Rate Ratios approached but did not reach significance in the difference-in-difference regression (RaRR Ratio=0.728, CI=0.464-1.141; p=0.166). The insignificance is partly attributable to the small size of the monthly fatal crash rate for Arkansas drivers in this age group. With so few fatal crashes per month, small deviations around the mean - a few more or a few less fatal crashes – result in large proportional changes and subsequently high variation.

Table 14. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.728	0.464-1.141
	Estimate	P Value
MCD-law effect	-0.318 (0.229)	0.166
Difference between pre- and post-law rates	-0.404 (0.225)	0.072
Difference between AR and AL	1.332 (2.724)	0.625
Population	0.091 (0.151)	0.546
Temperature	0.0130 (0.004)	<0.001
Precipitation	0.050 (0.022)	0.022

Notes: Figures in parentheses are standard errors.

There is a significant difference between the pre-law and post-law periods (-0.404; p=0.072). There is not a significant difference between the crash rates for Arkansas and Alabama drivers per VMT while adjusting for population (1.332; p=0.625), which reflects their similar crash rates (AR_{pre}=0.77; AR_{post}=0.40; AL_{pre}=0.76; AL_{post}=0.56). Precipitation and temperature each have a small positive effect on crash rates.

Research Question 2: Effect of AR MCD-Law Regulating Drivers Age 18-20

The average monthly number and rate per million VMT of fatal crashes involving drivers age 18 to 20 in Arkansas both decreased 37% in the three years after the state banned these drivers from handheld use of MCDs. When adjusting for population, precipitation and temperature, this amounted to a 38% decrease (aRR=0.623; 95% CI:

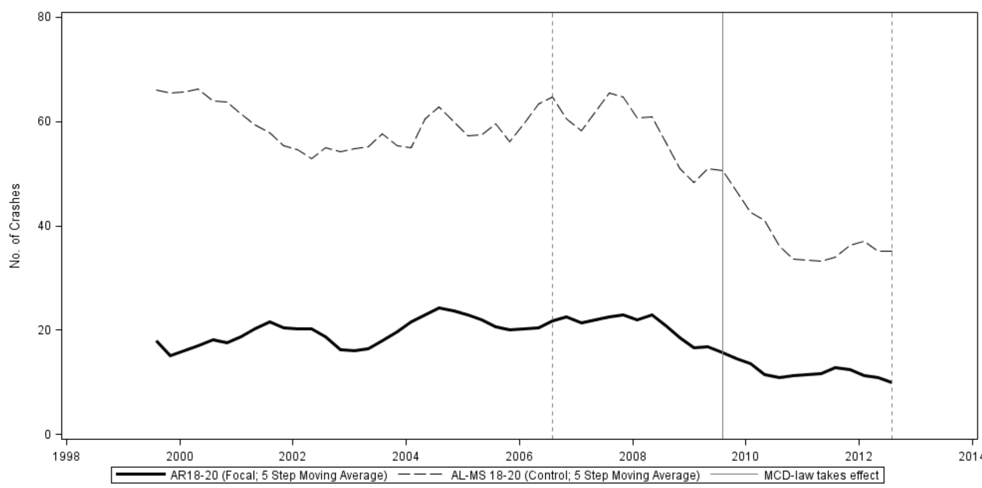
0.494-0.785; p<0.001). Similar decreases were observed in the number (34%), rate (33%) and adjusted rate ratio (34%) of fatal crashes involving drivers of the same age in Alabama and Mississippi over the periods (aRR=0.656; 95% CI: 0.569-0.756; p<0.001).

Table 15. Change in AR and AL-MS Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
AR 18-20	-37%	-37%	0.623 (0.494-0.785) **
AL-MS 18-20	-34%	-33%	0.666 (0.569-0.756) **
Difference	-3%	-4%	-4%

As depicted in Figure 56, the trends tracked each other closely over the two periods. Each trend displays a downward turn around the adoption of the MCD-law.

Figure 56. Fatal Crashes Involving AR 18-20 and AL-MS 18-20 by Quarter



Accounting for covariates, and modeled as a function of risk per VMT, the ratio of adjusted rate ratios did not differ from one in the difference-in-difference regression (RaRR= 0.950, CI=0.724-1.236; p=0.709), failing to provide evidence that the MCD-law influenced crash rates.

Table 16. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.950	0.724-1.246
	Estimate	P Value
MCD-law effect	-0.052 (0.138)	0.709

Table 16, continued

Difference between pre- and post-law rates	-0.422 (0.073)	0.002
Difference between AR and AL-MS	-0.123 (0.091)	0.176
Population	0.011 (0.004)	0.006
Temperature	0.007 (0.002)	0.002
Precipitation	0.004 (0.014)	0.800

Notes: Figures in parentheses are standard errors.

There is a significant reduction in the crash rate between the pre- and post-law periods (-0.422; p=0.002). There is not a significant difference between the crash rates for Arkansas drivers and Alabama-Mississippi drivers (-0.123; p=0.176). Although Figure 63 illustrates that the absolute number of monthly crashes in Alabama and Mississippi is much larger, as a rate per VMT, the number of crashes in AR (1.19) and AL-MS (1.14) for this age group are extremely similar, as is the difference in the rate across the two periods. Temperature had a small positive effect on crash rates (0.007; p=0.002); precipitation had a small but insignificant effect on crash risk (0.004; p=0.800).

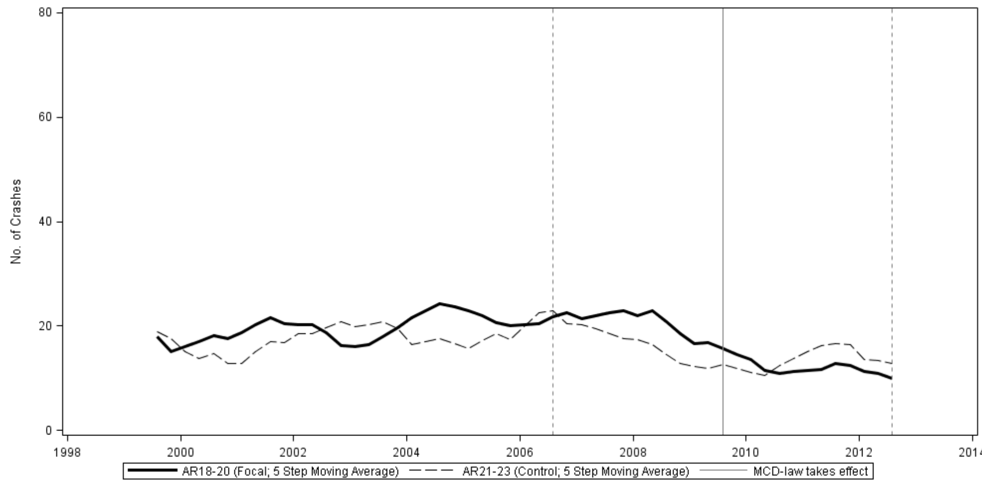
The second comparison yielded different results. The average monthly number and rate per VMT of fatal crashes involving Arkansas drivers age 21 to 23 decreased just 3% and 4% in the three years after the law regulating drivers age 18 to 20 took effect. This translated into a 4% reduction after adjusting for covariates (aRR= 0.965, CI=0.775-1.202; p=0.749).

Table 17. Change in AR 18-20 and AR 21-23 Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
AR 18-20	-37%	-37%	0.623 (0.494-0.785) **
AR 21-23	-3%	-3%	0.965 (0.775-1.202)
Difference	-34%	-34%	-34%

As depicted in Figure 57, the trends in these crash rates clearly reverse position shortly after the MCD-law took effect.

Figure 57. Fatal Crashes Involving AR-18-20 and Age 21-23 by Quarter



Accounting for variation attributed to precipitation and temperature, and modeled as a function of risk per VMT, the ratio of adjusted rate ratios was significantly smaller than one in the difference-in-difference regression (RaRR=0.650, CI=0.480-0.880; p=0.005), suggesting a protective effect for the MCD-law.

Table 18. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.650	0.480-0.880
	Estimate	P Value
MCD-law effect	-0.431 (0.155)	0.005
Difference between pre- and post-law rates	0.260 (0.168)	0.121
Difference between AR18-20 and AR21-23	0.263 (0.103)	0.011
Population	0.404 (0.172)	0.019
Temperature	0.010 (0.003)	0.000
Precipitation	0.014 (0.014)	0.329

Notes: Figures in parentheses are standard errors.

There is not a significant difference in the crash rate between the pre- and post-law periods, when adjusting for population (0.260; p=0.121). There was a significant difference between the crash rates for Arkansas drivers in the two age groups (0.263; p=0.011), which is consistent with the trending in Figure 57. Temperature had a small positive effect on crash risk (0.0096; p=0.003); precipitation had an insignificant effect on crash risk (0.014; p=0.329). As depicted in Figure 57, the crash rate of the focal group is higher than the control group in the three years preceding the MCD-law, but then falls below but close to the control group trend in the three year after the MCD-law.

Research Question 3: Effect of NC MCD-Law Regulating Drivers Age 16-17

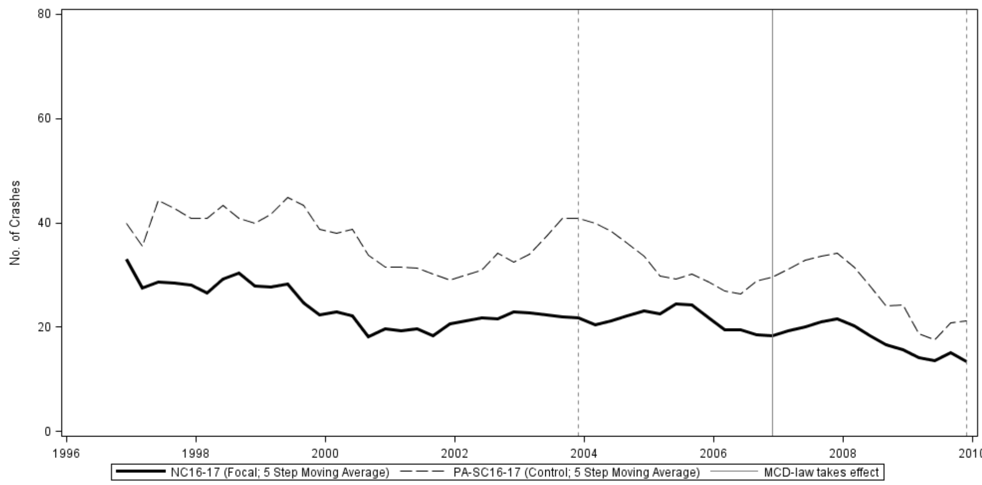
The average monthly number and rate per VMT of fatal crashes involving drivers age 16 and 17 in North Carolina decreased 23% and 26% in the three years after the state banned such drivers from all MCD-use. Similar decreases in the number (19%) and rate (18%) of crashers were observed for age 16 and 17 drivers in Pennsylvania and South Carolina over the same pre- and post-law periods. In adjusted analyses, these reductions were significant for North Carolina (aRR= 0.730, CI=0.584-0.914; p=0.006) and Pennsylvania and South Carolina (aRR= 0.797, CI=0.667-0.951; p=0.012)

Table 19. Change in NC 16-17 and PA-SC 16-17 Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
NC 16-17	-23%	-26%	0.730 (0.584-0.914) *
PA-SC 16-17	-18%	-21%	0.797 (0.667-0.951) *
Difference	-5%	-5%	-7%

As depicted in Figure 58, the trends in these crash rates have tracked each other very closely over these periods.

Figure 58. Fatal Crashes Involving NC and PA-SC Drivers Age 16-17 by Quarter



Accounting for variation attributed to precipitation and temperature, and modeled as a function of risk per VMT, the incident rate ratio did not differ significantly from one in the difference-in-difference regression (RaRR=0.917, CI=0.691-1.217; p=0.548), providing no evidence to suggest that the MCD-law influenced crash rates.

Table 20. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.917	0.691-1.217
	Estimate	P Value
MCD-law effect	-0.087 (0.146)	0.548
Difference between pre- and post-law rates	-0.228 (0.091)	0.012
Difference between NC and PA-SC	0.209 (0.098)	0.033
Population	0.003 (0.001)	0.014
Temperature	0.008 (0.003)	0.006
Precipitation	-0.026 (0.024)	0.284

Notes: Figures in parentheses are standard errors.

There is a significant difference between the pre- and post-law periods (-0.228; p=0.091). There was a marginally significant difference between the crash rates for North Carolina drivers and Pennsylvania and South Carolina drivers (0.209; p=0.098). Temperature had a small effect on crash rates in the expected direction (0.008; p=0.003); precipitation had no effect on crash risk (-0.026; p=0.284), which is common in more northerly states

(Pisano et al., 2004).

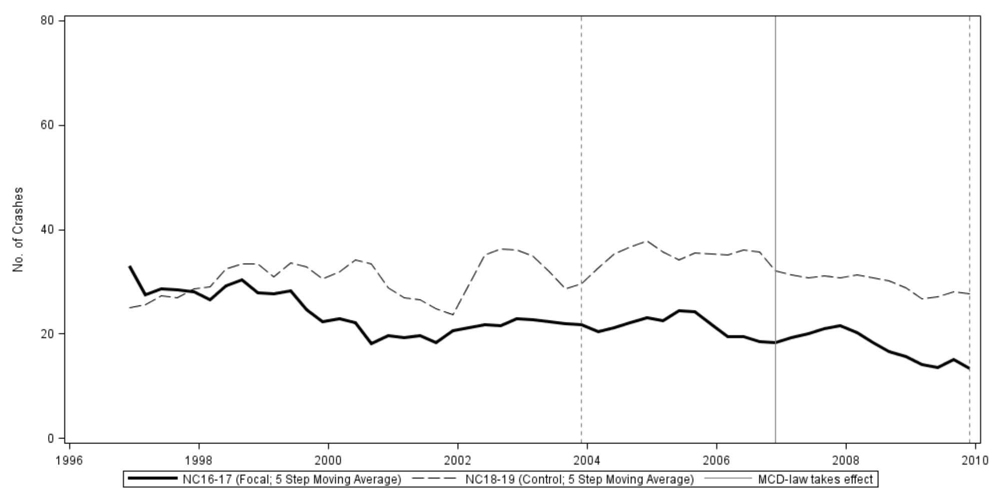
There were also decreases in the number (18%) and rate (21%) of fatal crashes involving drivers age 18 and 19 in North Carolina, the second comparison group, in the post-law period. The adjusted rate ratio for the two periods for this older age group was significantly less than one (aRR=0.800, CI=0.617-0.909; p=0.003).

Table 21. Change in NC 16-17 and 18-19 Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
NC 16-17	-23%	-26%	0.730 (0.584-0.914) *
NC 18-19	-18%	-21%	0.800 (0.617-0.909) *
Difference	-5%	-5%	-5%

The trends have followed parallel trajectories over recent years although they seem to be slowly drifting apart viewed over a longer perspective.

Figure 59. Fatal Crashes Involving NC Drivers Age 16-17 and 18-19 by Quarter



The difference-in-difference regression yielded no evidence that the crash rate for drivers age 16 and 17 decreased by more than the rate for drivers age 18 and 19 (RaRR=0.936, CI=0.739-1.185) after the MCD-law took effect.

Table 22. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.936	0.739-1.185

Table 22, continued		
	Estimate	P Value
MCD-law effect	-0.066 (0.121)	0.583
Difference between pre- and post-law rates	-0.170 (0.136)	0.212
Difference between NC 16-17 and 18-19	-0.514 (0.080)	<0.001
Population	0.007 (0.021)	0.001
Temperature	0.006 (0.002)	0.015
Precipitation	-0.002 (0.020)	0.940

Notes: Figures in parentheses are standard errors.

There is not a significant difference between the pre- and post-law periods (-0.170; p=0.136) once other covariates are added to the model. There is a significant difference between the crash rates for North Carolina drivers 16 and 17 and 18 and 19s (-0.514; p=0.080).Temperature has a positive effect on crash risk (0.006; p=0.002) and precipitation has no effect on crash risk (-0.002; p=0.940).

Research Question 4: Effect of TX MCD-Law Regulating Drivers Age 16-17

The average monthly number and rate per VMT of fatal crashes involving Texas drivers age 16 and 17 decreased 19% and 23% in the three years after the state banned their use of MCDs. This corresponded with a significant reduction measured as an adjusted rate ratio (aRR=0.794, CI=0.690-0.913; p=0.001). Similar decreases in the number (13%), rate (17%), and adjusted rate ratio of crashes were observed in age 16 and 17 drivers in Alabama, Arkansas, New Mexico and Oklahoma over the same pre- and post-law periods (aRR=0.857, CI=0.750-0.982; p=0.026).

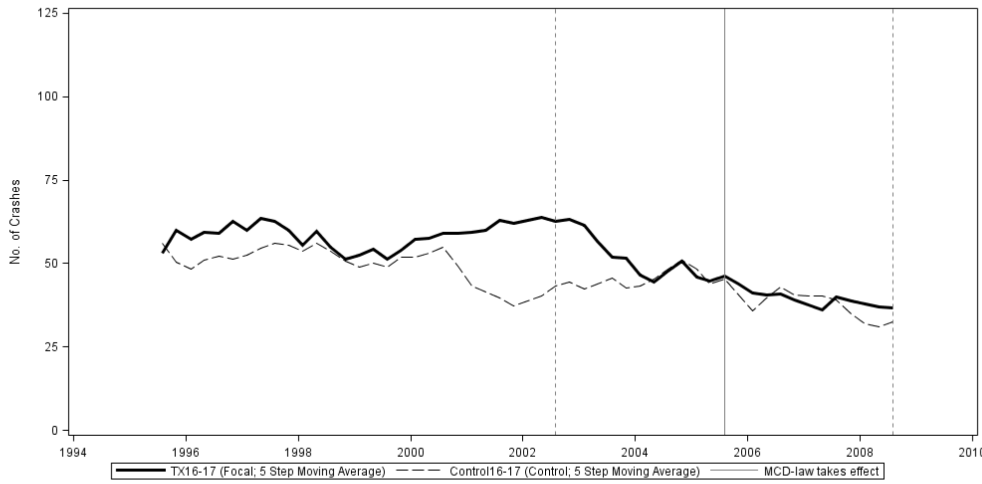
Table 23. Change in TX and AL-AR-NM-OK Age 16-17 Crash Rates Pre- to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
TX 16-17	-19%	-23%	0.794 (0.690-0.913) *
AL-AR-NM-OK 16-17	-13%	-17%	0.857 (0.750-0.982) *
Difference	-6%	-6%	-7%

At the quarterly resolution, the trends converge in the pre-law period and then trend together in the post-law period. In the period preceding the pre-law interval, the trend for

Texas is substantially larger, and it declines consistently across each subsequent three year period.

Figure 60. Fatal Crashes Involving TX and AL-AR-NM-OK Drivers Age 16-17 by Quarter



Accounting for variation attributed to precipitation and temperature, and modeled as a function of risk per VMT, the incident rate ratio was significantly smaller than one in the difference-in-difference regression (RaRR=0.766; CI=0.614-0.956; p=0.018) providing evidence indicating a protective effect of the MCD-law.

Table 24. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.766	0.614-0.956
	Estimate	**P Value**
MCD-law effect	-0.267 (0.113)	0.018
Difference between pre- and post-law rates	-0.178 (0.070)	0.011
Difference between TX and Control States	-2.292 (0.705)	0.001
Population	0.016 (0.004)	<0.001
Temperature	0.009 (0.002)	<0.001
Precipitation	0.015 (0.015)	0.317

Notes: Figures in parentheses are standard errors.

The coefficients in the model behave as expected. There was a marginally significant difference between the pre- and post-law periods (-0.178; p=0.011). There is a significant difference between the crash rates for Texas drivers and AL-AR-NM-OK drivers (-2.292;

p=0.001). The direction of the effect is consistent with the substantially higher per mile crash rate in the control states (0.88) compared to Texas (0.68). Precipitation (0.015; p=0.015) and temperature (0.009; p=0.002) each have a small effect on crash rates in the expected direction.

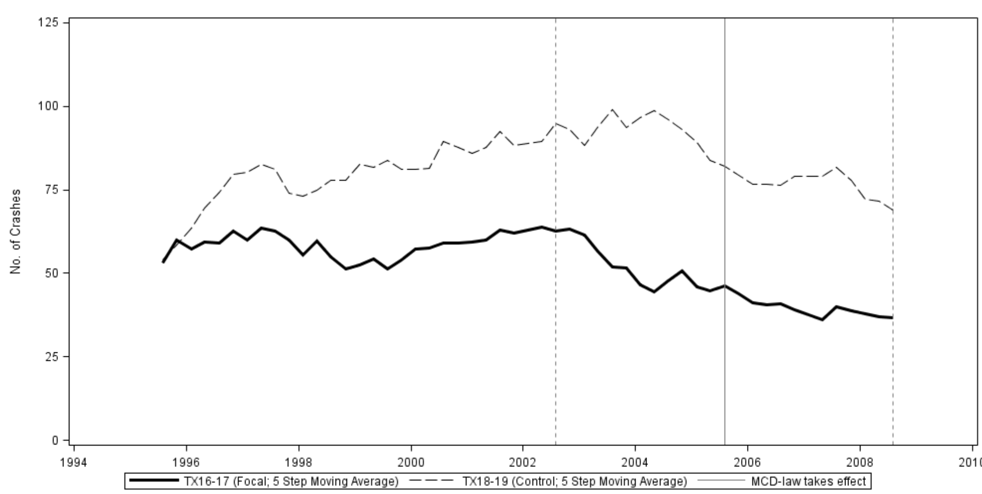
The rate of fatal crashes involving drivers age 18 and 19 drivers in Texas also decreased in the post law period. This corresponded with a significant reduction measured as an adjusted rate ratio (aRR=0.842, 95% CI=0.754-0.941; p=0.001).

Table 25. Change in TX Age 16-17 and 18-19 Crash Rates Pre-Law to Post-Law

Group	Δ in Absolute rate	Δ in Rate per VMT	Δ in adjusted Rate per VMT (aRR)
TX 16-17	-19%	-23%	0.794 (0.690-0.913) *
TX 18-19	-14%	-18%	0.842 (0.754-0.941) *
Difference	-5%	-5%	-5%

Despite a clear and persistent drifting apart of the two trends over the full interval, over the pre-law and post-law periods, the trends track each other relatively closely.

Figure 61. Fatal Crashes Involving TX Drivers Age 16-17 and 18-19 by Quarter



For this intra-state comparison, the difference-in-difference regressions failed to find an effect of the MCD-law (RaRR=0.942, 95% CI=0.788-1.126; p=0.489).

Table 26. Difference-in-Difference Estimates

	Estimate	Confidence Interval
Ratio of adjusted Rate Ratios (RaRR)	0.942	0.788-1.126
	Estimate	**P Value**
MCD-law effect	-0.060 (0.087)	0.489
Difference between pre- and post-law rates	0.125 (0.089)	0.158
Difference between TX 16-17 and TX 18-19	-0.612 (0.062)	<0.001
Population	-0.022 (0.005)	<.0001
Temperature	0.006 (0.002)	0.001
Precipitation	-0.004 (0.016)	0.810

Notes: Figures in parentheses are standard errors.

There is not a significant difference between the pre- and post-law periods (0.125; p=0.089). The difference between the crash rates for the two Texas age groups is apparent (-0.612; p<0.001). Temperature has a positive effect on crash risk (0.006; p=0.001) and precipitation has no effect on crash risk (-0.004; p=0.810). The plot of predicted trends in Figure 70 illustrates that there were no differences in trending for crash rates for drivers age 16-17 and 18-19 in Texas. Given the absence of evidence of an effect at the double difference-in-difference level there is no need to go to the triple difference in difference.

Basic descriptive analysis of monthly rates of fatal crashes involving young drivers demonstrated a consistent decreasing trend across the subgroups. In two of the seven difference-in-difference analyses, there was evidence to suggesting that MCD-laws are associated with fewer crash fatalities involving drivers in age groups covered by the law. Model diagnostics and behavior of covariates suggest that the models are reasonable. Table 27 provides a summary of the changes in the trends and ratios of adjusted rate ratios for the various comparisons.

Table 27. Summary Table of Adjusted Rate Ratios (aRRs) and Ratios of Adjusted Rate Ratios (RaRRs)

State-Group (F): focal group	Rate /VMT Pre-Law	Rate /VMT Post-Law	% Δ	aRR (95% CI) * p<0.05 ** p<0.001	Ratio of aRR (95% CI) * p<0.05 ** p<0.001
AR 16-17 (F)	0.77	0.40	-45%	0.49 (0.32-0.73) **	0.728 (0.464-1.141)
AL 16-17	0.76	0.56	-20%	0.67 (0.43-1.04)	-
AR 18-20 (F)	1.89	1.19	-37%	0.62 (0.49-0.78) **	0.950 (0.724-1.246)
ALMS 18-20	1.71	1.14	-33%	0.66 (0.57-0.76) **	-
AR 18-20 (F)	1.89	1.19	-37%	0.62 (0.49-0.78) **	0.650 (0.480-0.880) *
AR 21-23	1.50	1.41	-3%	0.96 (0.77-1.20)	-
NC 16-17 (F)	0.70	0.52	-26%	0.73 (0.58-0.91) *	0.917 (0.691-1.217)
PASC 16-17	0.66	0.54	-18%	0.80 (0.67-0.95) *	-
NC 16-17 (F)	0.70	0.52	-26%	0.73 (0.58-0.91) *	0.937 (0.735-1.193)
NC 18-19	1.17	0.92	-21%	0.80 (0.69-0.93) *	-
TX 16-17 (F)	0.68	0.52	-23%	0.79 (0.69-0.91) **	0.766 (0.614-0.956) *
Control 16-17	0.88	0.73	-17%	0.83 (0.73-0.95) *	-
TX 16-17 (F)	0.68	0.52	-23%	0.79 (0.69-0.91) **	0.942 (0.788-1.126)
TX 18-19	1.25	1.03	-18%	0.84 (0.75-0.94) *	-

CHAPTER 5: DISCUSSION

The purpose of this study was to examine the relationship between laws regulating use of MCDs by young drivers and crashes involving one or more fatalities. There are a number of studies that have explored this relationship. This study extends existing knowledge by using an identification strategy that is common in the evaluation of traffic safety evaluations but has not yet been applied to the study of MCD-laws. This strategy leverages the developing concept of legal epidemiology. There are three major findings of the study: 1) opportunities for quasi-experiments are limited but can be readily identified with systematic legal research; 2) there is some limited evidence supporting the effectiveness of MCD-laws regulating young drivers but the practical effect is small and differs in relation to identification strategy; and 3) challenges endemic to legal evaluation will continue to impede the identification of effective legal interventions, when effects are small and/or gradual. The concluding chapter summarizes the findings and elaborates on the results presented in Chapter Four. It also discusses study limitations, implications and directions for future research.

Summary of Key Findings

The process of moving from legal research to the design of quasi-experimental comparisons was an interesting and valuable exercise that yielded insights into both the spread of MCD-laws and prospects for ongoing research and reform. These laws are diverse and numerous, and continue to evolve. In all four states, new laws were passed after the study period. Understanding the effect of the earlier iterations of the laws is important to the extent that it informs ongoing reform. However, the persistent strengthening of laws reflects a common perception that existing laws are not strong enough to achieve desired effects.

In two of the seven sub-analyses, there was evidence suggesting that fatal crash rates involving drivers subject to the law decreased by a significantly greater degree than crash rates for the respective control groups. The first of the two sub-analyses compared crash rates for Arkansas drivers age 18 to 20 with crash rates for Arkansas drivers age 21 to 23. The former were prohibited from handheld use of MCDs pursuant to the MCD-law; the latter were subject to no restrictions in the study period. The Ratio of adjusted Rate Ratios for this sub-analysis (RaRR=0.650; 95% CI: 0.480-0.880) suggests that the law resulted in about 5.13 fewer fatalities per year. The second of the two sub-analyses compared crash rates for Texas drivers age 16 and 17 with aggregate crash rates for a group of drivers of the same age in four control states (AL, AR, NM, OK). The former were banned from all MCD use pursuant to the Texas MCD-law; the latter were subject to no regulation with respect to MCD use during the study period. The Ratio of adjusted Rate Ratios for this sub-analysis (RaRR=0.766; 95% CI: 0.614-0.956) suggests that the law resulted in 8.12 fewer fatal crashes per year in the post-law period.

The findings from these two sub-analyses represent meaningful differences in mortality. However, confidence in these findings should be discounted by the fact that a significant reduction was not observed in analyses that evaluated these laws by employing different comparison groups (See Table 27). The Ratio of adjusted Rate Ratios for the comparison of crash rates for Arkansas drivers age 18 to 20 versus a control group composed of Alabama and Mississippi drivers of the same age revealed no evidence of a protective effect (RaRR=0.950; 95% CI: 0.724-1.246). The Ratio of adjusted Rate Ratios for the comparison of crash rates for Texas drivers age 16 to 17 versus Texas drivers age 18 to 19 similarly revealed no evidence of a protective effect (RaRR=0.942; 95% CI: 0.788-1.126). These inconsistencies underscore the importance and influence of specification choices.

Limitations of the Study

This study is subject to a number of limitations. Difference-in-difference estimation relies on the assumption that trends between treatment and control groups are not subject to unobserved time variant factors, which is difficult to empirically validate. The adoption or revision of graduated driver licensing programs is identified as a potential confounding factor capable of distorting the observed effects of the MCD-laws. While GDP-laws represent an obvious problem, and were therefore addressed in the methods above, there are plenty of other potential confounding factors. These may include laws and policies but also range of other influences including, for example, local health education campaigns or shocking anecdotes of distracted driving crashes.

Another limitation in this study is the coarse nature of fatal accidents as the primary outcome. The weaknesses of fatalities as a measure of crash risk in this context is highlighted by a recent study comparing use of MCDs by drivers and crash rates before and after the 9:00 PM "free minutes" threshold; it found that MCD use by drivers increased after 9:00 PM, but fatal crash rates did not (Bhargava & Pathania, 2013). Indeed, one interesting observation is that increased prevalence and access to MCDs by drivers may have a protective effect in terms of crash fatalities because emergency personnel can be summoned more quickly (Redelmeier & Tibshirani, 1997).

In the late 1990s there was considerable interest in crash detection systems, and several researchers argued that mandating inboard crash detection systems that alert emergency response personnel automatically in the event a motor vehicle experienced the inertial forces typical of crashes, would considerably reduce mortality from crashes. (Clark & Cushing, 2002; Evanco, 1999); MCDs may be playing a similar role in facilitating emergency response through emergency notification by first, second and third parties.

Another problem with the use of crash fatalities – and crashes more broadly – is that many factors influence risk. Ideally, the dependent variable in these analyses would be crashes that involved MCD-use rather than all fatal crashes, many of which do not involve MCD-use. Emergency personnel and law enforcement are required to list MCD-involvement in fatal crashes and FARS include this information, but current data is notoriously inaccurate. As demonstrated in Table 28, the number and proportion of MCD-involved crashes varies widely across states. The state with the most reported crashes involving MCD use is Tennessee even though New York and California have populations and crash rates larger by orders of magnitude.

Table 28. Selected State Rates of Total Fatal Crashes and Fatal Crashes with Reported MCD Involvement

	Fatal crashes in which MCD use reported as factor			2010 State Population	2010 Road Fatalities	2010 Road Fatalities by VMT	MCD-Involved Fatal Crashes by Fatal Crashes in 2010
State	2010	2011	2012				
TN	83	107	96	6,375,431	1032	1.47	8.04%
MO	21	8	16	6,011,478	821	1.16	2.56%
CA	22	24	35	37,341,989	2720	0.84	0.81%
IL	15	15	9	12,864,380	927	0.88	1.62%
NY	10	1	3	19,421,055	1201	0.92	0.83%
NC	5	5	2	9,565,781	1320	1.29	0.38%
FL	9	23	15	18,900,773	2444	1.25	0.37%

Source: NHTSA, 2011

Non-fatal accidents, which are vastly more common than fatal crashes, might provide a better measure of crash risk and more power to detect an effect. Studies on the effects of laws banning MCD use by drivers on insurance claims suggest that non-fatal crashes are more responsive to legislation, although the effect has been inconsistent in direction.

Recommended Directions for Future Research

This study provides another data point in the evidence base related the MCD-laws. This research should be repeated with state crash data that includes non-fatal as well as fatal crashes. There are also new and emerging strategies for creating synthetic control groups, which may be valuable depending on the distribution of variation in evolving state MCD-laws. A definite research priority is exploring potential mediating and moderating factors including enforcement and social norms. Relating MCD-laws to distal health outcomes like fatalities will always be difficult because of contingent factors and unaccountable variation in fatal crash trends.

Implications of the Study

The use of MCDs by drivers remains a high profile and seemingly important public health issue. As with prior road safety challenges like child injury and driver inexperience, states have responded to the problem of distracted driving with a rapid onslaught of legislation aimed at reducing the high risk behavior. Such policy cascades often mark the beginning of a longer process of policy learning. In most instances, initial legislative approaches are hampered by empirical and popular uncertainty about the nature and pathology of the problem and associated political constraints. Policy experimentation and accumulating evaluation research gradually motivate an ongoing process of regulatory refinement. The response to distracted driving is following the same model with states experimenting with different legislative approaches to the problem and with evaluators testing the relative effects of different policy choices on different crash outcomes and/or risk behaviors.

Although this process will undoubtedly continue, there are some indications that the challenges for evaluators are likely to be considerable. The adoption of the Arkansas, North Carolina and Texas laws present good evaluation opportunities in theory with a number of reasonable control groups. However, even with large populations (at least for North Carolina and Texas), a stronger design would include comparing multiple states with similar laws against groups of matched control states. This approach is capable of generating strong inferences about policy changes when the policy change is discrete and varies in consistent ways across states like a change in the minimum drinking age (O'Malley & Wagenaar, 1991). It is difficult if not impossible to identify states similarly by MCD-laws because the laws vary along so many dimensions with differences in exceptions, prohibited activities, methods of enforcement, fines, and covered drivers. When states have enacted laws with similar features, the laws became effective at different times complicating longitudinal comparisons. A thorough search revealed no instances when two states adopted the same restriction on use for young drivers during the same 12 month period, as well as no or identical other related distracted driving laws within three years after. For example, California adopted a law banning drivers from under 18 from MCD use on July 1, 2008, but did so while also simultaneously banning handheld use for all drivers, and had adopted a law banning texting for all drivers the previous year. North Carolina eventually prohibited texting for all drivers but not within the post-law observation period in this study. Lumping North Carolina and California together as treatment states, and thereby ignoring the other related laws (and lawmaking -

itself a potential mechanism of influence), strains inference-making.

Finally, while restricting the application of law by age creates a good study design opportunity for evaluators, it may also impede some of the other mechanisms through which legal intervention influences behavior. Enforcing distracted driving laws that apply to all drivers is recognized as difficult; doing so for laws aimed exclusively at younger drivers is likely to be only more so, in so far as it requires not only a split second detection of the behavior but also a judgment as to the probable age of the driver. The finding in this paper is consistent with the study by Foss and colleagues that found that most high school students in North Carolina knew about the law, but observed MCD use rates increased in the five months after the law went into effect and less than a quarter of the surveyed teens believed the law was being widely enforced (Foss et al., 2009). Therefore, while laws aimed at younger age groups offer some design advantages, they may suffer relatively weaker enforcement compared with bans targeted at all drivers.

A second hazard of age-specific legal restrictions is the mixed signal the law sends about the nature of the proscribed behavior. The same feature of age-specific laws that make them attractive in quasi-experiments (i.e., the relatively arbitrary cut-point between covered and uncovered populations (Angrist and Kruger 1991)), make them problematic as vehicles for health messaging. Given the challenges of enforcing distracted driving laws, and many other behavioral restrictions in traffic safety, there is often a large and important role for normative change. In this instance, however, one could reasonably wonder whether age-delimited laws - or likewise laws prohibiting only texting - send misleading and even harmful signals about the nature of the risk as one of inexperience (or in the case of texting, manual manipulation), rather than one of cognitive overload, as the evidence suggests. It is often easier to regulate younger drivers for political reasons and due to the general riskiness of that population. It may likewise be a wise strategy to pass suboptimal laws early in the regulation of an emerging health problem, rather than nothing, to signal to the populace the significance of the problem and to provide a beachhead for further legislative action. But there may also be costs in the form of mixed signals and lost opportunities for more stringent enforcement.

Conclusion

The risks and harms associated with driver use of MCDs appear substantial. States have responded to the problem of MCD use behind the wheel with a diverse array of laws banning different activity for different groups. There is some evidence that one Arkansas law and one Texas law banning young drivers from using MCDs reduced rates of crash fatalities among drivers subject to each law's restrictions. However, these effects were only observed in analyses employing certain identification strategies. No evidence was found suggesting that a second Arkansas law or a North Carolina law targeting young drivers effectively reduced crash rates for covered drivers. Notwithstanding continued uncertainty about the effect of MCD-laws, laws regulating MCD use for young drivers are likely to figure prominently in future evaluations despite challenges to their enforcement and to inferences about their effect.

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APPENDIX A: TABLE OF STUDIES

Figure 62. Studies by Evidence Type and Year

Type	Authors	Year	Title
Peer-reviewed empirical study			
1	Brown et al.	1969	Interference between concurrent tasks of driving and telephoning.
2	Kames	1978	A study of the effects of mobile telephone use and control unit design on driving performance
3	Brookhuis et al.	1991	The effect of mobile telephoning on driving performance.
4	McKnight and McKnight	1993	The effect of cellular phone use upon driver attention.
5	Alm and Nilsson	1994	Changes in driver behavior as a function of hands free mobile phones: a simulator study
6	Alm and Nilsson	1995	The effects of mobile telephone task on driver behavior in a car following situation.
7	Briem and Hedman	1995	Behavioral effects of mobile telephone use during simulated driving
8	Violanti and Marshall	1996	Cellular phones and traffic accidents: An epidemiological approach.
9	Cremades et al.	1997	Hand-held car phones and driving performance: projected risks and implications for prevention.
10	Redelmeier and Tibshirani	1997	Association between cellular-telephone calls and motor vehicle collisions
11	Min and Redelmeier	1998	Car phones and car crashes: an ecologic analysis
12	Violanti	1998	Cellular phones and fatal collisions
13	Violanti	1998	Cellular phones and fatal traffic collisions
14	Dreyer et al.	1999	Cause-specific mortality in cellular telephone users
15	Hancock et al.	1999	The effects of in-vehicle distraction on driver response during a critical driving maneuver
16	Lamble et al.	1999	Cognitive load and detection thresholds in car following situations: safety implications for using mobile telephone (cellular) telephones while driving
17	Reed and Green	1999	Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialing task.
18	Haigney et al.	2000	Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes
19	Irwin et al.	2000	Effect of the intensity of wireless telephone conversations on reaction time in a braking response
20	Recarte and Nunes	2000	Effects of verbal and spatial imagery tasks on eye fixations while driving
21	Tokunaga et al.	2000	Cellular telephone conversation while driving: effects on driver reaction time and subjective mental workload.
22	de Waard and Brookhuis	2001	The feasibility of detecting phone-use related driver distraction
23	Fuse et al.	2001	The cause of traffic when drivers use car phones and the functional requirements of car phones for safe driving
24	Garcia-Larrea et al.	2001	Interference of cellular phone conversations with visual motor tasks: an ERP study
25	Graham and Carter	2001	Voice dialing can reduce the interference between concurrent tasks of driving and phoning
26	Sagberg Fridulv	2001	Accident risk of car drivers during mobile phone use
27	Strayer and Johnston	2001	Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone.
28	Nunes and Recarte	2002	Cognitive demands of hands-free-phone conversation while driving
29	Cohen and Graham	2003	A revised economic analysis of restrictions on the use of cell phones while driving
30	Consiglio et al.	2003	Effect of cellular telephone conversations and other potential interference on reaction time in a braking response.
31	Cooper et al.	2003	The impact of hands-free message reception/response on driving task performance.
32	Eby and Vivoda	2003	Driver hand-held mobile phone use and safety belt use
33	Hancock et al.	2003	The distraction effects of phone use during a crucial driving maneuver
34	Matthews et al.	2003	The effect of cell phone type on drivers subjective workload during concurrent driving and conversing
35	Recarte and Nunes	2003	Mental workload while driving: effects on visual search, discrimination, and decision making.
36	Strayer et al.	2003	Cell phone-induced failures of visual attention during simulated

			driving.
37	Wilson et al.	2003	Collision and violation involvement of drivers who use cellular telephones
38	Gugerty et al.	2004	Effects of remote and in-person verbal interactions on verbalization rates and attention to dynamic spatial scenes.
39	Johnson et al.	2004	Living Dangerously: Driver Distraction at High Speed
40	Laberge et al.	2004	The effect of passenger and cellular phone conversations on driver distraction
41	Lesch and Hancock	2004	Driving performance during concurrent cell-phone use: are drivers aware of their performance decrements?
42	McCarley et al.	2004	Conversation disrupts change detection in complex traffic scenes.
43	McCartt and Geary	2004	Longer term effects of New York State's law on drivers' handheld cell phone use
44	Patten et al.	2004	Using mobile telephones: cognitive workload and attention research allocation.
45	Rakauskas et al.	2004	Effects of cell phone conversations with naturalistic conversations.
46	Seo and Torabi	2004	The impact of in-vehicle cell-phone use on accidents or near-accidents among college students.
47	Strayer and Drews	2004	Profiles in driver distraction: effects of cell phone conversations on younger and older drivers.
48	Treffner and Barrett	2004	Hands-free mobile phone speech while driving degrades coordination and control
49	Amado and Ulupinar	2005	The effects of conversation on attention and peripheral detection: is talking with a passenger and talking on the cell phone different?
50	Crundall et al.	2005	Regulating conversation during driving: a problem for mobile telephones?
51	Lui and Lee	2005	Effects of car-phone use and aggressive disposition during critical driving maneuvers.
52	Ma and Kaber	2005	Situation awareness and workload in driving while using adaptive cruise control and a cell phone
53	McEvoy et al.	2005	Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study
54	Poysti et al.	2005	Factors influencing the use of cellular (mobile) phone during driving and hazards while using it.
55	Shinar et al.	2005	Effects of practice, age, and task demands, on interference from a phone task while driving.
56	Stutts et al.	2005	Driver’s exposure to distractions in their natural driving environment.
57	Tornros and Bolling	2005	Mobile phone use—Effects of handheld and hands free phones on driving performance
58	Wogalter and Mayhorn	2005	Perceptions of driver distraction by cellular phone users and nonusers.
59	Beede and Kass	2006	Engrossed in conversation: the impact of cell phones on simulated driving performance
60	Clayton et al.	2006	Active prompting to decrease cell phone use and increase seat belt use while driving.
61	Eby et al.	2006	Driver hand-held cellular phone use: a four-year analysis
62	Horberry et al.	2006	Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance.
63	Horrey et al.	2006	Modeling drivers’ visual attention allocation while interacting with in-vehicle technologies.
64	Lui and Lee	2006	In-vehicle workload assessment: effects of traffic situations and cellular telephone use.
65	McCartt et al.	2006	Effects of Washington, D.C. law on drivers' hand-held cell phone use
66	McGarva et al.	2006	Effects of driver cell-phone use on driver aggression
67	Rosebloom	2006	Driving performance while using cell phones: An observational study
68	Strayer et al.	2006	A comparison of the cell phone driver and the drunk driver
69	Törnros and Bolling	2006	Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments.
70	Harbluk et al.	2007	An on-road assessment of cognitive distraction: Impacts on drivers’ visual behavior and braking performance
71	McCartt and Hellinga	2007	Longer term effects of Washington DC, law on drivers’ hand-held phones.
72	McEvoy et al.	2007	The contribution of passengers versus mobile phone use to motor vehicle crashes resulting in hospital attendance by the driver
73	Braitman et al.	2008	Crashes of novice teenage drivers: Characteristics and contributing factors
74	Brusque and Alauzet	2008	Analysis of the individual factors affecting mobile phone use while driving in France: socio-demographic characteristics, car and phone use in professional and private
75	Chisholm et al.	2008	The effects of practice with MP3 players on driving performance.

76	Cooper and Strayer	2008	Effects of simulator practice and real-world experience on cell-phone-related driver distraction
77	Crisler et al.	2008	Effect of wireless communication and entertainment devices on simulated driving performance
78	Drews et al.	2008	Passenger and cell phone conversations in simulated driving
79	Horrey et al.	2008	Assessing the awareness of performance decrements in distracted drivers.
80	Maples et al.	2008	The effects of cell phone use on peripheral vision
81	Vivoda et al.	2008	Cellular phone use while driving at night
82	Walsh et al.	2008	Dialing and driving: factors influencing intentions to use a mobile phone while driving.
83	Wei	2008	Motivations for using the mobile phone for mass communications and entertainment.
84	Al-Darrab et al.	2009	An experimental study on the effect of mobile phone conversation on drivers' reaction time in braking response
85	Bellinger et al.	2009	The effect of cellular telephone conversation and music listening on response time in braking
86	Bruyas et al.	2009	Does making a conversation asynchronous reduce the negative impact of phone call on driving?
87	Charlton	2009	Driving while conversing: cell phones that distract and passengers who react
88	Constant et al.	2009	Road casualties and changes in risky driving behavior in France between 2001 and 2004 among participants in the GAZEL cohort.
89	Drews et al.	2009	Text messaging during simulated driving
90	Charlton	2009	Driving while conversing: cell phones that distract and passengers who react
91	Constant et al.	2009	Road casualties and changes in risky driving behavior in France between 2001 and 2004 among participants in the GAZEL cohort.
92	Drews et al.	2009	Text messaging during simulated driving
93	Foss et al.	2009	Short-term effects of a teenage driver cell phone restriction
94	Hosking et al.	2009	The effects of text messaging on young drivers
95	Kolko	2009	The effects of mobile phones and hands-free laws on traffic fatalities
96	Mohebbi et al.	2009	Driver reaction time to tactile and auditory rear-end collision warnings while talking on a cell phone
97	Nelson et al.	2009	The effects of perception of risk and importance of answering and initiating a cellular phone call while driving
98	Wang et al.	2009	Changing drivers' attitudes towards mobile phone use through participative simulation testing and feedback.
99	Young and Schreiner	2009	Real-world personal conversations using a hands-free embedded wireless device while driving: Effect on airbag-deployment crash rates.
100	Zhou et al.	2009	Young driving learners' intention to use a handheld or hands-free mobile phone when driving
101	Atchley et al.	2010	The choice to text and drive in younger drivers: behavior may shape attitude
102	Bendak and Al-Saleh	2010	The role of roadside advertising signs in distracting drivers
103	Braitman and McCartt	2010	National reported patterns of driver cell phone use in the United States
104	Dula et al.	2010	Differing types of cellular phone conversations and dangerous driving.
105	Farmer et al.	2010	Cell phone use while driving and attributable crash risk
106	Fowles et al.	2010	The cell phone effect on motor vehicle fatality rates: A Bayesian and classical econometric evaluation
107	Hafetz et al.	2010	Adolescent drivers' perceptions of the advantages and disadvantages of abstention from in-vehicle cell phone use
108	Liang and Lee	2010	Combining cognitive and visual distraction: Less than the sum of its parts.
109	Nemme and White	2010	Texting while driving: Psychosocial influences on young people's texting intentions and behavior
110	Nikolaev et al.	2010	Evaluating the impact of legislation prohibiting hand-held cell phone use while driving.
111	O'Brien et al.	2010	Talking and texting among teenage drivers: a glass half empty or half full?
112	Rozario et al.	2010	An examination of the factors that influence drivers' willingness to use hand-held mobile phones
113	Sperber et al.	2010	The cost-effectiveness of a law banning the use of cellular phones by drivers
114	Wang et al.	2010	The effect of feedback on attitudes toward cellular phone use while driving: a comparison between novice and experienced drivers.

115	White et al.	2010	Mobile phone use while driving: An investigation of the beliefs influencing drivers' hands-free and hand-held mobile phone use
116	Wilson and Stimpson	2010	Trends in fatalities from distracted driving in the united states, 1999 to 2008
117	Grøndahl and Sagberg	2011	Driving and telephoning: relative accident risk when using hand-held and hands-free mobile phones
118	Cook and Jones	2011	Texting and accessing the web while driving: traffic citations and crashes among young adult drivers
119	Ibrahim et al.	2011	State laws restricting driver use of mobile communications devices distracted-driving provisions, 1992-2010
120	Owens et al.	2011	Driver performance while text messaging using handheld and in-vehicle systems
121	Atchley et al.	2012	Stuck in the 70s: The role of social norms in distracted driving
122	Mouloua et al.	2012	The effects of iPod and text-messaging use on driver distraction: a bio-behavioral analysis.
123	Rudin-Brown et al.	2012	Driver distraction in an unusual environment: Effects of text-messaging in tunnels
124	Zhou et al.	2012	Mobile phone use while driving: Predicting drivers' answering intentions and compensatory decisions
125	Abouk and Adams	2013	Texting bans and fatal accidents on roadways: do they work? Or do drivers just react to announcements of bans
126	Asbridge et al.	2013	Cell phone use and traffic crash risk: a culpability analysis.
127	Bhargava and Pathania	2013	Driving under the (cellular) influence.
128	Cooper et al.	2013	Observational study of cell phone and texting use among California drivers 2012 and comparison to 2011 data
129	Lim and Chi	2013	Are cell phone laws in the U.S. effective in reducing fatal crashes involving young drivers?
130	Lim and Chi	2013	Cellphone bans and fatal motor vehicle crash rates in the United States
131	Ehsani et al.	2014	The impact of Michigan's text messaging restriction on motor vehicle crashes

Peer-reviewed systematic review

1	Haigney	1997	Mobile phones and driving: a literature review.
2	Haigney and Westerman	2001	Mobile (cellular) phone use and driving: a critical review of research methodology.
3	Horrey and Wickens	2006	Examining the impact of cell phone conversations on driving using meta-analytic techniques.
4	McCartt et al.	2006	Cell phones and driving: review of research.
5	Young and Regan	2007	Driver distraction: A review of the literature
6	Caird et al.	2008	A meta-analysis of the effects of cell phones on driver performance
7	Collet and Guillot	2010	Phoning while driving I: a review of epidemiological, psychological, behavioral and physiological studies
8	Collet and Guillot	2010	Phoning while driving II: a review of driving conditions influence
9	Zheng et al.	2013	The science of cell phone use: its past, present, and future
10	McCartt et al.	2014	Driver cellphone and texting bans: A review of the evidence

Report

1	Department of California Highway Patrol, USA.	1987	CHP: Mobile telephone safety study.
2	Green et al.	1993	On-the-road tests of driver interfaces: examination of a route guidance system and a car phone.
3	Serafin et al.	1993	Development of human factors tests of car phones. Technical report no. UMTRI-93-17 Ann Arbor, MI: University of Michigan Transportation Research Institute.
4	Burns et al.	2002	How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol
5	Hahn et al.	2002	Should you be allowed to use your cellular phone while driving?
6	Thulin and Gustafsson	2004	Mobile phone use while driving. Conclusions from four investigations.
7	Hahn et al.	2006	The impact of driver cell phone use on accidents
8	Klauer et al.	2006	The impact of driver inattention on near-crash/crash risk: an analysis using the 100-car naturalistic driving study data
9	Prieger and Hahn	2007	Are drivers who use cell phones inherently less safe?

11	O'Meara et al.	2008	The impact of legislation in Ireland on handheld mobile phone use by drivers
12	HLDI	2009	Hand-held cellphone laws and collision claim frequencies.
13	NHTSA	2009	An Examination of Driver Distraction as Recorded in NHTSA Databases. DOT HS 811 216.
14	HLDI	2010	Texting laws and collision claim frequencies
15	Huang et al.	2010	CAEP position statement on cellphone use while driving
16	Chase	2014	U.s. State and federal laws targeting distracted driving
17	Cheng	2014	The effect of cell phone bans on driver behavior, accidents, and casualties

Commentary

1	Maclure and Mittleman	1997	Cautions about car telephones and collisions
2	Carsten and Brookhuis	2005	The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems.
3	Lee	2007	Technology and teen drivers
4	Jacobson and Gostin	2010	Reducing distracted driving: regulation and education to avert traffic injuries and fatalities
5	Sampaio	2010	On the identification of the effect of prohibiting hand-held cell phone use while driving: Comment.
6	Ship	2010	The most primary of care – Talking about driving and distraction
7	Elvik	2011	The effects on accident risk of using mobile phones: problems of meta-analysis when studies are few and bad
8	Lerner	2011	Drunk driving, distracted driving, moralism, and public health
9	Coben and Zhu	2013	Keeping an eye on distracted driving

Law review

1	Horwitt	2002	Driving while distracted: How should legislators regulate cell phone use behind the wheel
2	Michael	2003	Liability for accidents from use and abuse of cell phones: When are employers and cell phone manufacturers liable?
3	Kalin	2005	The 411 on cellular phone use: an analysis of the legislative attempts to regulate cellular phone use by drivers
4	Bambry	2007	Chapter 290: California's message to hang up and pay attention
5	Amedola	2008	Can you hear me now?: the myths surrounding cell phone use while driving and Connecticut's failed attempt at a remedy
6	Croze	2008	How hands-on will regulation of hands-free be? An analysis of SB 1613 and the effectiveness of its proposed regulation
7	De Soto	2009	Intextication: Texting while driving. Does the punishment fit the crime?
8	Franklin	2012	Done with distracted driving: Implications of Pennsylvania's ban on text-based communication while driving under the state constitution
9	Gershowitz	2012	Texting while driving meets the fourth amendment: Deterring both texting and warrantless cell phone searches

Figure 63. Studies by Research Focus and Year

	Authors	Methods	Year	Title
Explores the behavioral effects of driver MCD use				
1	Kames	Experimental; open or closed course	1978	A study of the effects of mobile telephone use and control unit design on driving performance
2	Brookhuis et al.	Experimental; open or closed course	1991	The effect of mobile telephoning on driving performance.
3	McKnight and McKnight	Experimental; simulator	1993	The effect of cellular phone use upon driver attention.
4	Alm and Nilsson	Experimental; simulator	1994	Changes in driver behavior as a function of hands free mobile phones: a simulator study
5	Alm and Nilsson	Experimental; simulator	1995	The effects of mobile telephone task on driver behavior in a car following situation.
6	Briem and Hedman	Experimental; simulator	1995	Behavioral effects of mobile telephone use during simulated driving
7	Cremades et al.	Experimental; simulator	1997	Hand-held car phones and driving performance: projected risks and implications for prevention.
8	Hancocket al.	Experimental; open or closed course	1999	The effects of in-vehicle distraction on driver response during a critical driving maneuver
9	Lamble et al.	Experimental; open or closed course	1999	Cognitive load and detection thresholds in car following situations: safety implications for using mobile telephone (cellular) telephones while driving
10	Reed and Green	Experimental; simulator	1999	Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialing task.
11	Haigney et al.	Experimental; simulator	2000	Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes
12	Irwin et al.	Experimental; simulator	2000	Effect of the intensity of wireless telephone conversations on reaction time in a braking response
13	Recarte and Nunes	Experimental; open or closed course	2000	Effects of verbal and spatial imagery tasks on eye fixations while driving
14	Tokunaga et al.	Experimental; open or closed course	2000	Cellular telephone conversation while driving: effects on driver reaction time and subjective mental workload.
15	de Waard et al.	Experimental; simulator	2001	The feasibility of detecting phone-use related driver distraction
16	Fuse et al.	Experimental; simulator	2001	The cause of traffic when drivers use car phones and the functional requirements of car phones for safe driving
17	Garcia-Larrea et al.	Experimental; simulator	2001	Interference of cellular phone conversations with visuaomotor tasks: an ERP study
18	Graham and Carter	Experimental; simulator	2001	Voice dialing can reduce the interference between concurrent tasks of driving and phoning
19	Strayer and Johnston	Experimental; simulator	2001	Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone
20	Burns et al.	Experimental; simulator	2002	How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol
21	Nunes and Recarte	Experimental; open or closed course	2002	Cognitive demands of hands-free-phone conversation while driving
22	Consiglio et al.	Experimental; simulator	2003	Effect of cellular telephone conversations and other potential interference on reaction time in a braking response
23	Cooper et al.	Experimental; open or closed course	2003	The impact of hands-free message reception/response on driving task performance
24	Hancock et al.	Experimental; open or closed course	2003	The distraction effects of phone use during a crucial driving maneuver
25	Matthews et al.	Experimental; open or closed course	2003	The effect of cell phone type on drivers subjective workload during concurrent driving and conversing
26	Recarte and Nunes	Experimental; open or closed course	2003	Mental workload while driving: effects on visual search, discrimination, and decision making
27	Strayer et al.	Experimental; simulator	2003	Cell phone-induced failures of visual attention during simulated driving
28	Gugerty et al.	Experimental; simulator	2004	Effects of remote and in-person verbal interactions on verbalization rates and attention to dynamic spatial scenes.
29	Laberge et al.	Experimental; simulator	2004	The effect of passenger and cellular phone conversations on driver distraction
30	Lesch and Hancock	Experimental; open or closed course	2004	Driving performance during concurrent cell-phone use: are drivers aware of their performance decrements?

31	McCarley et al.	Experimental; simulator	2004	Conversation disrupts change detection in complex traffic scenes.
32	Patten et al.	Experimental; open or closed course	2004	Using mobile telephones: cognitive workload and attention research allocation.
33	Rakauskas et al.	Experimental; simulator	2004	Effects of cell phone conversations with naturalistic conversations.
34	Strayer and Drews	Experimental; simulator	2004	Profiles in driver distraction: effects of cell phone conversations on younger and older drivers.
35	Treffner and Barrett	Experimental; open or closed course	2004	Hands-free mobile phone speech while driving degrades coordination and control
36	Amado and Ulupinar	Experimental; simulator	2005	The effects of conversation on attention and peripheral detection: is talking with a passenger and talking on the cell phone different?
37	Crundall et al.	Experimental; open or closed course	2005	Regulating conversation during driving: a problem for mobile telephones?
38	Lui and Lee	Experimental; open or closed course	2005	Effects of car-phone use and aggressive disposition during critical driving maneuvers.
39	Ma and Kaber	Experimental; simulator	2005	Situation awareness and workload in driving while using adaptive cruise control and a cell phone
40	Shinar et al.	Experimental; simulator	2005	Effects of practice, age, and task demands, on interference from a phone task while driving.
41	Tornros and Bolling	Experimental; simulator	2005	Mobile phone use—Effects of handheld and hands free phones on driving performance
42	Harbluk et al.	Experimental; open or closed course	2007	An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance
43	Chisholm et al.	Experimental; simulator	2008	The effects of practice with MP3 players on driving performance.
44	Cooper and Strayer	Experimental; simulator	2008	Effects of simulator practice and real-world experience on cell-phone-related driver distraction
45	Crisler et al.	Experimental; simulator	2008	Effect of wireless communication and entertainment devices on simulated driving performance
46	Drews et al.	Experimental; simulator	2008	Passenger and cell phone conversations in simulated driving
47	Horrey et al.	Experimental; open or closed course	2008	Assessing the awareness of performance decrements in distracted drivers.
48	Maples et al.	Experimental; simulator	2008	The effects of cell phone use on peripheral vision
49	Al-Darrab et al.	Experimental; open or closed course	2009	An experimental study on the effect of mobile phone conversation on drivers' reaction time in braking response
50	Bellinger et al.	Experimental; simulator	2009	The effect of cellular telephone conversation and music listening on response time in braking
51	Bruyas et al.	Experimental; simulator	2009	Does making a conversation asynchronous reduce the negative impact of phone call on driving?
52	Charlton	Experimental; simulator	2009	Driving while conversing: cell phones that distract and passengers who react
53	Drews et al.	Experimental; simulator	2009	Text messaging during simulated driving
54	Hosking et al.	Experimental; simulator	2009	The effects of text messaging on young drivers
55	Mohebbi et al.	Experimental; simulator	2009	Driver reaction time to tactile and auditory rear-end collision warnings while talking on a cell phone
56	Dula et al.	Experimental; simulator	2010	Differing types of cellular phone conversations and dangerous driving.
57	Liang and Lee	Experimental; simulator	2010	Combining cognitive and visual distraction: Less than the sum of its parts
58	Owens et al.	Experimental; open or closed course	2011	Driver performance while text messaging using handheld and in-vehicle systems
59	Mouloua et al.	Experimental; simulator	2012	The effects of iPod and text-messaging use on driver distraction: a bio-behavioral analysis
60	Rudin-Brown et al.	Experimental; simulator	2012	Driver distraction in an unusual environment: Effects of text-messaging in tunnels
61	Brown et al.	Experimental; open or closed course	1969	Interference between concurrent tasks of driving and telephoning
62	Beede and Kass	Experimental; simulator	2006	Engrossed in conversation: the impact of cell phones on simulated driving performance
63	Horberry et al.	Experimental; simulator	2006	Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance
64	Horrey et al.	Experimental; simulator	2008	Modeling drivers' visual attention allocation while interacting with in-vehicle technologies.
65	Klauer et al.	Observational; naturalistic	2006	The impact of driver inattention on near-crash/crash risk: an analysis using the 100-car naturalistic driving study data

66	Lui and Lee	Experimental; open or closed course	2006	In-vehicle workload assessment: effects of traffic situations and cellular telephone use.
67	McGarva et al.	Experimental; open or closed course	2006	Effects of driver cell-phone use on driver aggression
Explores the health effects of driver MCD use				
1	Redelmeier and Tibshirani	Observational; administrative data	1997	Association between cellular-telephone calls and motor vehicle collisions
2	Min and Redelmeier	Observational; administrative data	1998	Car phones and car crashes: an ecologic analysis
3	Violanti	Observational; administrative data	1998	Cellular phones and fatal collisions
4	Violanti	Observational; administrative data	1998	Cellular phones and fatal traffic collisions
5	Dreyer et al.	Observational; administrative data	1999	Cause-specific mortality in cellular telephone users
6	Sagberg	Observational; survey	2001	Accident risk of car drivers during mobile phone use
7	Wilson et al.	Observational; administrative data	2003	Collision and violation involvement of drivers who use cellular telephones
8	Seo andTorabi	Observational; survey	2004	The impact of in-vehicle cell-phone use on accidents or near-accidents among college students.
9	McEvoy et al.	Observational; administrative data	2005	Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study
10	McEvoy et al.	Observational; administrative data	2007	The contribution of passengers versus mobile phone use to motor vehicle crashes resulting in hospital attendance by the driver
11	Braitman et al.	Observational; administrative data	2008	Crashes of novice teenage drivers: Characteristics and contributing factors
12	Young and Schreiner	Observational; administrative data	2009	Real-world personal conversations using a hands-free embedded wireless device while driving: Effect on airbag-deployment crash rates
13	Farmer et al.	Observational; survey	2010	Cell phone use while driving and attributable crash risk
14	Fowles et al.	Observational; administrative data	2010	The cell phone effect on motor vehicle fatality rates: A Bayesian and classical econometric evaluation
15	Wilson and Stimpson	Observational; administrative data	2010	Trends in fatalities from distracted driving in the united states, 1999 to 2008
16	Backer and Sagberg	Observational; administrative data	2011	Driving and telephoning: Relative accident risk when using hand-held and hands-free mobile phones
17	Asbridge et al.	Observational; administrative data	2013	Cell phone use and traffic crash risk: a culpability analysis
18	Bhargava and Pathania	Observational; administrative data	2013	Driving under the (cellular) influence
Explores the incidence of driver MCD use				
1	Eby and Vivoda	Observational; naturalistic	2003	Driver hand-held mobile phone use and safety belt use
2	Johnson et al.	Observational; naturalistic	2004	Living dangerously: driver distraction at high speed
3	Stutts et al.	Observational; naturalistic	2005	Driver's exposure to distractions in their natural driving environment
4	Vivoda et al.	Observational; naturalistic	2008	Cellular phone use while driving at night
5	NHTSA	Observational; administrative data	2009	An Examination of Driver Distraction as Recorded in NHTSA Databases. DOT HS 811 21Observational; survey
6	Braitman and McCartt	Observational; survey	2010	National reported patterns of driver cell phone use in the United States
7	O'Brien et al.	Observational; survey	2010	Talking and texting among teenage drivers: a glass half empty or half full?
8	Eby et al.	Observational; naturalistic	2001	Driver hand-held cellular phone use: a four-year analysis
Explores the determinants of driver MCD use				
1	Poysti et al.	Observational; survey	2005	Factors influencing the use of cellular (mobile) phone during driving and hazards while using it

2	Wogalter and Mayhorn	Observational; survey	2005	Perceptions of driver distraction by cellular phone users and nonusers.
3	Prieger and Hahn	Observational; survey	2007	Are drivers who use cell phones inherently less safe?
4	Brusque and Alauzet	Observational; survey	2008	Analysis of the individual factors affecting mobile phone use while driving in France
5	Walsh et al.	Observational; survey	2008	Dialing and driving: factors influencing intentions to use a mobile phone while driving
6	Wei	Observational; survey	2008	Motivations for using the mobile phone for mass communications and entertainment.
7	Constant et al.	Observational; survey	2009	Road casualties and changes in risky driving behavior in France between 2001 and 2004 among participants in the GAZEL cohort.
8	Nelson et al.	Observational; survey	2009	The effects of perception of risk and importance of answering and initiating a cellular phone call while driving
9	Wang et al.	Experimental; simulator	2009	Changing drivers' attitudes towards mobile phone use through participative simulation testing and feedback.
10	Zhou et al.	Observational; survey	2009	Young driving learners’ intention to use a handheld or hands-free mobile phone when driving
11	Atchley et al.	Observational; survey	2010	The choice to text and drive in younger drivers: behavior may shape attitude
12	Hafetz et al.	Observational; administrative data	2010	Adolescent drivers’ perceptions of the advantages and disadvantages of abstention from in-vehicle cell phone use
13	Nemme and White	Observational; survey	2010	Texting while driving: Psychosocial influences on young people’s texting intentions and behavior
14	Rozario et al.	Observational; survey	2010	An examination of the factors that influence drivers’ willingness to use hand-held mobile phones
15	Wang et al.	Experimental; simulator	2010	The effect of feedback on attitudes toward cellular phone use while driving: a comparison between novice and experienced drivers.
16	White et al.	Observational; survey	2010	Mobile phone use while driving: An investigation of the beliefs influencing drivers’ hands-free and hand-held mobile phone use
17	Cook and Jones	Observational; survey	2011	Texting and accessing the web while driving: traffic citations and crashes among young adult drivers
18	Atchley et al.	Experimental; vignette	2012	Stuck in the 70s: The role of social norms in distracted driving
19	Zhou et al.	Observational; survey	2012	Mobile phone use while driving: Predicting drivers’ answering intentions and compensatory decisions
Explores the incidence of laws regulating driver MCD use				
1	Ibrahim et al.	Systematic legal research	2011	State laws restricting driver use of mobile communications devices distracted-driving provisions, 1992-2010
2	Chase	Systematic legal research	2014	U.S. state and federal laws targeting distracted driving
Explores the effects of laws regulating driver MCD use				
1	Cohen and Graham	Observational; administrative data	2003	A revised economic analysis of restrictions on the use of cell phones while driving
2	McCartt and Geary	Observational; naturalistic	2004	Longer term effects of New York State's law on drivers' handheld cell phone use
3	McCartt and Hellinga	Observational; naturalistic	2007	Longer term effects of Washington DC, law on drivers’ hand-held phones
4	O'Meara et al.	Observational; administrative data	2008	The impact of legislation in Ireland on handheld mobile phone use by drivers
5	Foss et al.	Observational; naturalistic	2009	Short-term effects of a teenage driver cell phone restriction
6	HLDI	Observational; administrative data	2009	Hand-held cellphone laws and collision claim frequencies.
7	Kolko	Observational; administrative data	2009	The effects of mobile phones and hands-free laws on traffic fatalities
8	HLDI	Observational; administrative data	2010	Texting laws and collision claim frequencies
9	Nikolaev et al.	Observational; administrative data	2010	Evaluating the impact of legislation prohibiting hand-held cell phone use while driving.

10	Sampaio	Observational; administrative data	2010	On the identification of the effect of prohibiting hand-held cell phone use while driving: Comment.
11	Sperber et al.	Observational; administrative data	2010	The cost-effectiveness of a law banning the use of cellular phones by drivers
12	Abouk and Adams	Observational; administrative data	2013	Texting bans and fatal accidents on roadways: do they work? Or do drivers just react to announcements of bans
13	Cooper et al.	Observational; naturalistic	2013	Observational study of cell phone and texting use among California drivers 2012 and comparison to 2011 data
14	Lim and Chi	Observational; administrative data	2013	Are cell phone laws in the U.S. effective in reducing fatal crashes involving young drivers?
15	Lim and Chi	Observational; administrative data	2013	Cellphone bans and fatal motor vehicle crash rates in the United States
16	Cheng Cheng	Observational; administrative data	2014	The effect of cell phone bans on driver behavior, accidents, and casualties
17	Ehsani et al.	Observational; administrative data	2014	The impact of Michigan's text messaging restriction on motor vehicle crashes

Other (Commentaries, Systematic Reviews)

1	Dept. of CA Highway Patrol	Report	1987	CHP: Mobile telephone safety study (1987)
2	Green et al.	Report	1993	On-the-road tests of driver interfaces: examination of a route guidance system and a car phone.
3	Haigney	Systematic review	1997	Mobile phones and driving: a literature review.
4	Maclure and Mittleman	Commentary	1997	Cautions about car telephones and collisions
5	Haigney and Westerman	Systematic review	2001	Mobile (cellular) phone use and driving: a critical review of research methodology
6	Horwitt	Law review article	2002	Driving while distracted: how should legislators regulate cell phone use behind the wheel
7	Michael	Law review article	2003	Liability for accidents from use and abuse of cell phones: when are employers and cell phone manufacturers liable?
8	Carsten and Brookhuis	Commentary	2005	The relationship between distraction and driving performance: towards a test regime for in-vehicle information systems.
9	Kalin	Law review article	2005	The 411 on cellular phone use: an analysis of the legislative attempts to regulate cellular phone use by drivers
10	Bambry	Law review article	2007	Chapter 290: California's Message to Hang Up and Pay Attention
11	Lee	Commentary	2007	Technology and teen drivers
12	Young and Regan	Systematic review	2007	Driver distraction: A review of the literature
13	Amedola	Law review article	2008	Can you hear me now?: the myths surrounding cell phone use while driving and Connecticut's failed attempt at a remedy
14	Caird et al.	Systematic review	2008	A meta-analysis of the effects of cell phones on driver performance
15	Croze	Law review article	2008	How Hands-On Will Regulation of Hands-Free Be? An Analysis of SB 113 and the Effectiveness of Its Proposed Regulation
16	De Soto	Law review article	2009	Intextication: Texting While Driving. Does the Punishment Fit the Crime?
17	Bendak and Al-Saleh	Peer-reviewed empirical study	2010	The role of roadside advertising signs in distracting drivers
18	Collet and Petit	Systematic review	2010	Phoning while driving I: a review of epidemiological, psychological, behavioral and physiological studies
19	Collet and Petit	Systematic review	2010	Phoning while driving II: a review of driving conditions influence
20	Huang et al.	Report	2010	CAEP position statement on cellphone use while driving
21	Jacobson and Gostin	Commentary	2010	Reducing distracted driving: regulation and education to avert traffic injuries and fatalities
22	Ship	Commentary	2010	The most primary of care – talking about driving and distraction.
23	Elvik	Commentary	2011	The effects on accident risk of using mobile phones: problems of meta-analysis when studies are few and bad
24	Lerner	Commentary	2011	Drunk driving, distracted driving, moralism, and public health
25	Franklin	Law review article	2012	Done with distracted driving: implications of Pennsylvania's ban on text-based communication while

				driving under the state constitution
26	Gershowitz	Law review article	2012	Texting while driving meets the fourth amendment: deterring both texting and warrantless cell phone searches
27	Coben and Zhu	Commentary	2013	Keeping an eye on distracted driving
28	Zheng et al.	Systematic review	2013	The science of cell phone use: its past, present, and future
29	McCartt et al.	Systematic review	2014	Driver cellphone and texting bans: A review of the evidence
30	Horrey and Wickens	Peer-reviewed empirical study	2014	Examining the impact of cell phone conversations on driving using meta-analytic techniques.
31	McCartt et al.	Systematic review	2014	Cell phones and driving: review of research.

APPENDIX B: GRADUATED DRIVER LICENSING LAWS

Figure 64. Minimum Driving Age among Focal and Control States

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
AL	15	15	15	15	15	15	15	15	15	15	15	15	15	15
AR	14	14	14	14	14	14	14	14	14	14	14	14	14	14
MS	15	15	15	15	15	15	15	15	15	15	15	15	15	15
NM	15	15	15	15	15	15	15	15	15	15	15	15	15	15
NC	15	15	15	15	15	15	15	15	15	15	15	15	15	15
OK	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
PA	16	16	16	16	16	16	16	16	16	16	16	16	16	16
SC	15	15	15	15	15	15	15	15	15	15	15	15	15	15
TX	15	15	15	15	15	15	15	15	15	15	15	15	15	15

Notes: The laws regulating these states over this period include, respectively: Alabama (Ala. Code 32-6-7); Arkansas (ACA 27-16-804); Mississippi (Miss. Code 63-1-9); New Mexico (N.M.S.A. 1978, 66-5-8); North Carolina (N.C.G.S.A. 20-11); Oklahoma (47 Okl. St. Ann. 6-105); Pennsylvania (75 Pa. C.S.A 1503); South Carolina (SC. Code 56-1); Texas (Tx. Trans. Code 521). Legal research was conducted to retrieve the GDL laws for each state. Two lawyers examined each law and its legislative history. The changes were plotted by year. Findings were compared against information compiled by the Insurance Institute for Highway Safety and Highway Loss Data Institute.

Figure 65. Nighttime Driving Restriction among Focal and Control States

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
AL	.	.	.	12:00 - 6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00	12:00-6:00
AR	.	.	.	.	.	.	.	.	.	.	11:00-4:00	11:00-4:00	11:00-4:00	11:00-4:00
MS	.	.	.	.	.	.	.	.	.	.	10:00-6:00	10:00-6:00	10:00-6:00	10:00-6:00
NM	.	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00
NC	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00	9:00-5:00
OK	.	.	.	.	.	.	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00
PA	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00	11:00-5:00
SC	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00	8:00-6:00
TX	.	.	.	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00	12:00-5:00

Notes: See note in Figure D.1. above for information on the sources and method of data collection.

Figure 66. Minimum Driving Age among Focal and Control States

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
AL	.	.	.	17	17	17	17	17	17	17	17	17	17	17
AR	.	.	.	.	.	.	.	.	.	.	18	18	18	18
MS	16	16	16	16	16	16	16	16	16	16	16.5	16.5	16.5	16.5
NM	.	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
NC	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
OK	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
PA	17	17	17	17	17	17	17	17	17	17	17	17	17	17
SC	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
TX	.	.	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	17	17	17	17

Notes: See note in Figure D.1. above for information on the sources and method of data collection.

APPENDIX C: UNIVARIATE DISTRIBUTIONS

Figure C.1. Number of Crashes by Month Across the Pre-Law and Post-Law Periods