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Impact Analysis of Bicycle Safety Laws

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16. Abstract
Many States enacted bicycle traffic safety laws to improve safety for bicyclists. This study examined the effects of six laws (safe passing, mandatory helmet use, bicycling under the influence, where-to-ride, sidewalk riding, and the Idaho stop) on bicyclist safety metrics to determine if States and communities should create separate laws that govern bicyclists on roadways, and if bicyclist-specific traffic safety laws protect bicyclists from motor vehicle crash injuries and fatalities. Data on police-reported crashes involving bicyclists were collected from 34 States, with 28 coming from NHTSA's State Data System (SDS) over a number of years. Safety metrics of each law were modelled using generalized linear mixed models. States with safe passing (SP) or where-to-ride (WTR) laws experienced 23 percent and 13 percent fewer related crashes, respectively, relative to States with none. States with both SP and WTR laws had 12 percent fewer. Post-enactment, SP-only States had 11 percent more related crashes annually, while WTR-only States had 0.4 percent more, and States with both had 5 percent more. Helmet use was 20 percent higher in States with mandatory helmet use (MHU) laws and increased 7 percent each year after the laws were enacted. Fatalities and incapacitating injuries were found to decrease by 2 percent in States with MHU laws. States with bicycling-under-the-influence (BUI) laws had 38 percent fewer crashes of intoxicated bicyclists than States without such laws, and additional annual decreases of 8 percent post-enactment. Roadway crashes fell 4 percent in States with permissive sidewalk-riding (SR) laws compared to States with no SR law. States with permissive SR laws had 94 percent fewer intersection-related roadway crashes and 656 percent more intersection- related sidewalk crashes.

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Executive Summary

Bicycling is an increasingly popular form of transportation that is economical, environmentally friendly, and provides important cardiovascular benefits. Many States have enacted bicycle traffic safety laws with the goal of improving safety for bicyclists. These laws restrict or punish certain motorist actions such as safe passing, promote safer practices among bicyclists such as mandatory helmet use, or treat bicyclists as a separate class of road user, as with the Idaho Stop law.

This study analyzed the effectiveness of these laws on safety to answer, "Should States and communities create separate laws that govern bicyclists on the roadways?" and "Do bicyclist-specific traffic safety laws protect them from motor-vehicle-related crash injuries and fatalities?"

The study consisted of:

1. A legislative review to establish an inventory of laws that govern bicyclists.
2. A literature review to catalog and synthesize previous studies that examined safety outcomes associated with bicycle safety laws, as well as to identify knowledge gaps and methodological shortcomings.
3. An empirical analysis to examine safety outcomes associated with State-level bicycle safety laws, with emphasis on addressing gaps identified in the literature review.

The legislative review found that:

- Twenty-two States require helmet use among minors, with various age cut-offs.
- All but 2 States have some form of safe passing law, with various minimum clearance distances.
- Nearly half of all States prohibit impaired bicycling.
- Thirty States have laws explicitly addressing bicycling on sidewalks, some with exceptions.
- Nearly all States prohibit "dooring" (the opening of a car door into the path of an approaching vehicle or bicycle).
- Three States have implemented innovative laws that treat bicyclists differently from other road users. The *Idaho Stop, Delaware Yield,* and *Colorado Stop-as-Yield* laws allow bicyclists to treat stop signs as yield signs; no other States have such laws.

The literature review classified relevant studies into three categories:

- Laws that restrict or punish motorists' actions,
- Laws that promote safer bicycling practices, and
- Laws that treat bicyclists as a separate class of road user (Idaho Stop, Delaware Yield, and Colorado Stop-as-Yield).

Highlights of the literature review include the following points:

- The literature search did not identify any before-and-after evaluations of passing behaviors associated with enactment of safe passing laws. Three studies examined passing behavior with such laws already in place and found that most drivers comply with the minimum 3-foot lateral passing requirement (Chapman & Noyce, 2012; Love et al., 2012; Debnath et al., 2018). A before-and-after study of fatal bicycle crashes, however, found an increase in bicyclist fatalities following enactment of safe passing laws (Nehiba, 2018).

- The literature search did not identify any before-and-after evaluations of dooring laws, which requires motorists to look carefully before opening their car doors and provides a clear rule to assign responsibility for dooring crashes.
- Numerous before-and-after evaluations of helmet use laws establish increases in helmet use and reductions in head injuries associated with such laws, which are limited to children and young adults (Wesson et al., 2000; Ni, 1996; Liller et al., 2003; Macpherson et al., 2002).
- The literature search did not identify any before-and-after evaluations of bicycling-under-the-influence laws. Studies were identified that document effects of impairing substances on bicyclist behavior, establish elevated mortality rates for bicyclists who had consumed alcohol, and found that bicycling under the influence is correlated with bicycle crashes and injuries.
- The literature search did not identify any evaluations of where-to-ride laws. Studies have examined effects of bicyclist riding position within the travel lane on motorists' behaviors.
- Two studies were identified that evaluated the effects of sidewalk riding and injury rates. Both found that sidewalk riding was more likely to lead to injury than riding in the roadway (Aultman-Hall & Adams Jr., 1998; Reynolds et al., 2009).
- An evaluation of the Idaho Stop law reported a 15-percent decrease in bicyclist injuries in the year following the law's adoption (Meggs, 2010).

The empirical analysis used police-reported crash data, largely collected from the National Highway Traffic Safety Administration's State Data System, to examine the relationships between bicyclist safety laws and various bicyclist safety metrics. Rather than high-level crash counts, these metrics were developed to be relevant to each individual law. For example, bicycling-under-the-influence (BUI) laws were investigated using the number of crashes involving intoxicated bicyclists as the dependent variables. Several exposure variables were also included. Safety metrics were modelled using generalized linear mixed models. Treating State and year as random variables allowed for the quantification of overarching effects of exposure and law-related variables. Law-related variables included categorical variables denoting which laws were in effect in a given place and time, as well as how many years each law was in effect.

Highlights of the empirical analysis include the following findings.

- States with safe passing (SP) and/or where-to-ride (WTR) laws experienced statistically significantly fewer rear-end or sideswipe collisions than States without such laws, but increases in the years following enactment. Specifically, compared to States with neither law, SP-only States experienced 23 percent fewer related crashes, WTR-only States experienced 13 percent fewer, and States with both SP and WTR laws experienced 12 percent fewer. In the years following enactment, SP-only States experienced 11 percent more related crashes annually, while WTR-only States experienced 0.4 percent more, and States with both experienced 5 percent more.

- Helmet use was found to be 20 percent higher in States with mandatory helmet use (MHU) laws and increased 7 percent each year after the laws were enacted. No difference in fatal/incapacitating injuries was found between States with and without such laws, but fatalities and incapacitating injuries were found to decrease by 2 percent in States with MHU laws.
- States with bicycling-under-the-influence (BUI) laws exhibited 38 percent fewer crashes involving an intoxicated bicyclist than States without, and additional annual decreases of 8 percent in the years following enactment.
- Sidewalk-riding (SR) laws were analyzed in several ways. States that prohibit SR did not record *sidewalk* as a crash location, limiting much of the analysis to permissive SR laws. Permissive SR laws were not associated with statistically significant differences in the number of roadway or sidewalk crashes (regardless of relationship to intersections), but roadway crashes were observed to fall by 4 percent in States with permissive SR laws compared to States without any SR law. Both types of SR law were associated with decreases in fatal or incapacitating injuries (regardless of location and relationship to intersections), with prohibitive laws being associated with a greater decrease. States with permissive SR laws were also associated with 94 percent fewer intersection-related roadway crashes and 656 percent more intersection-related sidewalk crashes.
- The nature of the Idaho Stop prevented a cross-sectional analysis of its effects on intersection-related crashes wherein the bicyclist was recorded as failing to obey traffic controls or yield the right-of-way. Further, no evidence of an annual effect was detected.

Introduction

This study conducted a rigorous State-by-State review of bicycle traffic safety laws and a thorough analysis of the effects of these laws on various bicyclist safety metrics derived from law enforcement crash reports. The study approach included a review of current and historical legislation, a review of the academic literature, and the collection and analysis of crash data from States with a range of bicycle traffic safety laws.

This report is organized as follows. First, a brief background on the problem, followed by specific research objectives and findings from the legislative and literature reviews. Next is empirical analysis, with information on the data and analytic techniques used, and results for each law. Finally, limitations are acknowledged, followed by discussion of results and conclusions.

Legislators, transportation officials, bicycle safety advocates and researchers may find various parts of this report useful. The list of law variants and quantified effects of each on various aspects of safety may appeal to legislators, transportation officials, and advocates when considering the implementation of new laws or changes to existing laws. Researchers may benefit from the synthesized literature review findings and knowledge of how NHTSA's State Data System may be used and analyzed for future research.

Background

Bicycling is one of the oldest and most sustainable forms of human transportation and can be enjoyed by people of nearly all ages. Bicycling can reduce traffic congestion by taking motor vehicles off the road, and unlike cars, bicycles do not emit harmful air pollutants. Bicycles also use less roadway and parking space than cars; for example, approximately 10 bicycles can fit into one car parking space. In addition to serving as a means of transportation, regular bicycling throughout adulthood protects against a variety of age-related health issues (Duggal et al., 2018; Pollock et al., 2018).

Despite the many ecological and health benefits of bicycling, more than 600 bicyclists have been killed in traffic crashes in the United States each year since at least 1975, when national reporting on traffic fatalities became available through NHTSA's Fatality Analysis Reporting System (FARS). Most bicyclist fatalities occur in urban areas (68% from 2010 to 2015) as opposed to rural areas (30%), and about 30 percent of bicyclist fatalities occur at intersections (Coleman & Mizenko, 2018).

To help reduce the risk of bicyclist injuries and fatalities, many States as well as some local jurisdictions have enacted bicycle traffic safety laws. Such laws restrict or punish certain motorist actions while driving near bicycles (safe passing laws); promote safer practices among bicyclists (impaired bicycling laws, mandatory helmet use laws); or treat bicyclists as a separate class of road user (permissive sidewalk-riding laws and the "Idaho Stop" law).

Objective

The extent to which bicycle traffic safety laws succeed in making bicycling safer is not firmly established, with the exception of mandatory helmet use laws, for which extensive research has been conducted and fairly reliable estimates of effectiveness have been established. This study analyzed the effectiveness of these laws on safety to address the following research questions.

- Should States and communities create separate laws that govern bicyclists on the roadways?
- Do bicyclist-specific traffic safety laws protect them from motor-vehicle-related crash injuries and fatalities?

Legislative Review

A comprehensive search was performed to identify the types of bicycle laws that have been enacted across all 50 States. An unpublished draft of the *NHTSA Digest of Bicycle and Pedestrian Safety Laws* (n.d.) was used as a starting point, supplemented by a review of various legislative databases and communication with NHTSA regional pedestrian/bicycle coordinators.

Seven laws were identified, each with several variants (with the exception of the Idaho Stop). Figure 1 provides a summary of six of the identified laws and their variants. The Idaho Stop law is not included in this figure as there were not any variants.

Some municipalities enacted local laws that differed from those of their States. These municipalities were excluded entirely from the statistical analysis, not just for the years during which the laws differed. This was done to prevent biasing rate calculations in years surrounding an exclusion. For example, Tennessee State law does not expressly forbid bicycling under the influence (BUI), but the city of Murfreesboro did so in 1997. Excluding only Murfreesboro thereafter would result in a misleading decrease in the number of crashes counted. Because exposure metrics are statewide, crash rates would then falsely appear to decrease. The online municipal code and ordinance database Municode was used to identify municipalities with different laws (Code Library, 2019). Ultimately, 2 localities were excluded based on differing BUI laws, 27 based on helmet laws, 9 based on safe passing laws, and 63 based on sidewalk-riding laws.

State	Safe Passing	Dooring	Mandatory Helmet Usage	Bicycling Under the Influence	Where-to-Ride	Sidewalk Riding
Alabama	2	2	2	1	1	2
Alaska	4	2	4	4	1	4
Arizona	2	2	4	4	4	4
Arkansas	2	2	4	4	1	1
California	2	2	3	1	1	4
Colorado	2	2	4	1	2	1
Connecticut	2	4	2	4	2	1
Delaware	2	2	3	1	2	1
Florida	2	2	2	1	1	1
Georgia	2	2	2	1	1	2
Hawaii	3	2	2	1	1	1
Idaho	3	2	4	4	1	1
Illinois	2	2	4	4	1	1
Indiana	3	4	4	4	1	4
Iowa	3	4	4	4	1	4
Kansas	2	2	4	1	1	4
Kentucky	4	4	4	1	1	1
Louisiana	2	2	1	4	1	4
Maine	2	2	2	4	2	4
Maryland	2	2	2	1	2	2
Massachusetts	3	2	3	4	4	1
Michigan	3	4	4	4	1	1
Minnesota	2	2	4	4	1	1
Mississippi	2	2	4	1	1	4
Missouri	3	2	4	4	2	1

Key						
Value	Safe Passing	Dooring	Mandatory Helmet Usage	Bicycling Under the Influence	Where-to-Ride	Sidewalk Riding
1	"Not less than 4 feet"	Bicycle-specific	Applies to minors < 12-15 years old	Prohibited	As Far Right as Practicable (AFRAP)	Permitted
2	"Not less than 3 feet"	General	Applies to minors < 16 years old		AFRAP + Safe	Prohibited
3	"Safe Distance"		Applies to minors < 17-18 years old		AFRAP + Traffic	
4	No Legislation					

Figure 1. Law variants by State

State	Safe Passing	Dooring	Mandatory Helmet Usage	Bicycling Under the Influence	Where-to-Ride	Sidewalk Riding
Montana	3	2	4	4	3	1
Nebraska	2	2	4	4	1	1
Nevada	2	2	4	1	1	4
New Hampshire	2	2	2	1	1	2
New Jersey	3	4	3	4	1	4
New Mexico	3	2	3	1	1	4
New York	3	2	1	4	3	4
North Carolina	1	4	2	1	1	4
North Dakota	3	2	4	1	1	2
Ohio	3	2	4	1	1	2
Oklahoma	2	2	4	4	2	4
Oregon	3	1	2	1	1	1
Pennsylvania	1	2	1	1	1	1
Rhode Island	3	1	2	1	1	1
South Carolina	3	2	4	4	1	4
South Dakota	2	2	4	4	1	1
Tennessee	2	4	2	4	1	4
Texas	3	2	4	4	1	4
Utah	2	1	4	1	1	1
Vermont	3	2	4	1	1	4
Virginia	2	4	1	4	1	1
Washington	3	2	4	4	2	1
West Virginia	2	4	1	1	1	4
Wisconsin	2	2	4	4	1	1
Wyoming	2	2	4	1	1	1

Key						
Value	Safe Passing	Dooring	Mandatory Helmet Usage	Bicycling Under the Influence	Where-to-Ride	Sidewalk Riding
1	"Not less than 4 feet"	Bicycle-specific	Applies to minors < 12-15 years old	Prohibited	As Far Right as Practicable (AFRAP)	Permitted
2	"Not less than 3 feet"	General	Applies to minors < 16 years old		AFRAP + Safe	Prohibited
3	"Safe Distance"		Applies to minors < 17-18 years old		AFRAP + Traffic	
4	No Legislation					

Figure 1. Law variants by State (continued)

Literature Review

A systematic literature review was conducted to identify relevant research. Google Scholar,[1] the Transport Research International Documentation,[2] and ScienceDirect[3] databases were searched using relevant keywords and keyword combinations; both domestic and international sources were considered. Table 1 shows the informational sources and search terms used.

Table 1. Information Sources and Search Terms

Information Source	Search Terms
Google Scholar	"Bicycle Legislation," "Bicycle Laws," "Bicycle Passing Legislation," "Bicycle Passing Laws," "Safe Passing Laws," "Driver Behavior and Bicyclists," "Driver and Cyclist Interaction," "Bicycling Safety," "Bicycling Policy," "Bicycling Enforcement," "Vulnerable Road User Laws," "Vulnerable Road User Safety," "Idaho Stop," "Delaware Yield," "Impaired Bicycling Laws," "Bicycle Awareness," "Scofflaw Bicycling," "Bicycling Promotion"
TRID	"Bicycle Legislation," "Bicycle Laws," "Safe Passing Laws," "Vulnerable Road User Laws," "Idaho Stop," "Where to Ride"
ScienceDirect	"Bicycle Legislation," "Bicyclist Behavior at Stop Signs"

The initial search process identified 149 documents. A screening process then reduced this number to 93, of which 41 were domestic and 52 were international. Findings from the most relevant studies are organized with respect to specific laws, beginning with legislation and research in the 1980s that set the stage for the current legislation and recent research that has both tested and expanded upon bicycle legislation and its effect on safety and ridership. Laws are grouped into three categories: those that restrict or punish motorists' actions, those that promote safer bicycling practices, and those that treat bicyclists as a separate class of road user. Table 2 provides a summary of the literature review findings.

[1] Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines.
[2] TRID is an integrated database that combines the records from the Transportation Research Board's Transportation Research Information Services (TRIS) database and the Organisation for Economic Co-operation and Development's Joint Transport Research Centre's International Transport Research Documentation (ITRD) database. TRID provides access to more than 1.2 million records of transportation research worldwide. The OECD is an intergovernmental economic organization with 36 member countries, founded in 1961 to stimulate economic progress and world trade.
[3] ScienceDirect is a website that provides subscription-based access to a large database of scientific and medical research. It hosts over 12 million pieces of content from 3,500 academic journals and 34,000 e-books.

Table 2. Literature Review Summary

Category	Law	Study	Outcome Measures	Findings
Laws That Restrict or Punish Motorist Actions	Safe Passing	Chapman & Noyce, 2012 (Wisconsin)	Lateral clearance during overtaking maneuvers	Average passing distance between overtaking vehicles and bicycles was over 6 feet, double what is required by law.
		Love et al., 2012 (Maryland)	Lateral clearance during overtaking maneuvers	Of 586 recorded events, 17 percent occurred at distances of 3 feet or less.
		Debnath et al., 2018 (Queensland, Australia)	Lateral clearance during overtaking maneuvers	Although the observed mean passing distance was greater than the minimum specified in the law, 15.7 percent of observed passing events were less than the minimum required (1 meter) passing distance.
		Nehiba, 2018 (multiple States using FARS data)	Bicyclist fatalities	Safe passing laws are ineffective in reducing bicyclist fatalities and may result in an increase
	Dooring	-	-	The literature search did not identify any evaluations of Dooring laws.
Laws That Promote Safer Bicycling Practices	Mandatory Helmet Use	Wesson, 2000 (Toronto, Canada)	Helmet use among patients admitted to hospitals with head injuries	Helmet use rose from 4 percent to 67 percent while the number of bicyclist head injury admissions dropped from 46 percent to 24 percent from 1990 to 1996
		Ni, 1996 (Oregon)	Helmet use among patients admitted to hospitals with head injuries	Helmet use increased from 24.5 percent pre-law to 49.3 percent post-law. Bicycling-related head injuries decreased from 3.9 per 100,000 person-years pre-law to 2.9 post-law.
		Liller et al., 2003 (Hillsborough County, Florida)	Helmet use, injury rates	Helmet use among children rose from 3.6 percent in 1993 to 67.0 percent in 1998, and the average rate of motor vehicle related bicycle injuries was approximately 1.5 times greater during the pre-law years (1993–96) than in the post-law years.
		Macpherson, et al., 2002 (Canada)	Rate of bicycle-related head injuries	Canadian provinces with helmet laws exhibited 45 percent reduction in rates of bicycle-related head injuries than those without.
	Bicycling Under the Influence	-	-	The literature search did not identify any evaluations of Bicycling-Under-the-Influence laws.
	Where-to-Ride			The literature search did not identify any evaluations of Where-to-Ride laws.
	Sidewalk Riding	Aultman-Hall, 1998 (Ottawa and Toronto, Canada)	Injury rates	Sidewalk bicyclists exhibited higher rates (per reported travel distance) of collisions, falls, injuries and major injuries than non-sidewalk bicyclists.
		Reynolds, 2009 (Review of international studies)	Injury rates	Sidewalk bicycling was 1.8 to 16 times more dangerous than riding on the road.
Laws That Treat Bicyclists as a Separate Class of Road Users	Idaho Stop	Meggs, 2010 (Idaho)	Injury and fatality rates	Bicyclist injuries in the year following the law's adoption fell by 15 percent; no long-term change.

Laws That Restrict or Punish Motorists' Actions

Laws that prescribe safe passing distances, punish drivers for unsafe driving acts ("vulnerable road user laws"), prohibit distracted driving, and prohibit dooring seek to improve safety by restricting or punishing motorists' actions. Research on all such laws was sought, but only research on safe passing and dooring were identified.

Safe Passing Laws

A NHTSA survey conducted in 2012 found that 12 percent of respondents (N=1,551) felt threatened the last time they travelled by bicycle; 39 percent of these people felt threatened due to motorists driving "very close" (Schroeder & Wilbur, 2013). In response to such concerns, 48 States have enacted safe passing laws, which require vehicles to pass bicyclists at either a specified minimum distance, or at an unspecified "safe distance." Currently, 27 States require motorists to pass bicyclists at a distance of 3 feet, 2 States require a passing distance of no less than 4 feet, and 19 States require that motorists pass bicyclists at an unspecified safe distance (see Figure 1). Four studies were identified that provide insight into motorist behaviors while passing bicycles but did not evaluate passing behaviors prior to enactment of safe passing legislation; therefore, they did not indicate whether the legislation influenced driver behavior.

A 2010 study examined vehicle passing maneuvers on rural roads in Dane County, Wisconsin, which had a 3-foot lateral clearance law (Chapman & Noyce, 2012). Analysis of over 1,100 passing maneuvers showed the average passing distance between overtaking vehicles and bicycles was over 6 feet, double what is required by law. Although the average observed lateral distance was greater than required, additional concerns were noted due to potentially unsafe motorist actions, such as crossing the centerline.

A 2012 study assessed passing behavior following enactment of a Maryland 3-foot passing law that took effect in 2010; lateral clearance distances were measured by bicycle-mounted cameras during overtaking maneuvers (Love et al., 2012). Of 586 recorded events, 17 percent occurred at distances of 3 feet or less.

A 2018 Australian study examined compliance with Queensland's safe passing law, which requires that drivers maintain a lateral passing distance of at least 1 meter (3.3 feet) when overtaking bicyclists (Debnath et al., 2018). The naturalistic study collected video footage of passing maneuvers at 15 different locations 12 months after the enactment of the safe passing law. Although the observed mean passing distance was greater than the minimum specified in the law, 15.7 percent of observed passing events were less than the minimum required passing distance of 1 meter. Non-compliant passing distances were more common on higher speed roads, horizontal curves, and roads with dedicated bicycle lanes.

A 2017 U.S. study evaluated the effect of safe passing laws on the number of bicyclist fatalities that occurred from 1990 to 2014, using FARS data (Nehiba, 2018). The study found that safe passing laws are ineffective in reducing bicyclist fatalities and may actually result in an increase. Researchers suggest that the increase in fatalities could be due to motorists that had previously given bicyclists a lateral clearance greater than three feet, adjusting to allow only the minimum lateral distance required by law.

Dooring Laws

Dooring occurs when a bicyclist, pedestrian, or vehicle collides with an opened vehicle door. In a Swedish study conducted in 2013, researchers used the Volvo Car Cyclist Accident Database to determine common motorist-bicyclist conflicts and bicyclist injuries. Dooring crashes were the cause of approximately 10 percent of all bicycle injuries recorded between 2005 and 2013 (Lindman et al., 2015).

Many States have implemented dooring laws to help mitigate these crashes by requiring motorists to look carefully before opening their car doors. Currently, 40 States have dooring laws in place, but only 3 of those States, Oregon, Rhode Island, and Utah, mention bicyclists specifically. Despite the number of bicyclists involved in dooring crashes, the literature search did not identify any research evaluating the effectiveness of these laws.

Laws That Promote Safer Bicycling Practices

Laws that require bicyclists to wear helmets, prohibit bicycling under the influence, or prescribe where in the road bicyclists should ride seek to improve safety by promoting safer practices among bicyclists.

Mandatory Helmet Use Laws

Bicycle helmet legislation dominates the body of research on bicycle legislation. Mandatory helmet use laws for children and young adults have been adopted by many States since California became the first in 1986 (FHWA, n.d.). Extensive research has been conducted, both domestically and internationally, suggesting that helmet legislation reduces fatalities and injury severity (Carr et al., 1995; Wesson et al., 2000; Liller et al., 2003; Borglund et al., 1999; Robinson, 1996).

Several studies have examined the impact of bicycle helmet laws on helmet use and injuries. Among patients admitted to hospitals with head injuries in Toronto, Canada, helmet use rose from 4 percent to 67 percent, while the number of bicyclist head injury admissions dropped from 46 percent to 24 percent from 1990 to 1996 (Wesson et al., 2000). Authors suggest that awareness campaigns may have contributed to these favorable changes. A similar study evaluated the law's effects in Oregon, reporting an increase in helmet use from 24.5 percent pre-law to 49.3 percent post-law, and a decrease in the rate of bicycling-related head injuries from 3.9 per 100,000 person-years pre-law to 2.9 post-law, with the most significant reductions occurring in children under 16 years of age (Ni, 1996). A study conducted in Hillsborough County, Florida, examined the effect of a 1997 law. It found that helmet use among children rose from 3.6 percent in 1993 to 67.0 percent in 1998, and the average rate of motor-vehicle-related bicycle injuries was approximately 1.5 times greater during the pre-law years (1993–96) than in the post-law years (1997–2000) (Liller et al., 2003). A population-based study conducted in Canada found a 45 percent reduction in the rate of bicycle-related head injuries in provinces with helmet laws (Macpherson et al., 2002).

Bicycling-Under-the-Influence Laws

The literature search did not identify any evaluations of bicycling-under-the-influence laws. A 2017 Virginia study examined crash reports over a 5-year period and found that bicyclists who admitted or were found to have been drinking prior to the crash were 36.7 percent more likely to be fatally injured and twice as likely to be severely injured (Robartes & Chen, 2017). It is unclear if this study used the blood alcohol content (BAC) of .08 grams per deciliter typically applied to motorists to determine intoxication. A study conducted in 2016 at a Level 1 trauma center in New York City found that (a) alcohol use was inversely associated with helmet use, (b) intoxicated bicyclists were more likely to fall from their bicycles without interacting with a motor vehicle (i.e., falling from lack of control), and (c) mortality rates were higher for bicyclists who had consumed alcohol (Sethi et al., 2016). A 2014 study conducted in Canada found the use of alcohol or cannabis was associated with an increase in the risk of non-fatal injury crashes of bicyclists compared to non-users (Asbridge et al., 2014).

Where-to-Ride Laws

Many States as well as other countries have adopted where-to-ride laws for bicyclists riding in mixed-use traffic (i.e., shared lane between motorists and bicyclists). These laws state that bicyclists must ride in a specified location within the travel lane. The literature search did not identify any evaluations of where-to-ride laws but several studies have examined the effects of bicyclist riding position within the travel lane on motorists' behaviors (Duthie et al., 2010; Chapman & Noyce, 2012; Shackel & Parkin, 2014; Dozza et al., 2016). A naturalistic study of 83 overtaking maneuvers in France found an average lateral clearance of 1.29 meters (4.23 feet) (Walker, 2007). Though greater than the 3- or 4-feet requirements in some States, this distance is less than the 1.5-meters required by French law, and implies a substantial number of "unsafe" passes. Another study found that bicyclists who took the full lane were more likely to receive more than 3 feet of lateral clearance distance, while those who executed a dodging maneuver were more likely to receive the minimum or less than the minimum space required (LaMondia & Duthie, 2012).

Sidewalk-Riding Laws

Sidewalk riding is a contested issue. Altman-Hall (1998) found that sidewalk bicyclists in two major Canadian cities exhibited higher rates (per reported travel distance) of collisions with motor vehicles, other bicyclists, or pedestrians, as well as falls, injuries, and major injuries than non-sidewalk bicyclists. The same study noted that sidewalk bicycling may not be inherently more dangerous; rather, those bicyclists who use sidewalks are more dangerous than those who use the road. A meta-analysis of the effects of infrastructure found that sidewalk bicycling was associated with 1.8 to 16 times more collisions than riding on the road (Reynolds et al., 2009).

Laws That Treat Bicyclists as a Separate Class of Road Users

Bicyclists differ from motorists in several ways, including speed, agility, size, physical protection provided for the user, and vulnerability to serious injuries. SP laws treat bicyclists as a separate class of road users who require a certain amount of lateral clearance during passing maneuvers, MHU laws only require helmet use among (non-adult) bicyclists, WTR laws relegate bicyclists to the right of the travel lane rather than the center, and some SR laws permit bicyclists to ride on the sidewalk rather than the roadway. Only BUI laws treat bicyclists and motorists similarly.

In 1982, Idaho implemented a statutory rule that allows bicyclists to treat stop signs as yields and red lights as stop signs, using discretion when passing through intersections. While the "Idaho Stop" has stood alone in its class of legislation for decades, Delaware and Colorado have recently enacted similar laws. In 2017, Delaware adopted the "Delaware Yield" that permits bicyclists to stop at red lights, then proceed using discretion when right-of-way is provided. In

2018, Colorado passed a law standardizing language regarding the use of a "stop-as-yield" condition in the State.

Idaho Stop

The Idaho Stop permits bicyclists to treat stop signs as yield signs and treat red lights as stop signs, allowing bicyclists to continue through the stop signs or red lights with discretion when right-of-way is provided. A recent law review determined that the Idaho Stop had "neutral to good" results, as high-density and congested areas require bicyclists to stop at stop signs due to cross-street traffic, while areas with low volumes have shown more positive results (Tekle, 2017). An often-cited study compared injury and fatality rates in Boise, Idaho, to those of two similar cities in California. It reported a 15-percent decrease in bicyclist injuries in the year following the law's adoption, and no long-term change (Meggs, 2010). It should be noted, however, that this decrease included "numerous types of collisions" amid other data limitations.

For several decades, the Idaho Stop law was truly unique. Recently several States have adopted similar legislation. In 2017, the *Bicycle Friendly Delaware Act* was signed into law, requiring a bicyclist to stop before entering an intersection only "if required for safety." Notably, Delaware's law only applies to stop signs and roads with one or two traffic lanes (Shinkle, 2017). In 2018, Colorado passed the *Bicycle Operation Approaching Intersection Bill*, allowing municipalities to enact similar laws on a local level rather than expressly changing anything at the State level. In 2019, Arkansas enacted an Idaho Stop law (An Act Concerning Bicycle Safety, 2019), and Oregon lawmakers introduced similar legislation (Schmitt, 2019). The literature search did not identify any research evaluating the effectiveness of these laws.

Empirical Analysis

An empirical analysis was conducted to assess the effects of six bicycle traffic safety laws on various bicyclist safety metrics. Crash and injury data were sourced from law enforcement crash reports and used with several exposure metrics to quantify the impacts relevant to each law.

Data

Three main types of data were used in this analysis: crash data, exposure metrics, and legislative details.

Crashes

Law enforcement crash reports serve as a record of crashes involving motorists, pedestrians, and bicyclists. Since the early 1980s NHTSA has obtained from various States computer data files coded from police crash reports. NHTSA refers to the collection of these computerized State crash data files as the State Data System (SDS). SDS is maintained by NHTSA's National Center for Statistics and Analysis (NCSA). This report uses crash reports from 1989 to 2018. These records contain dozens of variables describing each reported crash, as well as the vehicles and persons involved. Approval from each State's authorizing representative is required prior to release of the data. SDS files differ among States in terms of time coverage, information content, and coding schemes. To overcome this lack of interoperability, comparable variables were manually generated for each State.

Attempts were made to collect data from all 48 contiguous States. Hawaii and Alaska were thought to differ significantly from the other States and therefore would not generalize well. Ultimately, crash data was attained from 34 States, with 28 coming from the SDS. Data for 5 additional States was collected from public, State-run online portals and similarly cleaned to remove personal identifiers. A representative from Idaho provided crash counts relative to the Idaho Stop law only.

Figure 2 summarizes the data source for each State.

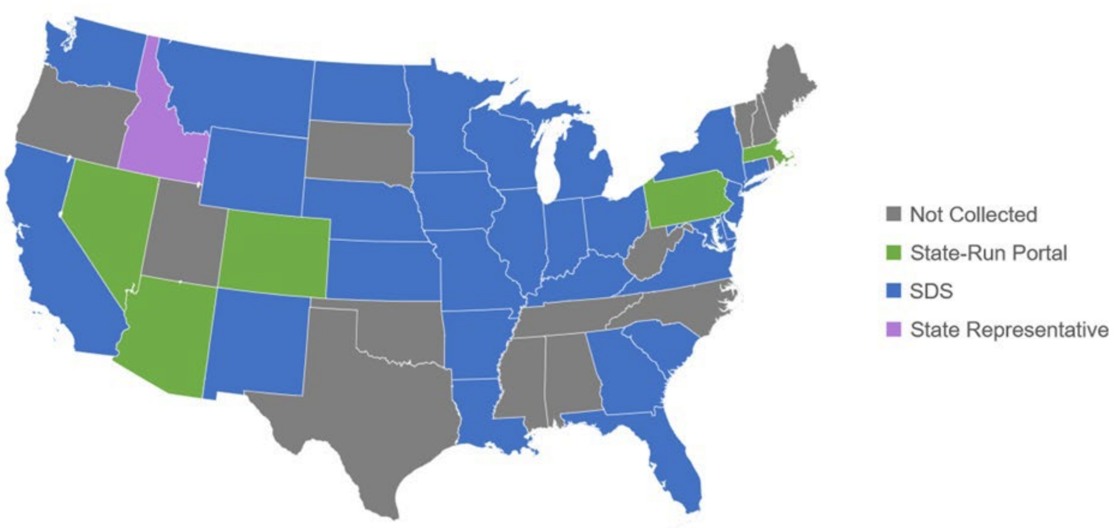

Figure 2. State crash data sources

The National Emergency Medical Services Information System (NEMSIS) was considered as a potential source for crash data, but ultimately was not pursued due to several limitations.

NEMSIS stores details related to EMS encounters in many States across the country, including the patient's injury and various aspects of the actions taken by EMS personnel. As described in the 2016 User Manual, NEMSIS "is a large convenience sample — it consists solely of data submitted by participating EMS agencies within states" (NEMSIS, 2017). Unless those participating agencies are uniformly distributed across each State and fluctuate in parallel over time, use of a convenience sample will lead to biased conclusions regarding the effect of laws on safety. The selection bias inherent in agency participation could also introduce bias.

Exposure

The number of law enforcement-reported crashes occurring in a given time and place depends highly on the number of opportunities to do so, known as *exposure*. Four relevant exposure metrics were collected and/or estimated:

- number of bicycle commuters,
- vehicle miles traveled,
- length of bikeable roads, and
- number of intersections.

Number of Bicycle Commuters

The American Community Survey (ACS) provides estimates of the percent of State residents who commute to work by bicycle. Both 1-year and 5-year estimates are provided. One-year estimates are derived from 1-year data collection periods and are more current than the 5-year estimates but use smaller sample sizes and produce greater year-to-year variation (U.S. Census Bureau, 2018). In addition, 1-year estimates are available for 1990, 2000, and 2005-2017 versus annually since 2009 for the 5-year estimates.

One-year ACS statistics were used to estimate the number of bicycle commuters in each State and year (1990 – 2017) by predicting the annual commuter percentage with a generalized linear model and multiplying by annual State populations. The result of these calculations is shown in Appendix A: Visualization of Exposure Metrics.

Although bicycles are ridden for purposes other than commuting to and from work, the number of bicycle commuters provides a reasonable surrogate measure of the overall level of bicycling in a given State and year. Local surveys and counting mechanisms provide information on the level of non-commuting bicycling, but these estimates cannot be aggregated to the State level.

Vehicle Miles Traveled

Vehicle miles traveled (VMT) measures the level of motor vehicle driving in a given State and year, and is the most frequently used exposure metric in transportation-related injury analysis (Federal Highway Administration, and Federal Transit Administration, 2017). The Federal Highway Administration provides annual measures of VMT from 1990 to 2017 for all States and roadway types. Because most bicyclist injuries occur in urbanized areas and bicycles are prohibited from using interstates, freeways, and expressways, total VMT was reduced to that which occurred on urban "bikeable" roads (arterials, collectors, and local roads only). No further estimation or interpolation was required. Figure 12 (see Appendix A: Visualization of Exposure Metrics) shows these values.

Length of Bikeable Roads

The space available for bicyclist-motorist interactions may affect crash rates. Urban arterial, collector, and local roads were considered "bikeable" roads for this analysis. If two States exhibit the same number of bicyclists and motorists, but State A has half the distance of bikeable roads than State B, road users in State A have less space to themselves and may therefore find themselves with more opportunities for conflict. Even within States, the lengths of these roadways vary significantly over time as more and more roads are built and areas convert from rural to urban. Roadway length data, extracted from the ACS, are presented in Figure 13 (see Appendix A: Visualization of Exposure Metrics).

Note that rural injuries were not excluded from the analysis. The length of (urban) bikeable roads was calculated and used as a surrogate measure of the space available to, and commonly used by, bicyclists.

Number of Intersections

Crashes related to the Idaho Stop occur exclusively at intersections. States with more intersections may therefore observe more Idaho Stop-related crashes and confound the effect of the law. To mitigate this risk, the annual number of intersections in each State was estimated.

Intersection density (intersections per square kilometer) in 2017 was provided by Boeing (2018) and converted to the number of intersections per mile of bikeable roadway in each State. This statistic was then multiplied by each State's annual bikeable roadway length to yield annual intersection counts, shown in Figure 14 (see Appendix A: Visualization of Exposure Metrics).

Legislation

Two aspects of each law were collected for this analysis, the specific wording and the effective date. Both data elements were sourced from respective State legislative websites.

Laws were classified into six categories.

- Safe Passing (SP)
- Where-to-Ride (WTR)
- Mandatory Helmet Usage (MHU)
- Bicycling Under the Influence (BUI)
- Sidewalk Riding (SR)
- Idaho Stop (IS)

Each category was further decomposed into several variants to capture meaningful differences in wording. For example, 2 States require motorists to pass bicyclists with "not less than four feet" of lateral clearance, while 27 require "not less than three feet" and 19 use an unspecified "safe distance." Variants were aggregated or analyzed separately where appropriate. These variants are shown in Figure 1.

When bills are enacted by legislatures and signed by governors they become law, but are not generally in force until sometime thereafter. In California, for example, most bills go into effect on January 1 of the following year whereas in Virginia, bills become effective on July 1 of the following year, and in Washington, laws go into effect 90 days after the legislative session that enacted them. The *effective* date marks when citizens must begin obeying the new law and law enforcement officers can begin enforcement. This latter (effective) date was used in the analysis.

This analysis focuses on State laws; many municipalities pass laws that differ from their respective States. Wichita, Kansas, prohibits bicycling under the influence but no such State law exists. California prohibits sidewalk riding, but the city of Irvine allows it in certain areas. Such differences could lead to misleading conclusions regarding specific laws and their effects on bicyclist safety.

The online municipal code and ordinance database, Municode, was used to identify municipalities with differing laws (Code Library, 2019). The completeness of this database is unknown, but includes over 3,800 municipal codes and 130,000 ordinances from all U.S. States and Territories. Municipalities with laws different from their respective States were excluded from statistical models. Ultimately, two were excluded based on differing BUI laws, 27 based on differing MHU laws, 9 based on differing SP laws, and 63 based on differing SR laws.

Method

Each law was analyzed separately (except for safe passing and where-to-ride laws, which were analyzed simultaneously due to a common relevant safety metric) using a statistical model that allows for State-by-State differences. The dependent variable was chosen as the most relevant subset of crashes for each law (see each respective section for details). Exposure variables were included to avoid misattributing changes in relevant crash counts to laws. Laws were investigated for both their immediate and subsequent effects on safety relative to their effective years.

Mixed-effects Poisson regression models were estimated for each law. "Mixed effects" refers to a combination of fixed and random effects, with the former applying to all States and the latter applying strictly within a given State (Stroup, 2012). State and year were considered random effects, effectively allowing for State-specific baselines and trends over time. This is an important consideration as States exhibit vastly different crash counts (due largely to varying population sizes) and long-term trends. The fixed effects apply uniformly to all States and include exposure variables and legislative variables. Such models have been shown to minimize the potential bias due to uncontrolled differences among people (Lockwood & McCaffrey, 2007). Two legislative variables were used: an indicator denoting whether or not the law was in force in the given year, and a count of the years passed since in effect. This combination allows for the detection of changing effects over time. For example, a law may initially improve safety, but the effect may diminish (or strengthen) over time. Finally, the Poisson model specification was chosen to account for the nature of the dependent variables. Counts are seldom normally distributed, so the Poisson distribution (and corresponding log link function) is used to overcome this limitation to ordinary linear regression. Exploratory data analysis confirmed the appropriateness of the Poisson distribution over the Gaussian (normal), as is required for valid inference from ordinary linear regression.

In the analysis of mandatory helmet use laws, a mixed-effects *logistic* regression model was applied to estimate helmet use reported in each crash. When helmet use was recorded, it was coded as either a zero (indicative of no helmet worn at the time of the crash) or a one (helmet worn). This variable was present in 36.8 percent of cases, and only these cases were used for the analysis of helmet laws. As with count data, the dichotomous nature of helmet use requires a specific statistical model. In this case, the logistic regression estimates the probability of reported helmet use given other covariates.

All data manipulation and analyses were conducted in R (R Core Team, 2019) with lme4 (Bates et al., 2015) and visualized with ggplot2 (Wickham, 2016).

Results

The following sections detail the safety metrics relevant to each law and the results of the statistical models of the effect of each law on the corresponding metrics. Table 2 provides a summary of these sections. The effect attributed to each law refers to the difference between States with and without the law, while the effect attributed to each year of enforcement refers to the change in safety metrics associated with each additional year of enforcement. See Appendix B: Statistical Model Results for further details about each model and the resulting estimates.

Table 3. Summary of Results

Law	Safety Metric	Effect Attributed to Law	Effect Attributed to Each Year of Enforcement
Safe Passing (SP) and Where-to-Ride (WTR)	Number of crashes involving rear-end or sideswipe collisions not occurring at intersections, OR those which the motorist's action was recorded as "passing" or "overtaking" a bicyclist.	SP Only: - 23% WTR Only: - 13% Both: - 12%	SP Only: + 11% WTR Only: + 0.4% Both: + 5%
Mandatory Helmet Use	Rate of reported helmet use among bicyclists ≤ 16yrs.	+ 20%	+ 7%
	Number of fatalities and incapacitating injuries among bicyclists < 16yrs.	None[1]	- 2%
Bicycling Under the Influence	Number of crashes involving an intoxicated bicyclist.	- 38%	- 8%
Sidewalk Riding[2]	Number of crashes in the roadway (regardless of relationship to intersection).	Prohibitive: Unknown Permissive: None[1]	Prohibitive: Unknown Permissive: - 4%
	Number of crashes on the sidewalk (regardless of relationship to intersection).	Prohibitive: Unknown Permissive: None[1]	Prohibitive: Unknown Permissive: None[1]
	Number of fatalities and incapacitating injuries (regardless of location and relationship to intersection)	Prohibitive: - 29% Permissive: - 15%	Prohibitive: - 3% Permissive: - 2%
	Number of intersection-related crashes in the roadway.	Prohibitive: Unknown Permissive: - 94%	Prohibitive: Unknown Permissive: + 18%
	Number of non-intersection-related crashes in the roadway.	Prohibitive: Unknown Permissive: None[1]	Prohibitive: Unknown Permissive: None[1]
	Number of intersection-related crashes on the sidewalk.	Prohibitive: Unknown Permissive: + 656%	Prohibitive: Unknown Permissive: None[1]
	Number of non-intersection-related crashes on the sidewalk.	Prohibitive: Unknown Permissive: None[1]	Prohibitive: Unknown Permissive: - 4%
Idaho Stop[3]	Number of crashes that occurred at intersections (stop-controlled or signal-controlled) and the bicyclist's action is recorded as either a failure to obey traffic controls or a failure to yield the right of way.	Unknown	None[1]

Notes:
[1] Indicates that $p > 0.10$.
[2] The data collected did not allow for an analysis of prohibitive sidewalk-riding laws.
[3] The statistical model used did not allow for an analysis of the Idaho Stop law because Idaho was the only State with such a law and the model used State- specific effects, thus leading to over-specification.

Safe Passing and Where-to-Ride Laws

Bicyclists generally travel at much lower speeds than motorists, so when the two must share the same roadway, motorists must be able to safely pass bicyclists. SP and WTR laws attempt to promote safety for bicyclists without impeding traffic flow. Nearly all States have some form of SP law, whether it requires a lateral distance of 3 feet, 4 feet, or a “safe distance” when motorists pass bicyclists. WTR laws are nearly ubiquitous and generally require bicyclists to ride “as far right as practicable.” These two laws were analyzed simultaneously as they both are believed to affect the same subset of relevant crashes.

To maintain some statistical power (the ability to reliably detect changes in the dependent variable), the variants of these laws were reduced to binary variables indicating whether or not each State did or did not enforce a given law during a given year.

SP and WTR laws attempt to reduce potential conflicts when motorists and bicyclists share the roadway while traveling in the same direction. When motorists fail to comply with a required distance and/or bicyclists fail to ride in the designated area of the roadway, one of two collision types can occur, rear-end or sideswipe. Given available crash data details, crashes relevant to SP and WTR laws were defined as:

- Crashes wherein the crash type was either “rear-end” or “sideswipe (same direction)” *and* the crash did not occur at an intersection; or
- Crashes wherein the motorist’s action was recorded as “passing” or “overtaking” a bicyclist.

The annual count of relevant crashes in each State was modeled as a function of three groups of variables: State-specific effects, exposure effects, and law effects. States vary in the number of reported crashes simply due to population differences, as well as different temporal trends. Thus, each State received its own intercept (i.e., overall mean number of crashes) and regression coefficient on time (year). Exposure effects include the number of bicycle commuters, length of bikeable roadway, and VMT. Two variables were used for the law: a nominal variable describing the law in each State and year (no law, SP only, WTR only, or both), and how many years had passed since going into effect. Thus, if a State goes from either SP-only or WTR-only to both, the number of years since going into effect resets to zero when the second law is enacted and increases by one each year. The interaction of these two variables was used to examine different temporal effects of each legal situation.

Figure 3 visualizes the effects of each law as well as the combination thereof, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 15 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States with available data.) SP-only States experienced 22.8 percent fewer relevant crashes compared to those without ($p < 0.01$), while WTR-only experienced 12.7 percent fewer ($p < 0.01$) and States with both experienced 11.9 percent fewer ($p < 0.10$). However, in States with these laws increases in relevant crashes were observed in the years following enactment. Each year a SP law was in effect was associated with an 11.3 percent increase ($p < 0.01$) in relevant crashes, while each year a WTR law was in effect was associated with a 0.4-percent increase ($p < 0.01$) and each year that both laws were in effect simultaneously was associated with a 5.4-percent increase.

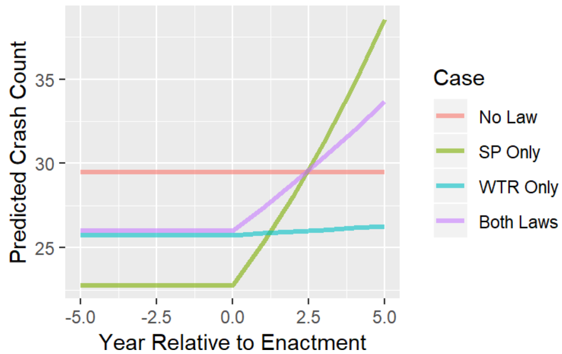

Figure 3. Predicted effects of SP and WTR laws on relevant crashes

Dooring

A widely recognized source of bicyclist injury involves motorists opening their doors into the path of oncoming traffic, presenting an unexpected obstacle for approaching bicyclists. This type of crash is known as Dooring. Many States prohibit such motorist actions in general; few have language specifically pertaining to bicyclists. An analysis of these laws on bicyclist safety was intended, but the required data was not recorded by any State whose data was acquired for this analysis. Data contributed to SDS does include incidents involving parked vehicles, but dooring is not provided as a contributing factor. Contributing factors include "unsafe speed," "improper passing," "brakes," and many others, but nothing readily interpreted as dooring-related.

Mandatory Helmet Use

Ample evidence exists in support of the harm reduction benefit of bicycle helmets. MHU laws attempt to leverage this safety effect by requiring riders to wear bicycle helmets. Less than half of all States have MHU laws. Five States apply MHU to bicyclists younger than 15, while 12 apply to those younger than 16, and 5 apply to those up to 17 or 18 years old.

Mandating the use of helmets while bicycling is not meant to reduce the number of crashes. Rather, MHU laws seek to increase helmet use and take advantage of the helmet's potential to reduce injury *severity.* Two metrics were investigated: the rate of reported helmet use, and the numbers of fatalities and incapacitating injuries. Both metrics were restricted to bicyclists 16 or younger. Although different age cutoffs are used across the country, 16 serves as a reasonable cutoff for States that enforce MHU at other ages. Helmet use was not recorded by all States or all years within a State, but it was analyzed when available. In contrast, injury severity was almost always recorded, but may not be the most reliable metric for safety relative to MHU laws as it may be affected by numerous factors. In addition, although bicycle commuters tend to be above the age of 16, the number of commuters was used as a proxy for the overall level of bicycling in the statistical models.

The claim that MHU laws reduce ridership was considered but deemed untestable due to a lack of data on ridership among the affected population. These laws mandate helmet use for minors, whereas bicycle commuters (measured and reported by the ACS) tend to be adults. Therefore, no change in ridership among these people would be expected.

First, a mixed-effects logistic regression model was used to estimate helmet use in each crash. Second, a mixed-effects Poisson regression model was applied to estimate the combined number of fatalities and incapacitating injuries. As with analyses of other laws, these models included State-specific intercepts and time trends, several exposure variables, and two law variables (a 0/1 indicator of whether or not the law was in force in a given year, and how many years had passed since the effective year).

Figure 4 visualizes the effects of MHU laws on reported helmet use, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 16 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of helmet use in all States.) States with MHU laws experienced a 20.0 percent higher rate of helmet use compared to those without ($p < 0.05$), and each year an MHU law was in effect in a given State was associated with an additional 7.1-percent increase ($p < 0.05$).

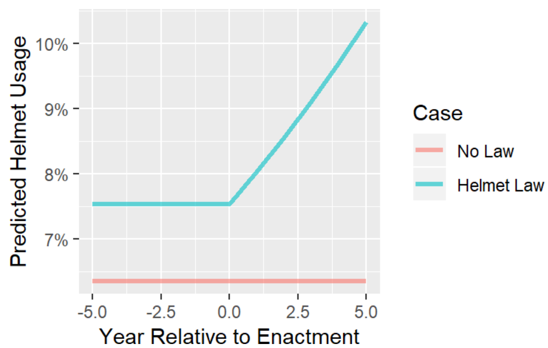

Figure 4. Predicted effects of MHU laws on helmet use

Figure 5 visualizes the effects of MHU laws on fatal and incapacitating injuries, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 17 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) States with MHU laws did not experience a statistically significant difference in such injuries (difference = -2.2 percent, $p >$ 0.10), but States with MHU laws experienced a 1.6-percent decrease for each year that the law was in effect ($p < 0.10$).

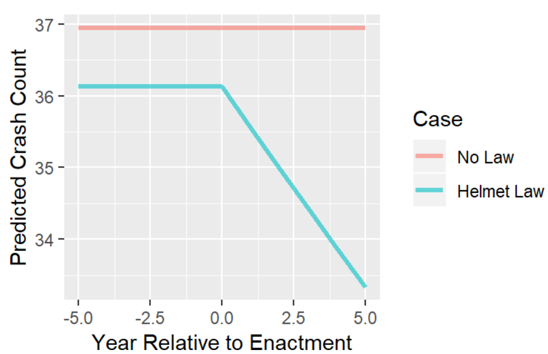

Figure 5. Predicted effects of MHU laws on fatal and incapacitating injuries

Bicycling Under the Influence

Bicyclists and motorists are treated very differently in the case of riding/driving under the influence of alcohol. Just half of all States prohibit BUI whereas all States prohibit driving under the influence (DUI).

BUI laws are aimed at reducing the number of intoxicated bicyclists on the road. In theory, an intoxicated bicyclist is more likely to be involved in a crash than a non-intoxicated one (due to slower reaction times, reduced motor control, etc.). Therefore, the number of crashes involving an intoxicated bicyclist was used as the relevant subset in the analysis of BUI laws.

The annual count of crashes involving intoxicated bicyclists was modeled as a function of three groups of variables: State-specific effects, exposure effects, and law effects. As with analyses of other laws, these models included State-specific intercepts and time trends, several exposure variables, and two law variables (a 0/1 indicator of whether or not the law was in force in a given year, and how many years had passed since the effective year).

Figure 6 visualizes the effects of BUI laws on crashes involving intoxicated bicyclists, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 18 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) States with BUI laws experienced 37.9 percent fewer relevant crashes than States without ($p < 0.01$), and each year a BUI law was in effect in a given State was associated with an additional 7.9-percent decrease ($p < 0.01$).

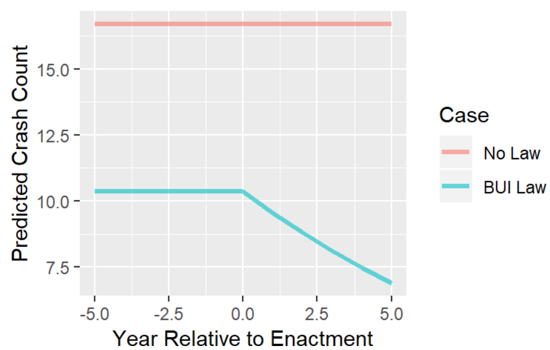

Figure 6. Predicted effects of BUI laws on relevant crashes

Sidewalk Riding

Sidewalks offer bicyclists an alternative to riding in the roadway with motor vehicles, but the safety of sidewalk riding is the subject of much debate. Riding exclusively on sidewalks could reduce conflicts between bicyclists and motorists (except at intersections, where being out of motorists' field of view could put bicyclists at greater risk), which could result in a decrease in fatalities and incapacitating injuries. On the other hand, sidewalks are generally built for the speed and mechanics of pedestrians; introducing bicyclists could thus put pedestrians at risk. This debate has produced two types of SR laws: those that explicitly permit bicycles on the sidewalk, and those that explicitly prohibit them.

SR laws may affect bicyclist safety in several ways. Those that prohibit SR may lead to more crashes on roadways. Conversely, laws that permit SR may lead to more crashes on sidewalks, and these crashes may be of a different severity than those in the roadway. Three metrics were investigated: the number of crashes in roadways, the number of crashes on sidewalks, and fatalities and incapacitating injuries (regardless of location). An analysis of bicycle-pedestrian crashes was attempted, but too few crashes were recorded. Mixed-effects Poisson regression models were used to estimate the change in these metrics relative to SR laws. As with analyses of other laws, these models included State-specific intercepts and time trends, several exposure variables, and two law variables, a 0/1 indicator of whether or not the law was in force in a given year, and how many years had passed since the effective year. The model of crash severity also included an interaction term between law type and the time since enactment.

Only six States recorded "sidewalk" as a distinct crash location: Delaware, Kansas, Maryland, Minnesota, Nebraska, and South Carolina. Of these, only Maryland has a law prohibiting sidewalk riding. Because the statistical models used State-specific terms, Maryland was excluded from the roadway- and sidewalk-specific models to avoid over-identification. Thus, States with permissive SR laws were compared to those with no SR law. To increase the sample size while maintaining relevancy of crashes, the effects of both types of laws on fatal and incapacitating injuries (regardless of relationship to intersections) were also analyzed.

Figure 7 visualizes the effects of permissive SR laws on crashes in the roadway, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 19 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) Though statistically insignificant, States with permissive SR laws experienced 99.6 percent more roadway crashes than States without ($p > 0.10$). In States with such laws, roadway crashes decreased by 3.7 percent for each year that the law was in effect ($p < 0.10$).

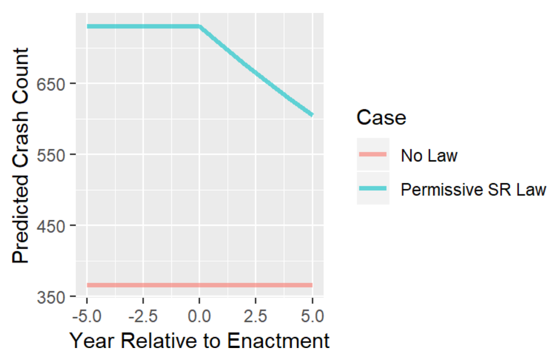

Figure 7. Predicted effects of permissive SR laws on crashes in the roadway

Figure 8 visualizes the effects of permissive SR laws on crashes on the sidewalk, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 20 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) Though statistically insignificant, States with permissive SR laws experienced 124.6 percent more sidewalk crashes than States without ($p > 0.10$), and States with such laws experienced a statistically insignificant 0.1-percent decrease for each year that the law was in effect ($p > 0.10$).

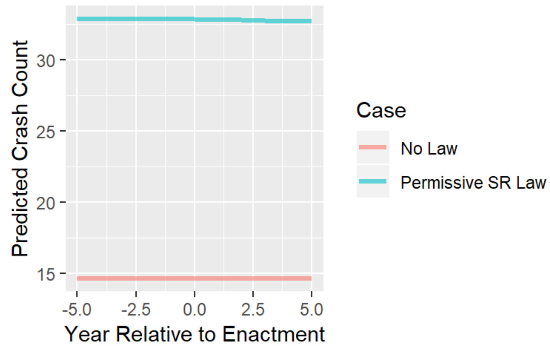

Figure 8. Predicted effects of permissive SR laws on crashes on the sidewalk

Figure 9 visualizes the effects of permissive and prohibitive SR laws on fatal and incapacitating injuries regardless of location, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 21 in Appendix B: Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) Compared to States with no SR law, those that permit sidewalk riding experienced 14.8 percent fewer serious injuries ($p < 0.01$) while those that prohibit it experienced 29.5 percent fewer serious injuries ($p < 0.01$). States with permissive SR laws experienced an additional 2.3percent decrease each year following enactment ($p < 0.10$), and those with prohibitive SR laws experienced annual decreases of 3.5 percent ($p < 0.10$).

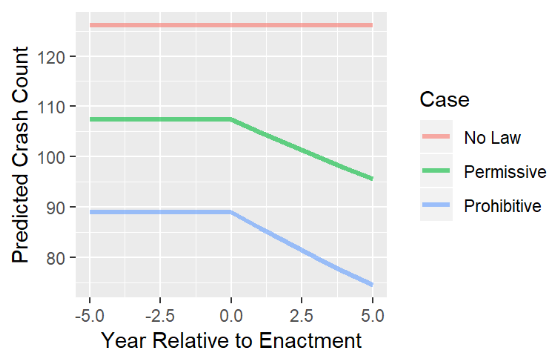

Figure 9. Predicted effects of permissive SR laws on fatal and incapacitating injuries

Intersections are particularly problematic for sidewalk bicycling. Bicyclists on sidewalks are at greater risk for injury than those on roadway due to blind conflicts at intersections (Wachtel & Lewiston, 1994). As such, the effects of (permissive only) SR laws were also analyzed with respect to intersections. States with permissive SR laws experienced 93.9 percent fewer intersection-related roadway crashes than States without ($p < 0.01$), but 18.1 percent annual increases for each year that the law was in effect ($p < 0.01$). These States also experienced 655.7 percent more intersection-related sidewalk crashes ($p < 0.05$) and statistically insignificant 1.3 percent annual decreases. Non-intersection-related crashes were not statistically significantly affected by permissive SR laws, except for annual 4.2-percent decreases in non-intersection-related sidewalk crashes following enactment ($p < 0.05$).

Figure 10 visualizes the effects of permissive SR laws on intersection-related and non-intersection-related roadway and sidewalk crashes, ignoring the random effects of State and year with exposure metrics (averaged across all States) held constant. (See Figure 22 in Appendix B:

Statistical Model Results for a visual comparison of the observed and predicted counts of relevant crashes in all States.) States with permissive SR laws experienced 93.9 percent fewer intersection-related roadway crashes than States without ($p < 0.01$), but 18.1-percent annual increases for each year that the law was in effect ($p < 0.01$). These States also experienced 655.7 percent more intersection-related sidewalk crashes ($p < 0.05$) and statistically insignificant 1.3-percent annual decreases. Non-intersection-related crashes were not statistically significantly affected by permissive SR laws, except for annual 4.2-percent decreases in non-intersection-related sidewalk crashes following enactment ($p < 0.05$).

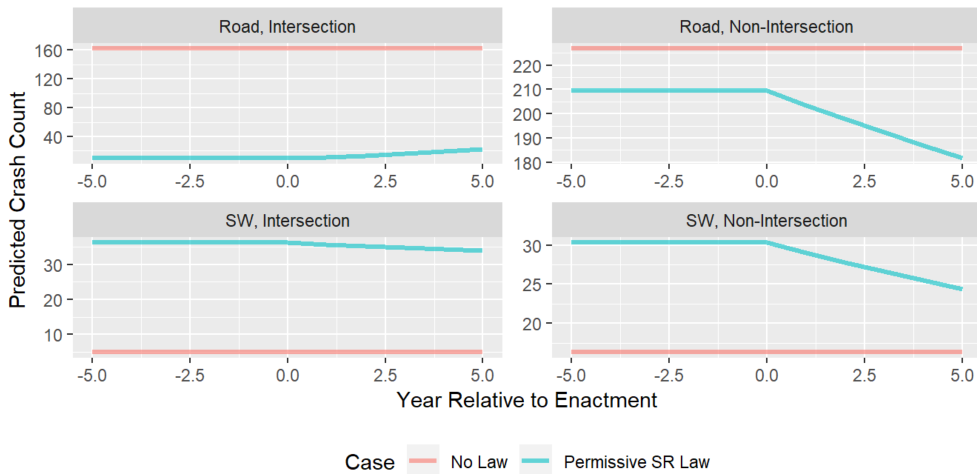

Figure 10. Predicted effects of permissive SR laws on intersection-related and non-intersection-related roadway and sidewalk crash counts

Idaho Stop

Starting from a dead stop requires substantially more physical effort from bicyclists than drivers in motor vehicles. At intersections, this can translate into longer wait times for motorists, and an annoyance to bicyclists. The Idaho Stop (IS) law was enacted in its titular State in 1982 to combat this. The IS law allows for bicyclists to treat stop signs as yield signs and traffic signals as stop signs, provided they visually scan the intersecting roadway and determine that it is safe to proceed. Not requiring bicyclists to come to a complete stop decreases the time required to proceed through an intersection and is believed by some to make intersections safer for bicyclists. However, if bicyclists fail to adequately scan the intersecting roadway, they could be putting themselves at a greater risk of collision with motorists, regardless of how little time is spent in the intersection.

The IS law affects a very specific subset of crashes: those that occur at intersections (whether stop-controlled or signal-controlled) and when the bicyclist's action is recorded as either a failure to obey traffic controls or a failure to yield the right of way.

Counts of IS-related crashes were modeled as mixed-effects Poisson regression models, but with the number of *intersections* as an exposure variable instead of the length of bikeable roads. This was done because such crashes can only occur at intersections, thus it was considered the more relevant covariate.

The ideal analysis of the IS law requires metrics on relevant crashes in Idaho and comparable States before and after 1982. Such data was not available. Crash counts were modelled but because Idaho is currently the only State with the IS law, the State-specific effects would be redundant with an indicator variable. Therefore, quantifying the impact of the presence of the law is impossible with the current data; the effect of the IS law over time was modelled and analyzed, but found statistically insignificant. See Figure 23 for estimated and actual crash counts relative to the IS law, and Table 4 for model coefficients.

Limitations

This analysis was limited by several factors, most notably: crash data availability and reliability.

Many States submitted data to NHTSA's SDS but varied in both breadth and depth of content. For example, only six States recorded "sidewalk" as a possible crash location. Many States did not reliably record "collision type," occasionally necessitating looser definitions for crashes relevant to each law. For example, many States recorded a variable indicating whether or not the crash was "intersection related" or occurred in an intersection, but Georgia (and several other States) did not. Instead, Georgia provided information on traffic control types. This variable was used to identify crashes that occurred in intersections (and thus were relevant to the Idaho Stop law). Other similar substitutions were made.

Some variables exhibited obvious abnormalities in some years. All variables used in this analysis were quality checked via tabulating, cross-tabulating, and graphing. Years with obvious errors or unexplained changes in definitions or protocols were excluded from the analysis.

The true number of bicyclists cannot be measured as reliably as other metrics, such as VMT. This analysis uses the number of commuters as a proxy measurement for the overall level of bicycling in a given time and place. In theory, the number of commuters is closely correlated with the number of people bicycling for other reasons. The American Community Survey provides this information and is considered a very reliable source of this data.

As with any statistical analysis, the relationships presented here are correlational and not necessarily causal. Enacting bills to promote bicyclist safety may be one part of a larger effort and thus may not be the true cause of the change, but rather a coinciding event or trend. For example, a State may pass a safe passing bill and simultaneously invest in dedicated bicycle lanes or substantial targeted enforcement as part of a broader safety program. Without reliable data on bicycle lane inventories or frequency of citations, one may attribute an observed change to the law rather than the bicycle lanes.

The nature of this analysis makes it susceptible to regression toward the mean – the tendency of a time series to exhibit a value close to the average after exhibiting an extreme value. Traffic safety bills are sometimes proposed and adopted in response to high-profile incidents or unusual spikes in crashes. After the law goes into effect, the crash rate may fall, but rather than falling in response to the law, the decrease would likely happen in the absence of the law, as the rate falls back to (or "regresses toward") the average value. Regression toward the mean, however, is more likely to be associated with engineering treatments at specific high-crash locations than for statewide legislative changes (Wright et al., 1988).

Discussion

Six bicycle safety traffic laws were analyzed for effects on law-specific bicyclist safety metrics. Noteworthy associations surfaced among SP and WTR laws and relevant crashes. Overall, States with these laws experience fewer related crashes than those without, but increases in these crashes in the years following their enactment. This may reflect an evolution of drivers' and bicyclists' reactions to the law. If a high-profile event triggers the legislation or it is accompanied by a far-reaching media campaign, drivers may react by giving bicyclists ample room when passing. Likewise, bicyclists may make an extra effort to abide by a newly enacted where-to-ride law. Over time, as attention to the issue wanes, both groups of road users may slip into old patterns, explaining the subsequent crash increases observed in the years following enactment.

The substantial increases in reported helmet usage and decreases in crashes involving intoxicated bicyclists may be related to social norms in either of two ways. MHU and BUI laws may arise due to changes in underlying social norms, or in order to formalize and enforce societal norms.

Either way, these laws are strongly associated with improvements in bicyclist safety.

Statistically significant associations between SR laws and various relevant crash types – as well as serious injuries – were observed. Specifically, permissive SR laws were associated with fewer intersection-related crashes in roadways, and more intersection-related crashes on sidewalks. The variable in Delaware's data dictionary (a State with a permissive SR law) that differentiates between roadway and sidewalk crashes is defined as "the location of the non-motorist prior to the impact" and may therefore describe bicyclists who cross through an intersection via the sidewalk, without being seen by drivers prior to collisions. If so, this supports previous findings found in the literature.

The timing of the Idaho Stop law and the unavailability of comparable data prevent a thorough analysis of the law on bicyclist safety. However, if the Idaho Stop law were associated with positive or negative effects on safety at the time of its enactment and exerted different effects over time, such changes would have manifested in a significant "Time since law in effect" coefficient. The fact that this coefficient was not statistically significant from zero implies that related crashes in Idaho neither increased nor decreased over time. Because this law is unique to Idaho and the statistical models were estimated with State-specific intercepts, it was not possible to quantify the difference in States' Idaho Stop-related crashes associated with the law. As more localities begin to adopt this legal framework, this relationship will become testable in 5 to 10 years.

Lack of public awareness may limit the ability of legislation to improve bicyclist safety. Laws can only affect road user actions if the public is aware of them, and if they are enforced. Ideally, surveys would be administered in the years following each law's passage to provide a measure of the public's awareness. As awareness increases, compliance would likely increase as well. Thus, to better quantify safety effects of these and other laws, States and advocacy groups should consider ways to measure public awareness in some way.

In addition to bicycle safety laws, bicycle infrastructure plays an important role in promoting bicycle safety. Studies have demonstrated that bicycle facilities enhance safety for bicyclists (Duthie et al., 2010; Reynolds et al., 2009). Separated bike lanes, for example, were found to have a positive safety effect, consistently reducing injury rates and collision rates by approximately 50 percent compared to unchanged roadways (Reynolds et al., 2009). Therefore, it is important that bicycle safety efforts at the State and local levels incorporate both legislative and infrastructure issues.

Conclusions

The goal of this study was to provide empirical evidence to address the questions "Should States and communities create separate laws that govern bicyclists on the roadways?" and "Do traffic safety laws specific for the safety of bicyclists protect them from motor vehicle related crash injuries and fatalities?" Some laws were associated with statistically significant changes in bicyclist safety and thus deserve consideration from State and local legislatures.

SP and WTR laws were associated with fewer related crashes, but these effects eroded over time. Why this happens is unclear; it may imply that subsequent action – possibly including investments in bicycle infrastructure or cultivation of pro-bicycling attitudes among motorists – is needed to complement these laws to reduce these crashes in the long term. Such data was beyond the scope of this analysis. In the absence of such data, the present findings suggest that these laws – which treat bicyclists as a separate class of road user who should not ride in the center of the lane and require a specified lateral clearance distance when being passed – are insufficient to protect bicyclists in the long term. Alternatively, the general driving public may be unaware of such laws. Before concluding that these laws are harmful, more research should be conducted to investigate this awareness factor.

MHU and SR laws also treat bicyclists as a separate class of road user and were associated with statistically significant changes in bicyclist safety. Specifically, MHU laws were associated with increased helmet usage and decreased fatalities and incapacitating injuries among bicyclists less than 16 years old; both prohibitive and permissive SR laws were associated with decreases in the number of fatalities and incapacitating injuries overall, though permissive SR laws are associated with increases in intersection-related sidewalk crashes. In the latter case, treating bicyclists as a separate class of road user may put bicyclists at greater risk.

BUI laws treat bicyclists the same as motorists and were associated with dramatic decreases in the number of crashes involving intoxicated bicyclists, thus promoting safety. In this respect, treating bicyclists as a separate class of road user – not explicitly forbidding them from bicycling while under the influence – puts them at greater risk. States and municipalities that expand their *driving under the influence* laws to include bicyclists may observe fewer crashes involving intoxicated bicyclists.

The IS law treats bicyclists as a separate class of road users who are not always obligated to come to a complete stop at intersections. Unfortunately, the available data did not permit a thorough analysis of the effects of this distinct law on bicyclist safety.

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Appendix A: Visualization of Exposure Metrics

The figures on the following pages graphically display the exposure metrics used in the statistical models described in the Methods and Results sections.

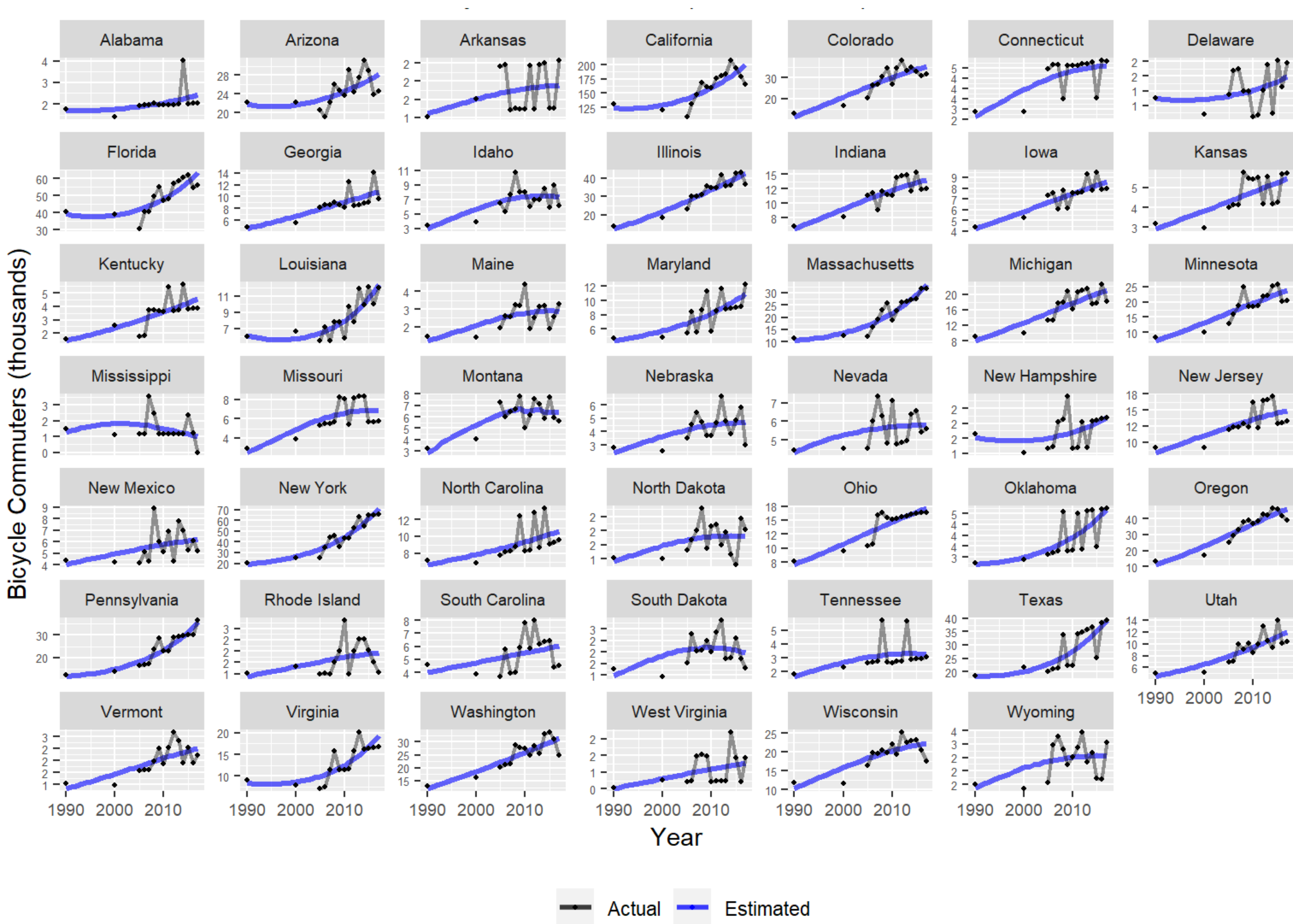


Figure 11. Actual and estimated annual bicycle commuters by State

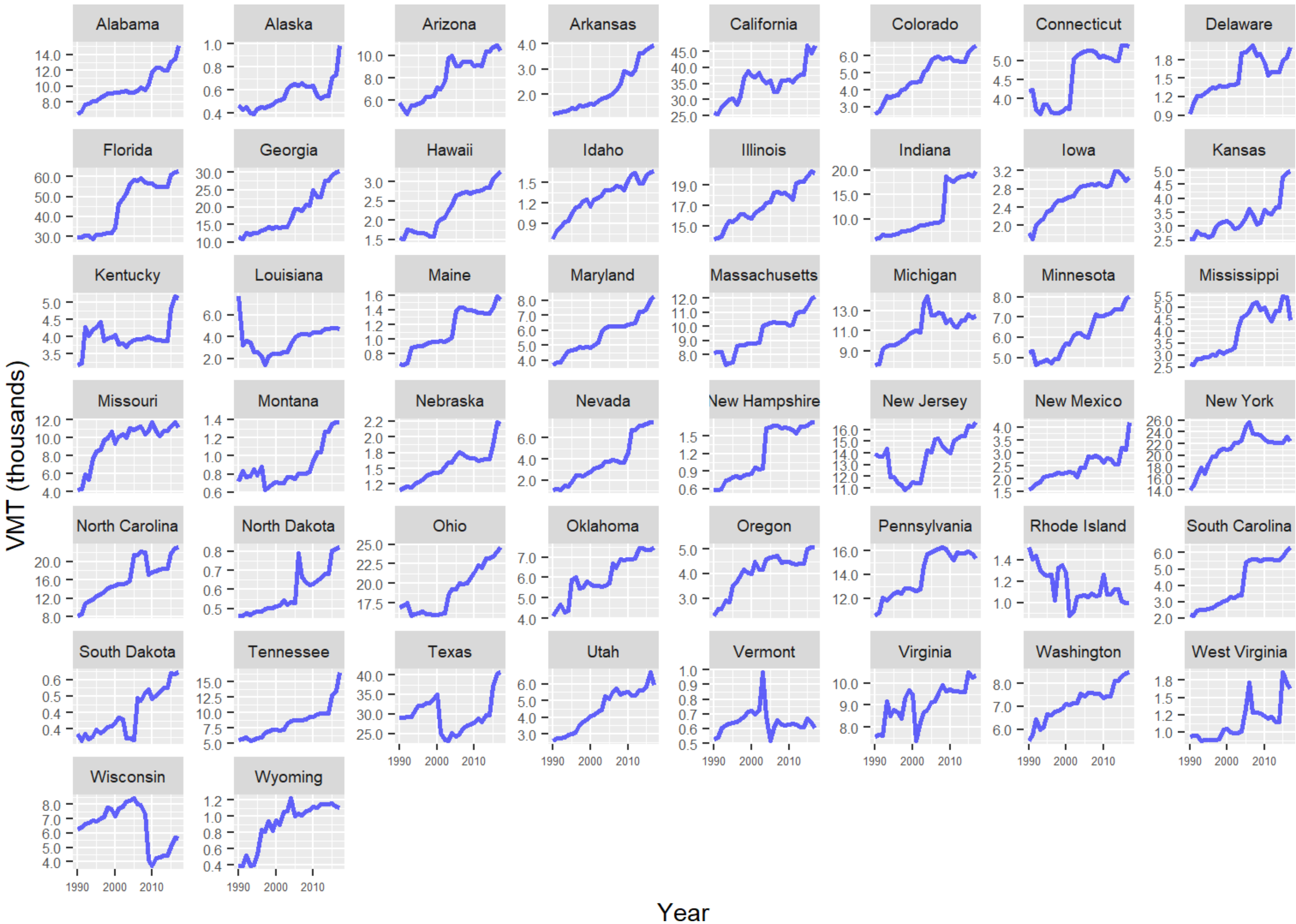


Figure 12. Annual VMT on urban bikeable roads by State

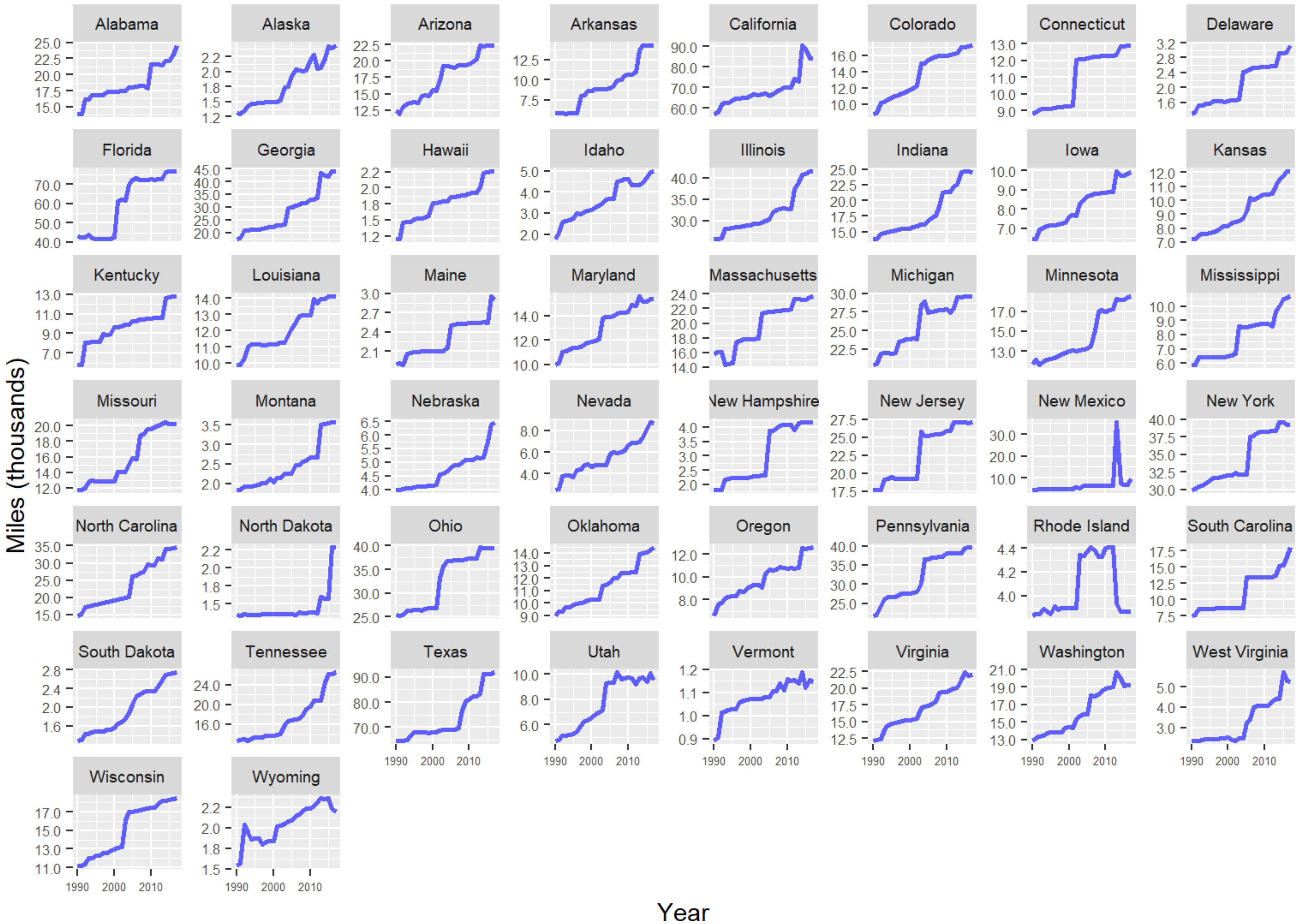


Figure 13. Annual length (miles) of urban bikeable roads by State

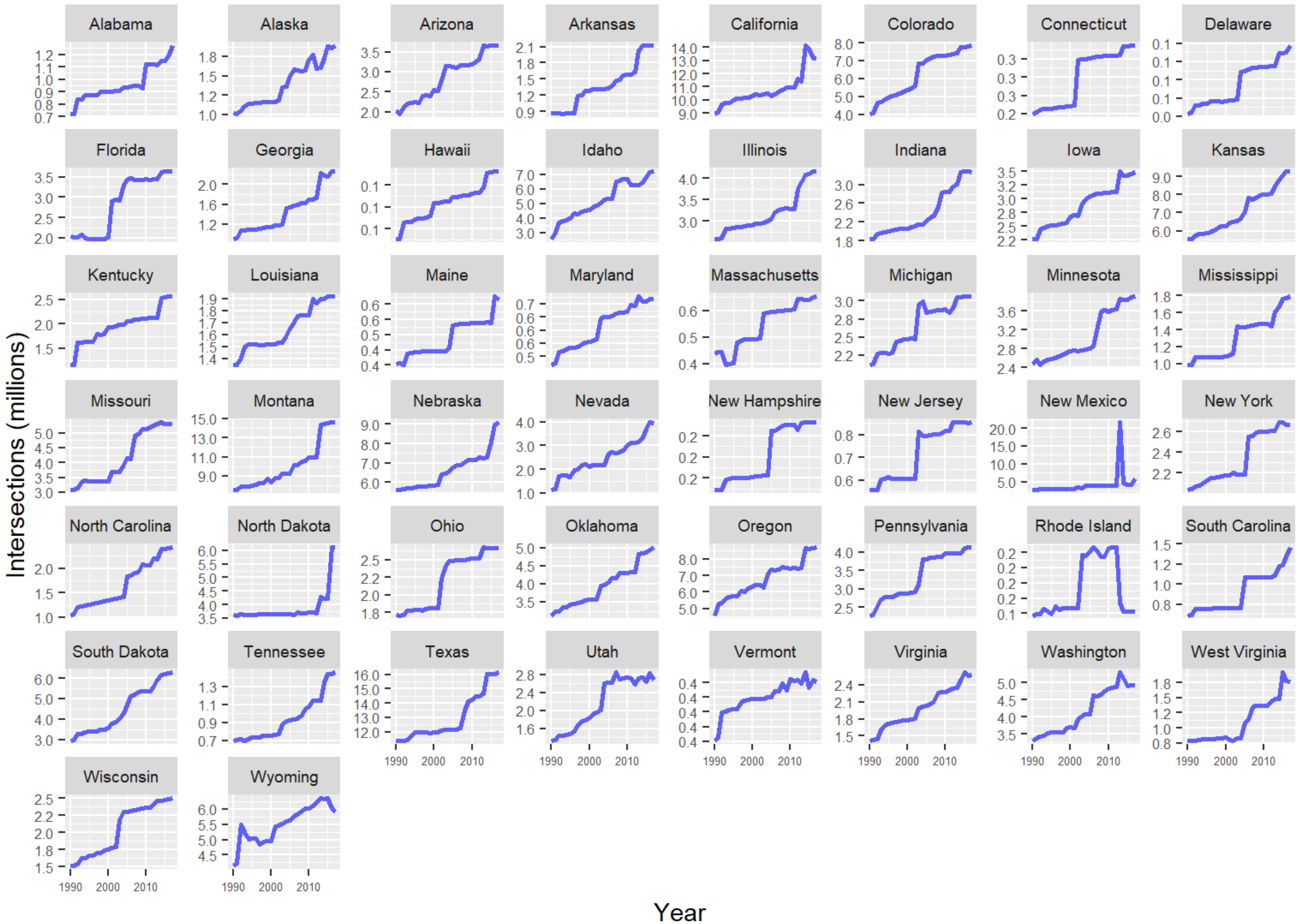


Figure 14. Estimated annual number of intersections on urban bikeable roads by State

Appendix B: Statistical Model Results

The following tables and figures present estimated model coefficients and visualizations of model predictions versus observed values.

The performance of generalized linear mixed models cannot be described by the conventional r-squared statistic due to more complicated correlation structures. Nakagawa and Schielzeth (2013) outline a method to calculate a similar statistic for these models: Nakagawa and Schielzeth's marginal r-squared, which conveys the variance explained by the fixed factors. The following tables provide this statistic for each model, when enough observations were available to calculate it. When the Nakagawa marginal r-squared could not be calculated, model fit was assessed by visually comparing observed and predicted values.

Table 4 provides details on the count-based statistical models. The first model listed, *SP and WTR,* refers to the analysis of crashes relevant to safe passing and where-to-ride laws. *MHU (K and A)* refers to the analysis of fatal and incapacitating injuries ("K" and "A" in the traditional KABCO Injury Classification Scale) in relation to mandatory helmet use laws. *BUI* refers to the analysis of crashes involving an intoxicated bicyclist in relation to bicycling-under-the-influence laws, and *IS* refers to the analysis of Idaho-stop-related crashes. With counts as the dependent variables, these models estimate coefficients in the log scale. The coefficients in this table have been back-transformed to report percent changes in the dependent variable. For example, the first coefficient listed for the *SP and WTR* model can be interpreted as: a 1.76-percent increase in SP- and WTR-related crashes is associated with each additional 1,000 bicycle commuters; States with only the SP law in effect experienced 22.83 percent more crashes than States without.

Confidence limits have been similarly back-transformed (Bland & Altman, 1996).

Table 5 provides details on the models concerning SR laws. *SR (Road)* and *SR (Sidewalk)* refers to the analysis of roadway and sidewalk crashes, respectively, regardless of relation to intersections. The four following models describe intersection-related (denoted as *Int*) and non-intersection-related (*Non-Int*) roadway and sidewalk crashes. The last model, *SR (K and A)* refers to the analysis of fatal and incapacitating injuries ("K" and "A" in the traditional KABCO Injury Classification Scale) in relation to SR laws. The coefficients and confidence intervals in this table can be interpreted similar to those in Table 4.

Table 6 provides details on the model of helmet use in relation to mandatory helmet use laws, *MHU (Use)*. The dependent variable for this model is a percentage; the coefficients have been back-transformed from the logit scale to describe the percent change in helmet use rates (0 to 100%) associated with changes in the independent variables. For example, an additional 1,000 bicycle commuters are associated with a 1.0-percent increase in a State's helmet use rate among bicyclists 16 and younger.

Table 4. Count-Model Coefficients, 95 Percent Confidence Intervals, and Significance Levels

	SP and WTR	**MHU (K and A)**	**BUI**	**IS**
Bicycle commuters (1,000s)	1.76^{***} (1.75, 1.76)	0.11 (0.10, 0.11)	-0.81^{*} (-0.82, -0.80)	2.01^{***} (2.00, 2.01)
Miles of bikeable roadway (1,000s)	-1.16^{***} (-1.16, -1.15)	-0.36 (-0.36, -0.35)	1.47^{***} (1.46, 1.48)	
State-wide intersection count (1,000,000s)				-2.48^{*} (-2.50, -2.45)
VMT (10,000s)	18.57^{***} (18.49, 18.64)	-9.43^{**} (-9.51, -9.35)	-14.03^{**} (-14.16, -13.91)	-4.68^{***} (-4.71, -4.65)
SP and WTR laws both in effect	-11.90^{*} (-12.03, -11.76)			
Only SP law in effect	-22.83^{***} (-22.97, -22.68)			
Only WTR law in effect	-12.73^{***} (-12.80, -12.65)			
MHU law in effect		-2.21 (-2.32, -2.09)		
BUI law in effect			-37.90^{***} (-38.11, -37.68)	
Years law has been in effect	-1.54^{***} (-1.55, -1.53)	-1.60^{*} (-1.62, -1.58)	-7.87^{***} (-7.91, -7.82)	1.05 (0.94, 1.16)
Years since SP and WTR laws have both been in effect	6.97^{***} (6.94, 7.00)			
Years since SP law has been in effect	12.84^{***} (12.81, 12.87)			
Years since WTR law has been in effect	1.98^{***} (1.97, 1.98)			
Constant	$2,103.25^{***}$ (2,102.73, 2,103.77)	$4,275.80^{***}$ (4,275.29, 4,276.31)	$1,610.06^{***}$ (1,609.49, 1,610.64)	$6,270.33^{***}$ (6,269.84, 6,270.82)
Observations	470	452	482	497
Nakagawa's marginal r-squared	0.14	0.02	0.09	0.16

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5. SR Model Coefficients, 95 Percent Confidence Intervals, and Significance Levels

	SR (Road)	SR (Sidewalk)	SR (Road, Int)	SR (Road, Non-Int)	SR (Sidewalk, Int)	SR (Sidewalk, Non-Int)	SR (K and A)
Bicycle commuters (1,000s)	8.44 (8.30, 8.57)	-5.50 (-5.59, -5.41)	0.87 (0.83, 0.91)	14.43*** (14.40, 14.47)	-4.69 (-4.82, -4.56)	6.41** (6.36, 6.46)	1.09*** (1.09, 1.10)
Miles of bikeable roadway (1,000s)	3.10 (3.05, 3.15)	4.90 (4.75, 5.06)					0.47** (0.47, 0.48)
State-wide intersection count (1,000,000s)			-7.88*** (-7.93, -7.82)	-15.69*** (-15.74, -15.65)	16.65** (16.51, 16.78)	-9.84*** (-9.91, -9.78)	
VMT (10,000s)	-50.93 (-52.06, -49.80)	38.76 (35.59, 41.94)	144.12*** (143.57, 144.67)	-3.46 (-3.96, -2.96)	1,481.30** (1,478.77, 1,483.83)	142.13 (140.71, 143.54)	-3.82* (-3.86, -3.77)
Permissive SR law in effect	99.63 (98.58, 100.67)	124.60 (123.54, 125.66)	-93.94*** (-96.07, -91.82)	-7.69 (-8.82, -6.56)	655.65** (653.64, 657.66)	86.44 (85.45, 87.44)	-14.81*** (-14.92, -14.70)
Years since SR law has been in effect	-3.69* (-3.73, -3.64)	-0.11 (-0.13, -0.08)	18.12*** (18.01, 18.23)	-2.80 (-2.86, -2.74)	-1.33 (-1.42, -1.23)	-4.24** (-4.28, -4.20)	
Prohibitive SR law in effect							-29.46*** (-29.64, -29.28)
Years since permissive SR law has been in effect							-2.32** (-2.34, -2.30)
Years since prohibitive SR law has been in effect							-3.47** (-3.50, -3.44)
Constant	19,437.08*** (19,436.24, 19,437.91)	1,144.03*** (1,143.26, 1,144.81)	15,400.86*** (15,400.67, 15,401.05)	17,669.34*** (17,669.16, 17,669.52)	20.66 (19.86, 21.47)	1,047.78*** (1,047.36, 1,048.21)	9,580.52*** (9,580.07, 9,580.97)
Observations	56	56	56	56	56	56	479
Nakagawa's marginal r-squared	0.57	Not available	Not available	Not available	Not available	Not available	0.27

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6. MHU Model Coefficients, 95 Percent Confidence Intervals, and Significance Levels

	MHU (Use)
Bicycle commuters (1,000s)	0.01** (0.001, 0.03)
Miles of bikeable roadway (1,000s)	0.001 (-0.01, 0.01)
VMT (10,000s)	-0.08 (-0.22, 0.07)
MHU law in effect	0.20** (0.02, 0.38)
Years since permissive MHU law has been in effect	0.07** (0.02, 0.12)
Constant	-0.96*** (-1.33, -0.58)
Observations	124,348
Nakagawa's marginal r-squared	0.12

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

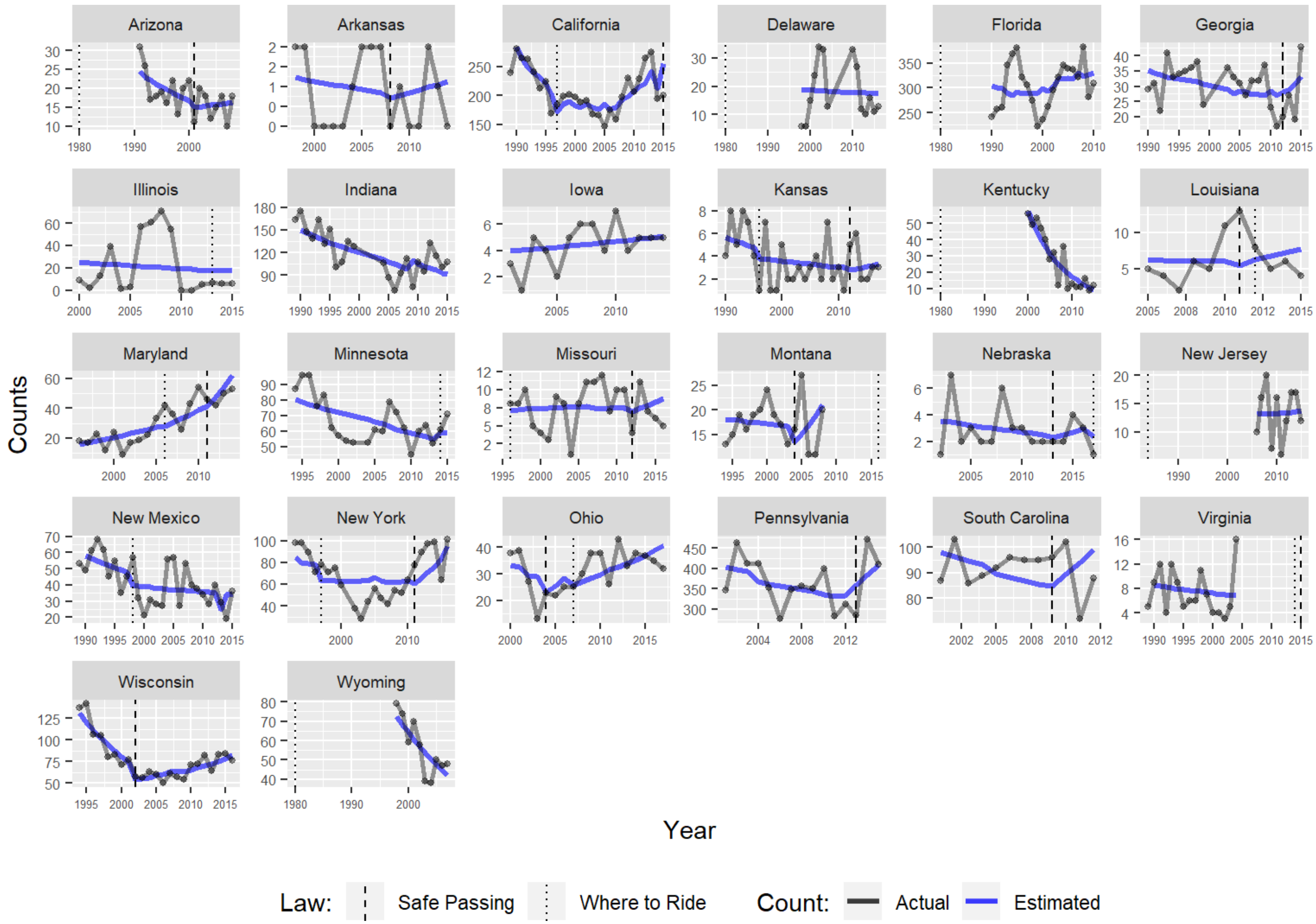


Figure 15. SP and WTR laws: Actual and estimated relevant crash counts

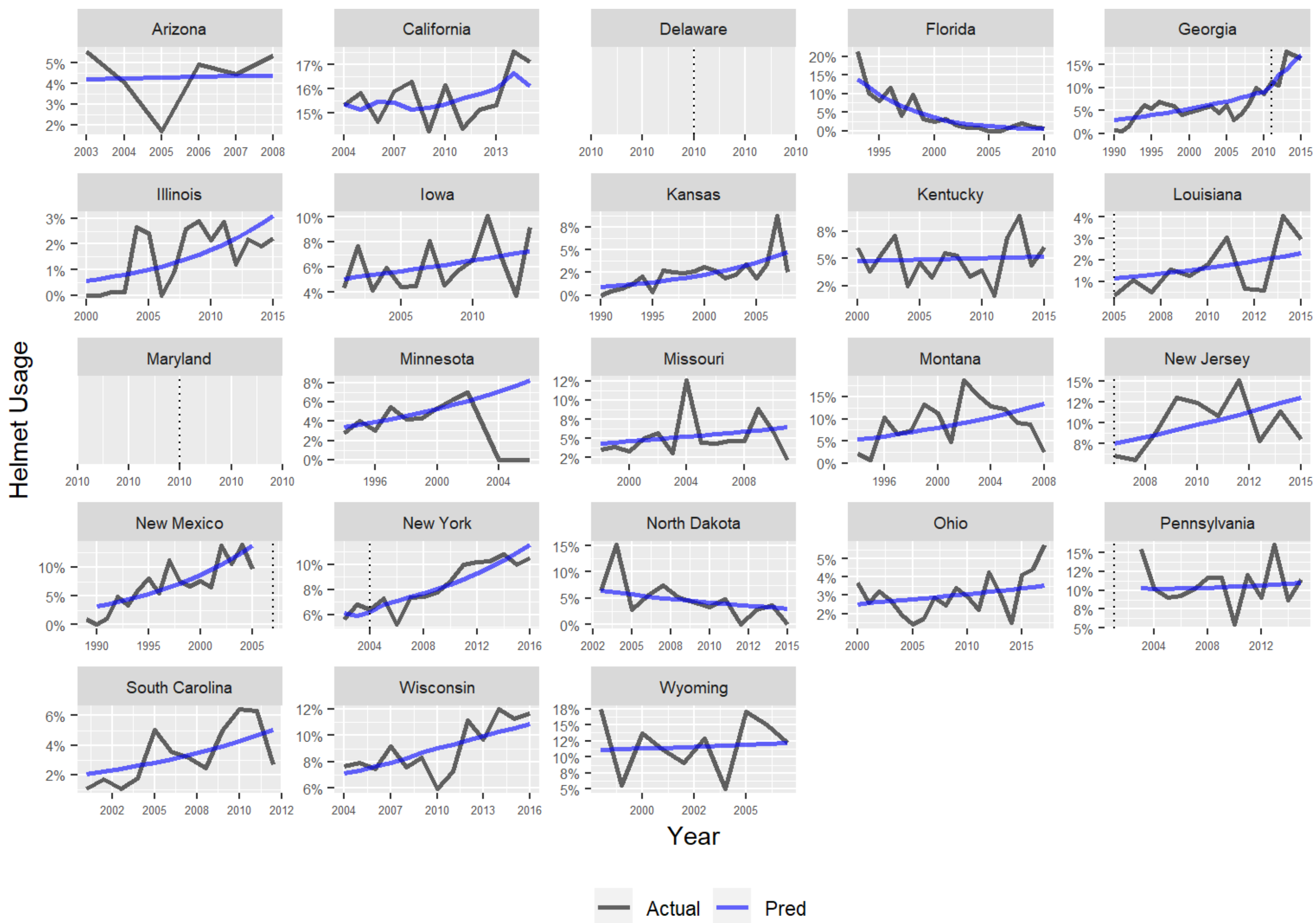


Figure 16. MHU laws: Actual and estimated helmet usage

Note: The vertical line corresponds to the year in which the law was enacted.

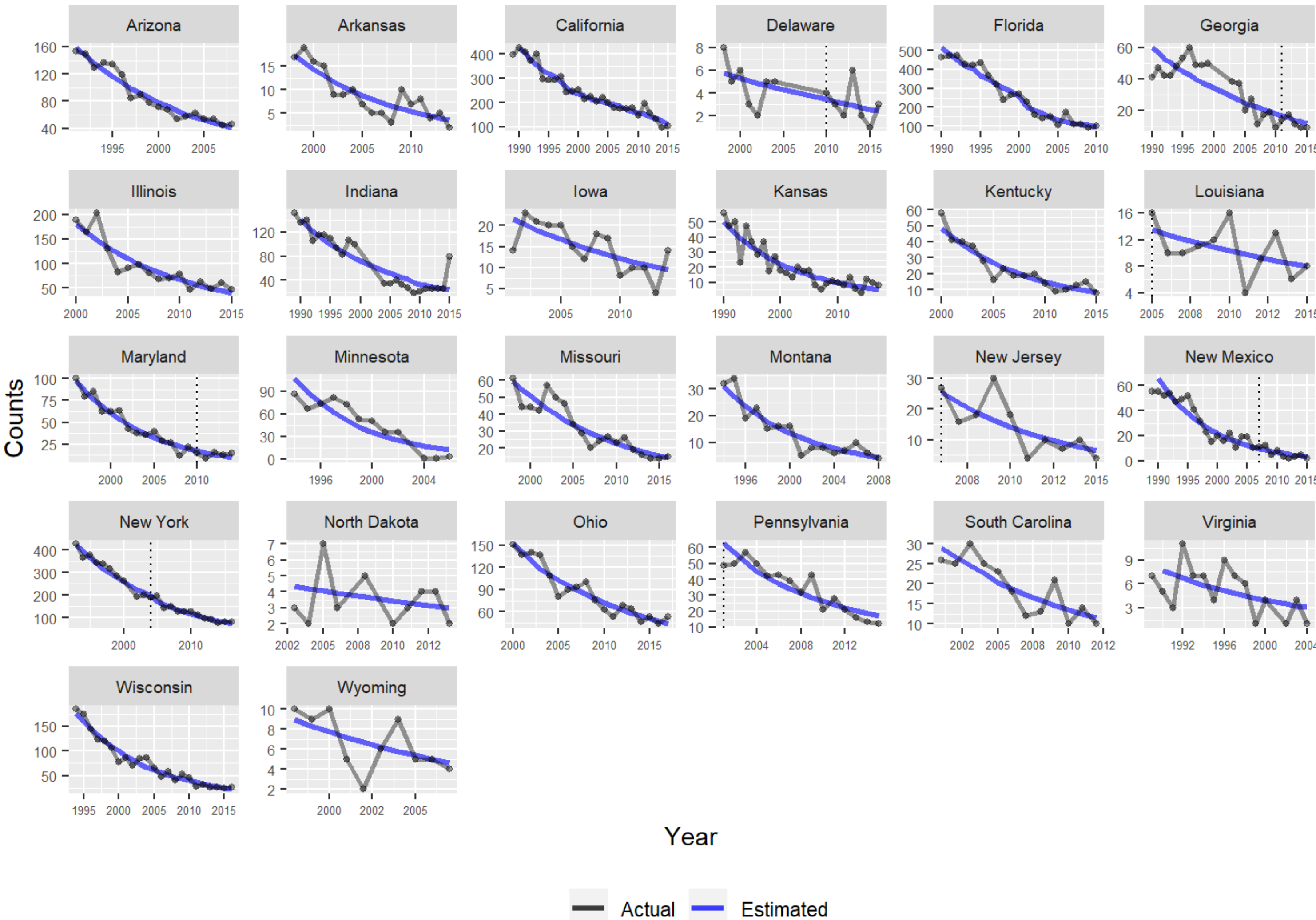


Figure 17. MHU laws: Actual and estimated relevant crash counts

Note: The vertical line corresponds to the year in which the law was enacted.

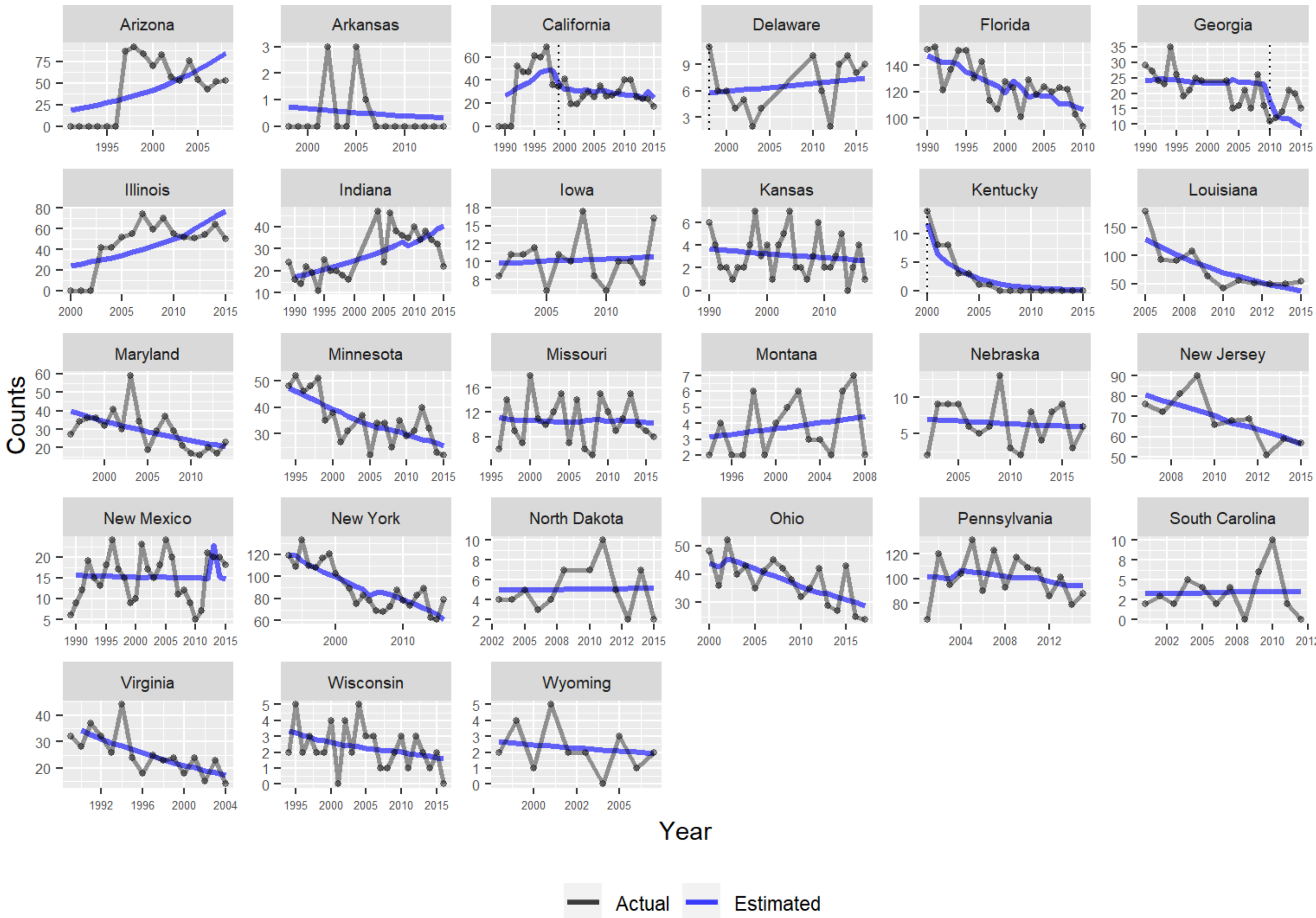


Figure 18. BUI laws: Actual and estimated relevant crash counts

Note: The vertical line corresponds to the year in which the law was enacted.

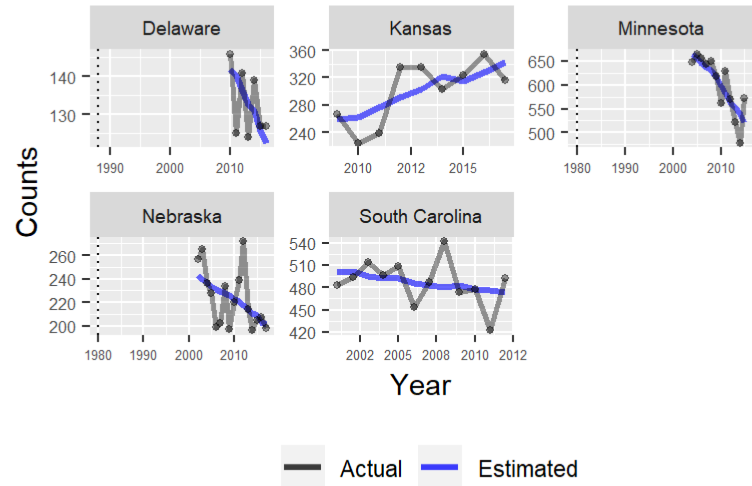


Figure 19. Permissive SR laws: Actual and estimated crashes in the roadway

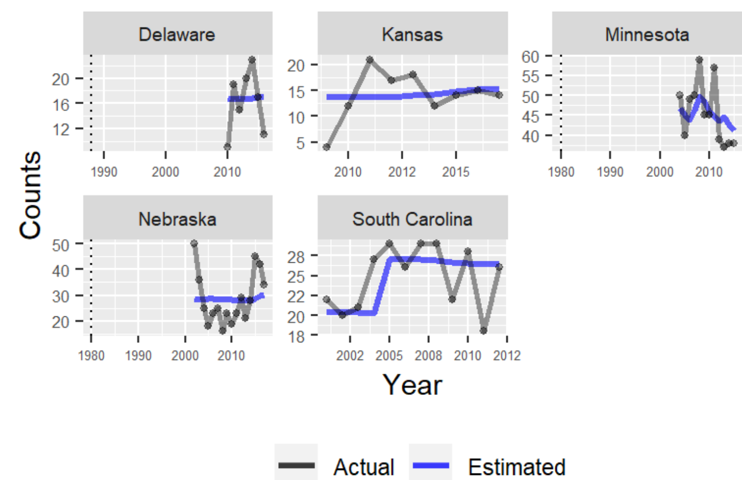


Figure 20. Permissive SR laws: Actual and estimated crashes on the sidewalk

Note: The vertical line corresponds to the year in which the law was enacted.

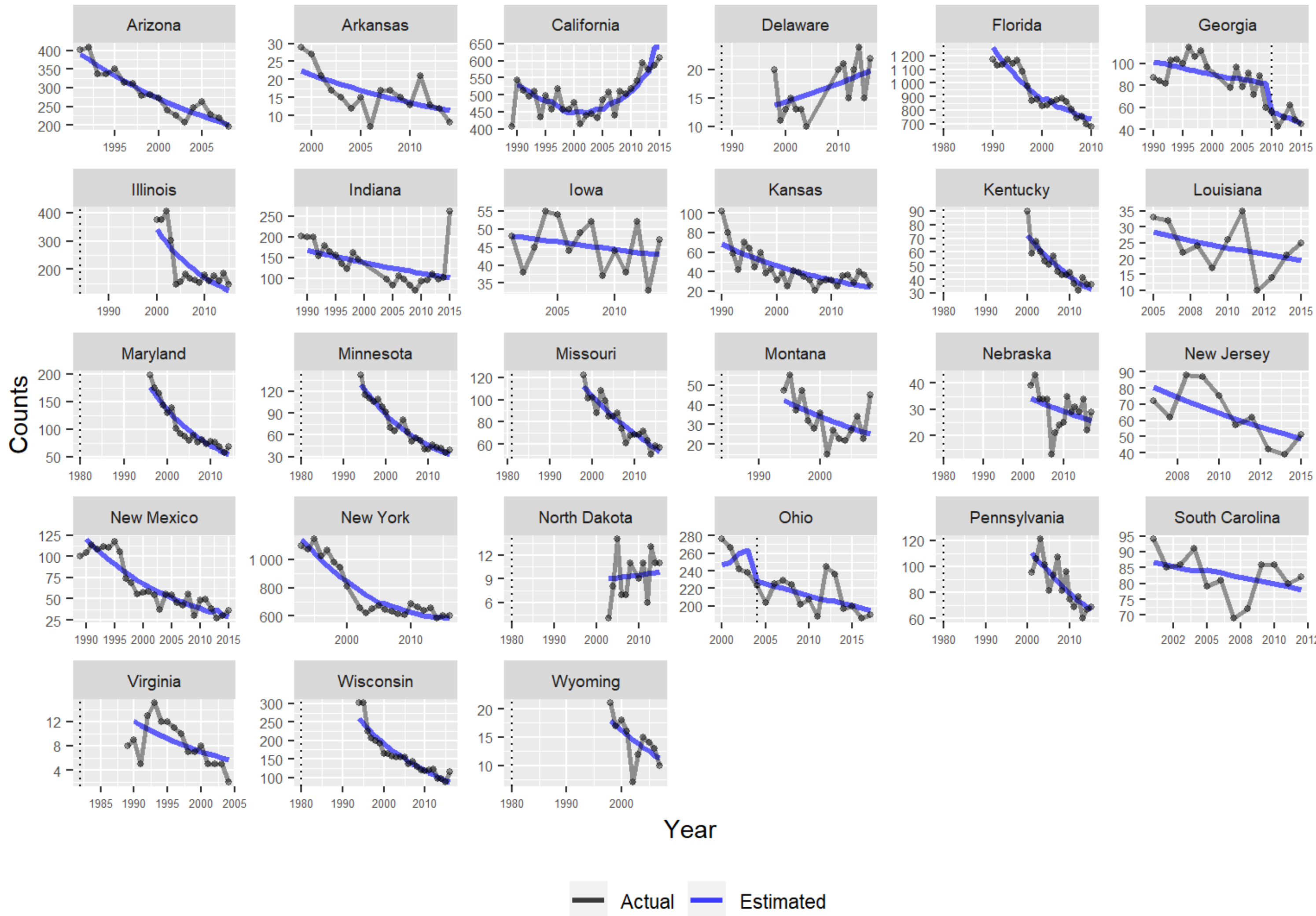
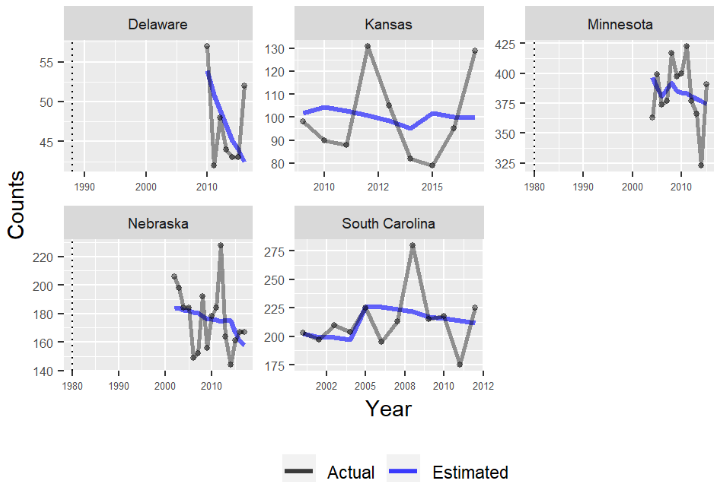
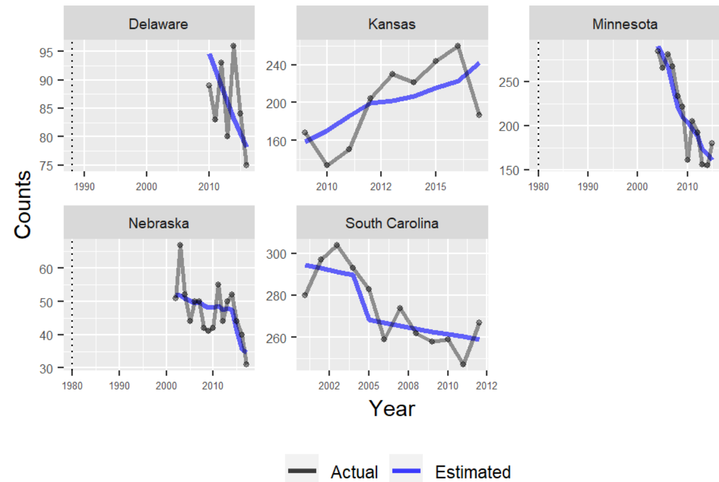


Figure 21. SR laws: Actual and estimated fatal and incapacitating injuries

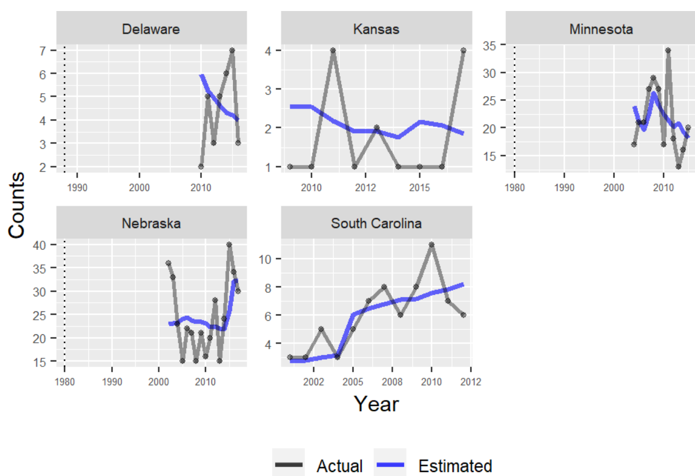
Note: The vertical line corresponds to the year in which the law was enacted.



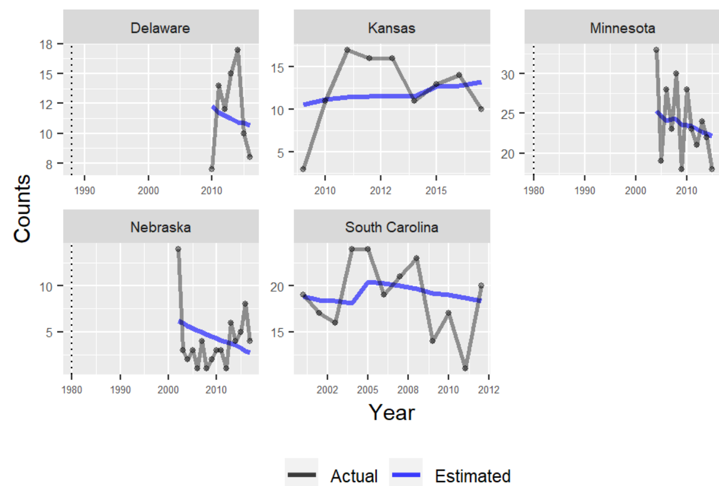
Intersection-Related Roadway Crashes



Non-Intersection-Related Roadway Crashes



Intersection-Related Sidewalk Crashes



Non-Intersection-Related Sidewalk Crashes

Figure 22. Permissive SR laws: Actual and estimated intersection-related and non-intersection-related roadway and intersection crashes

Note: The vertical line corresponds to the year in which the law was enacted

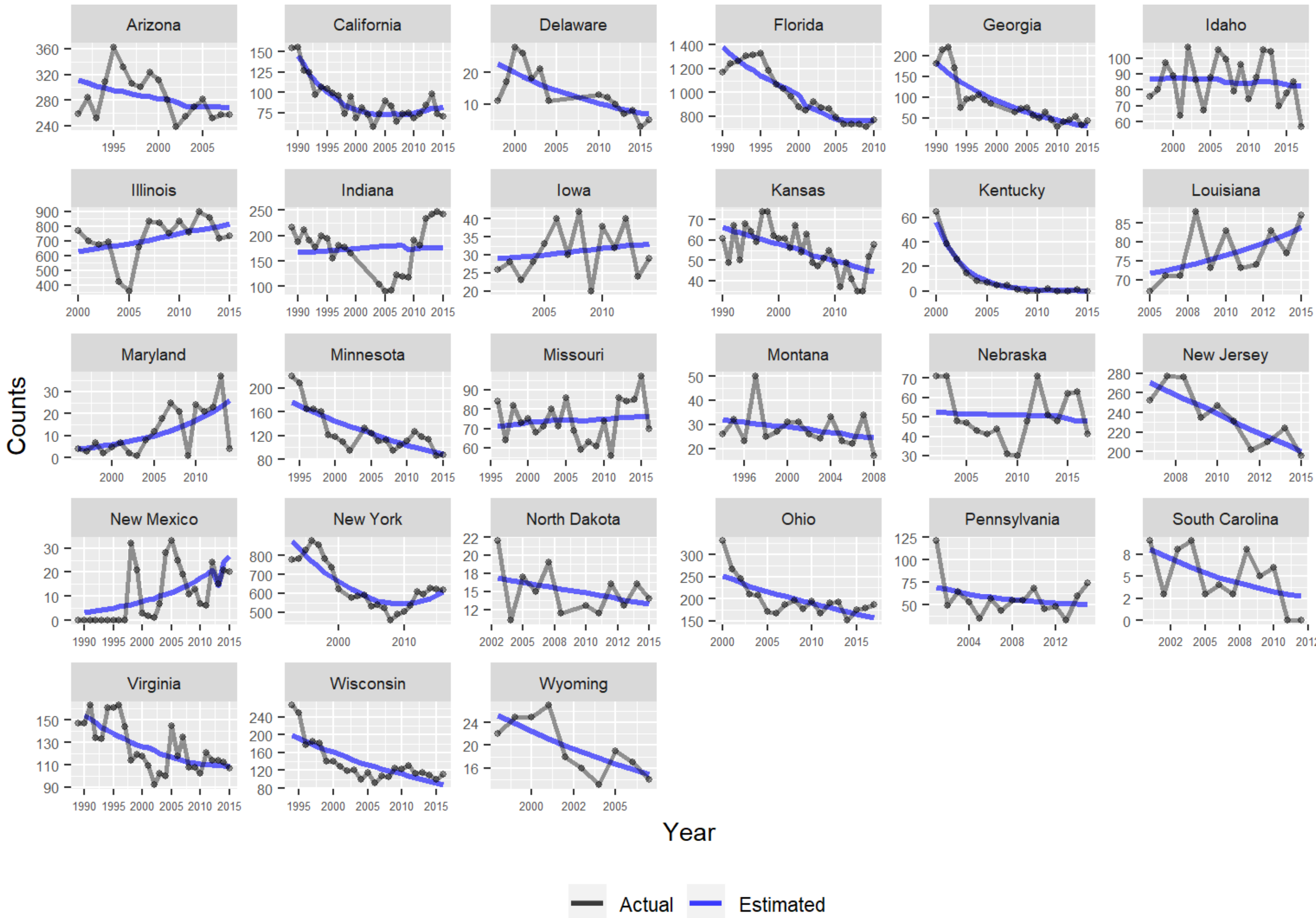


Figure 23. The IS law: Actual and estimated relevant crash counts

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