Increasing the Speed Limit in Georgia

Have Rural Highways Become More Dangerous?

by George W. Dougherty, Jr.

Carl Vinson Institute of Government
The University of Georgia

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Public Policy Research Series

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PUBLIC POLICY RESEARCH SERIES

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Richard W. Campbell, *Series Editor*

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Foreword

Driving is one of the most dangerous activities that Georgians engage in on a daily basis, claiming the lives of 1,569 Georgians in 1998. The Georgia General Assembly, in April 1996, passed legislation that raised the maximum speed limits on Georgia's interstate highways—highways with wide medians, large shoulders, and limited access—distinguishing between urban and rural highways by setting different limits for each. Most Georgians assume that increasing speed limits automatically leads to drivers traveling at higher rates of speed. Others feel that drivers become less comfortable as speeds increase and that increasing speed limits from 65 mph to 70 mph is simply a means of making most drivers' behavior legal. In truth, analyzing the impact of speed limit changes is complicated at best, and more so since the state has opted to increase speed limits on some types of highway, but not others.

The question of whether rural highway safety decreases with increases in speed limits is the subject of this policy paper, *Increasing the Speed Limit in Georgia: Have Rural Highways Become More Dangerous?* In-depth attention is given to factors that should lead to more crashes, such as increases in the speeds drivers choose, as well as changes in the number of crashes, injuries, and fatalities on Georgia's rural highways. The study addresses three primary questions: What effect do increased speed limits have on interstate highways with increased speed limits? What effect do increased speed limits have on rural highways without increased speed limits (i.e., primary and minor arterials)? What effect do increased speed limits have on rural highway safety throughout the state?

The author of the paper is George W. Dougherty, Jr., a research coordinator at the Vinson Institute. A number of individuals reviewed early drafts of the paper. They include Jerome S. Legge, Jr., of the Vinson Institute; George W. Dougherty, Sr., of the Oglethorpe County Board of Education; and William Chittick, Edward Kellough, Hal G. Rainey, and Laurence O'Toole of the University of Georgia's Department of Political Science. While the paper benefits from the comments of these reviewers, the findings of this report remain the responsibility of the author.

The Public Policy Research Series, published by the Carl Vinson Institute of Government, strives to present the results of objective and systematic research on complex policy problems and the issues confronting the state of Georgia and its local governments. Clearly, any activity that claims the lives of so many is an important policy issue that should be included in the series. While this paper focuses on information specific to rural highways in Georgia, its methodology and broad scope should make it useful for policy makers in all states.

Henry M. Huckaby
Director
Carl Vinson Institute of Government

May 2000

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Executive Summary

In November of 1995, President Clinton signed a bill repealing the National Maximum Speed Limit (NMSL). Georgia was one of many states that quickly increased speed limits within their borders. Montana responded by setting no numerical speed limit during daylight hours (Brooke 1996). While many Americans applauded the new legislation and subsequent state speed limit increases, public safety organizations expressed concern over the likelihood of increases in fatalities, injuries, and property damage on rural interstates (Brooke 1996).

It appears that public safety advocates have sufficient reason to be concerned. The National Center for Statistics and Analysis reports that 37,000 Americans were killed and 2 million injured on U.S. highways in 1998. The report also lists Georgia as having 1,415 fatal crashes resulting in 1,569 fatalities in 1998. On average, automobile accidents in the United States cause over $150.5 billion in property damages each year (U.S. Department of Transportation 1999). The National Center for Statistics and Analysis estimates that speed-related accidents in Georgia alone accounted for 332 fatalities and over $744 million in property damages during 1998. To put this in perspective, "the number of fatalities on America's roadways exceeds the nation's total combat fatalities in all wars; motor vehicle accidents represent the leading cause of death of Americans 15–34 years of age" (Mauldin 1990, 1).

The question of whether higher speed limits affect highway safety may be a foregone conclusion for most. The most common assumption is that increasing speed limits will necessarily lead to drivers going faster. The faster a car travels, the more likely it is to be involved in a crash. Higher speeds mean less reaction time to recognize and avoid hazards as well as greater force when crashes do occur (NHTSA 1995). It is assumed that greater probability of crashing combined with more force on impact should lead to greater numbers of crashes, injuries, and fatalities on highways.

The consequences of speed limit changes on highway safety statewide are not straightforward. The overall effects of speed limits become more difficult to identify when one considers how states have chosen to regulate speed. Like most other states, Georgia chooses to set different speed limits on different types of rural highways. Varying posted limits by road type allows researchers to determine the effects of new speed limits on highway safety statewide as well as on highways with raised speed limits. Since conditions are not equal on each type of highway, it is possible that higher speed limits may decrease highway safety on roads with the new limits, but increase overall highway safety within the state. This can occur if speed limit increases are limited to interstate highways, thereby attracting more drivers to highways with safety features like wide medians, large shoulders, and limited access. New legislation passed by the Georgia General Assembly in 1996 allows higher speed limits only on interstate highways with these safety features.

Interstate Highway

Limited access divided highway of at least four lanes with overpasses at major intersections.

There are numerous reasons for conducting a speed limit study of Georgia. The results of past empirical tests on speed limit changes have been inconclusive, and it is unclear how significant a speed limit increase from 65 mph to 70 mph is in terms of highway safety. It has now been five years since repeal of the NMSL and four since Georgia amended O.C.G.A. §40-6-181(b) enacting the new speed limits. That no recent studies have been conducted to measure the effects of these speed limit changes in Georgia, with its population of 7 million, justified new research efforts.

Eight policy questions are addressed in this study. Four of these concern the effect that speed limit increases have had on highway safety on Georgia's rural interstate highways—the roads on which speed limits have been increased. Specific to these interstates:

1. Do higher speed limits lead to increased driver speeds?
2. Do higher speed limits increase the number of crashes, injuries, and fatalities?
3. Do higher speed limits increase driver compliance?
4. Do higher speed limits decrease speed variance?

Empirical tests showed that while the speed limit boost from 65 mph to 70 mph did not result in a significant increase in crashes or injuries, the new law did coincide with higher average speeds and an increase of almost two interstate highway fatalities per month. The increased fatalities are best explained by tests of compliance and variance measures that found (1) a significant increase in the percentage of drivers traveling greater than 86 miles per hour and (2) greater variance in the speeds drivers choose. This explanation is consistent with and supports past studies showing rapidly increasing levels of fatalities as speeds and the change in speed at impact (DV) increase (Bowie and Waltz 1993, Joksch 1993, West and Dunn 1971).

The findings that average speed increased with a higher speed limit is consistent with previous studies. There is some evidence that the increase in average speed predicted by Fildes and Lee (1993) materialized on Georgia's interstate highways. While the findings presented here concerning mean speeds and speed limits are not conclusive, the results do warrant further investigation

Four additional policy questions are derived from the discussion of the effects of higher speed limits on all rural highways in our state highway system. All rural highways in this discussion encompass not just interstates but also Georgia's primary and minor arterial highways.

Primary Arterial
Major highway, often with multilane design, for high-volume traffic between major cities or towns.
Minor Arterial
Highway linking cities and larger towns in rural areas.

5. Do higher speed limits on interstates lead to increased speeds and less compliance on the primary and minor arterials?
6. Do higher speed limits on interstates affect the number of crashes, injuries, and fatalities on primary and minor arterials?
7. Do higher speed limits on interstates affect the overall number of crashes, injuries, and fatalities on the rural highways?
8. Do higher speed limits on interstates lead drivers to choose those routes?

Questions 5 and 6 were tested to determine if increasing speed limits on interstate highways affected highway safety on the two additional types of rural highways in Georgia. While neither minor nor primary arterials exhibited increases in average speed, the percentage of drivers on primary arterials traveling more than 10 mph over the speed limit or traveling 86 mph and faster has increased significantly. The primary arterial results complicate our understanding of the relationship between driver behavior and highway safety. The relationship that seemed to hold true on interstate highways, that increasing speed and change of velocity on impact lead to greater fatalities, was not evident on Georgia's primary arterials.

It was surprising, then, to find that while primary arterials have experienced no change in the number of crashes, injuries, or fatalities, minor arterials have seen statistically significant increases in all three variables. This study can offer no conclusive explanation for the decrease in highway safety on Georgia's minor arterials since none of the driver behavior variables changed in connection with increased speed limits on Georgia's interstate highways.

Other empirical tests concerned whether increasing speed limits on Georgia's interstate highways has decreased highway safety measures and changed driver behavior across all of the state's rural highways. Highway safety on Georgia's rural highways has not been diminished with the increase in speed limits on the state's rural interstate highways. No significant increases in the total number of crashes, injuries, or fatalities on Georgia's rural highways were found. There were significant increases in the percentage of drivers choosing interstate highways and a significant increase in the total number of automobiles on the state's rural highways, but these findings may be related to summer travel patterns rather than the increased speed limit.

Given that statewide measures of highway safety have not changed, it might be easy to conclude that any policy changes are unnecessary. However, the goal of public policy in highway safety is not to increase the freedom and convenience of automobile travel alone, but to reduce the risks associated with automobiles. This research has pinpointed some areas with the potential for substantial improvements in rural highway safety despite the increased speed limit. Any policy changes in Georgia should focus on reducing the incidence of drivers traveling at the highest rates of speed, especially on rural interstate highways. Reducing speed variance would be one beneficial change. The most obvious policy change is to increase the level of patrols on interstate highways. While Lave and Elias (1994) suggest that this approach has worked in other states, it ignores the significant increase in drivers traveling 86+ mph on primary arterials and the significant decreases in highway safety on minor arterials. Another policy option might be to require, as suggested by one Georgia legislator, that police officers reduce or do away with the “buffer zone” that allows drivers to exceed speed limits without fear of sanction (Emling 1996b). Strict adherence to speed limits may lead the fastest drivers to slow down, since speed choice is related to the probability of being sanctioned. Finally, policy makers in Georgia should explore highway design options that make it less comfortable to travel at the highest rates of speed.

Introduction

In November 1995, the 104th Congress of the United States passed, and President Clinton signed, a bill to repeal the National Maximum Speed Limit (NMSL). Many states, including Georgia, rushed to increase speed limits within their borders. Montana responded by setting no numerical speed limit during daylight hours (Brooke 1996). While many Americans applauded the new legislation and the subsequent increases in state speed limits, public safety organizations expressed concern over the possibility of increases in fatalities, injuries, and property damages that were likely on rural interstates (Brooke 1996).

A brief review of basic statistics shows that public safety advocates have sufficient reason to be concerned. The National Center for Statistics and Analysis reports that 37,000 Americans were killed and 2 million injured on U.S. highways in 1998. The same report lists Georgia as having 1,415 fatal crashes resulting in 1,569 fatalities in 1998. On average, automobile accidents in the United States cause over $150.5 billion in property damages each year (U.S. Department of Transportation 1999). The National Center for Statistics and Analysis estimates that speed-related accidents in Georgia alone accounted for 332 fatalities and over $744 million in property damages during 1998. To put this in perspective, it has been noted that "the number of fatalities on America's roadways exceeds the nation's total combat fatalities in all wars; motor vehicle accidents represent the leading cause of death of Americans 15–34 years of age" (Mauldin 1990, 1).

Automobiles remain the most common form of transportation in American society despite the high levels of suffering and damage attributed to their use. The number of registered vehicles in the United States more than doubled between 1950 and 1980, rising from 32.5 to 68.7 automobiles per 100 citizens. The average number of miles driven, a major factor in the risk of involvement in an accident, also increased during this time (Friedland et al. 1990). Estimates put the number of vehicles in operation in the United States at 130 million cars and 40 million trucks traveling a road system covering 3.9 million miles (Lewis 1986, Mauldin 1990). Georgia had 5 million registered drivers and 6.3 million registered vehicles in 1997 (U.S. Department of Transportation 1999).

The high levels of property destruction and human suffering associated with automobile-related accidents make highway safety an important issue on this country's policy research agenda. The speeds drivers choose is an essential element in that research. Bowie and Waltz (1994) identified speed as an important factor in approximately 30 percent of fatal crashes.

It has been five years since the repeal of the national speed limit law, and it is important to now assess the impact of these speed limit changes.

In 1998, excessive speed was an important factor in approximately 11,100 fatalities in the United States. A detailed and comprehensive review of over 2,000 crashes found excessive speed to be the second most common of more than 50 causal factors identified (Treat et al. 1977). In a recent report published by the Federal Highway Administration, researchers concluded that "vehicle speed remains an important public policy, engineering, and traffic safety issue" (Warren 1998, 1).

Despite such concerns about the relationship between vehicle speed and highway safety, states have been willing to pass laws setting higher speed limits for a number of reasons. Foremost is the popularity of these reform efforts, especially among residents of large western states where people believe that the 65 mph speed limit was too restrictive and affected their lives by making automobile trips unnecessarily long. State legislatures felt pressure from many important industries as well, including trucking companies, regional distributors, and corporations with large sales forces. While public safety was a consideration in most states, groups opposing higher speed limits were hard pressed to convince legislators that a 5–10 mph increase would make much of a difference, since most drivers were already choosing speeds above 65 mph.

It has been five years since the repeal of the national speed limit law, and it is important now to assess the impact of these speed limit changes. The results of previous empirical tests on speed limit changes are inconclusive, with some showing decreases in highway safety while others show benefits to increasing speed limits (Warren 1998). The inconclusive results suggest that the outcome of speed limit changes may depend on state or regional characteristics or the types of highways with higher limits. Furthermore, it is unclear how significant a speed limit increase from 65 mph to 70 mph is in terms of highway safety.

As one of the more than 40 states that has passed legislation raising the speed limit to above 65 mph since 1995, Georgia is an appropriate venue for such an assessment. The last comprehensive study of highway safety in Georgia was conducted in 1989 and dealt with the use of seatbelts (Legge 1989). No previous studies have measured the effects of speed limit changes in Georgia.

This study focuses on rural highways in Georgia. The many differences between rural and urban travel call for separate treatment of rural highways, including highway characteristics and the environment as well as the relationship of setting to the posted speed limits. In explaining the rationale for the different classifications, the American Association of State Highway and Transportation Officials (1994, 9) noted that "urban and rural areas have fundamentally different characteristics with regard to density and types of land use, density of street and highway networks, nature of travel patterns, and the way in which these elements are related." Moreover, research has shown that changing the speed limit on urban highways does not change the speeds at which drivers travel on those highways (Spitz 1984, Parker 1997). In 1996, in its speed limit law, the Georgia General Assembly distinguished between urban and rural highways, setting different maximum speed limits in each setting.

Important Policy Questions for Georgia

Eight specific research questions are examined in this study. Four of the questions focus on the impact of the speed limit change on the state's interstate highways in rural areas, which are covered directly by the speed limit policy.

1. Do higher posted speed limits lead to increased driver speeds on rural interstate highways?
2. Do higher speed limits increase the number of crashes, injuries, and fatalities on rural interstate highways?
3. Do higher speed limits increase driver compliance on rural interstate highways?
4. Do higher speed limits decrease speed variance on rural interstate highways?

The study examines eight policy questions concerning the impact of higher speed limits on Georgia's rural highways—interstates as well as primary and arterials.

Other important policy questions relate to how interstate speed limit increases affect state highway systems as a whole, including their primary and minor arterials. As a rule, most states have increased legal speed limits only on interstate highways and their "look alikes," which offer important safety features like wide medians, large shoulders, and limited access. Assuming that drivers choose their routes to maximize a number of variables including safety and travel times, increasing speed limits on interstates may attract more drivers to these highways. More drivers going faster on highways with these safety features could increase the number of crashes, injuries, and fatalities on interstates, but it may decrease the number of crashes, injuries, and fatalities statewide if enough drivers are drawn away from the state's less safe highways.

The advantages of attracting more drivers to interstate highways may be offset by the possibility of "spillover effects." A spillover effect is said to occur when drivers become comfortable with a higher rate of travel and fail to adjust to changing highway conditions. It is particularly harmful when drivers exit interstate highways for roads with fewer safety features without slowing down. On a grand scale, then, spillover effects from increased speed limits on interstate highways may cause drivers to increase speed on highways throughout the state highway system. Higher speeds on highways with fewer safety features, such as primary and minor arterials, may lead to increased numbers of crashes, injuries, and fatalities throughout the state even if fewer drivers travel these highways.

The remaining four policy questions concern the effects of higher speed limits on all rural highways in a state highway system.

5. Do higher speed limits on interstate highways lead to increased speeds and less compliance on primary and minor arterial highways?
6. Do higher speed limits on interstate highways affect the number of crashes, injuries, and fatalities on primary and minor arterial highways?
7. Do higher speed limits on interstate highways affect the overall number of crashes, injuries, and fatalities on states' rural highways?
8. Do higher speed limits on interstate highways lead drivers to choose those routes?

Background

Federal and State Changes to Speed Limit Laws

In November 1995, President Clinton signed a bill into law that repealed the National Maximum Speed Limit Law, 23 U.S.C. §154 (1974), which had been amended in 1986 to increase the maximum allowable rate of travel to 65 mph. The 1995 repeal gives states complete discretion over setting speed limits. The 1995 changes did away with the national speed limit, compliance reporting requirements, and a “crossover sanction” for noncompliant states that threatened to transfer highway construction funds to highway safety programs. All that remained of Section 154 of Title 23 was the definition of a “motor vehicle.”

As predicted by highway safety experts, many states quickly moved to increase speed limits on rural and urban highways. Brooke (1996, A12) noted states’ reactions to the amendment, saying, “[state] legislatures raced to raise speed limits” soon after the bill was signed. Among the leaders in the “race” were Montana and Texas. For a while, Montana posted no speed limit on rural highways during daylight hours, while Texas has allowed speeds up to 70 mph on almost half of its two-lane “farm to market” highways. Georgia is among the more than 40 states that have passed legislation to raise their speed limits above 65 mph.

Georgia was clearly among those in the race for higher speed limits....

A number of reasons explain the willingness of states to pass laws for higher speed limits. As stated earlier, foremost is the popularity of these reform efforts, especially among residents of large western states who considered the 65 mph limit too restrictive, making automobile trips unnecessarily long. Also, state legislatures felt pressure from many important industries such as trucking companies, regional distributors, and corporations with large sales forces. While public safety was a consideration in most states, groups opposing higher speed limits had difficulty convincing legislators that a 5–10 mph increase would make much of a difference, when most drivers were already choosing speeds above 65 mph.

Georgia was clearly among those in the race for higher speed limits as Gov. Zell Miller signed S.B. 606 into law on April 2, 1996. Among other things, the act amended O.C.G.A. §40-6-181(b) with regard to speed limits (see box). Essentially, the law raised the limit to 70 mph on federal interstate highways and on physically divided highways outside urbanized areas of 50,000 population or more that have full control access; 65 mph on federal interstate highways within an urbanized area of 50,000 people; and 65 mph on sections of physically divided highways without full access. Also, the law requires that no more than a 20 mph differential between maximum and minimum posted speed limits shall exist. The only parts of the previous legislation left unchanged were speed limits in residential areas and on small rural highways.

Another change provided by the amendment to O.C.G.A. §40-6-181(b) was changing the state seatbelt violation from a secondary to a primary offense. Under the old seatbelt law, citizens could not be stopped or cited for seatbelt violations unless a primary violation had occurred. Because of primary violation status, peace officers in Georgia are allowed to stop drivers solely for not wearing a seatbelt. The passage of a primary seatbelt law and an increase in speed limit results from a political compromise between Speaker Tom Murphy and highway safety advocates Lt. Gov. Pierre Howard and Rep. DuBose Porter (Emling 1996b). Speaker Murphy, who has spoken publicly about his disdain for seatbelts, was determined to increase speed limits to avoid giving an economic advantage to other states with higher speed limits, but could not muster enough support without help from public safety advocates (Foskett 1996, Enright 1997). The compromise was an exchange of stricter safety belt legislation in return for approval of higher speed limits (Emling 1996a, Enright 1997).

Act amending O.C.G.A. §40-6-181(b), passed on April 2, 1996 (amendment additions in bold):

(b) **Consistent with the provision of engineering and traffic investigations regarding maximum speed limits as provided in Code Section 40-6-182, no** person shall drive a vehicle at a speed in excess of the following maximum limits:

(1) Thirty miles per hour in any urban or residential district;

(1.1) **Thirty-five miles per hour on an unpaved county road unless designated otherwise by appropriate signs;**

(2) **Seventy** miles per hour on a highway on the federal interstate system **and on physically divided highways with full control access** which are outside of an urbanized area of 50,000 population or more, provided that such speed limit is designated by appropriate signs;

(3) **Sixty-five miles per hour on a highway on the federal interstate system which is inside of an urbanized area of 50,000 population or more, provided that such speed is designated by appropriate signs;**

(4) **Sixty-five miles per hour on those sections of physically divided highways without full access control on the state highway system, provided that such speed is designated by appropriate signs;**

(5) Fifty-five miles per hour in other locations**, and**

(6) **In all cases the minimum speed limit on any highway on the federal highway interstate highway system shall not exceed a differential of 20 miles per hour difference between the maximum and minimum posted limit.**

Combining the amendments to Title 23 of the United States Code and Section 40-6-181 of the Georgia State Code constituted a repeal of the national maximum speed limit and resulted in a 70 mph maximum speed limit on many of Georgia's rural highways. The changes outlined in Georgia's amendment took effect on July 1, 1996.

The changes in federal and state laws concerning maximum speed limits are interesting from a policy standpoint because they may alter driver behavior, change enforcement strategies, and affect highway safety. The amendments to the federal code change the relationship between the federal government and states by doing away with crossover sanctions that were tied to speed limit compliance and enforcement. Drivers are now faced with a wider span of legal speeds from which to choose on some highways and may change their routes to minimize travel times. At the same time, state police departments may need to react to higher speed limits by changing where and how they focus their enforcement efforts.

According to Mazmanian and Sabatier (1989, 21) "The crucial role of implementation analysis is the identification of the variables which affect the achievement of *legal objectives*"(emphasis added). Advocates for increasing maximum speed limits in Georgia had two primary objectives, the most obvious being reduced travel time within the state. A higher speed limit is a boon to many big businesses, especially those in the shipping and/or trucking industries or with numerous traveling salespeople (Enright 1977). Reduced travel time is also a quality of life issue in that citizens can spend less time in cars and more time being productive or relaxing. Despite the time advantages, most Georgians did not support the speed limit increase (*Atlanta Journal–Constitution* 1996, "Georgia Legislative Session").

Surprisingly, the second stated objective of Pub. L. 748 is to improve public safety. It is argued that increasing the speed limit to match driver behavior and setting the minimum speed limit at 20 mph below the maximum will decrease the variance in speeds among drivers on rural highways (Lave and Elias 1994, Monroe 1996). It is also believed that allowing the State of Georgia to set its own speed limit will increase "buy in" by the state patrol, leading to stricter enforcement of the new limit (Emling 1996b). Drivers would be less willing to ignore the state law and increased enforcement would lead to fewer drivers traveling at rates far above or below the maximum and minimum limits (Friedland et al 1990).

Summary of Related Studies

The question of whether higher speed limits affect highway safety may be a foregone conclusion for most. The most common assumption is that increasing speed limits will cause drivers to go faster. The faster a car travels, the more likely it is to be involved in a crash. Higher speeds mean less reaction time to recognize and avoid hazards, as well as greater force when a crash occurs (NHTSA 1995). It would seem logical, then, that a greater probability of crashing combined with more force on impact would lead to greater numbers of crashes, injuries, and fatalities on highways.

However, the consequences of speed limit changes on highway safety statewide are not so straightforward. The overall effects of speed limits become more difficult to identify when one considers how states have chosen to regulate speed. Georgia, like most of the states, chose to set different speed limits on different types of rural highways. The posted limits varied by road type, making it possible for researchers to determine the effects of new speed limits on highway safety statewide as well as on highways with raised speed limits. Since conditions are not equal on each type of highway, it is possible that higher speed limits may decrease highway safety on roads with the new limits, but increase overall highway safety within the state. This is a possibility if speed limit increases are limited to interstate highways, thereby attracting more drivers to interstates with safety features like wide medians, large shoulders, and limited access. The 1996 Georgia legislation allows higher speed limits only on interstate highways with these safety features.

Speed variance—the difference between maximum and minimum speeds—is an important factor in the occurrence of highway crashes. Georgia law sets the posted variances at 20 mph.

Justifications in the highway safety literature for increasing speed limits on certain highways usually follow two lines of reasoning. The first is that speed limits should be increased on interstate highways to increase driver compliance (Friedland et al. 1990). Speed limits that are too low or substantially lower than driver preferences are deemed unreasonable. Some have argued that lawlessness in simple areas like speed limits may contribute to a general disregard for government and law in society (Friedland et al. 1990). The idea that higher speed limits increase compliance is intuitive, but it assumes that the new speed limit will incorporate the preferences of a significant number of drivers and that drivers who were noncompliant previously will not speed up. It is common for enforcement officials to ticket only drivers caught going more than 10–15 miles per hour over the legal limit, thereby creating a “buffer zone” of noncompliance. While Sen. Mary Margaret Oliver argued that “motorists… would not be allowed to drive 10 mph over the speed limit before they are ticketed” under the new speed limit, experts did not expect a change in the buffer zone (Emling 1996b, Julian 1997). It may be the case that increasing the speed limit while maintaining a buffer would have no significant effect on compliance.

The second justification for raising speed limits concerns speed variance. Speed variance, or the dispersion of speeds drivers choose, has been found to be an important factor in the occurrence of highway crashes (Lave 1985, Rodriguez 1990). When variance is high, the number of cars changing lanes and passing increases, thereby increasing the probability of a crash. Increasing speed limits in line with driver preferences may decrease variance by allowing more drivers to travel legally at comfortable speeds. Again, this justification assumes that any speed limit increase will incorporate the preferences of a large number of drivers. However, it is also plausible that increasing the legal choices drivers can make may lead to more drivers choosing different speeds, thereby increasing variance. The Georgia General Assembly's inclusion of a minimum speed limit of no more than 20 mph lower than the maximum limit is an attempt to curb variance created by slow-moving vehicles (Julian 1997, Enright 1997).

The relationship between speed and driver performance is "the quintessential traffic safety issue, probably due to the clearly perceived relationship between vehicle velocity and human capabilities and limitations" (FHWA 1998, 1). Higher speeds decrease the time available to maneuver around objects and vehicles in the road and increase the distance traveled during an avoidance maneuver. The distance required to stop a car is also higher at higher speeds.

Speeds and Speed Limits

While the speed limit is generally among the many factors that affect a driver's choice of speed, the value assigned to speed limits has been questioned. One study (Harkey, Robertson, and Davis 1990) found that 70 percent of vehicles exceeded the posted speed limit on low- and moderate-speed highways in four states. This finding prompts questions regarding how speed limits are set, as well as how reasonable they are. Such a large proportion of drivers exceeding the speed limit suggests that either the criteria for setting speed limits are unreasonable or drivers are poor judges of speed and safety.

The fact that so many exceed the speed limit does not preclude speed limits having an important effect on driver behavior, especially since many jurisdictions do not issue citations unless a driver exceeds the speed limit by 10 mph or more. While speed limits are usually exceeded, they are often used by drivers to draw a "real" limit over which speeds are seen as unsafe or the threat of a violation is high. Mustyn and Sheppard's (1980) research on driver attitudes supports the notion of speed limits as a limiting factor despite the low level of compliance.

One means of testing the salience of speed limits for driver behavior is to measure changes in driver behavior associated with changes in speed limits. Researchers have found that setting (urban vs. rural) plays a large part in impact of speed limits. Two studies showed that changing speed limits on urban highways has little or no effect on driving speeds (Spitz 1984, Parker 1997). In contrast, changing speed limits on rural highways generally leads to significant increases in speeds. Warren (1998) notes, but does not cite, a meta-analysis of numerous international studies and found that change in mean speed on rural highways is approximately one quarter (25 percent) of the change in posted speed limit, regardless of direction. Table 1 below presents the increases recorded by a number of researchers when speed limits on U.S. highways were increased from 55 mph to 65 mph.

Speed Limits and Highway Safety

One should expect to find changes in the number and severity of crashes when posted limits are altered, since speed limits do have some effect on speed choice on rural highways. Tables 2a and 2b list a number of studies that focused on the relationship between speed limit changes and highway safety. Taken together, these studies show that highway safety has generally increased when speed limits are decreased, while speed limit increases have had the opposite effect. Following examples of models used in Sweden, Nilsson (1981) created a mathematical model for the relationship between highway safety measures and speed limit changes. He predicts that mean speed increases change highway safety measures by a factor of four for fatalities, three for severe injuries, and two for injury crashes in terms of change in velocity. In a similar study, Fildes and Lee (1993) estimate that every one mph increase in mean speed leads to a 5 percent increase in injury crashes.

Table 1. Summary of Studies Showing Increased Driver Speeds Resulting from 10 MPH Increase in Speed Limit

Authors	Speed Increase (55 ➔ 65 mph)
Brown, Maghsoodloo, and Ardle (1990)	2.4 mph
Freedman and Esterlitz (1990)	2.8 mph
Mace and Heckard (1991)	3.5 mph
Pfefer, Stenzel, and Lee (1991)	4–5 mph
Parker (1997)	0.2–2.3 mph

Table 2a. Summary of Studies of Highway Safety and the Effect of Speed Limit Decreases

Authors	Country	Speed Limit Decreases	Results
Peltola (1991)	United Kingdom	62–50 mph	Speeds declined by 4 km/h.
Sliogeris (1992)	Australia	68–62 mph	Injury crashes declined by 19 percent.
Newstead and Mullan (1996)	Australia	3–12 mph	No significant change. (4 percent increase relative to sites not changed.)
Parker (1997)	United States	5–20 mph	No significant changes.

Table 2b. Summary of Studies of Highway Safety and the Effect of Speed Limit Increases

Authors	Country	Speed Limit Increases	Results
McKnight and Klein (1990)	United States	55–65 mph	Fatal crashes increased by 22 percent. Speeding increased by 48 percent.
Garber and Graham (1990)	United States (40 States)	55–65 mph	Fatalities increased by 15 percent. Decrease or no effect in 12 states.
Lave and Elias (1994)	United States (40 states)	55–65 mph	Statewide fatality rates decreased by 3-5 percent. (Significant in 14 of 40 states.)
Newstead and Mullan (1996)	Australia (Victoria)	3–12 mph	Crashes increased overall by 8 percent, but 35 percent declined in zones raised from 60–80 mph.
Rock (1995)	United States (Illinois)	55–65 mph	Crashes increased by 33 percent. Fatalities increased by 40 percent. Injuries increased by 19 percent.
Parker (1997)	United States (22 states)	5–15 mph	No significant changes.

The first sophisticated analysis of the effects of the speed limit increase from 55 to 65 mph was conducted by Garber and Graham (1990). The authors estimated regressions on monthly fatality data from 40 states using a dummy variable to represent the change in speed limits. Their findings are mixed, with 9 states showing a statistically significant increase in fatalities on rural interstates. Two states, Indiana and Montana, were found to have significant decreases in highway fatalities. These results led Garber and Graham to conclude that

> the new 65 mph limit appears to be increasing rural interstate fatalities in some states, reducing them in others, and having no detectable effect (given the experiences to date) in the remainder. The number of states experiencing increased fatalities exceeds the number experiencing reduced fatalities (1990, 45).

Lave and Elias (1994) attempt to improve the Garber and Graham (1990) study by changing the dependent variable. Lave and Elias criticize earlier studies for measuring changes in highway safety on small stretches of highway that may experience greater annual shifts in fatalities than a safety intervention might be expected to predict and are not good measures of risk. These criticisms are translated into two changes in the Garber and Graham (1990) dependent variable. First, the authors repeated the earlier study using statewide fatality data that included all fatalities on urban and rural highways. Second, Lave and Elias constructed a new dependent variable that divided monthly statewide fatalities by an estimate of vehicle miles traveled (VMT). Repeating the Garber and Graham (1990) regression with the statewide fatality data resulted in none of the 40 states experiencing a statistically significant change in fatalities. Regression techniques on the second dependent variable, statewide fatalities divided by vehicle miles traveled, resulted in significant decreases in fatalities in 10 states and significant increases in 4 states.

Lave and Elias (1994) give a number of explanations for the decreased fatalities in a number of states. Possible explanations for the lower fatality rates are that

> (i) drivers may have switched to safer roads—the aggregate data support this; (ii) highway patrols may have shifted resources to activities with more safety payoff—testimony by highway patrol chiefs supports their intention to do so; (iii) finally . . . it is also possible that the new law caused a decline in speed variance: it might decline on interstates as law-abiding drivers caught up with the speeder, and it might decline on other highways as their speeders switched to the interstates (1994, 61).

While each of the explanations is plausible, Lave and Elias were not able to provide enough evidence to support any individual explanation.

Criticisms of Lave and Elias's work center on both their construction of the dependent variable and their methodology. While using a dependent variable that includes statewide measures is an improvement over variables that include only one stretch of highway, mixing urban and rural measures may be cause for concern. Factors such as stoplights, number of automobiles encountered, congestion, number of curb cuts (driveways), speed limits, and number of lanes make the driving environment and causes of fatalities in urban areas very different than on rural highways. As noted earlier, changes in speed limits have been found to have no impact in urban settings, but significant impacts on driver behavior on rural highways (Spitz 1984, Parker 1997). Furthermore, the 1986 speed limit legislation did not allow for the increase of speed limits in urban areas. If the important factors leading to urban fatalities are different from those leading to rural fatalities, Lave and Elias's (1994) findings may be due to urban factors, rather than the speed limit change on rural highways.

Lave and Elias's estimation of vehicle miles traveled may also be problematic. The monthly measure is constructed using an annual estimate of vehicle miles traveled for each state. The annual estimate is then transformed into monthly data using patterns of vehicle miles traveled as estimated by the Nationwide Personal Transportation Survey. Lave and Elias's monthly measure is an estimated proportion of annual vehicle miles traveled. The problem with this measure is that it does not actually measure monthly changes in vehicle miles traveled, especially those thought to have occurred in response to the increase in speed limit. While there is no doubt the authors used the best available data, the measure they used may not represent a significant improvement over other control variables.

The Garber and Graham (1990) and Lave and Elias (1994) studies suffer from their choice of methodologies. Each study uses ordinary least squares (OLS) regression techniques to determine estimates for monthly time series data. As will be explained in detail, the method of using ordinary least squares may not be appropriate because of its inability to capture autoregressive, moving average, or seasonal trends in time-series data.

Research Approach: Methods and Measures

The purpose of this section is to present the statistical methods, data sources, and measures used to test the policy questions that were presented. The section begins with an introduction to ARIMA (autoregressive integrated moving average) modeling and its use in highway safety research. An explanation of how the data were collected and the measures used to test policy questions concerning the State of Georgia follows. (The appendix, page 45, presents a more detailed review of the methodology.)

Time-Series Analysis

The analysis tests all of the crash, injury, and fatality policy questions presented earlier, using ARIMA techniques on monthly data between January 1993 and December 1997. The decision to use ARIMA methods instead of the more common ordinary least squares (OLS) regression is based on the unique challenge that time-series data present to the assumptions of OLS. Time-series data are problematic in that observations are often much more highly correlated to the observations just before or after than others, thereby defying the OLS requirement that "residuals, or error terms associated with each time-series observation be independent" (McCain and McCleary 1979). OLS is not the appropriate methodology for this study since each of the policy questions is to be tested using time-series data that may exhibit autocorrelation. McCain and McCleary suggest ARIMA analysis as a better alternative.

The advantage of ARIMA modeling is that it allows one to separate the effects of speed limit changes from other possible explanatory variables by removing confounding trends in the data, thereby eliminating many alternative explanations for results, and isolating the intervention effects. ARIMA analysis also allows the researcher to estimate what kind of change occurs if the intervention has had an effect. The method requires that transfer functions be used as the primary independent variable to determine whether the change is abrupt, gradual, or temporary. An abrupt, constant change occurs when an intervention has a significant effect at the time of intervention that is long lasting. Gradual, constant changes occur when the intervention corresponds with a change in rate or direction in the dependent variable that does not return to preintervention levels over time. Abrupt, temporary changes signify an initial change due to the intervention, but a relatively quick return to preintervention levels. McCain and McCleary note that "the analyst will sometimes have a priori notion as to the nature of the hypothesized effect and will choose a transfer function accordingly" (1979, 265). Rock (1995) suggests that speed limit changes should be modeled as abrupt, constant changes. For this reason, the independent variable in this study is a step function dummy variable consisting of "0" before speed limits were changed and "1" thereafter.

Data and Measures

Data for testing policy questions related to Geogia were collected from the state Department of Transportation (DOT). DOT collects, archives, and analyzes these data for the purposes of federal reporting, construction and safety planning, and providing information to the Georgia General Assembly. While fatality data are readily available through states' reports to the federal government's Fatality Analysis Reporting System (FARS), no federal source of monthly crash and injury data for the State of Georgia could be identified. Georgia DOT was able to provide data for three classifications of highways in the state highway system: minor arterials, primary arterials, and interstate highways. The measures presented below do not include statistics for municipal or county highways that meet the standards for the three classifications. For this reason, Georgia DOT fatality statistics do not always match those reported by FARS, leading the researcher to use Georgia state data to assure consistency between crash, injury, and fatality data. Eight policy questions were introduced on pages 7 and 8. The first four concern changes on rural interstate highways in Georgia, while the last four involve changes on primary and arterial state highways. Table 3 defines the three types of rural highways included in the study.

Testing policy question 1 provides information about the relationship between increasing speed limits on Georgia's rural interstate highways and the expected subsequent increase in driver speeds. If the Georgia case is

Table 3. Types of Rural Highways

Interstate Highways	A limited access (full or partial control) divided highway of at least four lanes for through traffic with grade separations (overpasses) at major intersections.
Primary Arterials	Major highways, many with multilane or freeway design, serving high-volume traffic corridor movements that connect major generators of travel (cities or towns).
Minor Arterials	Highways linking cities and larger towns in rural areas in distributing trips to small geographic areas in urban areas (not penetrating identifiable neighborhoods).

consistent with findings in the literature, one would expect an increase in average speed of 1.25 mph (25 percent of 5 mph) or more due to the speed limit increase (Fildes and Lee 1993).

The speed and count information necessary to test this and the two related policy questions are collected by Georgia's DOT Office of Information Services via a system of roadside Automated Traffic Recorders (ATR). Speed estimates are recorded into 1 of 11 speed ranges. The ranges reported by the Office of Information Services are 0–40, 41–45, 46–50, 51–55, 56–60, 61–65, 66–70, 71–75, 76–80, 81–85, and 86+ mph.

It should be noted that speed estimates generated by ATR are not as accurate as those provided by radar or laser speed detectors. The over- or underestimation of automobile speeds should not prove problematic for testing speed policy questions for two reasons. First, the collection of data into speed ranges of 5 mph should allow the speeds of most automobiles to be classified correctly even if the ATR's calibration is off by a few miles per hour. Second, the speed analysis conducted here should not be hampered even if the speed estimates are consistently off, since the speed policy questions are concerned with *changes* in speed choice after the intervention rather than actual speeds. The largest threat to the validity of speed data would occur if ATRs were recalibrated at or near the time speed limits changed. While Office of Information Services officials note that no wholesale efforts were made by the Georgia Department of Transportation to calibrate all ATRs around July 1996, the effects of recalibration of a single ATR are controlled by using results from at least two ATRs for each of the three highway classifications.

The collection of speed data was made difficult by computer and staffing problems at the Georgia DOT. The main computer used to collect information from ATRs throughout Georgia was not able to communicate with the roadside counters between May and December 1995. Resources were not available to allow the Office of Information Services to retrieve the missing data. The analysis of speed and count data is therefore limited to data collected from January 1996 to December 1997, with 6 preintervention observations and 18 postintervention observations. The small series of preintervention observations limits the ability of ARIMA analysis to factor out trend and seasonal variations. This study uses a simple pre-test, post-test difference of means test for all speed and count variables for this reason.

The speed and count data for each month represent an aggregate of samples of individual ATR data for one 24-hour period per month. The dates for each ATR were chosen randomly, but efforts were made to assure that no ATRs were sampled on the same day or day of the week in any given month for each highway classification. This sampling method follows NHTSA guidelines used by states until the repeal of the NMSL in 1995. See Table 4 for a complete listing of the variables used in empirical analysis.

The 2d policy question focuses on whether higher speed limits lead to significantly higher numbers of automobile crashes, injuries, and fatalities on Georgia's rural interstate highways. Assuming a 1 mph change in average speed on Georgia's interstates, one would expect a 2 to 5 percent increase in each of the highway safety variables. No change in average speed should coincide with no changes in crashes, injuries, and fatalities.

Injury and fatality data are complete for the period of January 1993 through December 1997 with 42 preintervention and 18 postintervention observations. Crash data were not collected from July through December 1994 due to administrative errors. For this reason, analysis of crash data consists of observations from January 1995 through December 1997 with 18 preintervention and 18 postintervention observations.

Table 4. Variables Used in Analysis

CRASH	The number of automobile crashes with injury occurring on Georgia highways in a month.
INJURY	The number of injuries occurring on Georgia highways in a month.
FATALITY	The number of fatalities occurring on Georgia highways in a month.
AVGSPEED	The grouped mean rate of travel for automobiles on rural highways in Georgia for each month.
SPEEDING	The percentage of automobiles traveling more than 10 miles per hour above the legal limit on rural highways in Georgia for each month.
FASTEST	The percentage of automobiles traveling 86+ mph on rural highways in Georgia for each month.
COUNT	The total number of automobiles traveling Georgia's rural highways in a month.
PERINTER	The percentage of total travel on Georgia's rural interstates in a month.
PERPRIMARY	The percentage of total travel on Georgia's primary arterials in a month.
PERMINOR	The percentage of total travel on Georgia's minor arterials in a month.

Two variables, *SPEEDING* and *FASTEST*, were constructed to test the 3d policy question, whether higher speed limits lead to greater driver compliance. One would expect that compliance would increase as speed limits are increased in line with driver preferences. As with the speed data, the time series are limited to data collected between January 1996 and December 1997.

The 4th policy question tests whether increasing speed limits and mandating a difference of 20 mph between the maximum and minimum speed limits decrease speed variance on Georgia's interstate highways. Assuming the new speed limits are closer to driver's preferences, one would expect an increase in speed limits to decrease variance as more drivers approach the mean speed. However, simply giving drivers a greater range of speed choices, which the minimum speed limit is intended to prevent, should lead to greater variance on Georgia's interstates. Since there is no reason to believe either force is more prevalent than the other, especially if one assumes that minimum speed limits are not strictly enforced, one would not expect any significant changes in variance on interstate highways. Again, this time series is limited to data collected between January 1996 and December 1997.

Policy questions 5 through 8 concern changes in rural highway safety statewide and on primary and minor arterials in Georgia due to new speed limit legislation. Whether increased speed limits on rural interstate highways lead to the occurrence of a spillover effect statewide may be answered by testing policy question 5. It is expected that the speed limit increase on interstate highways should change driver behavior on other highways. The policy question is tested using speed data for minor and primary arterials collected in the same manner as interstate speed data.

The 6th policy question tests whether higher speed limits on interstate highways affects highway safety on primary and minor arterial highways in the state system. If average speeds have increased on the state's arterials, one would expect an increase in crashes, injuries, and fatalities. Each of these variables are constructed in the same manner as policy questions 1 and 5.

Policy question 7 focuses on whether higher speed limits on interstates lead to significantly higher numbers of automobile crashes, injuries, and fatalities on *all* rural highways in Georgia. This policy question guards against the possibility that small decreases in highway safety in each highway classification may result in significant decreases in highway safety statewide. It also tests the measures most likely to be considered by state legislators and policy makers.

The 8th policy question focuses on whether increasing speed limits on interstate highways changes driver behavior and the routes drivers choose. One variable (*COUNT*) was constructed to measure changes in travel statewide due to the increased speed limits, while three variables (*PERINTER, PERPRIMARY, PERMINOR*) were constructed to test whether drivers follow higher speed limits to interstate highways. It is expected that increased speed limits will lead more drivers to choose interstate highways for their travels as well as increase driving levels statewide.

Results

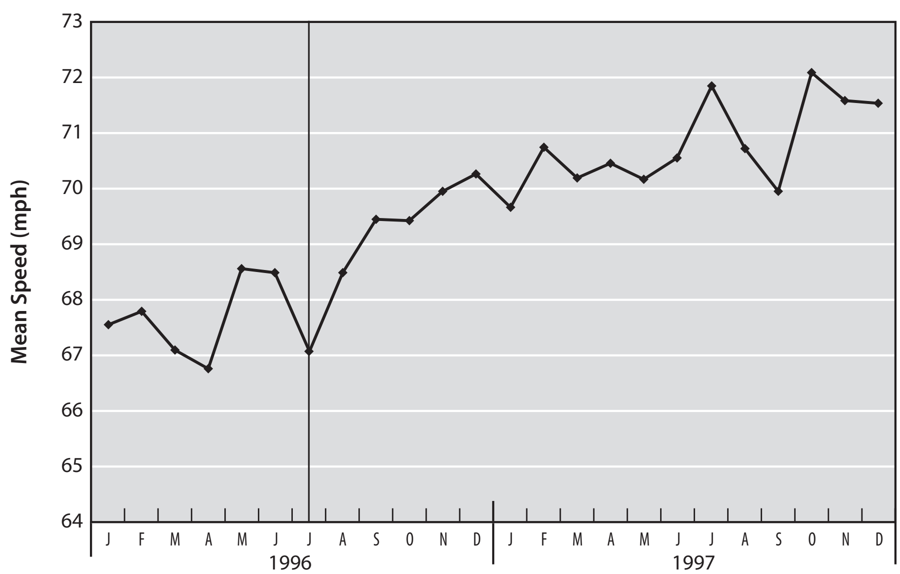
The purpose of this section is to present and discuss the results of empirical tests conducted on the highway safety variables discussed above. The section begins with the results concerning the effects of increased speed limits on Georgia's rural interstates and follows with a presentation of the effects of the speed limits on the state's other rural highways. All of the results will be discussed in the order the policy questions were presented.

Impacts on Rural Interstate Highways

The first group of policy questions tested attempt to determine if and how increased speed limits on Georgia's rural interstate highways have affected highway safety and driver behavior on those highways. Data were collected and four policy questions were tested. The results of those tests are discussed in detail below.

The 1st policy question measured changes in driver behavior regarding the speeds drivers choose. Figure 1 reveals a clear increase in mean speed on Georgia's interstates since January 1996 and an increased slope since July 1996, but the time series is too short to determine whether the data are consistent with trends and seasonal variations prior to 1996. Discussions with the National Highway Traffic Safety Administration's liaison for the State of Georgia revealed that speeds in Georgia have been increasing steadily since 1992 (Julian 1997, Monroe 1996). Data problems did

Figure 1. Mean Speed on Rural Interstates in Georgia, 1996–1997



not allow the researcher to confirm this expert opinion. Note, however, that the difference of means test for AVGSPEED, shown in Table 5, is statistically significant at the 0.01 level and indicates an increase in mean speed from 67.7 mph to 70.2 mph.

This result might be explained in one of two ways. The first explanation is that the pretest period of January to June does not include the summer travel months, making the pretest mean artificially low and resulting in statistical significance. The difference of means might also be a reflection of the trend toward higher speeds noted above. The difference of means test does provide some evidence that average speed has increased. One must make the assumption that average speed has increased significantly due to the increased speed limit despite the absence of more conclusive test results.

Policy question 2 was tested with traditional measures of highway safety: the number of crashes, injuries, and fatalities on Georgia interstate highways. It was expected that increasing the speed limit from 65 mph to 70 mph would lead to significantly more crashes, injuries, and fatalities. The following figures (2, 3, and 4) show the behavior of all three highway safety variables on Georgia's interstates from 1993 to 1997.

The plots do not make obvious the effects of the speed limit increase on highway safety on Georgia's interstate highways. Interstate crashes (Figure 2) do not show any upward trend or seasonal pattern. Both injuries and fatalities exhibit slight upward trends and some seasonality, especially in terms of the months with the highest and lowest numbers of injuries and fatalities. None of the figures show a step change in highway safety.

ARIMA analysis shows that the increased speed limit on Georgia's rural interstates has had a mixed effect on safety on those highways (see Table 6). While there was no significant change in the number of crashes or injuries, Georgia's rural interstates have seen an increase of 1.65 fatali-

Table 5. Driver Behavior on Georgia's Rural Interstates

Dependent Variable	Mean before July 1996	Mean after July 1996	Observations Pre/Post	DF	T Statistics
AVGSPEED	67.71	70.23	6/18	15	− 6.11**
SPEEDING	0.178	0.083	6/18	9	8.27**
FASTEST	0.017	0.030	6/18	19	− 2.51*
VARIANCE	6129.99	6653.24	6/18	17	− 1.96*

*Statistically significant at 0.05 level (one-tailed test)
**Statistically significant at 0.01 level (one-tailed test)

Figure 2. Rural Interstate Highway Crashes in Georgia, 1995–1997

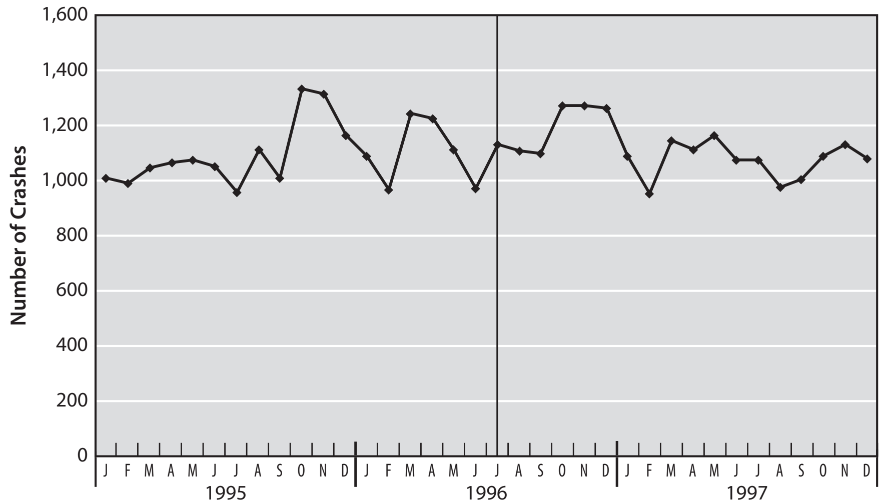


Figure 3. Rural Interstate Highway Injuries in Georgia, 1993–1997

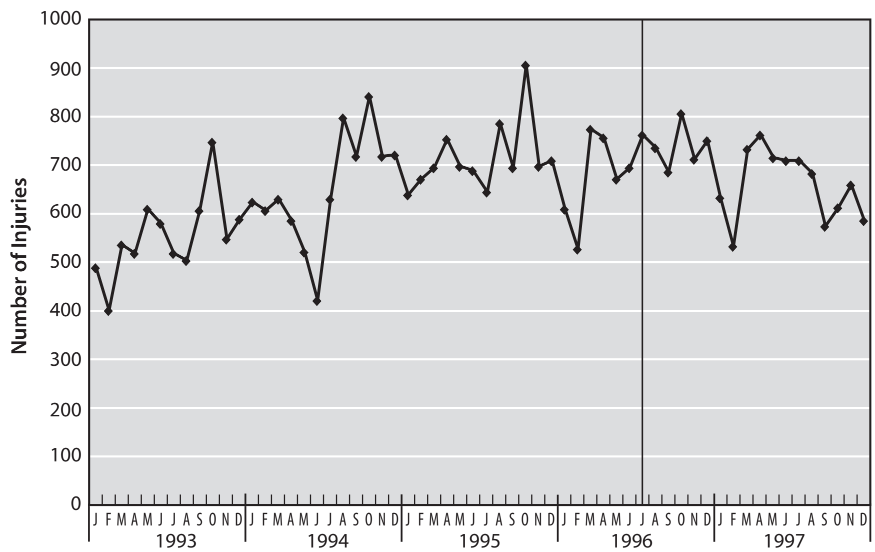
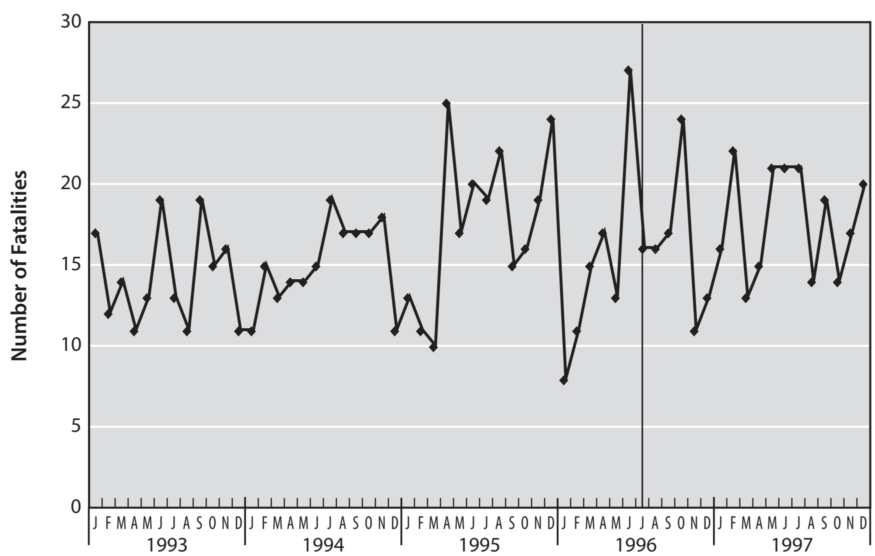


Figure 4. Rural Interstate Highway Fatalities in Georgia, 1993–1997



ties per month since July 1996. These results suggest that while conditions on Georgia's interstates have remained consistent, some of the factors leading to fatal crashes have changed. The mixed results are unexpected, but may be explained by changes in driver behavior.

The 3d Georgia interstate policy question attempted to measure whether making speed limits closer to the speeds drivers choose increases driver compliance. Two dependent variables were tested measuring the percentage of drivers traveling more than 10 mph over the speed limit (SPEEDING) and the percentage of drivers in the 86+ mph category (FASTEST) as shown in Figures 5 and 6, respectively. Two significant features stand out in the plots. The first is the presence of a large drop in the percentage of drivers exceeding the speed limit by more than 10 mph. The second is presence of an outlier in both plots during October 1997. The significance of these features was tested using difference of means tests.

The results of difference of means tests on both dependent variables are displayed in Table 5. The first test confirms the significant decrease in SPEEDING visible in the plot. Significance at the 0.01 level, combined with the absence of an adjustment for trends in the ARIMA analysis, provides reasonable evidence that the percent of drivers exceeding the legal limit by more than 10 mph has decreased from almost 18 percent to 8 percent since the speed limit was increased. This finding suggests that the new speed limit has simply codified drivers' speed preferences. Controlling for the October 1997 outlier did not change the results.

Analysis of the FASTEST variable counters the visual plot as well, resulting in a statistically significant increase in the percentage of drivers traveling 86+ mph. The results of the difference of means test in Table 5

Table 6. Crashes, Injuries, and Fatalities on Georgia's Rural Interstates

Dependent Variable	Variable	Intervention Coefficient	T Ratio
CRASH	Constant	1093.800	41.16
	AR(1)	0.343	2.12
	AR(2)	− 0.232	− 1.44
	ΔCrashes	25.69	0.68
INJURY	Constant	− 4.41	− 0.22
	ΔInjuries	− 5.03	− 0.16
FATALITY	Constant	15.57	25.00
	ΔFatalities	1.65	1.45*

*Statistically significant at 0.10 level (one-tailed test) present evidence that the percent of drivers exceeding 86 mph has increased significantly, from 1.7 percent to 3.0 percent of drivers. Again, controlling for October 1997 did not change the results.

These results are consistent with the earlier finding of increased fatalities, but no change in crashes and injuries on Georgia's interstates. That SPEEDING decreased with higher speed limits, while AVGSPEED and FASTEST increased is not consistent with the highway safety measures presented in Table 6. One would expect an increase in crashes, injuries, and fatalities with an increase in mean speed. These findings suggest that drivers in this highest speed category (FASTEST) are responsible for the increased fatalities. This is consistent with the results of crash severity

Figure 5. Percent of Drivers *Speeding* on Georgia Rural Interstate Highways, 1996–1997

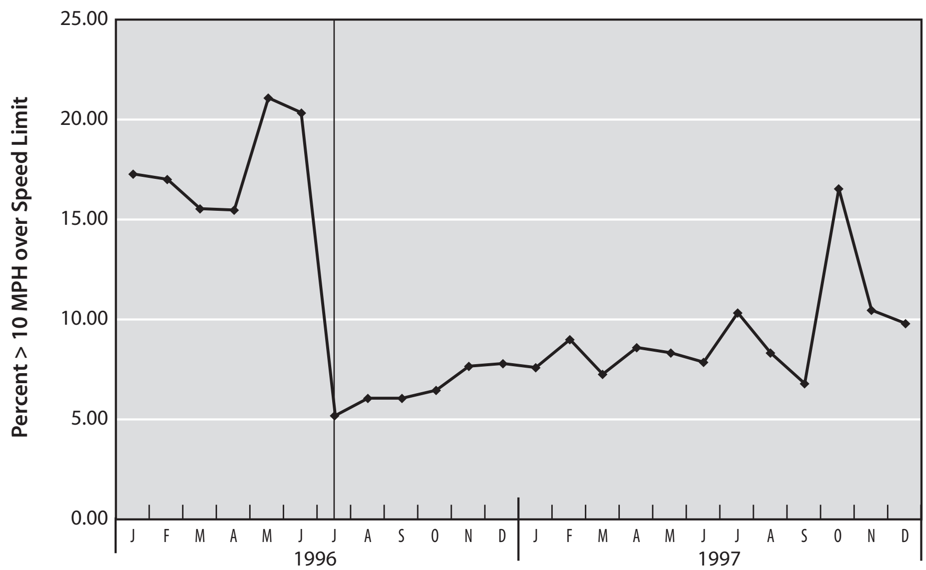
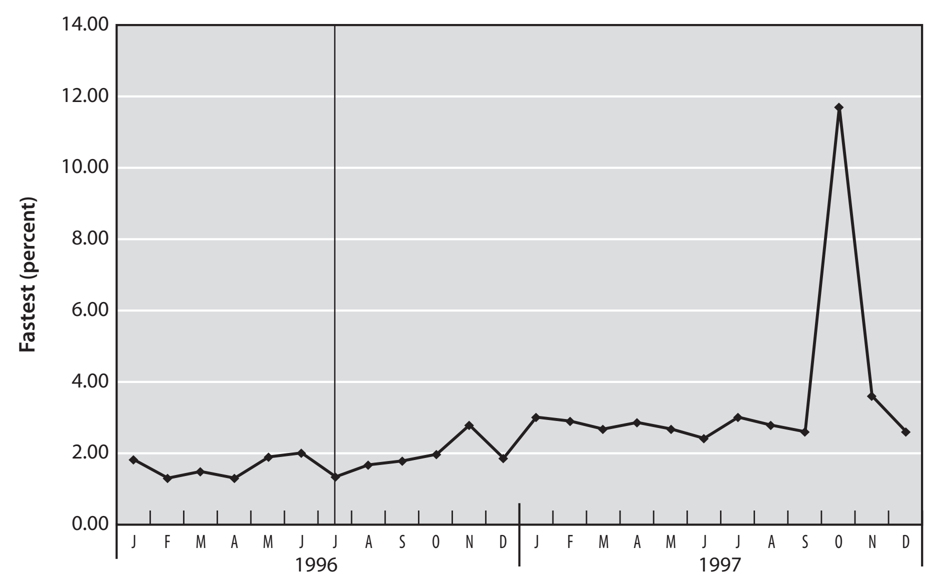


Figure 6. Percent of Drivers Traveling 86+ MPH *(Fastest)* on Georgia Rural Interstate Highways, 1996–1997



studies that show rapidly increasing levels of fatalities with increases in speeds (FHWA 1998, Soloman 1964, Bowie and Waltz 1994, Joksch 1993). It is possible that drivers in the fastest category are killing themselves and others at a statistically significant increased level.

This explanation is supported further by the empirical tests on policy question 4 concerning speed variance. The relationship between speed variance and increased speed limits is presented in Table 5. The statistically significant increase in VARIANCE means more passing and lane changes on interstate highways as well as greater change in speed at the moment of impact (DV) during crashes. An increase in the number of crashes where DV is high could lead to an increase in fatalities without significantly affecting the number of injuries on Georgia's rural interstates.

To review, the relationship between increased speed limits and highway safety on Georgia's rural interstate highways is mixed with a greater number of fatalities and no significant increases in crashes or injuries. The increase in fatalities on interstate highways is likely due to a significant jump in drivers exceeding 86 mph and the increase in speed variance. The fatality findings are generally consistent with previous studies concerning the safety effects on highways with increased speed limits. Analysis of interstate variables does not, however, give a broad enough perspective to measure the effects of increased speed limits throughout Georgia. Whether the interstate highway results hold true on a statewide basis and how speed limit increases on interstates affect highway safety on smaller highways is the next subject.

Impacts on Rural Primary and Minor Arterials

This section reviews the outcome of empirical tests designed to determine the effects of increased interstate speed limits on Georgia's primary and minor arterial highways. These results measure whether increased speed limits on the interstate highways lead to more crashes, injuries, and fatalities as well as increased speeds. Tests of policy questions 5 through 8 are presented in detail.

The question of whether increased speed limits on interstate highways leads to similar increased speeds on primary and minor arterials is the subject of the next analysis. As noted in policy question 5, increased speed limits and speeds on interstate highways could affect driver behavior on arterials by either sending the message that higher speeds are more acceptable in general or through spillover effects where drivers fail to adjust for changes in safety features on arterials by reducing speed. Because the data were available, compliance measures were constructed and tested as well. Figures 7, 8, and 9 represent the trends in variables used to measure average speed, speeding, and drivers traveling greater than 86 mph on minor and primary arterials.

Figure 7. Average Speed on Rural Minor and Primary Arterials in Georgia, 1996–1997

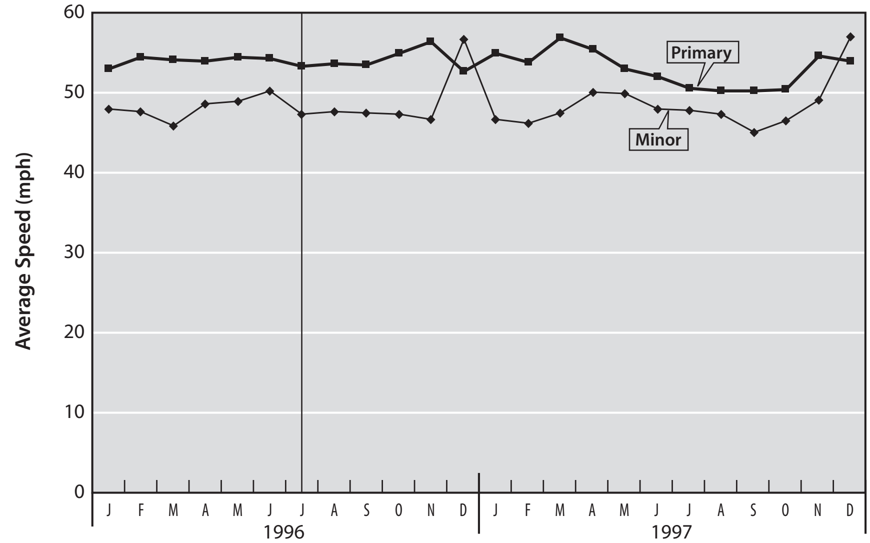


Figure 8. Percent of Drivers Traveling >10 MPH over Speed Limit on Rural Minor and Primary Arterials in Georgia, 1996–1997

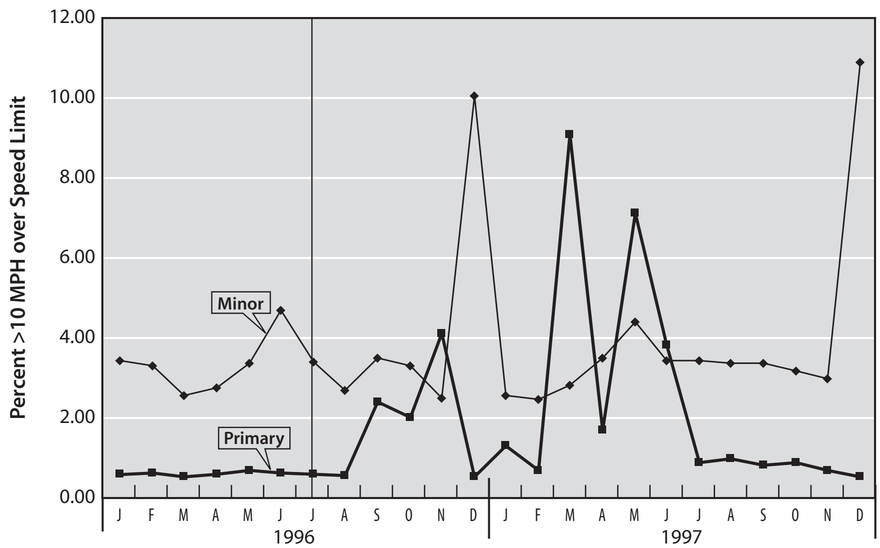
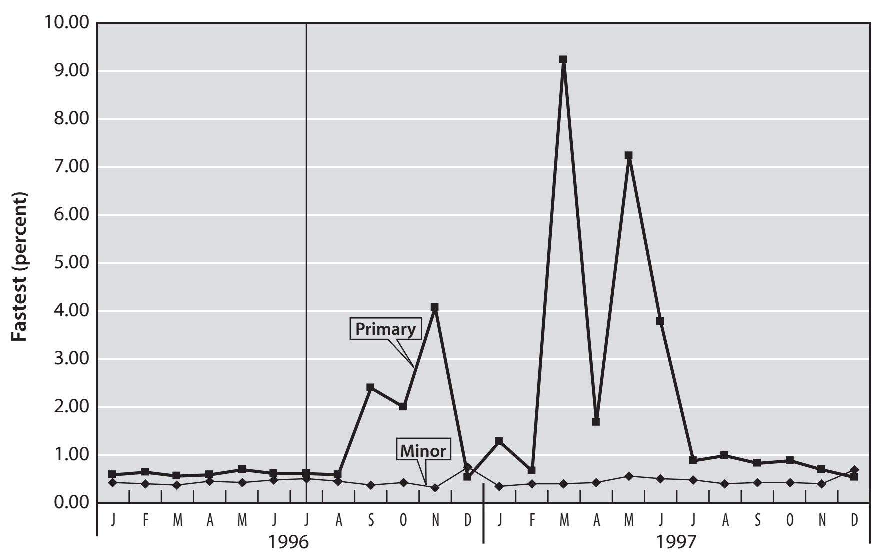


Figure 9. Percent of Drivers Traveling 86+ MPH (*Fastest*) on Rural Minor and Primary Arterials in Georgia, 1996–1997



The plots exhibit some interesting characteristics with respect to changes in the speed-related variables. Figure 7 does not show any speed change or trend on minor or primary arterials. Figures 8 and 9 do imply a noticeable increase in speeding on both classes of highway soon after the speed limit change and a pronounced increase in drivers traveling greater than 86 mph on primary arterials. Whether these changes are statistically significant is left to statistical analysis.

The results of means analysis of the driver behavior variables for minor arterials are presented in Table 7. Minor arterials did not experience significant increases in average speed, drivers traveling more than 10 mph over the speed limit, or greater than 86 mph. The increase in interstate speed limits has not led to a significant change in driver behavior on the smallest state highways.

Empirical results are mixed concerning whether primary arterials experienced significant changes in average speed (see Table 8). The difference of means tests indicate a decrease in AVGSPEED of almost 1 mph. There is no plausible explanation for a decrease in speeds unless a large number of the fastest drivers have transferred to interstate highways. Tests are consistent, however, in finding significant increases in SPEEDING and FASTEST. Drivers choosing speeds more than 10 miles per hour over the speed limit increased by 3.5 percent in July of 1996, while drivers traveling 86 miles per hour or faster increased by 1.8 percent. One would expect these results to be reflected in the highway safety measures associated with each

Table 7. Driver Behavior on Georgia's Rural Minor Arterials

Dependent Variable	Mean before July 1996	Mean after July 1996	Observations Pre/Post	DF	T Statistics
AVGSPEED	48.05	48.41	6/18	19	−0.36
SPEEDING	0.033	0.039	6/18	22	−0.98
FASTEST	0.0023	0.0026	6/18	22	−0.94

Table 8. Driver Behavior on Georgia's Rural Primary Arterials

Dependent Variable	Mean before July 1996	Mean after July 1996	Observations Pre/Post	DF	T Statistics
AVGSPEED	54.32	53.37	6/18	17	1.78*
SPEEDING	0.062	0.097	6/18	20	−3.19**
FASTEST	0.004	0.020	6/18	17	−2.67**

*Significant at .05 level
**Statistically significant at 0.01 level (one-tailed test)

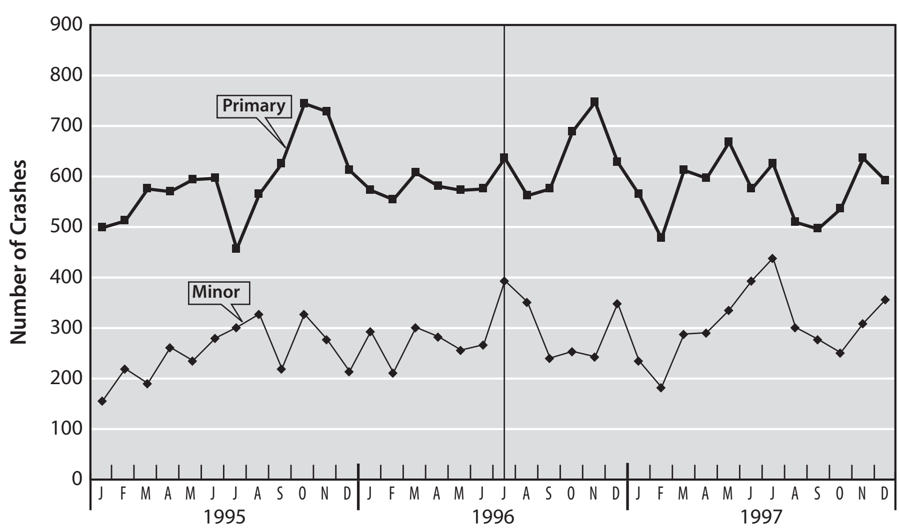
type of highway, with minor arterials exhibiting no change in highway safety and primary arterials experiencing decreased highway safety.

Analysis of crashes, injuries, and fatalities on minor arterials and primary arterials was conducted to determine if changes in driver behavior have resulted in changed highway safety on Georgia's minor and primary arterials. Figures 10, 11, 12a, and 12b display the numbers of crashes, injuries, and fatalities on both types of highways for the period studied.

The results of ARIMA analysis on the three highway safety measures for minor arterials are presented in Table 9. Minor arterials have seen a significant increase in the number of crashes and fatalities since speed limits were increased on interstate highways. There was no significant change in the number of injuries on minor arterials. The increase in fatalities suggests that crash severity has increased. Drawing on the highway safety literature concerning severity of crashes, these results suggest that increased speed or speeding may be contributing to increases in crashes and fatalities on Georgia's minor arterials. If this is the case, Georgia may be suffering the consequences of spillover effects from raising speed limits on interstate highways. These results are surprising since there was no change in the driver behavior variables (SPEEDING, FASTEST).

Table 10 shows that the number of crashes, injuries, and fatalities on primary arterials have remained at similar levels since the speed limit increases on interstate highways. These findings suggest that speeds and speeding on primary arterials should have remained unchanged. As noted above, AVGSPEED, SPEEDING, and FASTEST on primary arterials all increased significantly.

Figure 10. Rural Minor and Primary Arterial Crashes in Georgia, 1995–1997



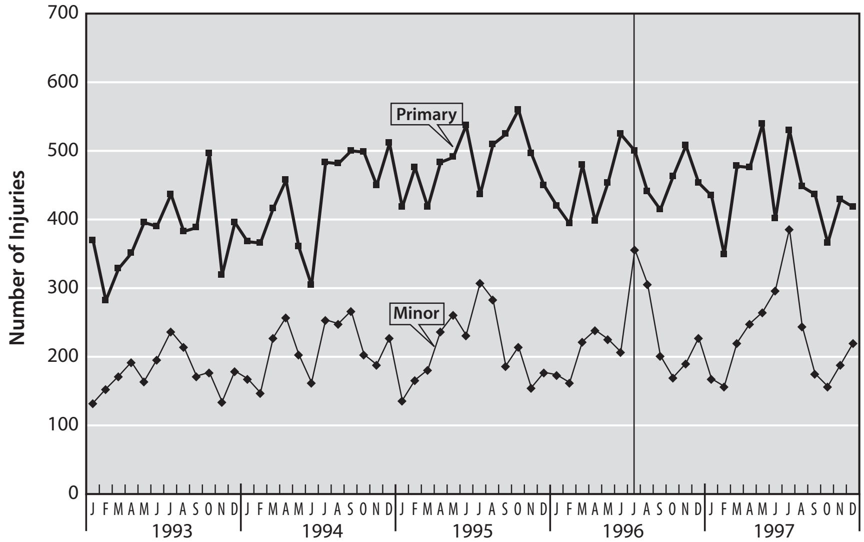


Figure 11. Rural Minor and Primary Arterial Injuries in Georgia, 1993–1997

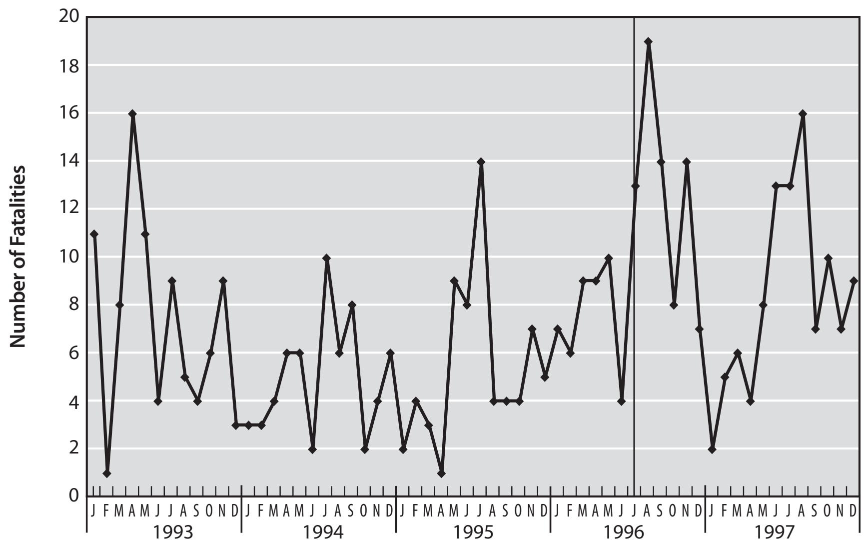


Figure 12a. Rural Minor Arterial Fatalities in Georgia, 1993–1997

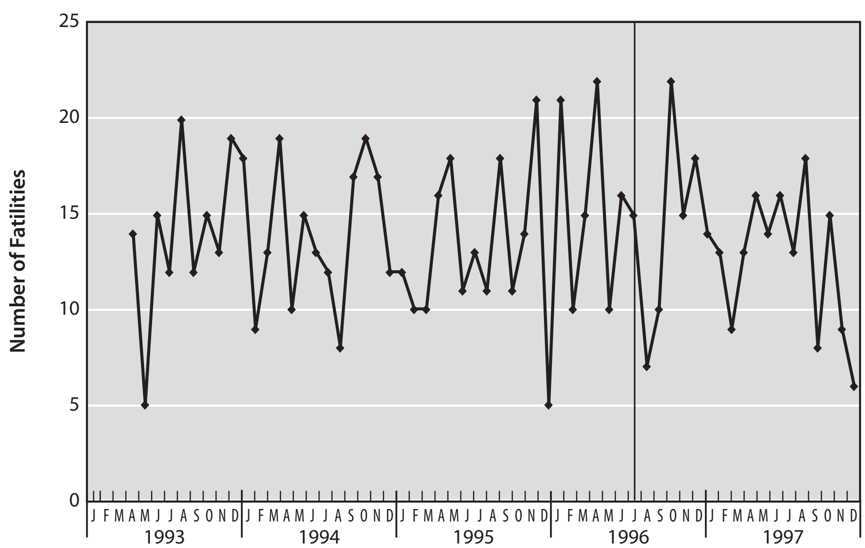


Figure 12b. Rural Primary Arterial Fatalities in Georgia, 1993–1997

Table 9. Crashes, Injuries, and Fatalities on Georgia's Rural Minor Arterials

Dependent Variable	Variable	Intervention Coefficient	T Ratio
Crashes	Constant	351.444	27.00
	ΔCrashes	45.833	2.49*
Injuries	Constant	16.40	2.88
	MA(1)	− 0.305	− 2.10
	MA(2)	0.606	3.56
	ΔInjuries	− 9.937	− 0.77
Fatalities	Constant	6.119	10.50
	Δ Fatalities	3.603	3.39*

*Significant at 0.01 level

Table 10: Crashes, Injuries, and Fatalities on Georgia's Rural Primary Arterials

Dependent Variable	Variable	Intervention Coefficient	T Ratio
Crashes	Constant	4.129	0.41
	AR(1) (3)	− 0.546	− 3.49
	ΔCrashes	− 5.699	− 0.40
Injuries	Constant	3.382	.080
	AR(1)	− 0.608	− 4.76
	AR(2)	− 0.351	− 2.42
	AR(3)	− 0.353	− 2.74
	ΔInjuries	− 7.252	− 0.92
Fatalities	Constant	13.952	21.61
	ΔFatalities	− 0.841	− 0.71

The absence of change in average speed and drivers exceeding the speed limit does not help explain the significant decrease in highway safety on Georgia's minor arterials. One would expect that significant changes in any of the driver behavior variables would be necessary to link an increase in speed limits on interstate highways to decreased highway safety on minor arterials. The best possible explanation of the increased crashes, injuries, and fatalities on minor arterials is increased exposure due to the increased daylight and number of young drivers without school restrictions during summer months. It may be that the total amount of travel on minor arterials increased even though the speeds drivers chose did not change. Preliminary analysis of traffic count data shows that the number of vehicles crossing the minor arterial polling stations used in this study increased by approximately 800 cars per day after the speed limit increase.

Explanations for the unexpected results on primary arterials may be available. The first is that the preintervention series used to estimate driver behavior variables may be too small (six data points) to capture the effects of the intervention on primary and minor arterials. It may be that the significant increases found on primary arterials are due to seasonal factors such as family vacations that naturally occur during June, July, and August of each year and the vacationers are more likely to choose larger highways. This makes sense since drivers who are traveling greater distances are more likely to exceed the speed limit (Solomon 1964). No significant increases on minor arterials may be due to drivers choosing safer highways with higher speed limits to travel to their vacation destinations. Another explanation is that the methods used to collect data are flawed. It may be that the small number of ATR sites used to collect the data are biased and do not reflect driver behavior on each type of highway statewide. While there is no further reason to believe the data are flawed, much more extensive data collection would be needed to assure there is no bias. The small number of sample sites and limited preintervention series leads to relatively low confidence in the results of the driver behavior analyses on minor and primary arterials.[1]

Impacts on Rural Highway System

Perhaps the most important policy question is whether increased speed limits on interstate highways have led to an increase in the overall number of crashes, injuries, and fatalities on the state's rural highway system. Figures 13, 14, and 15 plot the number of crashes, injuries, and fatalities on Georgia's rural highways for the period studied. Note that the injury and fatality variables exhibit a noticeable upward trend, signifying a move toward decreases in highway safety on Georgia's rural highways.

An ARIMA analysis was conducted on each statewide highway safety variable. The results are shown in Table 11. None of the measures changed significantly due to the intervention. While it may be that increased seatbelt use and enforcement played a part in keeping the number of injuries and fatalities stable, this does not explain the lack of increase in automobile crashes. According to risk compensation theory as presented by Peltzman (1975) and Wilde (1988), the incidence of riskier driving should increase as more drivers wear seatbelts, thereby increasing the number of crashes. The number of injuries and fatalities would not necessarily change.

1. Driver behavior variables for interstate highways are less susceptible to biases since data were collected from four sites instead of two. The small preintervention series remains a problem for interstate driver behavior variables.

Figure 13. Rural Highway Crashes in Georgia, 1995–1997

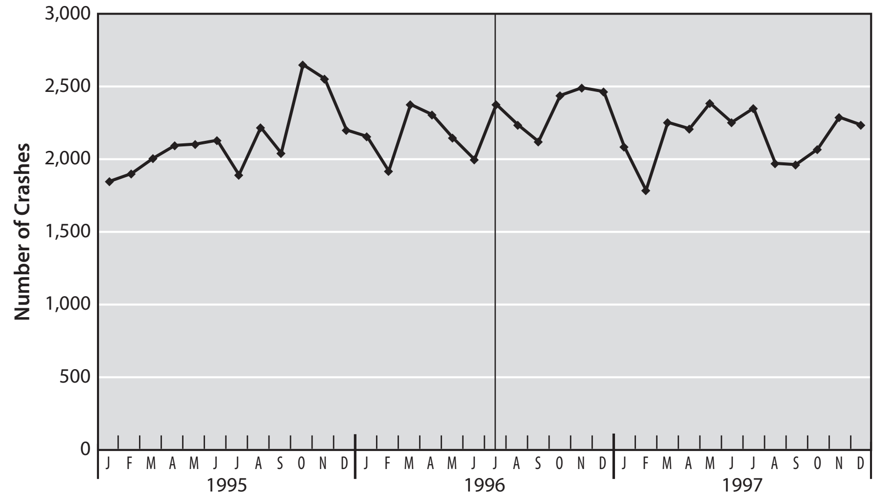


Figure 14. Rural Highway Injuries in Georgia, 1993–1997

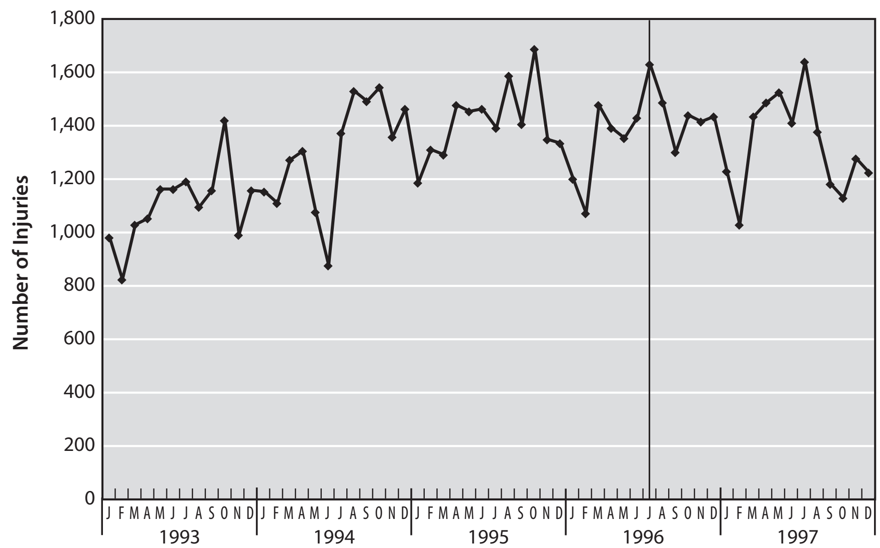
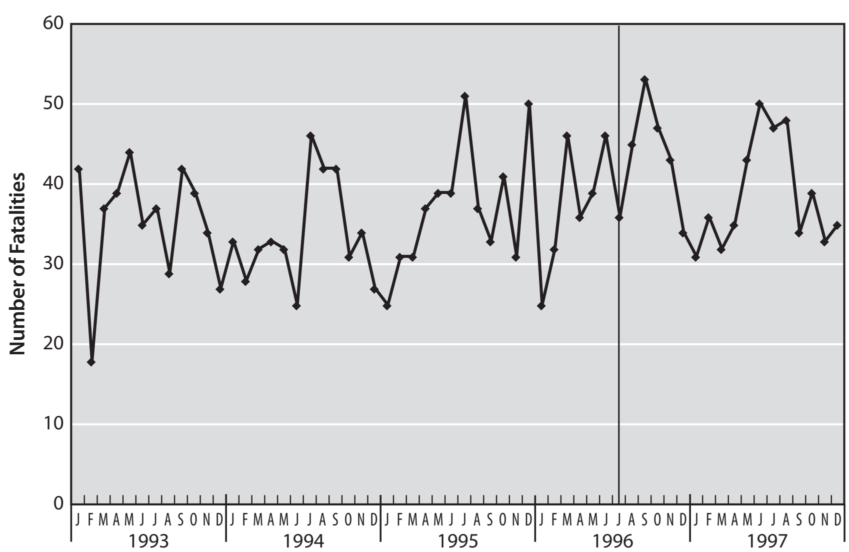


Figure 15. Rural Highway Fatalities in Georgia, 1993–1997



A more likely explanation is that increasing speed limits on interstates has not reduced safety on Georgia's rural highway system.

The final state highway system policy question concerns whether increased speed limits on Georgia's interstate highways led to more drivers choosing to travel more often and on interstate highways. The results of empirical analysis are presented in Table 12. The percentage of drivers choosing to travel on interstate highways increased by 2.9 percent, representing a significant increase. Results for minor and primary arterials indicate no significant changes. Less than significant changes on smaller highways have led to significant increases in travel on Georgia's interstate highways. While enough data were not available to rule out seasonal trends, these results imply that drivers have chosen to travel safer highways with higher speed limits.

The results of analysis on whether increased speed limits led to increased travel levels are also found in Table 12. The number of automobiles crossing polling stations, or TCOUNT, increased by 54,442 automobiles in July 1996. The difference of means test shows this increase to be statistically significant. It should be noted that this finding is consistent with summer vacation travel patterns, which offers a more likely explanation for changes in route choice and increased travel than do speed limit increases. While the result is consistent with the finding that the number of fatalities have increased on Georgia's interstates, it does not explain the absence of increase in interstate crashes or injuries or in statewide highway safety variables.

Table 11. Crashes, Injuries, and Fatalities on Georgia's Rural Highways

Dependent Variable	Variable	Intervention Coefficient	T Ratio
Statewide Crashes	Constant	16.288	0.66
	AR(1)	− 0.384	− 2.29
	AR(2)	− 0.299	− 1.70
	AR(3)	− 0.407	− 2.38
	ΔCrashes	− 17.347	− 0.49
Statewide Injuries	Constant	12.287	0.59
	AR(1)	− 0.328	− 2.60
	ΔInjuries	− 24.637	− 0.64
Statewide Fatalities	Constant	0.095	0.12
	AR(1)	− 0.421	− 3.61
	AR(2) (7)	− 0.257	− 2.13
	ΔFatalities	− 0.401	− 0.27

Table 12. Travel Patterns and Counts on Georgia's Rural Highways

Dependent Variable	Mean before July 1996	Mean after July 1996	Observations Pre/Post	DF	T Statistics
PERINTER	0.853	0.882	6/18	8	− 1.77*
PERPRIM	0.073	0.061	6/18	7	1.33
PERMINOR	0.072	0.057	6/18	9	1.37
TCOUNT	196044.7	250487.2	6/18	13	− 2.01**

*Statistically significant at 0.10 level (one-tailed test)
**Statistically significant at 0.05 level (one-tailed test)

Policy Implications

This study was prompted by a series of legislative changes concerning highway safety at the federal and state levels over the last 30 years. An integral part of making automobile travel safer was the introduction of the National Maximum Speed Limit of 55 mph in 1975, an attempt to both save petroleum and protect people from the dangers of choosing high speeds. The tenor of legislative activity began to change in the late 1970s as Congress put greater emphasis on making government operations more efficient and regulation less restrictive. Compliance measures were weakened, fines for noncompliance were placed under moratorium, and in 1986 the national speed limit was increased to 65 mph. The National Maximum Speed Limit was repealed in 1995, allowing states to set their own speed limits. Many states, including Georgia, responded by setting their speed limits at 70 mph or higher. This paper tested the impact of higher interstate speed limits in Georgia.

The first empirical tests concerned the effects of increased speed limits on Georgia's rural interstate highways. While the speed limit boost from 65 mph to 70 mph did not result in a significant increase in crashes or injuries, the new law did coincide with higher average speeds and an increase of almost two interstate highway fatalities per month. The increased fatalities are best explained by tests of compliance and variance measures that found (1) a significant increase in the percentage of drivers traveling greater than 86 miles per hour and (2) greater variance in the speeds drivers choose. This explanation is consistent with and supports past studies showing rapidly increasing levels of fatalities as speeds and the change in speed at impact (DV) increase (Bowie and Waltz 1994, Joksch 1993, West and Dunn 1971).

The findings that AVGSPEED increased is consistent with previous studies. There is some evidence that the increase in average speed predicted by Fildes and Lee (1993) and noted in the studies presented in Tables 2a and 2b did occur on Georgia's interstate highways. While the findings presented here concerning mean speeds and speed limits are not conclusive, the results do warrant further investigation.

The second set of policy questions were tested to determine if increasing speed limits on interstate highways affected highway safety on two additional types of rural highways in Georgia. While neither minor nor primary arterials exhibited increases in average speed, the percentage of drivers on primary arterials traveling more than 10 mph over the speed limit or traveling 86 miles per hour and faster has increased significantly. The primary arterial results complicate our understanding of the relation-

The most obvious policy change is to increase levels of patrols on interstate highways.

ship between driver behavior and highway safety. The relationship that seemed to hold true on interstate highways, that increasing speed and change of velocity on impact lead to greater fatalities, was not evident on Georgia's primary arterials.

It was surprising, then, to find that while primary arterials have experienced no change in the number of crashes, injuries, or fatalities, minor arterials have seen statistically significant increases in all three variables. This study can offer no conclusive explanation for the decrease in highway safety on Georgia's minor arterials, since none of the driver behavior variables changed in connection with increased speed limits on Georgia's interstate highways.

Other empirical tests concerned whether increasing speed limits on Georgia's interstate highways has decreased highway safety measures and changed driver behavior across all of the state's rural highways. Highway safety on Georgia's rural highways has not been diminished with the increase in speed limits on the state's rural interstate highways. No significant increases in the total number of crashes, injuries, or fatalities on Georgia's rural highways were found. There were significant increases in the percentage of drivers choosing interstate highways and a significant increase in the total number of automobiles on the state's rural highways, but these findings may be related to summer travel patterns rather than the increased speed limit.

Given that statewide measures of highway safety have not changed, one could easily conclude that no policy changes are necessary. However, the goal of public policy in highway safety is not to increase the freedom and convenience of automobile travel alone, but to reduce the risks associated with automobiles. This research highlights some areas with potential for substantial improvements in rural highway safety despite the increased speed limit.

…do away with the buffer zones that allow drivers to exceed speed limits without fear of sanction.

Any policy changes in Georgia should focus on reducing the incidence of drivers traveling at the highest rates of speed, especially on rural interstate highways. Such action should reduce speed variance and would benefit drivers by protecting the fastest drivers from themselves while reducing the risks to drivers that choose more reasonable speeds. The most obvious policy change is to increase the level of patrols on interstate highways. While Lave and Elias (1994) suggest this approach has worked in other states, it ignores the significant increase in FASTEST on primary arterials and the significant decreases in highway safety on minor arterials. Another policy option might be to follow Georgia Sen. Mary Margaret Oliver's suggestion that police officers reduce or do away with the "buffer zone" that allows drivers to exceed speed limits without fear of sanction (Emling 1996b). Strict adherence to speed limits may lead the fastest drivers to slow down, since speed choice is related to the probability of being sanctioned. Finally, policy makers in Georgia should explore highway design options that make it less comfortable to travel at the highest rates of speed. Epidemiologist William Haddon (1972) has suggested that changes in the driving environment may provide the best chance for significant improvements in highway safety over the long run.

The research presented in this report requires that further inquiry be conducted in at least two areas. The first area concerns the sudden decrease in highway safety on Georgia's minor arterials since July 1996. The causes of the increase in crashes, injuries, and fatalities on these smaller highways need to be identified so that their negative effects may be remedied.

The relationship between speed limits, intervening variables such as average speed, and highway safety is another area that requires further research. The fact that the results of speed limit increases are not consistent across studies, highway types, and states suggests that important variables have not been accounted for correctly. If important regional and/or local factors and their relative effects are identified, future studies could advance understanding of when speed limit increases are reasonable. Longitudinal data that allow for ARIMA analysis of driver behavior variables would also benefit future studies. The result of identifying and adjusting for regional and local factors should be the increased welfare of society through safer highways.

...explore highway design options that make it less comfortable to travel at the highest rates of speed.

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Appendix: ARIMA and Controlling for the 1996 Summer Olympics

This appendix presents a more detailed review of the statistical methods used to test the policy questions than is given in the text of the paper. An introduction to ARIMA (autoregressive integrated moving average) modeling and its use in highway safety research is first presented and then followed by an explanation of how ARIMA allowed the researcher to control for the occurrence of the 1996 Summer Olympic Games.

All of the crash, injury, and fatality hypotheses presented in this policy paper are tested using ARIMA techniques on monthly data between January 1993 and December 1997. The decision to use ARIMA methods instead of the more common ordinary least squares (OLS) regression is based on the unique challenge time-series data present to the assumptions of OLS. Time-series data are problematic in that observations are often much more highly correlated to the observations just before or after than others, thereby defying the OLS requirement that "residuals, or error terms associated with each time-series observation, be independent" (McCain and McCleary 1979). OLS is not the appropriate methodology for this study since each of the hypotheses is to be tested using time-series data that may exhibit autocorrelation. McCain and McCleary suggest ARIMA analysis as a better alternative.

The use of ARIMA in highway safety research is a common and accepted practice. Noting that "[ARIMA] is particularly appropriate to identify significant shifts in transportation data associated with legal changes," Steven Rock (1995) describes the technique:

> The goal of the ARIMA method is to describe the stochastic autocorrelation structure of the data series and, in effect, filter out any variance in a dependent variable (e.g., monthly traffic accidents or consequences) that is predictable on the basis of the past history of that variable. This includes trends over time, such as the influence of changes in VMT (itself affected by number of vehicles, driving age population, and economic conditions).... ARIMA offers a number of advantages (Wagenaar 1984). It explicitly takes into account all of the significant autocorrelations within each variable and does not simply assume that the error terms are independent (as does regression) or only characterized by first-order autoregression. This implies that any regular pattern over time in the dependent variable that is similar to the pattern of potential independent variables over time is not considered as a possible causal effect between the variables; such interseries regularities are filtered

> out first. Effects of many exogenous variables are controlled, independent error terms are obtained, and these procedures are a conservative test of the causal connection between two variables. (Rock 1995, 209–10)

ARIMA modeling, then, allows us to separate the effects of speed limit changes from other possible explanatory variables.

ARIMA analysis is conducted in four steps to model the stochastic error in a dependent variable. Steven Rock explains the steps:

> The procedure starts with building a model to pattern the preintervention data. This involves displaying the autocorrelation and partial autocorrelation functions (ACF, PACF) and comparing them to specific known patterns. From these, a preliminary model is identified, indicating the nature of up to three filters that may need to be applied to the raw data. If secular trends in the data are evident, the first filter will be used to account for them. The coefficients for the parameters of the autoregressive and/or moving average filters, if needed, are next estimated. Using diagnostic tests (including the statistical significance of the parameters, the residual ACF and PACF, the Box-Ljung Q statistic, and the Akaike information criterion) the model is critiqued and reidentified, if necessary. . . . The raw data are then passed through the specified filters. Remaining changes in the data can be related to the effects of an intervention term that began at a specified time (such as a speed limit change); the value and statistical significance of this term will indicate to what extent the policy had an impact. (1995, 210)

ARIMA analysis allows the researcher to remove confounding trends in the data, thereby removing many alternative explanations for results and isolating the intervention effects.

ARIMA analysis also allows the researcher to estimate what kind of change occurs if the intervention has had an effect. The method requires that transfer functions be used as the primary independent variable to determine whether the change is abrupt, gradual, or temporary. An abrupt, constant change occurs when an intervention has a significant effect at the time of intervention that is long lasting. Gradual, constant changes occur when the intervention corresponds with a change in rate or direction in the dependent variable that does not return to preintervention levels over time. Abrupt, temporary changes signify an initial change due to the intervention, but a relatively quick return to preintervention levels. McCain and McCleary note that "the analyst will sometimes have an a priori notion as to the nature of the hypothesized effect and will choose a transfer function accordingly" (1979, 265). Rock (1995) suggests that speed limit changes should be modeled as abrupt, constant changes. For this reason, the independent variable in this study is a step function dummy variable consisting of "0" before speed limits were changed and "1" thereafter.

The 1996 speed limit changes coincided with the Summer Olympic Games of 1996 held in Atlanta. The event provides a substantial rival explanation for any changes in highway safety occurring during the Summer of 1996. The surge of out-of-state visitors driving unfamiliar highways to athletic venues throughout Georgia could easily inflate crash, injury, and fatality statistics. However, one would expect that the inflationary factors associated with the Olympics would disappear after their conclusion. For this reason, the time series presented in the paper were first modeled as abrupt, temporary changes. These models did not provide a good fit to the data, signifying that the Olympic games did not have a significant impact on the highway safety measures associated with the introduction of higher speed limits on Georgia's rural highways. Modeling the change in speed limit as an abrupt, constant change as suggested by Rock (1995) provided a better fit to the data.