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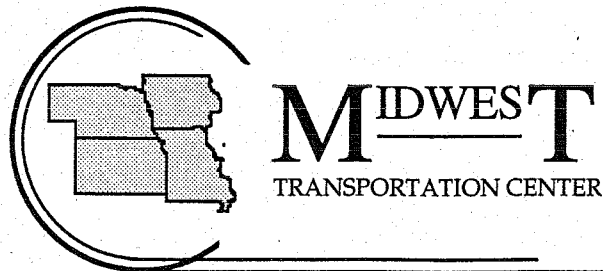
# SAFETY IMPACT OF THE INCREASED 65 MPH SPEED LIMIT ON IOWA RURAL INTERSTATES

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Commissioned by the  
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a consortium of Iowa State University  
and the University of Iowa

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## PREFACE

In response to a change in federal policy, on May 12, 1987, the state of Iowa raised the maximum speed limit on most of its rural interstate highway system to 65 miles per hour. Higher speeds on interstates are generally thought to produce many economic benefits, largely due to reductions in travel time. Quite often, however, higher speeds are associated with increased risk of vehicle accidents. The objective of this research is to examine whether a significant change in accident rates can be detected following implementation of the higher speed limit on rural interstate highways in Iowa.

Our analysis incorporates data on vehicle miles of travel (VMT) and accidents involving at least one fatality or a major injury. These data are quarterly, for the period of 1981 to 1991. They have been separated into several classifications of roads, including rural interstate highways, which are the subject of this analysis.

Safety on Iowa roads improved during the 1980s. From 1981 through 1991, the risk of being in a fatal accident, per vehicle mile traveled, decreased by 20 percent; for major-injury accidents the reduction was 37 percent. These reductions probably can be attributed to safer cars, safer roads, seat belt laws, and more effective enforcement of traffic regulations. These factors are not explicitly treated in our analysis.

Applying time series analysis, and controlling for a general growth in VMT, an increase in fatal accidents is detectable around the middle of 1987 on rural interstates. This leads to the conclusion that the increase in speed limit on Iowa's rural interstate highways in May of 1987 has contributed to a rise in fatal accidents. We did not find a similar increase in major-injury accidents, however.

Research for this project was carried out at the University of Iowa Department of Statistics and Actuarial Science. Funding was provided by the U.S. Department of Transportation, University Transportation Centers Program. This program was created by Congress in 1987 to "contribute to the solution of important regional and national transportation problems." Following a national competition, the program established university-based centers in each of the ten federal regions. The Midwest Transportation Center that funded this project is one of those centers; it is a consortium that includes Iowa State University and the University of Iowa. Matching funds were provided by the Iowa Department of Transportation, which also provided the extensive data needed to complete this project. Additional support was provided by the National Science Foundation (grant DMS 91-18626).

## ACKNOWLEDGMENTS

In the preface, we mention financial support of our research by the U.S. Department of Transportation, University Transportation Centers Program; the Iowa Department of Transportation; and the National Science Foundation. These organizations have our gratitude for their support.

Data needs for this project were sizable. Dr. Joyce Emery of the Iowa Department of Transportation assisted us in acquiring the accident data upon which our analysis is based. We greatly appreciate her efforts.

Drs. Aladdin Al-Bakri and Michael Suelzer provided research assistance at various stages of the project. Particularly important to us was their work in preparing the data for analysis.

While the conclusions of the analysis are those of the authors, these people made important contributions. We are very grateful for their help.

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## SECTION 1 INTRODUCTION

The Surface Transportation and Uniform Relocation and Assistance Act of 1987 allowed states to raise the maximum speed limit on rural interstate highways from 55 mph to 65 mph. By the end of 1987, 38 states, including the state of Iowa (on May 12, 1987), had raised the maximum speed limit on designated rural portions of their interstate highway system.

A lingering issue is what impact this increase in speed limit has had on safety. In this research we examine changes in traffic accidents on rural interstate highways, using the state of Iowa as a case study.

Special problems arise when examining changes in accident rates on rural interstate highways. There are few accidents per 100 million vehicle miles traveled (VMT) on these highways, far fewer than on other types of roadway. Analyzing changes in accident rates before and after the speed limit change is difficult because both rates are very low. Specifically, statistical models that require the usual normal distribution assumption are not appropriate for such small count data. We develop a statistical model that is appropriate for these data and apply it to quarterly figures of fatal accidents on rural and urban interstate highways.

The objective of this research, then, is to examine fatal accident rates on Iowa rural interstates prior to and after institution of the 65 mph speed limit in 1987. Controlling for seasonal variations in fatality rates, we assess the extent to which these rates have changed following this change in speed limit. We begin by reviewing the conclusions of other studies of fatal accident rate change when speed limits were changed. Then we describe the specific circumstances present in Iowa during the period of analysis, as well as the data used in our analysis. A statistical analysis of the Iowa data is performed, followed by our interpretation of what reasonably can be concluded from this analysis.

### WHAT OTHER STUDIES HAVE FOUND

In the early 1980s, the National Research Council (1984) predicted that returning the speed limit on rural interstates to their pre-1974 level in all states would result in 500 more fatalities annually, a 20–25 percent increase on these highways. Following the 1987 Act, states began adopting 65 mph speed limits. Several studies have investigated the impact of changing rural interstate speed limits on actual travel speeds and traffic safety, using different time periods, data, and statistical methods. While not every study reaches the

same conclusion, the combined evidence suggests that the speed limit change did negatively affect safety.

On the other hand, in an analysis of Illinois data, Pfefer and Stenzel (1989) found that the speed limit change raised the actual traffic speed on rural interstates, but it was not accompanied by a corresponding increase in accidents. Yet Sidhu (1990) found that during the initial 12 months following the higher speed limit, the numbers of fatal accidents in Illinois on 65 mph rural interstates were higher than expected. We should note that Sidhu's estimate of a 15 percent increase is subject to large uncertainty and was not statistically significant.

Nakao (1989) showed that within a few months, the average traffic speed and 85th speed percentile on 65 mph rural interstates in California had increased by 2.5 mph. On 55 mph interstates, traffic speed increased by 1.1 mph, suggesting a possible carryover effect from the adjacent 65 mph sections. Bamfield (1989), however, concluded that during the first year of the higher speed limit, the number of fatal accidents and injury accidents in California did not increase.

Epperlein (1989), in an analysis of Arizona data, concluded that during the 20 months following the increase in speed limit, the number of traffic accidents on 65 mph rural interstates increased by 32 percent, and the number of deaths and injuries increased by 36 percent. On the other hand, the corresponding frequencies on 55 mph interstates were largely unaffected. Epperlein estimated that since the speed limit was raised, Arizona's rural interstates experienced about three deaths and 50 injuries per month more than would have occurred if the speed limit had remained at 55 mph.

Jernigan and Lynn (1989) analyzed data on fatal accidents in Virginia (which increased the speed limit in 1988), as well as in other 65 mph and 55 mph states. Comparing 1987 (prior to speed limit increase) and 1989 (post), Jernigan and Lynn reported a 47 percent increase in the number of fatal accidents on Virginia's rural interstates. Other 65 mph states experienced a 32 percent increase in fatal accidents, almost twice the increase for 55 mph states (17 percent).

Baum, Lund, and Wells (1989) presented a summary analysis of fatalities on rural interstates with a posted 65 mph speed limit. The study, using the combined evidence from 38 states which elected to raise the speed limit, found that the speed limit change is associated with a 15 percent increase in fatalities. An analysis for states that kept the 55 mph speed limit showed no corresponding increase.

McKnight and Klein (1990) compared fatal accidents for 55 mph and 65 mph states. In states that adopted the new 65 mph maximum speed limit, the number of fatal accidents on rural interstates increased by 22 percent. This increase translates into approximately 300 more fatal accidents a year. In states that retained the 55 mph speed limit, fatal accidents on rural interstates and other 55 mph highways rose an estimated 10 and 13 percent, which incidentally amounts to an annual increase of about 300 fatal accidents per year, as well. In states where the speed limit was not raised, the increase in fatal accidents was attributed to a rise in speed limit infractions.

Garber and Graham (1989) conducted separate analyses for each of the 40 states that had adopted the 65 mph speed limit by mid-1988. Their results suggest an increase in both rural interstate and rural non-interstate fatalities. However, the effects differ substantially across states. For rural interstate fatalities the estimates suggest a median increase of approximately 15 percent; for rural non-interstate roads, the median increase is five percent.

Brackett and Pendleton (1988) analyzed the effects of a May 1987 speed limit change, using Texas traffic speed and accident data. Their analysis suggests that accidents and accident severity increased on 65 mph roadways. In the first year of the 65 mph speed limit, the number of serious accidents on 65 mph roadways increased by 20 percent. No increases could be found for intersecting and contiguous 55 mph road sections.

## **SUMMARY**

Thus, while the results of previous studies and the methodologies used to derive them have varied, the general pattern has been for fatal accident rates to climb after speeds on rural interstates were increased to 65 mph. The studies we reviewed examined the impacts of speed limit changes in different states, which adds credence to the pattern we observed using data from the state of Iowa.

## SECTION 2 DATA FOR THE IOWA STUDY

To carry out our time series analysis of fatal and major-injury accident rates prior to and after the change in the speed limit on rural interstate highways, numerous data were needed. In this section we describe the data we used in our analysis. These data fall into three categories: traffic speed, traffic volume, and number of fatal and major-injury accidents. All of these data were obtained for quarters of years (three-month intervals) for the period of 1981 through 1991. Each category of data is briefly described in turn.

### TRAFFIC SPEED DATA

Traffic speed data were obtained from the Office of Transportation Inventory of the Iowa Department of Transportation. Detailed records from 24-hour monitoring periods for 13 control and five standard stations were available each quarter. The same 13 control stations (three on rural interstates, two on urban interstates, six on rural principal and minor arterials, and two on rural major collectors) were used each quarter. Measurements on 20 standard stations (four on rural interstates, 12 on rural principal and minor arterials, and four on rural major collectors) were taken once a year; a different set of five standard stations was used each quarter.

Rural principal and minor arterials are two-lane or four-lane non-interstate highways (either federal or state) which are subject to the 55 mph maximum speed limit. Rural major collectors are paved county roads, also subject to the 55 mph maximum speed limit.

Measurements obtained during each 24-hour observation period include the number of passing cars, average traffic speed, median traffic speed, speed standard deviation, 85th speed percentile, and proportions of cars exceeding 55 mph, 60 mph, and 65 mph. Furthermore, information on the measurement location and the day of week when measurements were taken are part of the available data.

In this report we analyze average traffic speed and proportions of cars exceeding 55, 60, and 65 mph. Quarterly summary statistics are calculated from roughly 1,000 individual 24-hour measurement periods. Weighted averages, with numbers of passing cars as weights, are used to estimate quarterly speed averages for urban interstates, rural interstates, rural principal and minor arterials, and rural major collectors.

Time series plots of quarterly speed averages for the four road classifications are given in Figure 2-1. The average traffic speed on rural interstates, shown in the upper left-hand corner, increases gradually from about 59 mph in 1985-86 to around 66 mph in 1990-91. The other graphs in Figure 2-1 show that average traffic speeds on roads subject to the 55 mph maximum speed limit changed very little; average speed increases were around one mph.

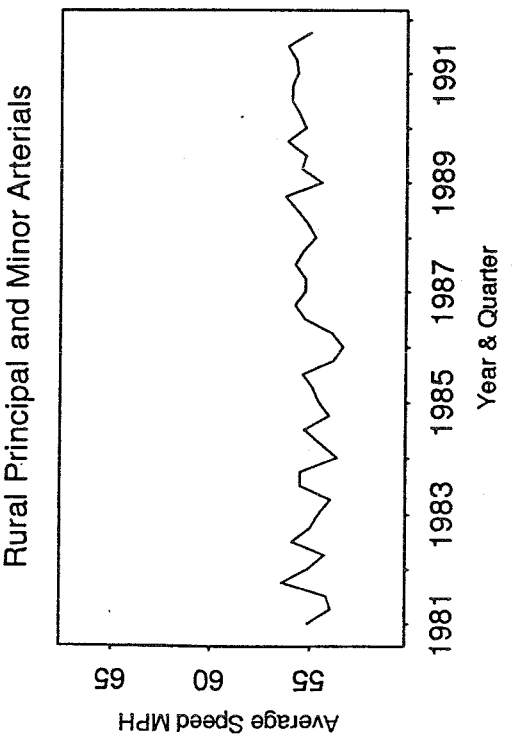
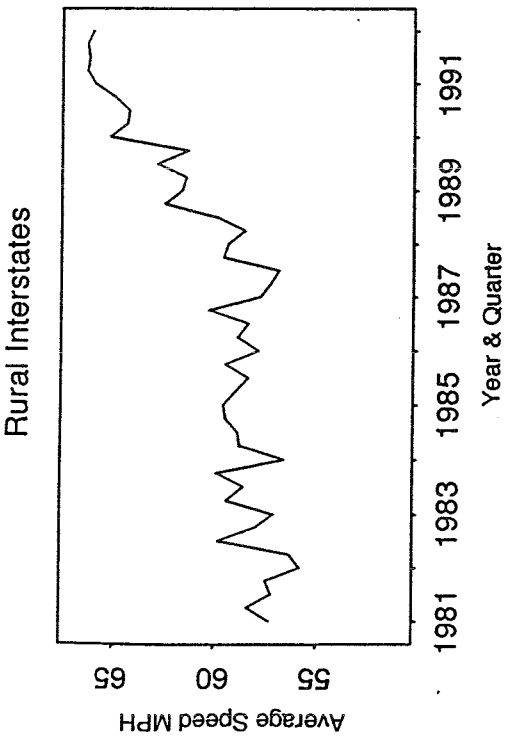
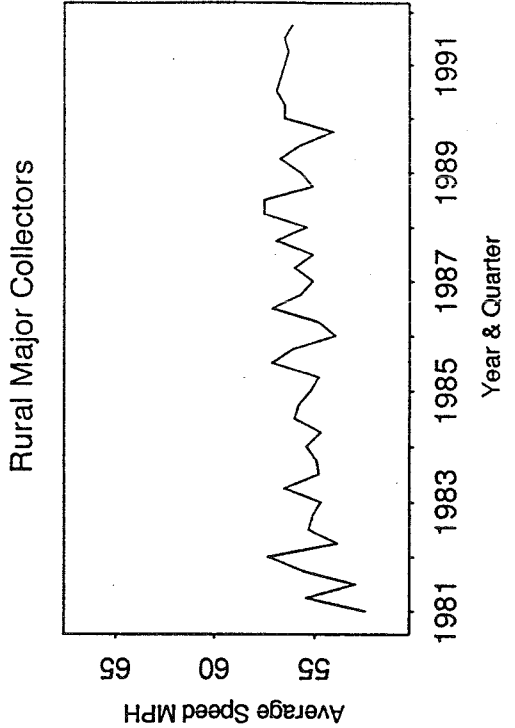
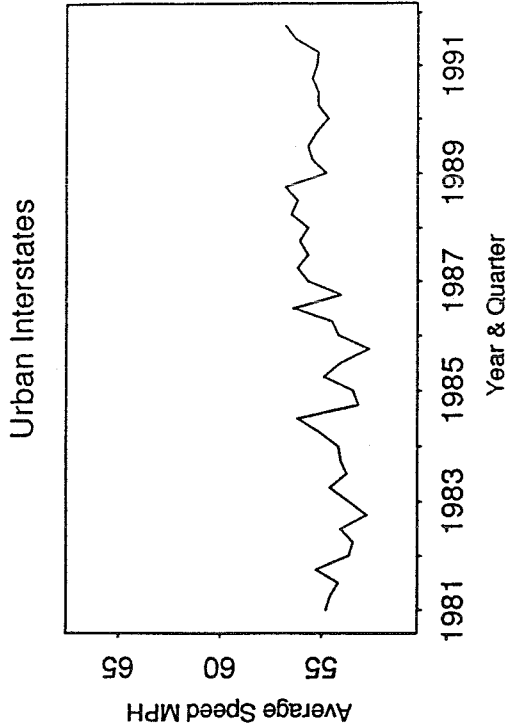
Time series plots of quarterly proportions of cars exceeding 55, 60, and 65 mph are given in Figure 2-2. For rural interstates these proportions increase quite substantially. The proportion of cars exceeding 60 mph increases from 37 percent in 1985-86 to 87 percent in 1990-91; for 65 mph the proportion increases from 12 to 57 percent.

It is often argued that automobiles traveling at different speeds compromise traffic safety. For this reason we also investigated time sequence plots of quarterly speed standard deviations,  $s$ . No trends could be detected at any of the four road systems. Furthermore, there was no change in  $s$  in response to the speed limit change on rural interstates. The time averages of  $s$  on rural interstates, rural principal and minor arterials, and urban interstates are very similar (4.9, 5.3, and 5.1 mph). The average speed standard deviation for rural major collectors (6.7 mph) is larger, indicating a wider range of travel speeds on this particular road system.

We also looked at time sequence plots of quarterly 85th speed percentiles. These graphs are very similar to the time sequence plots of speed averages in Figure 2-1; this is to be expected as standard deviations exhibit no trend. On rural interstates, the 85th speed percentiles increase gradually following the introduction of the new maximum speed limit, from 64 mph in 1985-86 to 71 mph in 1990-91. Increases on the other three road systems are much smaller.

## TRAFFIC VOLUME DATA

Information on estimated vehicle miles of travel (VMT) was obtained from the Office of Transportation Inventory of the Iowa Department of Transportation. Monthly and quarterly data on total VMT, as well as VMT for rural roads (interstate, primary, and secondary) and urban roads (interstate, primary, and secondary or city streets) were analyzed. The "rural primary" classification refers to federal and state non-interstate roads and is comparable to "rural principal and minor arterials" in the traffic speed classification. "Rural secondary" refers to county roads, comparable with the "rural major collector" classification for traffic speed data. VMT is estimated from 123 automatic continuous traffic recorder stations spread throughout the state. These counts are averaged and multiplied by the length of each road system.



**Figure 2-1. Quarterly average traffic speeds on rural interstates, urban interstates, rural principal and minor arterials, and rural major collectors**

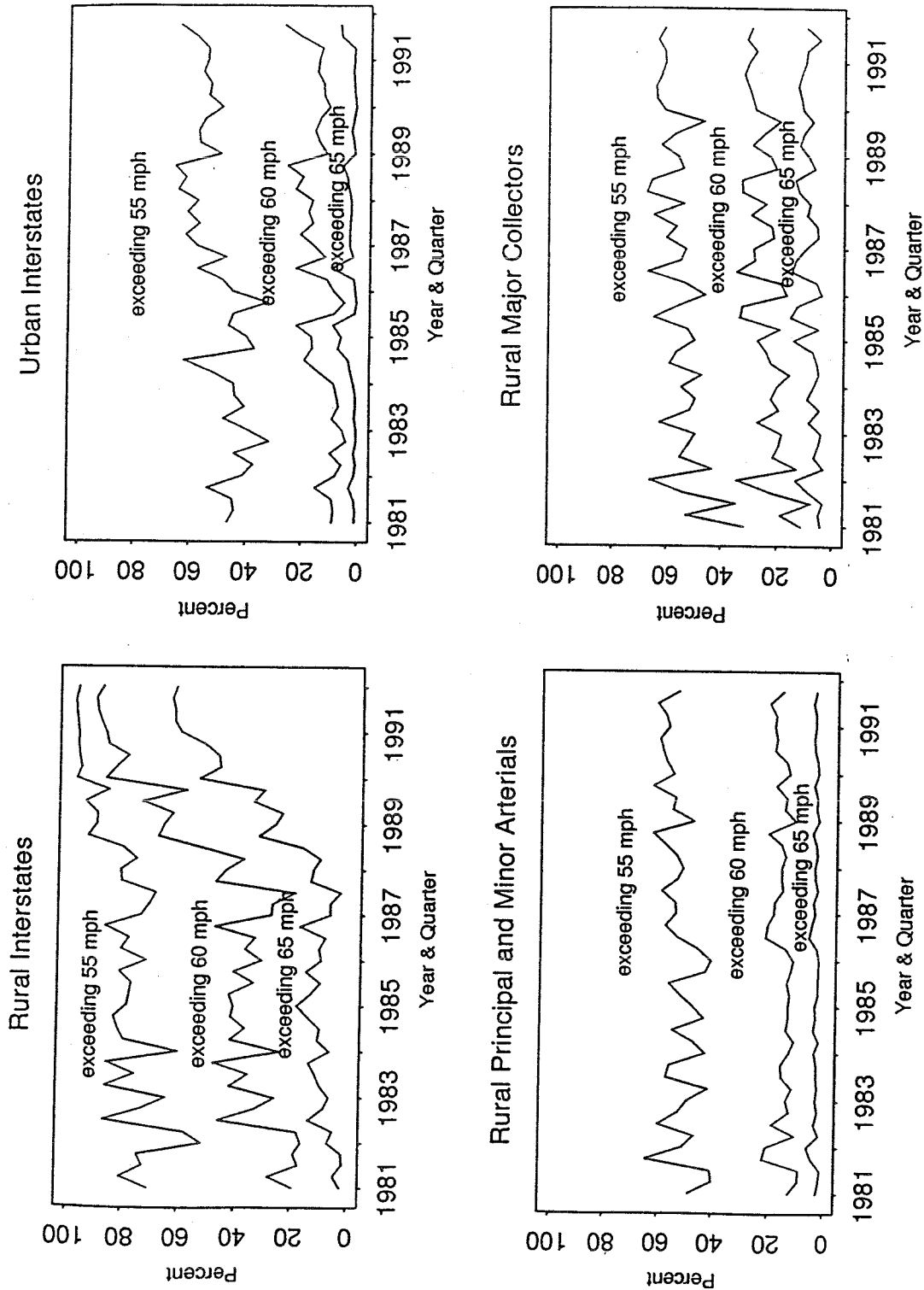


Figure 2-2. Quarterly percentages of vehicles exceeding 55, 60 and 65 mph: rural interstates, urban interstates, rural principal and minor arterials, and rural major collectors



Time sequence plots of quarterly VMT (Iowa total, as well as individual road classifications) are given in Figure 2-3. The time series graphs show that VMT has increased steadily from an annual average of 19,000 million miles in 1981-82 to 23,400 million miles in 1990-91. This amounts to an increase of 23 percent over nine years, or a 2.5 percent average annual increase. This increase applies to most road classifications, with perhaps the exception of rural secondary roads which experienced a somewhat smaller increase. VMT is seasonal with high values during the summer and low values during the winter months.

### FATALITY/INJURY DATA

Monthly and quarterly numbers of traffic accidents resulting in at least one fatality and numbers of major-injury accidents were obtained from the Traffic Safety Bureau of the Iowa Department of Transportation.

Time series plots of quarterly numbers of fatal and major-injury accidents are shown in Figure 2-4, for all Iowa roads combined and for rural interstates. About five percent of fatal and major-injury accidents occur on rural interstates. The number of fatal accidents on rural interstates increased around the middle of 1987.

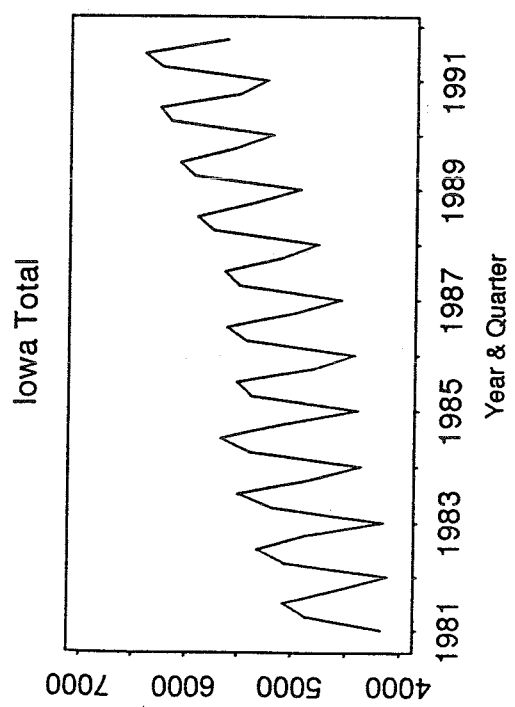
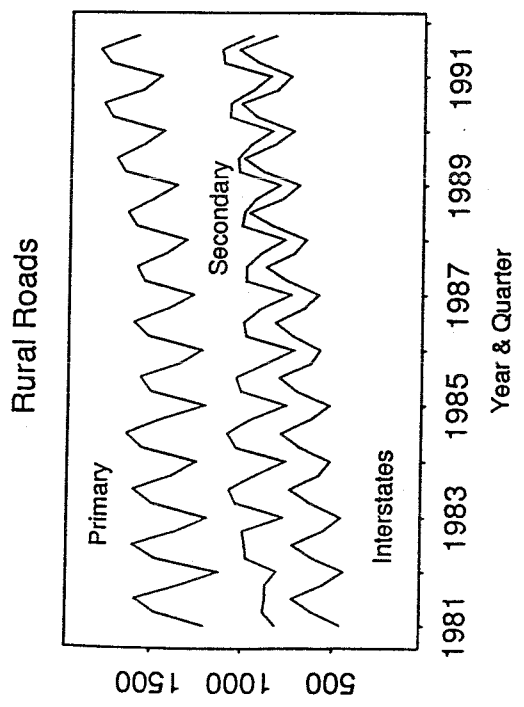
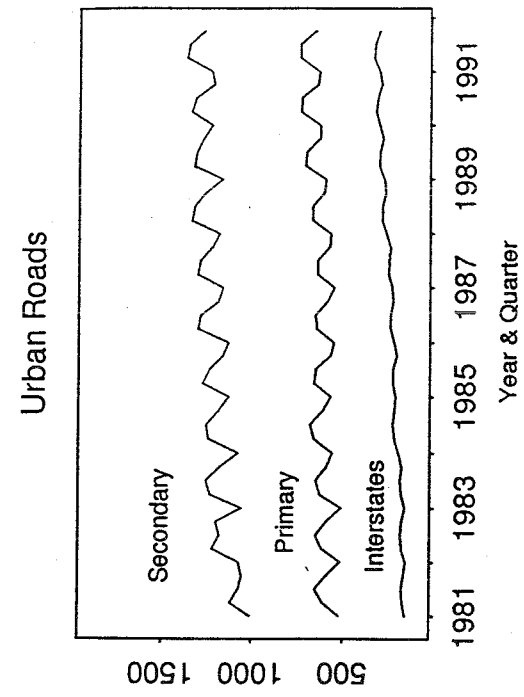
Numbers of accidents are also set in relation to the traffic volume (VMT). Quarterly numbers of accidents per million traveled miles for all Iowa roads combined and for rural interstates are shown in Figure 2-5. These ratios characterize the exposure to accidents. In Iowa the risk of being in a fatal accident, per each million traveled miles, is about 0.02, or two accidents per 100 million traveled miles. For major-injury accidents the risk is about sixfold greater. The risks decrease over time. On rural interstates the risk of being in a fatal accident is about half the risk for all roads combined. The risk of a fatal accident on rural interstates, however, did increase around the time of the speed limit change.

Figure 2-6 shows that while the rural interstate system is the safest, with the lowest risk of fatal accidents, the rural secondary road system appears to be the most dangerous. Figure 2-7 shows that for major-injury accidents, the risks on interstates (both rural and urban) are considerably smaller than those on the primary and secondary road systems. We have added centered four-point moving averages,  $MA_t = (1/8)(Y_{t-2} + Y_{t+2}) + (1/4)(Y_{t-1} + Y_t + Y_{t+1})$ , to the graphs in Figures 2-6 and 2-7. These weighted averages smooth out the seasonality in the series.

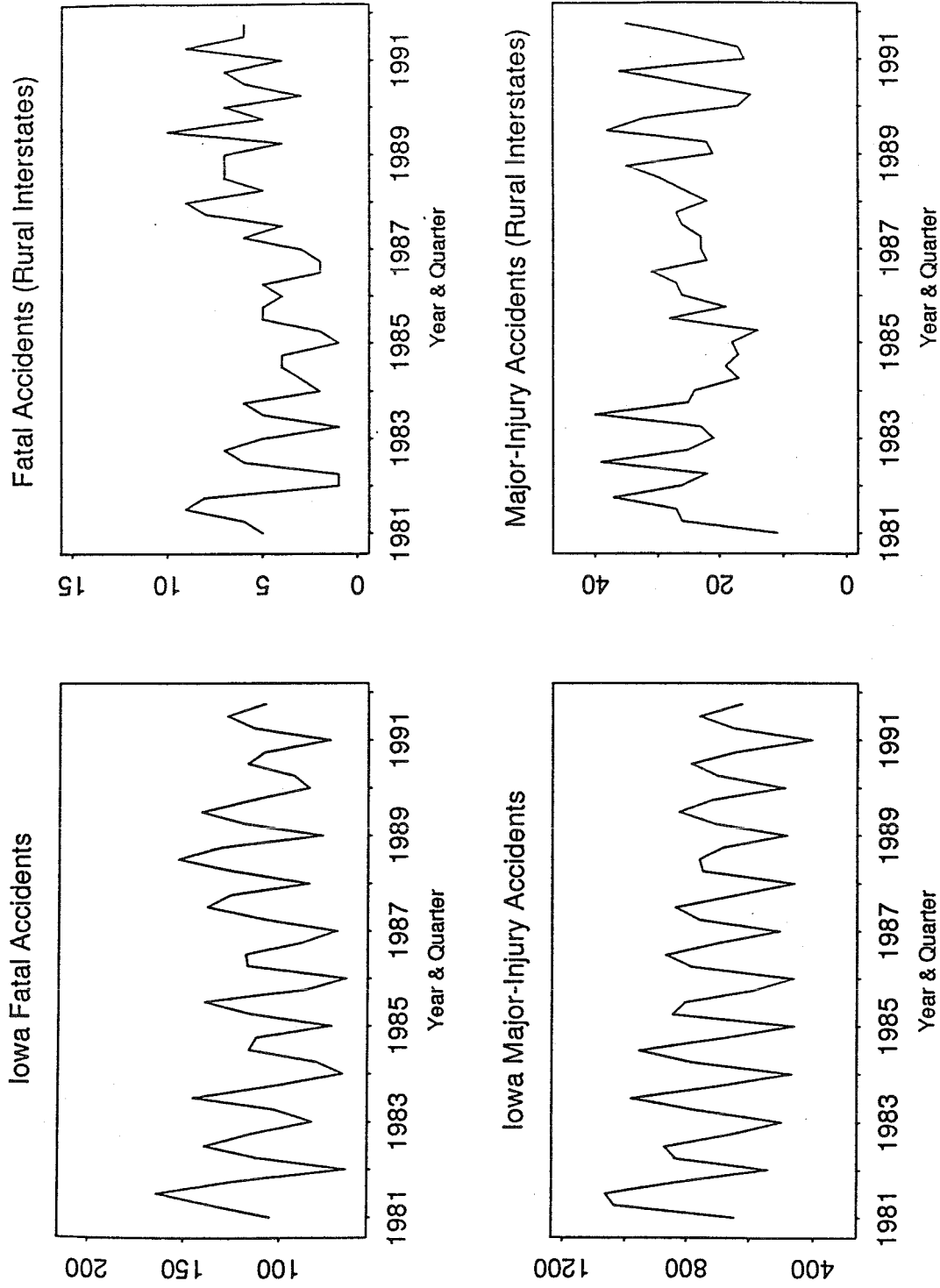
All time series graphs in Figures 2-5 through 2-7, with perhaps the exception of fatal accidents on rural interstates, show decreasing risks of fatal (major-injury) accidents. This reduction reflects safety improvements on cars and roads, and stricter enforcement of old and

new traffic laws. New cars are equipped with passive restraint systems, such as automatic seat belts and air bags. Furthermore, more drivers and passengers comply with the Iowa seat belt law, which has been enforced since January 1987. According to Iowa DOT surveys, the proportion of front seat motorists using seat belts from 1988 through 1991 remained fairly consistent (about 60 percent). Prior to the enforcement of the seat belt law the compliance was under 30 percent. The fact that in 1990 more than 60,000 seat belt citations were issued is evidence of the enforcement of this law. A TRB Special Report on Safety Belts, Airbags and Child Restraints (1989) estimated that these safety systems have led to a five to 10 percent reduction in the number of traffic fatalities.

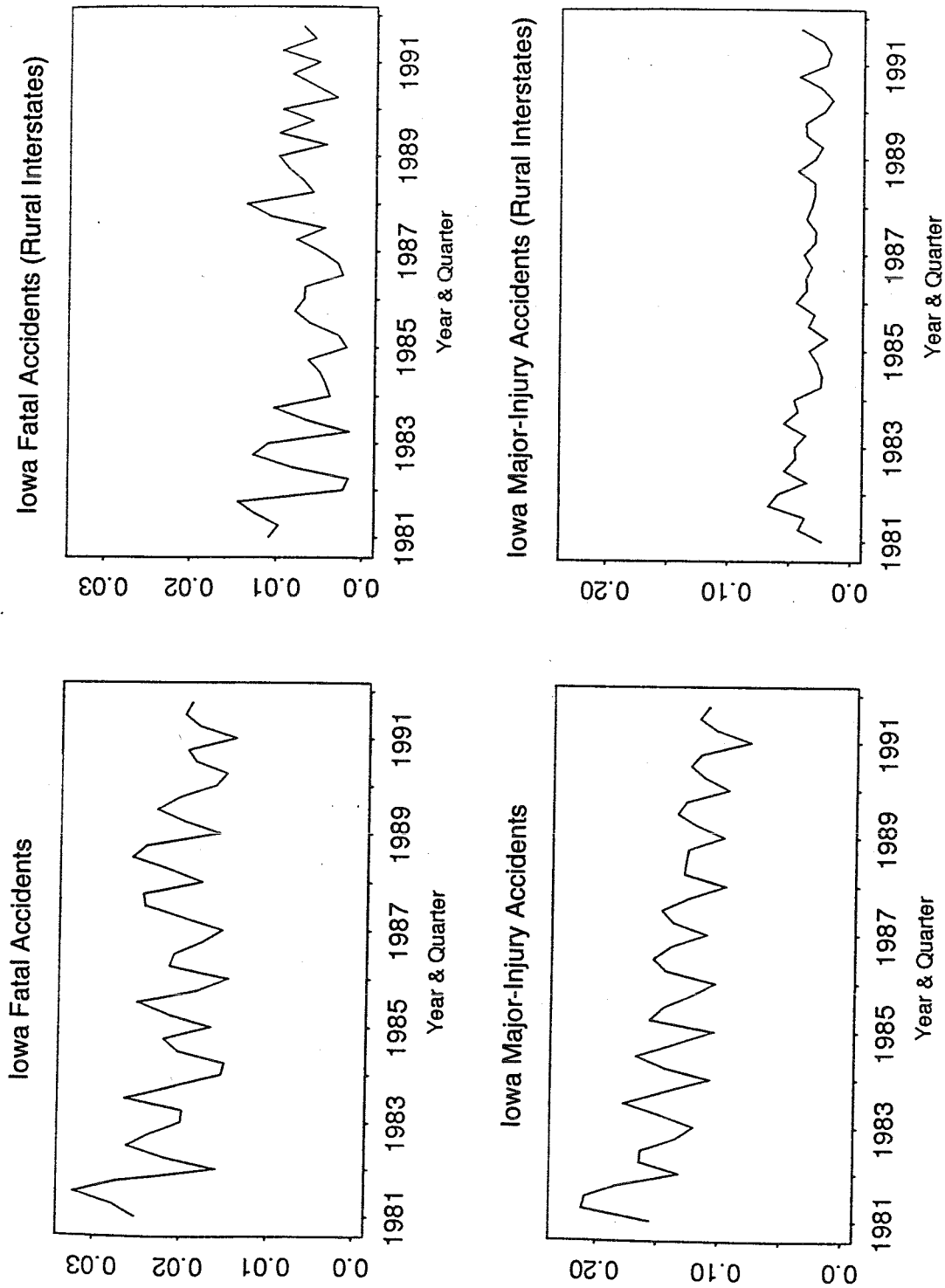
Alcohol plays another major role in traffic safety. In September of 1986 Iowa increased the minimum drinking age from 19 to 21 years. A report by the U.S. DOT (1989) on the impact of minimum age drinking laws estimated that this change has reduced the number of fatal accidents by about two percent.



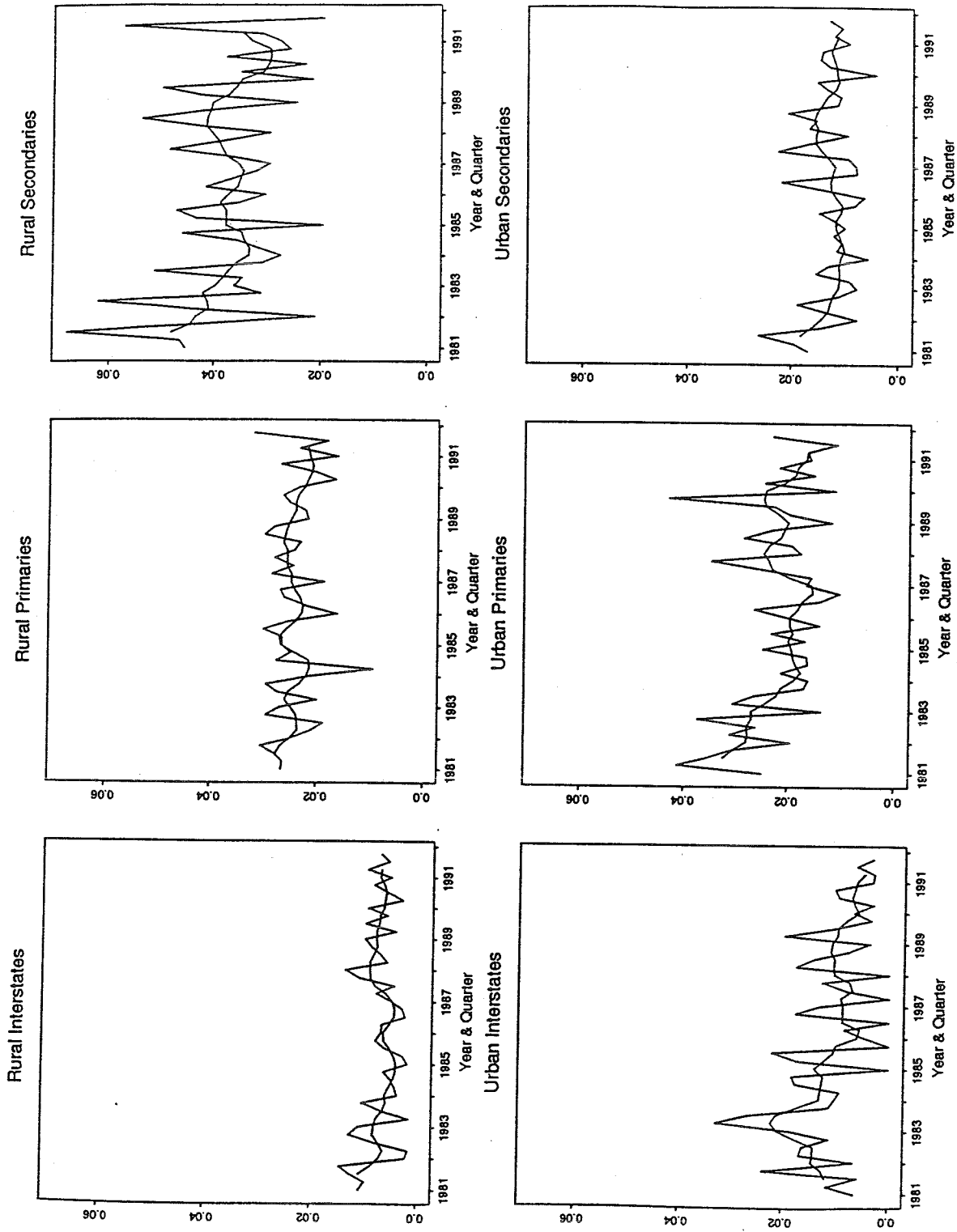
**Figure 2-3. Quarterly vehicle miles of travel (in millions): rural roads, urban roads and Iowa total**



**Figure 2-4. Quarterly numbers of fatal and major-injury accidents:  
all Iowa roads combined and rural interstates**



**Figure 2-5. Quarterly numbers of fatal and major-injury accidents per million vehicle miles of travel: all Iowa roads combined and rural interstates**



**Figure 2-6. Quarterly numbers of fatal accidents per million vehicle miles of travel: lowa rural and urban roads; smooth lines connect centered four-point moving averages**

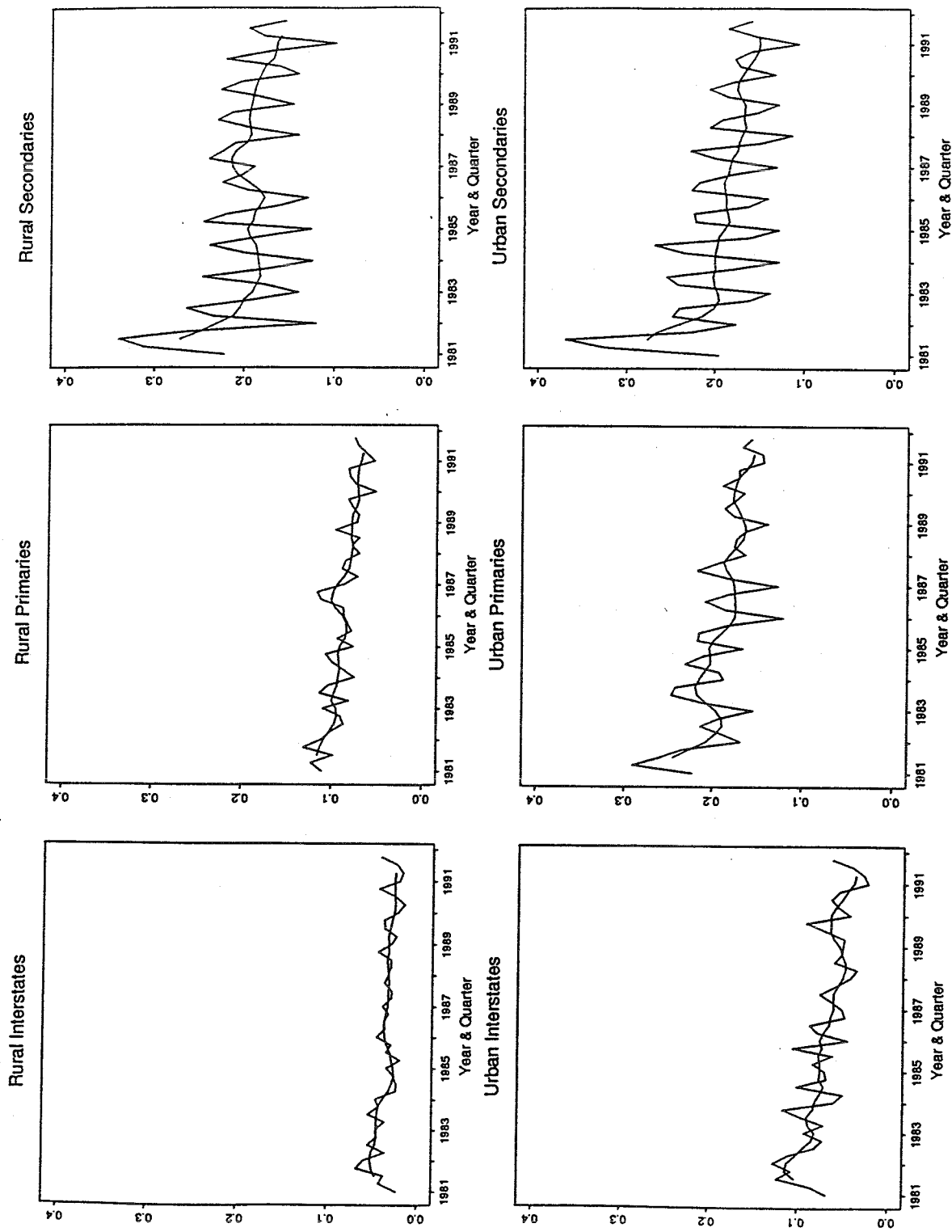


Figure 2-7. Quarterly numbers of major-injury accidents per million vehicle miles of travel: Iowa rural and urban roads; smooth lines connect four-point moving averages

**SECTION 3**  
**TIME SERIES ANALYSIS OF ACCIDENT RATES IN IOWA**

A main objective of this study is to assess the highway safety impact of the 65 mph rural interstate speed limit increase. We start with a simple “before-after” comparison where the four years from 1983 through 1986 reflect the 55 mph speed limit period (before) and the four years from 1988 through 1991 the 65 mph speed limit period (after). Comparisons with different data windows (such as 1984–1986 for before, and 1988–1990 for after) were also tried. Because the analyses with shorter data windows led to similar conclusions, we focus on the 1983–86 and 1988–91 periods.

**PRELIMINARY ASSESSMENT OF THE IMPACT OF THE SPEED LIMIT INCREASE**

This preliminary analysis examines yearly numbers of fatal (major-injury) accidents that occur on the various rural and urban road systems. In order to adjust the analysis for possible changes in traffic volume, we use vehicle miles of travel as a covariate and also analyze the numbers of fatal (major-injury) accidents, standardized by VMT. Table 3–1 shows the percentage increases for numbers of fatal (major-injury) accidents before and after adjustment by VMT. The last column in Table 3–1 lists the percentage increases in average traffic speed.

**Table 3–1. Percent increases in the number of fatal accidents and major-injury accidents**

Road system	Percent Increase				
	Raw data		VMT-adjusted data		Average speed
	Fatal accidents	Major-injury accidents	Fatal accidents	Major-injury accidents	
Rural interstates	82.1	11.3	38.2	-15.6	8.2
Rural primary roads	8.1	-14.0	-2.7	-22.6	1.7
Rural secondary roads	1.5	-0.9	-3.3	-5.6	1.4
Urban interstates	-18.2	-6.2	-42.1	-33.6	2.5
Urban primary roads	14.4	-8.3	4.6	-16.2	*
Urban secondary roads	19.5	-10.8	11.7	-16.6	*

\* No traffic speed data available

Fatal accidents on rural interstates increased by 82 percent (38 percent if increases are adjusted by VMT). This is a very large increase when compared with the numbers of fatal accidents on the other road classifications, which changed only little. The large increase in the number of fatal accidents on rural interstates correlates well with the increased average travel speed on rural interstates. The numbers of fatal accidents on urban interstates and on rural non-



interstate roads are essentially unchanged; on these road systems travel speeds increased only very little.

This preliminary analysis adjusts the number of fatal accidents for traffic volume. But, could it be that changes in other variables such as weather or road conditions are responsible for the observed increase? If the weather in 1988–1991 was indeed responsible for an increase in the number of fatal accidents on rural interstates, then one would also expect similar increases on 55 mph road systems, as the weather very likely affects all roads similarly. This is not the case.

It is important to determine the margin of error of the estimated impact. This is especially important here as our analysis is based on relatively small counts. The total number of fatal accidents on rural interstates between 1983 and 1986 is 56; the total for the period 1988 through 1991 is 102, resulting in the 82 percent increase given in Table 3–1. Assuming independence and a Poisson distribution for the number of fatal accidents, the standard error of the difference amounts to 12.6 fatal accidents. The observed difference of 46 fatal accidents exceeds three times its standard error. Thus there is rather strong evidence that the observed difference is not due to chance. One should not interpret too much into the 18 percent reduction on urban interstates. The numbers involved are small, and the decrease from 44 fatal accidents in 1983–86 to 36 in 1988–91 does not exceed its standard error of 8.9.

We also investigate changes in the number of major-injury accidents. The raw data show that on rural interstates the counts increased by 11 percent, as compared to a decrease on rural primary roads and mostly unchanged numbers on rural secondary roads and urban interstates. After adjusting major-injury accidents for traffic volume, the reductions in the risk of a major-injury accident are fairly similar across the various road classifications. The differences in the adjusted numbers for major-injury accidents are not nearly as striking as they are for fatal accidents, and the differences are within the natural variability for such numbers. While there is evidence that the increased traffic speeds on rural interstates have played a role in increasing the number of fatal accidents, it is not obvious that the same effect is also true for major-injury accidents.

A direct comparison between data from rural and urban interstates is informative, as only rural interstates experienced a substantial increase in traffic speeds. Table 3–1 shows that the numbers of fatal accidents, and to a lesser degree the numbers of major-injury accidents, increased on rural interstates, while the numbers for urban interstates decreased. Also the VMT-adjusted data show that on rural interstates the risk of a fatal accident increased while

the corresponding risk on urban interstates decreased. For major-injury accidents the risks decreased on both interstate systems; however, it could be argued that on urban interstates the risk decreased somewhat faster than on rural interstates. This information provides evidence that the new speed limit, and the resulting increase in actual traffic speed, did have an adverse impact on traffic safety.

## STATISTICAL MODELS FOR ASSESSING THE IMPACT OF THE SPEED LIMIT CHANGE

Building on our preliminary analysis, we conducted a more sophisticated statistical analysis of changes in accident rates on Iowa highways during the 1980s. First, we present the results of our aggregate analysis of accident frequencies on the state's rural and urban road systems. We then examine changes in accident frequencies on individual road systems, including rural interstate highways. Finally, we discuss our findings when a bivariate intervention model is applied to address the small counts of fatal accidents on rural and urban interstate highways.

### Analysis of aggregate accident frequencies

We develop a statistical model for the numbers of Iowa fatal (and major-injury) accidents  $Y_t$ . We model  $f_t$ , the expected number of accidents in quarter  $t$  ( $t = 1, \dots, 44$ ), as

$$f_t = \alpha_0 \text{VMT}_t \exp\{\beta_1 t + \beta_2 \text{INTER}_t + \sum_{j=2}^4 \delta_j \text{SEAS}_{tj}\} \quad (3.1)$$

We assume that the expected number of accidents is proportional to the exposure VMT. The parameter  $\beta_1$  reflects the trend reduction; over the 11 years from 1981 to 1991 the proportionate reduction in the number of fatal (major-injury) accidents amounts to  $100[1 - \exp(44\beta_1)]$ . This reduction can be attributed to improvements in car safety, such as safer designs and seat belt features, improvements of roads, and increased minimum drinking age; see the discussion in Section 2. The intervention indicator,  $\text{INTER}_t = 1$  for quarters after the speed limit change in May 1987 and 0 before, assesses the impact of the maximum speed limit change on rural interstates. The proportionate increase in the number of accidents that can be attributed to the speed limit change is  $100[\exp(\beta_2) - 1]$ . Seasonality is modeled with indicator variables;  $\text{SEAS}_{tj} = 1$  if  $t$  corresponds to quarter  $j$  and 0 otherwise.

The above expression leads us to analyze the logarithm of  $Y_t/\text{VMT}_t$ ,

$$\log(Y_t/\text{VMT}_t) = \beta_0 + \beta_1 t + \beta_2 \text{INTER}_t + \sum_{j=2}^4 \delta_j \text{SEAS}_{tj} + n_t \quad (3.2)$$

Here  $\beta_0 = \log(\alpha_0)$ . A first-order autoregressive (AR) model (see Abraham and Ledolter (1983), Box and Jenkins (1976))

$$n_t = \phi n_{t-1} + a_t \tag{3.3}$$

allows for possible correlation among successive observations. The (serially) independent innovations  $a_t$  follow a normal distribution with mean zero and standard deviation  $\sigma_a$ .

Maximum likelihood estimates of the parameters, for fatal and major-injury accidents separately, are obtained with the SCA computer software. They are shown in Table 3-2. The trend reductions for fatal and major-injury accidents are fairly similar and their difference, when compared with its standard error, is not significantly different from zero. The estimation results in Table 3-2 also show that the adjusted numbers of major-injury accidents were not affected by the 1987 speed limit change; the estimate  $\hat{\beta}_2 = 0.013$  is considerably smaller than its standard error 0.056. For fatal accidents the estimate  $\hat{\beta}_2 = 0.205$ , with standard error 0.080, is significantly different from zero and implies a 23 percent increase in the number of fatal accidents. The considerable uncertainty should be kept in mind, however, as the impact could easily be as low as seven percent; the lower bound of a 90 percent confidence interval is  $0.205 - (1.645)(0.08) = 0.073$ , or  $100[\exp(0.073) - 1] = 7.6$  percent.

**Table 3-2. Estimation results for the model in equations (3.2) and (3.3) \***

		Fatal accidents		Major-injury accidents	
Constant	$\beta_0$	-3.92	(0.06)	-2.02	(0.05)
Trend	$\beta_1$	-0.0125	(0.0033)	-0.0109	(0.0025)
INTER	$\beta_2$	0.205	(0.080)	0.013	(0.056)
SEAS2	$\delta_2$	0.20	(0.04)	0.29	(0.02)
SEAS3	$\delta_3$	0.37	(0.04)	0.37	(0.02)
SEAS4	$\delta_4$	0.29	(0.04)	0.25	(0.02)
AR	$\phi$	0.31	(0.14)	0.47	(0.13)
Std Dev	$\sigma_a$	0.0952		0.0604	

\* Values in parentheses are standard errors.

A bivariate model for fatal and major-injury accidents which restricts the trend coefficients in equation (3.2) to be the same and which allows the innovations  $(a_{t1}, a_{t2})$  in the first-order autoregressive models

$$n_{t1} = \phi_1 n_{t-1,1} + a_{t1} \text{ and } n_{t2} = \phi_2 n_{t-1,2} + a_{t2} \quad (3.4)$$

to be correlated, is fitted next. This model allows for situations in which omitted variables, such as the weather, introduce a contemporaneous correlation. Positive correlation can be expected; bad weather, for example, should lead to above average counts in both categories.

The parameter estimates of  $\beta_2$  in Table 3-3 show that the speed limit change increased the number of fatal accidents by 20 percent, but left major-injury accidents unaffected. The trend reduction over the studied 11-year period (ignoring the increase in fatal accidents that is due to the new speed limit) amounts to 39 percent.

**Table 3-3. Estimation results for the bivariate model in equations (3.2) and (3.4), assuming equality of the trend parameters \***

		Fatal accidents		Major-injury accidents	
Constant	$\beta_0$	-3.94	(0.05)	-2.01	(0.04)
Trend	$\beta_1$		-0.0114	(0.0022)	
INTER	$\beta_2$	0.183	(0.061)	0.024	(0.052)
SEAS2	$\delta_2$	0.20	(0.04)	0.29	(0.02)
SEAS3	$\delta_3$	0.37	(0.04)	0.37	(0.02)
SEAS4	$\delta_4$	0.29	(0.04)	0.25	(0.02)
AR	$\phi$	0.33	(0.13)	0.44	(0.12)
Std Dev	$\sigma_a$	0.0953		0.0604	
Correlation		0.32			

\* Values in parentheses are standard errors.

The fitted models imply that the speed limit change increased the number of fatal accidents by about 20 percent. One wants to know how this proportionate increase translates into actual numbers of fatal accidents. In 1990-91 there are 103 fatal accidents each quarter, on average. Our results imply that without the speed limit change it may have been possible to avoid 17 of these fatal accidents (since  $103 - (103/1.20) = 17$ ). However, one should note the large uncertainty in the estimate. The lower limit of a 90 percent confidence interval for  $\beta_2$ , calculated from the information in Table 3-3, is given by  $0.183 - (1.645)(0.061) = 0.083$ , implying

a 8.6 percent increase. Thus a lower bound for the number of fatal accidents that could have been avoided in each quarter by not raising the speed limit is about eight.

### Analysis of accident frequencies on individual rural road systems

We now use the quarterly number of fatal (major-injury) accidents, broken down according to the three different *rural* road systems, to estimate a multivariate model of the form

$$\log(Y_{it}/VMT_{it}) = \beta_0^{(i)} + \beta_1 t + \beta_2^{(i)} \text{INTER}_t + \sum_{j=2}^4 \delta_j^{(i)} \text{SEAS}_{ij} + n_{it}$$

$$n_{it} = \phi^{(i)} n_{t-1,i} + a_{it} \quad (3.5)$$

where  $t$  stands for time ( $t = 1, \dots, 44$ ) and  $i = 1, 2, 3$  denotes rural interstates, rural primary, and rural secondary roads. Accidents on urban interstates are not included in this particular model as zero counts in several quarters do not permit a logarithmic transformation. The intercepts  $\beta_0^{(i)}$  are allowed to differ as the graphs in Figures 2-6 and 2-7 show considerable safety differences among the three rural road systems. The parameter  $\beta_1$  reflects the trend component and it is assumed that it does not depend on the particular rural road system. In other words, we assume that the proportionate trend reduction in the number of accidents is the same for rural interstates, rural primary, and rural secondary roads. This assumption is later justified by fitting a model that allows for different trend parameters and testing the equality of the coefficients. The term  $\beta_2^{(i)} \text{INTER}_t$  measures the impact of the speed limit change in the form of a level shift. (The appropriateness of the level shift model is confirmed by the analysis embodying models with average traffic speed later in this section.) We expect the impact on rural interstates (that is  $\beta_2^{(1)}$ ) to be larger than the ones for the other two 55 mph road systems, since, as shown in Figure 2-1 and Table 3-1, the new maximum speed limit affected mostly traffic speeds on rural interstates. Seasonality is modeled with seasonal indicators; the coefficients  $\delta_j^{(i)}$  express how observations in quarter  $j$  differ from those in the first quarter. In order to capture possible serial correlation we model the noise in (3.5) by a first-order autoregressive process. Furthermore, to capture the contemporaneous correlation we allow for a general covariance matrix  $\Sigma_a$  for the serially independent innovations  $a_t = (a_{t1}, a_{t2}, a_{t3})'$ .

The SCA statistical software is used to obtain maximum likelihood estimates of the parameters and the results are given in Table 3-4. The estimated trend coefficient  $\hat{\beta}_1 = -0.0096$  implies a 34 percent reduction in the number of fatal accidents over the 11-year period from 1981 through 1991. The estimated intervention coefficient  $\hat{\beta}_2^{(1)} = 0.451$  implies that the speed limit change in 1987 increased the average number of fatal traffic accidents on rural interstates by about 57 percent. Proportionate increases for road systems that were not subject

to the increased speed limit are considerably smaller; 19 percent for rural primary roads and 13 percent for rural secondary roads. Moreover, judging from its standard error, the effect for rural secondary roads is barely significant. The effect on rural interstates is about four times as large as the effects on rural primary and secondary roads. This is reasonable as the actual speed increase on rural interstates is about five times larger than the ones for the other two rural systems.

In 1990–91 the quarterly numbers of fatal accidents on rural interstates, rural primary, and rural secondary roads average six, 36, and 33 accidents respectively. Our estimates in Table 3–4 imply that without the speed limit change we could have avoided, in all likelihood, two fatal accidents on rural interstates, six fatal accidents on rural primary roads and four on rural secondary roads. We use the lower bounds of 90 percent confidence intervals to obtain a lower bound for the number of fatal accidents that could have been avoided in each quarter. These bounds translate into one fatal accident on rural interstates and two fatal accidents on rural primary and secondary roads combined, for a total of three fatal accidents per quarter.

For major-injury accidents the trend estimate  $\hat{\beta}_1 = -0.0090$  implies a 33 percent reduction over the 11 years from 1981 through 1991. This trend reduction is virtually the same as the one for fatal accidents. Estimates for the intervention effects on all rural road systems are small and statistically insignificant. This implies that there is little evidence that the speed limit change has had an effect on the number of major-injury accidents.

A critical assumption in our model is that the trend parameters in (3.5) are the same. We tested this constraint by estimating the general model that allows for three different trend coefficients;  $\beta_1^{(1)}$ ,  $\beta_1^{(2)}$ , and  $\beta_1^{(3)}$ . Using the estimates and their covariance matrix we constructed a chi-square statistic for testing  $\beta_1^{(1)} = \beta_1^{(2)} = \beta_1^{(3)}$ . The results justified the constraint as these statistics (2.0 for fatal accidents and 3.7 for major-injury accidents) were statistically insignificant when compared with the critical values of a chi-square distribution with two degrees of freedom.

### **Models with average traffic speed**

We now explore models that replace the indicator variables by a measure of the actual traffic speed. Figure 2–1 indicates increasing average traffic speeds on rural interstates, but also considerable variability from one quarterly average to the next. The variability can be attributed to sampling error and seasonal effects. Considerable sampling error can be expected from the adopted sampling scheme which estimates the quarterly average traffic speed on

**Table 3–4. Estimation results of the multivariate time series intervention model with autoregressive errors in equation (3.5): number of fatal accidents and major-injury accidents \***

		Fatal accidents		Major-injury accidents		
Trend	$\beta_1$	-0.0096	(0.0025)	-0.0090	(0.0025)	
<i>Rural interstates</i>						
Constant	$\beta_0^{(1)}$	-5.11	(0.17)	-3.08	(0.09)	
INTER	$\beta_2^{(1)}$	0.451	(0.166)	-0.092	(0.100)	
SEAS2		-0.26	(0.22)	-0.27	(0.09)	
SEAS3		0.05	(0.22)	-0.05	(0.09)	
SEAS4		0.32	(0.22)	0.11	(0.09)	
AR	$\phi^{(1)}$	0.01	(0.13)	0.22	(0.13)	
<i>Rural primary</i>						
Constant	$\beta_0^{(2)}$	-3.68	(0.07)	-2.33	(0.05)	
INTER	$\beta_2^{(2)}$	0.178	(0.076)	-0.073	(0.063)	
SEAS2		-0.03	(0.09)	0.06	(0.05)	
SEAS3		0.12	(0.08)	0.13	(0.05)	
SEAS4		0.25	(0.09)	0.21	(0.05)	
AR	$\phi^{(2)}$	-0.14	(0.15)	-0.08	(0.14)	
<i>Rural secondary</i>						
Constant	$\beta_0^{(3)}$	-3.40	(0.08)	-1.83	(0.06)	
INTER	$\beta_2^{(3)}$	0.123	(0.069)	0.060	(0.076)	
SEAS2		0.28	(0.12)	0.42	(0.05)	
SEAS3		0.54	(0.08)	0.56	(0.05)	
SEAS4		0.14	(0.11)	0.37	(0.05)	
AR	$\phi^{(3)}$	-0.43	(0.13)	0.36	(0.13)	
<i>Error standard deviations</i>		(0.500, 0.190, 0.188)		(0.218, 0.119, 0.123)		
<i>Error correlation matrix</i>						
		1.00		1.00		
		0.08	1.00	0.29	1.00	
		0.54	0.11	1.00	1.00	
				0.13	0.29	1.00

\* Values in parentheses are standard errors.

rural interstates from measurements at a few selected locations on just a few selected days. One way to remove the sampling error is to decompose traffic speed into the sum of trend, seasonal and irregular components. The trend in the traffic speed for each of the three rural road systems is estimated by centered four-point moving averages of average traffic speed; the smoothed average traffic speed is designated as  $SMSP_{it}$ . These moving averages reduce the sampling error and hence result in a more accurate estimate of the trend.

In order to explore the relationship between fatal accidents and speed we construct partial residual plots for smoothed average speed. That is, we estimate the multivariate model

$$\log(Y_{it}/VMT_{it}) = \beta_0^{(i)} + \beta_1 t + \beta_2 SMSP_{it} + \sum_{j=2}^4 \delta_j^{(i)} SEAS_{ij} + n_{it}, \quad (3.6)$$

calculate the partial residuals  $\hat{n}_{it} + \hat{\beta}_2 SMSP_{it}$ , and plot them against smoothed average speed. See Larson and McCleary (1972) for an introduction to the use of partial residuals in regression diagnostics.

Figure 3-1 shows the partial residual plot for rural interstates (plots for rural primary and secondary roads are not shown). The large range of traffic speeds on rural interstates allows us to study the relationship between the number of fatal accidents and traffic speed. On this graph we also include the least squares fit of the regression of partial residuals on smoothed speed (solid line) as well as a non-parametric estimate of the mean level. This estimate is obtained from a Gaussian kernel with interquartile range 0.75 mph (see Silverman, 1986).

Figure 3-1 provides evidence for a level shift around 60 mph and it confirms that the indicator model of Section 3 provides a good approximation of the relationship between the number of fatal accidents and average speed. Note that average speeds below 60 mph are from the 55 mph speed limit period, while the larger speeds are observed under the 65 mph speed limit.

Figure 3-1 also provides some, although weaker, evidence that the partial residuals increase linearly with smoothed traffic speed. It shows that a model with a linear speed component is likely to overestimate the impact of higher speeds. The speed coefficient estimate in model (3.6),  $\hat{\beta}_2 = 0.0931$  with standard error 0.0275, implies that the 1 mph increase of average traffic speeds on rural primary and secondary roads results in a 10 percent increase in the fatal accident risk. On rural interstates, where average traffic speeds increased by seven mph, the increase amounts to 90 percent. The lower limit of a 90 percent confidence interval implies that the effect on rural interstates is at least 40 percent.



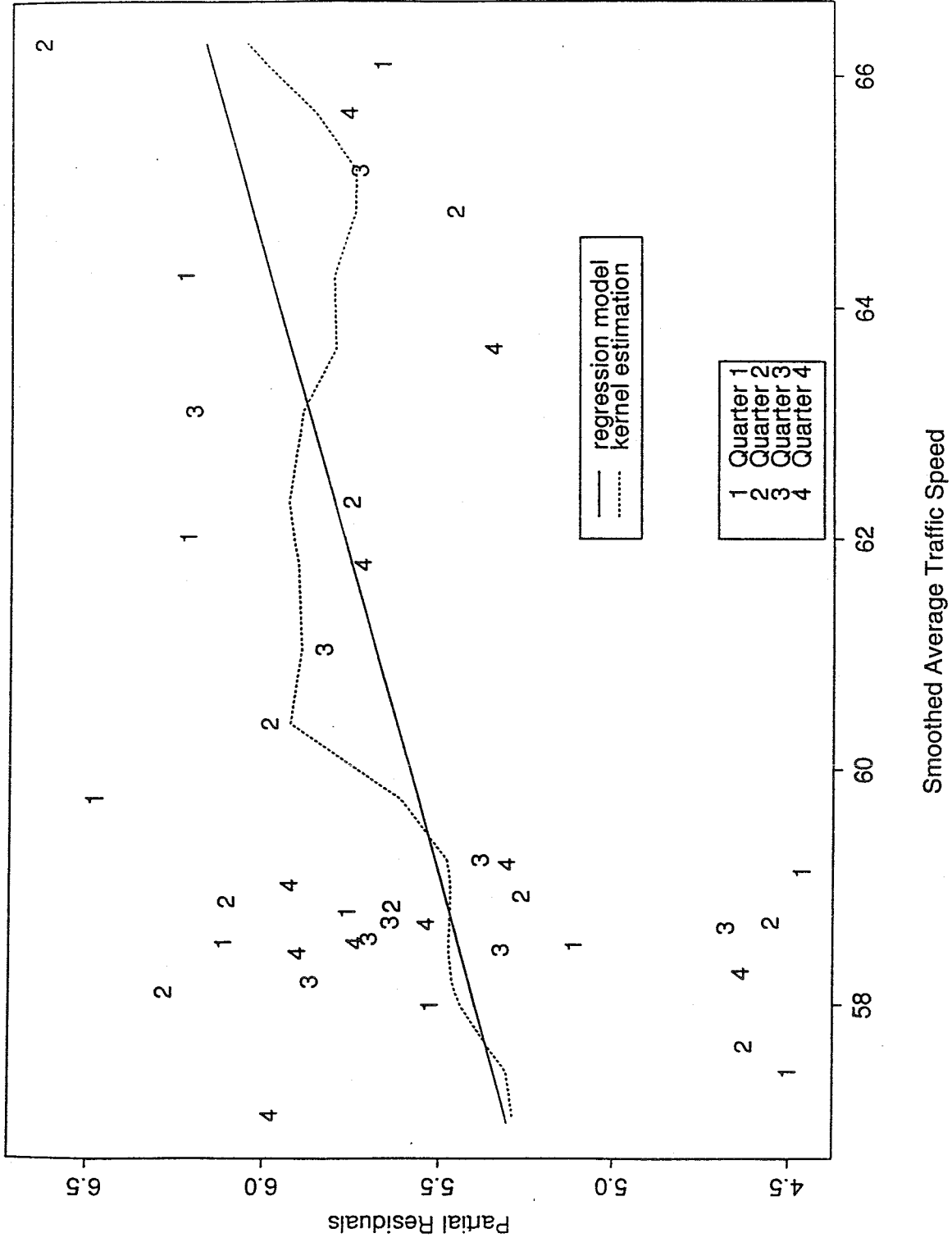


Figure 3-1. Partial residual plot of smoothed average traffic speed: rural interstates

Although we prefer a level shift model to a linear model on smoothed average traffic speed, it should be noted that the large variability in the data renders the determination of the functional form of SMSP highly uncertain. Further analysis using panel data from other states may provide a more definite conclusion on the functional form of SMSP. Nonetheless, a level shift model, if accepted, suggests a nonlinear response of the “system” to the intervention of the increased maximum speed limit, perhaps indicating some “feedback” from the system. Plausible feedback mechanisms include: (1) people gradually learning to drive more safely with higher speeds and (2) tighter enforcement of traffic regulations on rural interstates in response to a surging number of fatal accidents. Clearly, further analyses are desirable to check these hypotheses.

### A BIVARIATE INTERVENTION MODEL FOR SMALL COUNTS: COMPARISON OF FATAL ACCIDENTS ON RURAL AND URBAN INTERSTATES

Models that rely on the logarithmic transformation (Models 3.2, 3.5, and 3.6) are inappropriate for quarterly numbers of fatal accidents on urban interstates because these small counts include several zeroes. A multivariate model that can accommodate zero counts is developed next, and is applied to quarterly numbers of fatal accidents on rural and urban interstates,  $\{Y_t\} = \{(Y_{t1}, Y_{t2})\}$ . Such a comparison is of interest as the increase in traffic speeds on rural interstates, where higher speeds are permitted, is considerably larger than that on urban interstates, which are subject to the old 55 mph limit. While our model, given below, allows for contemporaneous correlation due to unaccounted common factors, we assume that errors are serially uncorrelated. This is a reasonable assumption given the insignificant AR coefficient estimate for fatal accidents on rural interstates (see Table 3-4). The marginal distributions of the  $Y$ 's are modeled by Poisson distributions. Since there is no obvious way to specify dependence among the distributions, we specify our model in terms of only the first two moments of the  $Y$ 's:

$$\mu_{it} = E(Y_{it}) = VMT_{it} \exp\{\beta_0^{(i)} + \beta_1 t + \beta_2^{(i)} \text{INTER}_t + \sum_{j=2}^4 \delta_j^{(i)} \text{SEAS}_{jt}\}, \quad (3.7)$$

$$\text{var}(Y_{it}) = \mu_{it}, \quad (3.8)$$

and  $\rho = \text{corr}(Y_{t1}, Y_{t2})$ . Following the previous sections, the trend coefficients are constrained to be equal. Let  $\theta$  be the vector of parameters, excluding  $\rho$ . For  $\rho$  known, we estimate  $\theta$  by solving the estimating equation

$$\sum_{t=1}^n \left[ \frac{\partial \mu_{t1}}{\partial \theta}, \frac{\partial \mu_{t2}}{\partial \theta} \right] \Omega_t^{-1} (Y_{t1} - \mu_{t1}, Y_{t2} - \mu_{t2})' = 0, \quad (3.9)$$

where  $\Omega_i$  is the variance-covariance matrix of  $Y_i$ , with  $\mu_{i1}, \mu_{i2}$  as its diagonal elements and  $\rho\sqrt{\mu_{i1}\mu_{i2}}$  as its off-diagonal element. The derivatives of  $\mu_{i1}$  can be obtained from equation (3.7). Equation (3.9) is optimal among the class of unbiased estimating equations of the form

$$\sum_{i=1}^n \Lambda_i(\theta, \rho)(Y_{i1} - \mu_{i1}, Y_{i2} - \mu_{i2})' = 0, \quad (3.10)$$

where  $\Lambda_i(\theta, \rho)$  does not depend on the  $Y$ 's; see Hutton et al. (1991). Equation (3.9) can be solved iteratively using the method of Fisher scoring or, alternatively by an iteratively reweighted least squares scheme similar to the one discussed in McCullagh and Nelder (1989, pp. 40-43). Denote the LHS of equation (3.9) by  $A(\theta)$  and let  $B(\theta) = \sum_{i=1}^n \left[ \frac{\partial \mu_{i1}}{\partial \theta}, \frac{\partial \mu_{i2}}{\partial \theta} \right] \Omega_i^{-1} \left[ \frac{\partial \mu_{i1}}{\partial \theta}, \frac{\partial \mu_{i2}}{\partial \theta} \right]'$ . For given  $\hat{\theta}_k$ , the estimates are revised according to  $\hat{\theta}_{k+1} = \hat{\theta}_k + B^{-1}(\hat{\theta}_k)A(\hat{\theta}_k)$ . Iterations stop when changes in the parameters are sufficiently small. Since  $\rho$  is unknown, the preceding iterative scheme is augmented at each iteration, estimating  $\rho$  by the mean of the cross products of  $\{(Y_{i1} - \mu_{i1})/\sqrt{\mu_{i1}}, (Y_{i2} - \mu_{i2})/\sqrt{\mu_{i2}}\}$ . The resulting estimates are denoted by  $\hat{\theta}$  and  $\hat{\rho}$ . Using linearization techniques it can be shown that under suitable regularity conditions,  $\sqrt{n}(\hat{\theta} - \theta, \hat{\rho} - \rho)$  is asymptotically normal. The limiting normal distribution has zero mean. The asymptotic variances for  $\hat{\theta}$  and  $\hat{\rho}$  are  $B^{-1}(\theta)$  and  $\sum_{i=1}^n (Y_{i1} - \mu_{i1})^2 (Y_{i2} - \mu_{i2})^2 / \{n^2 \mu_{i1} \mu_{i2}\} - \rho^2 / n$ . The asymptotic covariance of  $\hat{\theta}$  and  $\hat{\rho}$  is

$$n^{-1} B^{-1}(\theta) \sum_{i=1}^n \left[ \frac{\partial \mu_{i1}}{\partial \theta}, \frac{\partial \mu_{i2}}{\partial \theta} \right] \Omega_i^{-1} \left\{ (Y_{i1} - \mu_{i1})^2 (Y_{i2} - \mu_{i2}) / \sqrt{\mu_{i1} \mu_{i2}}, (Y_{i1} - \mu_{i1})(Y_{i2} - \mu_{i2})^2 / \sqrt{\mu_{i1} \mu_{i2}} \right\}'.$$

The estimation results are summarized in Table 3-5.

**Table 3-5. Estimation results of the bivariate intervention model in equations (3.7) and (3.8): number of fatal accidents on rural and urban interstates\***

		Rural interstates		Urban interstates	
Constant	$\beta_0$	-4.58	(0.19)	-4.56	(0.29)
Trend	$\beta_1$		-0.0282	(0.0079)	
INTER	$\beta_2$	0.727	(0.225)	0.147	(0.270)
SEAS2		-0.30	(0.21)	0.70	(0.32)
SEAS3		-0.12	(0.19)	0.71	(0.32)
SEAS4		0.15	(0.19)	0.59	(0.33)
Correlation	$\rho$		-0.18	(0.14)	

\* Values in parentheses are standard errors.

The estimate of the common trend is negative and significant. While it is somewhat larger than the one reported in Table 3–4, the difference in magnitude can be explained by a relatively large standard error. The estimate of the intervention effect for rural interstates is significant, whereas the corresponding estimate for urban interstates is essentially zero. This correlates well with the increased traffic speeds on rural interstates and the mostly unchanged speeds on urban interstates.

In a supplemental analysis we consider differences in fatal accident risks on rural and urban interstates,  $(Y_{11}/VMT_{11}) - (Y_{12}/VMT_{12})$ . Such differences cancel the common trend component in the two series, and a time series graph shows that there is no trend remaining. The average difference prior to the speed limit change in 1987 is  $-0.0058$ . Over this span the average risk on urban interstates was  $0.0124$ , implying that the fatal accident risk on urban interstates was about twice the risk on rural interstates. The average difference after 1987 is essentially zero, implying that after the speed limit change the risks on rural and urban interstates are about the same.

#### **CONCLUDING REMARKS**

Our analysis leads us to conclude that higher fatality rates are associated with the increased maximum speed limit on rural interstate highways. While we are fairly confident about the conclusions from this study, certain caveats do apply. Most important, our analysis of Iowa transportation trends uses aggregate data on fatal and major-injury accidents, but does not use factors such as gender and age of driver, special information on road and weather conditions at the time of the accident, type of vehicle involved, evidence of alcohol involvement, and speed-related circumstances. One may wonder whether this extra information could change our conclusions. A follow-up analysis of individual fatal accidents would be of interest in order to confirm (or refute) the conclusions found on the aggregate level. The Iowa Department of Transportation collects micro-data on each fatal accident, with detailed information on various contributing factors, and this data could be used in a confirmative follow-up study.

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