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THE 65-MPH SPEED LIMIT IN MICHIGAN: A SECOND YEAR ANALYSIS OF EFFECTS ON CRASHES AND CRASH CASUALTIES

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16. Abstract Effective December 1987 and January 1988, the maximum speed limit on rural limited-access highways in Michigan was raised from 55 mph to 65 mph. This study examined the effects of the raised limit on traffic crashes and crash casualties.

A multiple time-series design was used, comparing roads where the speed limit was raised with roads where the limit remained unchanged. Data were collected on the numbers and rates of crashes, injuries, and deaths from January 1978 through December 1989. Time-series intervention analyses were conducted to estimate effects associated with the speed limit change while controlling for long-term trends, cycles, and other patterns. Statistical controls were also included for major factors known to influence crash and injury rates in the state.

Results revealed significant increases in casualties on roads where the speed limit was raised:

- 28.4% increase in fatalities
- 38.8% increase in serious (A-level) injuries
- 24.0% increase in moderate (B-level) injuries.

These increases in crash casualties on 65-mph roads have resulted in 31 additional deaths, 420 serious injuries, and 491 moderate injuries over the 25-month period studied. The societal cost of these casualties is nearly $98 million.

No changes in crash casualty figures was found for 55-mph limited-access highways or other roads. There was also no change in the number of traffic units involved in crashes on 65-mph roads suggesting the major influence of the higher speed limit is increased injury severity for crash involved persons.

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INTRODUCTION

In last year's report (Wagenaar, Streff, and Schultz, 1989), we found that increasing the speed limit on Michigan's rural interstates and other rural highways built to interstate standards significantly increased deaths and injuries resulting from motor vehicle crashes on those roads. This report describes estimates of the effects of the speed limit increase using an additional year of crash data.

Last year we summarized studies from other states which, taken as a whole, indicated that the 65-mph speed limit had a detrimental effect on traffic safety. This year we conducted a similar review of studies on the effects of the 65-mph limit that became available since the previous review. The results of this review are consistent with the finding that increasing the speed limit on rural interstate and other highways has led to significant increases in traffic crash casualties.

Gallaher, Sewell, and Flint et al. (1989) used linear regression modeling to assess the effects of the 65-mph speed limit on fatal crashes in New Mexico. These researchers found a significant 95% increase in the fatal crash rate per 100 million vehicle miles traveled on rural interstates. They also found that the proportion of crashes that resulted in a fatality increased after the higher speed limit was enacted.

Effects of the increased speed limit on speeds and crashes in Illinois were examined using time-series analysis by Pfefer and Stenzel (1989). Examining speed data from four individual speed monitoring sites and an aggregate of 15 sites (all on rural interstates), they found an increase in the 85^{th} percentile speed of between four and five miles per hour. They also found no evidence that speed variance at these sites was affected by the increased speed limit. While they found a significant increase of 14% in overall crash frequency, they found no significant effect when examining injury-crash frequencies. They also found no effects of the speed limit change when examining crash rates per vehicle mile traveled. Unfortunately, the ability of this study to thoroughly examine effects of the speed limit change is weakened by the small number of sites at which crash experience was examined.

Upchurch and Rahman (1989) examined effects of the speed limit change in Arizona. From their analyses these researchers concluded that driving speeds increased by about three miles per hour on rural interstates after the speed limit was increased, but speeds did not change on urban interstates over the same period. They also found that the number and rate of crashes on rural interstates increased, and the fatal crash rate on rural interstates increased after the speed limit was changed, but that no change in the number or rate of crashes was observed on urban interstates. This study is seriously weakened by its lack of analysis using inferential statistics to better determine the magnitude and nature of observed effects.

Using time-series analysis, Chang and Paniati (1990) examined the fatal crash experience of the 32 states that raised their speed limit on rural interstates prior to June 30, 1987. The authors report that they were unable to determine the effects of the change in speed limit on fatal crashes because an insufficient amount of post-change data was available for effective modeling. They note that although estimated effects were nonsignificant, initial results showed that fatalities were higher than predicted in the months following the speed limit change.

Baum, Wells, and Lund (1990) examined the effects of the speed limit increase on crash fatalities in the 40 states which had raised their limits by the end of 1988. This study examined odds ratios of fatal crash experience before and after the speed limit was increased in the 40 states studied. They found that the 65-mph speed limit caused 26-29% more crash fatalities in 1988 than would have occurred if the speed limit had remained at 55 mph. They extended this analysis to estimate that the 65-mph speed limit was responsible for over 700 additional fatalities nationwide on rural interstates since states began to post 65-mph limits in 1987.

While research evidence remains mixed on the effects of the 65-mph speed limit on crash casualties, the consensus of information from research conducted from other states and the nation taken as a whole is that the higher speed limit has had a detrimental effect on traffic safety. This study extends our previous analyses of Michigan's experience with the 65-mph speed limit using an additional year of crash data.

METHODS

Research Design

Our goal was to answer the question: Did the increase in the maximum speed limit from 55 to 65 mph on rural interstates and rural highways built to interstate standards in Michigan **cause** a change in motor vehicle crash deaths, injuries, and property damage? It is not sufficient to find that changes in these outcomes are associated with implementation of the law. The research should be designed so that observed changes can be best explained by the increased speed limit. Other possible explanations for observed changes must be controlled as much as possible.

Alternate explanations for observed changes in deaths and injuries at the time of the speed limit change were controlled in three ways. First, a monthly time-series design was used to control for multi-year trends, cycles, and other regular patterns in the outcome variables. Measurement of a significant change beginning the exact month the speed limit was raised strengthens the argument that observed differences were due to changes in speed limit.

Second, the time-series statistical models included several covariates, such as unemployment rate and alcohol consumption, to control for their effects on deaths, injuries, and property damage. Inclusion of covariates in the time-series models further increases confidence that observed differences are a result of changes in speed limit. In addition, the effects of other major policy changes known to influence injury rates, such as the compulsory safety belt law, were statistically controlled.

The use of multiple comparison time series is the third strategy used to increase confidence that the raised speed limit is responsible for observed changes in deaths, injuries, and property damage. Comparisons were made between specific road segments where the speed limit was raised and roads where the limit remained unchanged. Specifically, we compared changes in the outcome measures for road segments where the limit was raised to 65 mph with (1) limited-access highway segments where the limit remained at 55 mph, and (2) all other roads. The primary effects of the new 65-mph limit were expected only on those segments with the higher limit. While there may be some spillover effects on other road segments where the speed limit remained unchanged, any such spillover effects were expected to be small compared to the main effects.

Data Collection

Crashes

Data on motor vehicle crashes from January 1978 through December 1989 were obtained from the Michigan State Police. Records were available on all traffic crashes occurring in Michigan reported to any state, county, or municipal police agency. Monthly time-series variables were constructed one year at a time by generating multiple bivariate tables stratified by a combination of variables of interest (e.g., fatal crashes on rural interstates where the speed limit was increased to 65 mph). Frequency counts in such tables were extracted to form individual 12-month time series. These eleven 12-month time series were then combined to produce the 132-month time series used in these analyses. Specific variables and code values used to construct the time series are summarized here. Complete descriptions of each variable are available in codebooks prepared and distributed annually by the University of Michigan Transportation Research Institute Data Center. Variable numbers and code values corresponding to the 1989 codebook are enclosed in parentheses for reference. For example, "V1:1-2" refers to variable number one, code values one and two as documented in the 1989 codebook.

Cases included in all time-series were filtered to exclude motor vehicle crashes involving pedestrians and/or pedalcycles (V41:1). This global filter limited data analyzed to crashes which involve motor vehicles, since the raised speed limit is unlikely to affect the behavior of pedestrians and pedalcyclists.

Each crash and injury record in the data set was stratified by whether the crash occurred on a section of limited-access highway currently posted at 65, a section of limited-access highway where the speed limit remained 55 mph, or another class of road. The Michigan Department of Transportation provided a list of speed limits by specific road segments for all of Michigan's limited-access highways. This list provided data on the speed limit of limited-access roads by "control section" and the mile location within each control section.

Exact crash location and the speed limit in effect at the location of each crash were identified by merging the speed limit by control section data with data available on each traffic crash. First, all crashes on roads without a highway number in the Michigan crash data (V20:9--highway class: county road, city street, or unknown) were classified as occurring on "other roads." Remaining roads were classified based on the list of speed limits for each control section. The highway control section was derived for each crash by combining the county code (V12) with the route code through the county (V14). The mile point in the control section is recorded by the police officer investigating each crash (V15). Using these variables, each crash was classified as occurring on: (1) a limited-access highway posted 65 mph, (2) a limited-access highway posted 55 mph, or (3) other road.

The following monthly (V2) time-series variables were constructed for each road segment type.

A. Total number of vehicles involved in crashes per month by highway type.

B. Total number of crashes per month by:

(1) single vehicle involved (V39:01)
(2) car-car crash (V39:02)
(3) car-truck crash (V39:03).

C. Total number of vehicles involved in crashes per month by:

(1) vehicle damage low (V118:1-2)
(2) vehicle damage medium (V118:3-4)
(3) vehicle damage high (V118:5-8).

D. Total number of vehicles involved in crashes per month by:

(1) male driver (V150:1)
(2) female driver (V150:2).

E. Total number of vehicles involved in crashes per month by:

(1) driver age 15-24 years (V147:15-24)
(2) driver age 25-54 years (V147:25-54)
(3) driver age 55 years and older (V147:55-98).

F. Total number of vehicles involved in crashes per month by:

(1) vehicle sustained property damage only (V139:5)
(2) vehicle occupant sustained injury (no fatality) (V139:2-4)
(3) vehicle occupant was killed (V139:1).

G. Total number of injured occupants per month by:

(1) injury severity=fatal (V210:1), weighted by number of fatalities (V140)
(2) injury severity=serious (V210:2), weighted by number of serious injuries (V141)
(3) injury severity=moderate (V210:3), weighted by number of moderate injuries (V142)
(4) injury severity=minor (V210:4), weighted by number of minor injuries (V143).

Covariates

Covariates used include implementation of the adult safety belt law, proportion of licensed drivers under age 25, aggregate beer consumption in the state, and percent of the labor force unemployed. Data on the number of licensed drivers by age and gender were also obtained from the Federal Highway Administration and the Michigan Department of State. Monthly wholesale beer distribution in Michigan was obtained from the U.S. Beer Institute and the State Liquor Control Commission. Data on percent of the labor force unemployed were obtained from the Michigan Department of Management and Budget. These data are derived from the U.S. Bureau of Labor Statistics' monthly estimates of civilian labor force (CLF), employed, and unemployed based on the Current Population Survey.

Travel Speeds

Quarterly data on measured speeds of vehicles on the road were obtained from the Michigan Department of Transportation (MDOT) for the 1982-89 period. MDOT measures speeds throughout the state for compliance with the compulsory federal 55-mph speed limit monitoring program and a separate state speed monitoring program. Data are collected with pneumatic tube speed measuring devices at some locations, and permanent magnetic speed loops imbedded in the pavement at other locations. Speeds are sampled at 44 sites annually.[1] Approximately one-third of these sites are sampled quarterly, with the remaining sampled annually. With the cooperation of MDOT, we identified the location of each sample site and the current posted speed limit at each site. Of interest was the long-term trend of vehicles exceeding 55 mph and 65 mph for roads currently posted at 55-mph and 65-mph speed limits.

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[1]Data on measured travel speeds are missing for the first quarter of 1986 and the first quarter of 1987 due to problems with the monitoring equipment.

Statistical Analyses

Each dependent variable was plotted for the full 1978 through 1989 period, including a centered moving average line, useful for discerning overall trends (Appendix A). The moving average line was created by summing the six data points preceding and the six data points following each point and dividing this sum by twelve. This procedure is repeated for each of the data points in the series with the exception of the first and last six points. Monthly crash frequencies and rates often have substantial "noise" or variance around a general trend that masks underlying patterns. Moving average trend lines eliminate much of this "noise," making visual identification of general trends more straightforward.

The goal of the time-series analyses is to estimate changes in motor vehicle crash involvement and severity associated with increasing speed limits from 55 to 65 mph on rural interstates and other limited-access highways built to interstate standards. Box-Jenkins and Box-Tiao (Box and Jenkins, 1976; Box and Tiao, 1975) methods were employed to control for long-term trends and seasonal cycles, and to estimate changes beginning the first month after the increased speed limit took effect. The Box-Jenkins approach is a versatile time-series modeling strategy that can model a wide variety of trend, seasonal, and other recurring patterns.

At a conceptual level, the analytic strategy involves explaining as much of the variance in each variable as possible on the basis of its past history, before attributing any of the variance to another variable, such as the increased speed limit. The intervention-analysis approach is particularly appropriate for this study, because the objective is to identify significant changes in deaths, injuries, and crashes associated with the increased speed limit, independent of observed regularities in the history of each variable. In short, controlling for baseline trends and cycles with time-series models produces more accurate estimates of the effects of the speed limit change.

After controlling for long-term trends, cycles, and other regularities with Auto-Regressive Integrated Moving Average (ARIMA) models, we added a transfer function to each model with a step function for the month the speed limit was raised to estimate the associated change in each outcome variable. In addition, we added a second transfer function to the time-series models to estimate the anticipatory effect of the policy change. Considerable debate and media coverage of the speed limit issue occurred throughout 1987, as bills were introduced, passed, and signed at the federal and state level. The resulting publicity may have resulted in a small portion of the law's effects occurring before the law actually took effect. To determine whether this was the case, we constructed a second intervention variable *a priori*, based on knowledge of publicity concerning the speed limit (see Wagenaar, Streff, and Schultz, 1989 for additional details).

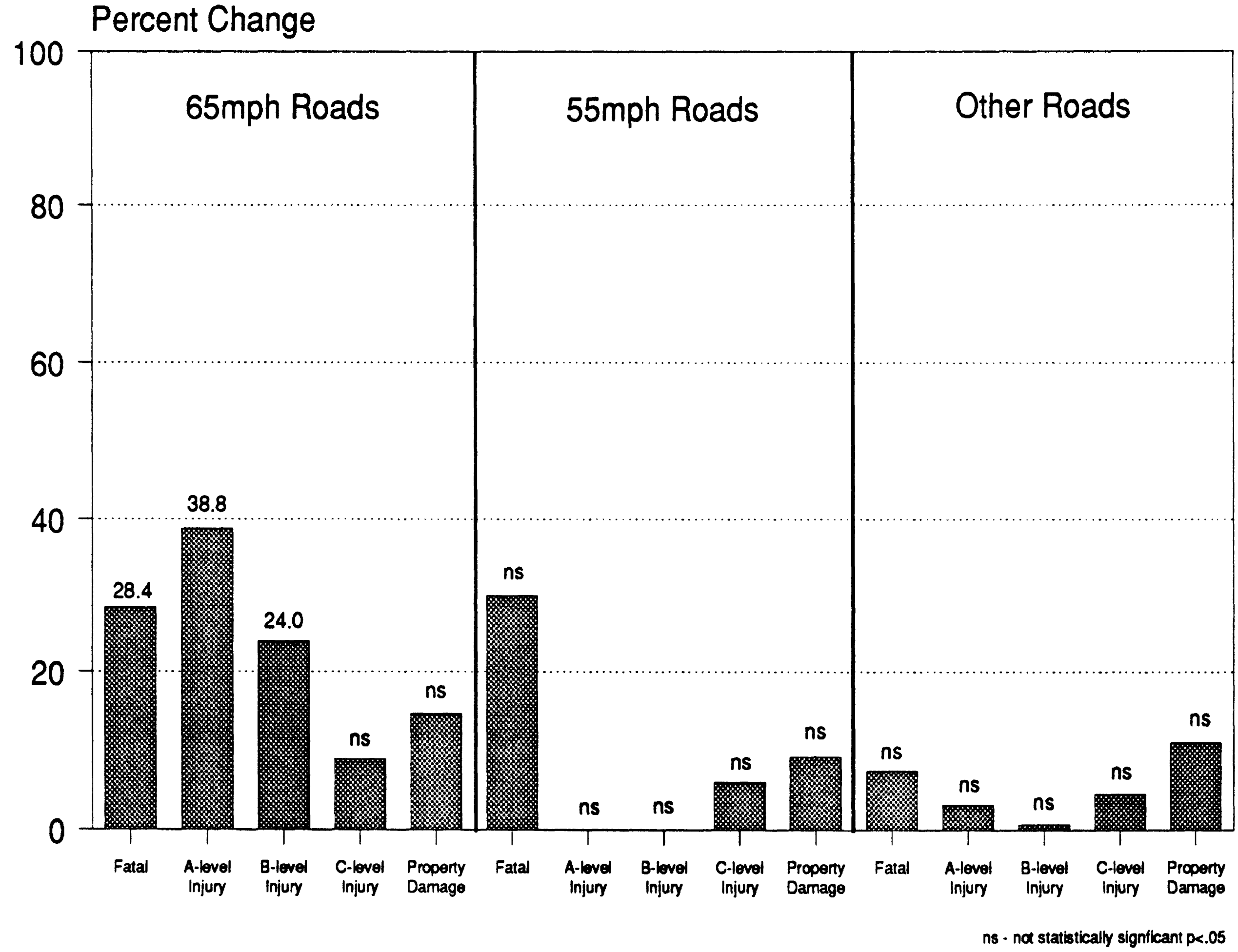
A number of covariates were included in the time-series models to account for changes in casualties due to these other factors, and to obtain a more accurate estimate of the effect attributable specifically to the speed limit change. Covariates included Michigan's compulsory safety belt use law, proportion of the licensed driver population under age 25, beer consumption, and unemployment. These variables are potential confounding factors because of established associations with traffic crash involvement. The safety belt law significantly reduced injury rates in Michigan (Streff, Wagenaar, and Schultz, 1990). The proportion of young drivers influences injury rates because of the overrepresentation of young drivers in traffic crashes. A measure of alcohol consumption was included because of the substantial proportion of crashes that involve alcohol-impaired drivers. Wholesale beer distribution was selected as the measure of alcohol consumption in preference to total absolute alcohol from all beverages (beer, wine, and distilled spirits) because the majority of impaired drivers are impaired as a result of beer consumption (Berger and Snortum, 1985). Furthermore, previous research has documented the relationship between wholesale beer distribution and the number of traffic crashes (at lags of zero to two months; Wagenaar, 1984a). Finally, the unemployment rate was included (with lags of zero to three months) because previous research has shown its relationship with motor vehicle crash involvement (Wagenaar, 1984b; Evans and Graham, 1987; Wagenaar and Streff, 1989; Streff, Wagenaar and Schultz, 1990).

Finally, results from time-series models were compared across road segments experiencing the recent increase in speed limit and those with unchanged limits. Differential effects of the speed limit change were compared across men and women, number and type of vehicles involved in the crash, driver age groups, vehicle damage level, and injury severity.

RESULTS

Significant increases in fatal, A-level (serious), and B-level (moderate) injuries caused by motor-vehicle crashes associated with the 65-mph speed limit were found only on road segments where the maximum speed limit was increased from 55 mph to 65 mph (Figure 1[2]). Fatal injuries increased 28.4%, serious injuries increased 38.8%, and moderate injuries increased 24.0% on road segments with the 65-mph speed limit. There were no significant effects on minor (C-level) injuries or on the number of crash-involved vehicles in which no vehicle occupants were injured on these road segments. There were also no significant changes in crash outcomes on limited access highways posted at 55 mph or other roads.

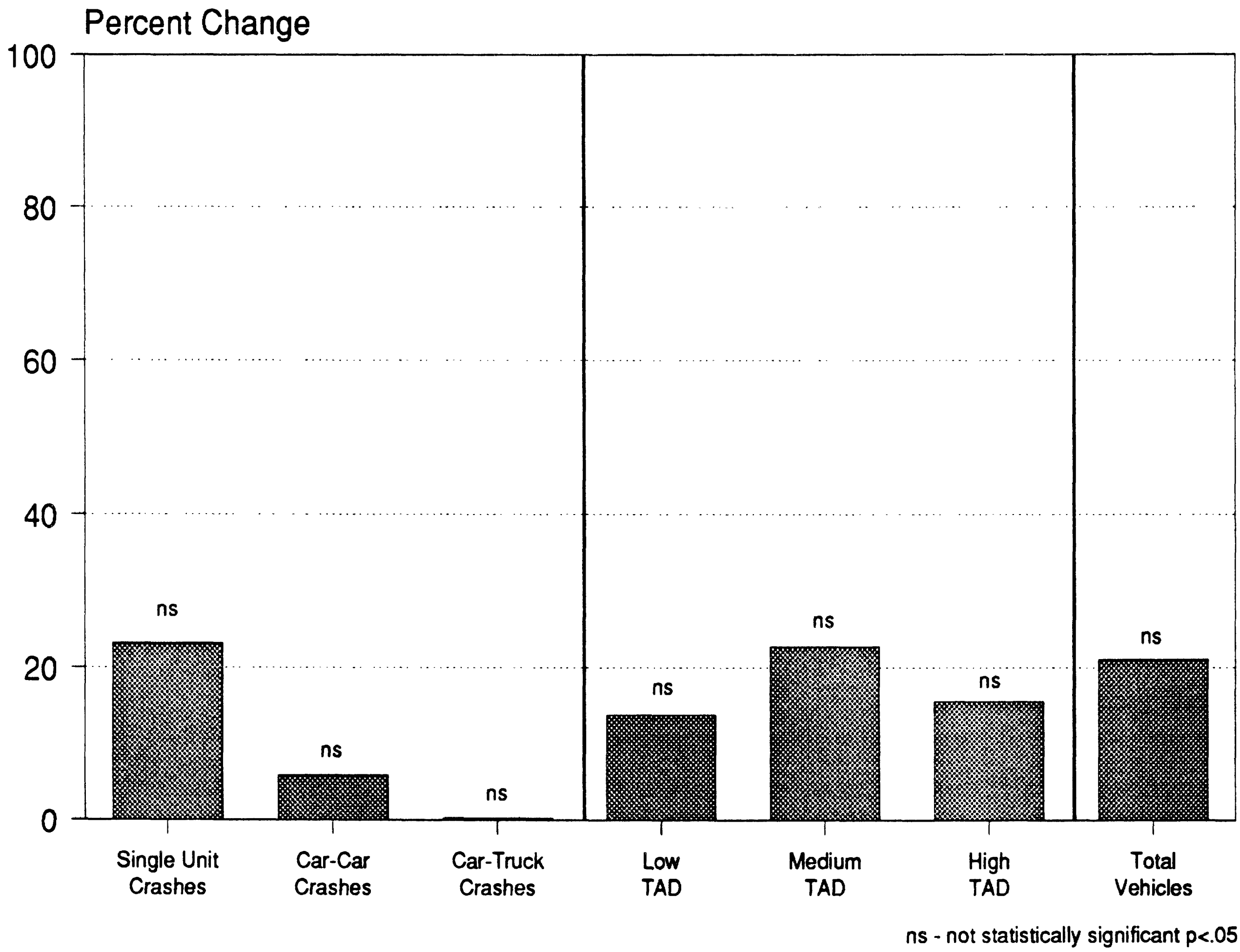
Figure 1. Effects of Increase in Maximum Speed Limit by Injury Level



[2]Detailed time-series model results can be found in Appendix B.

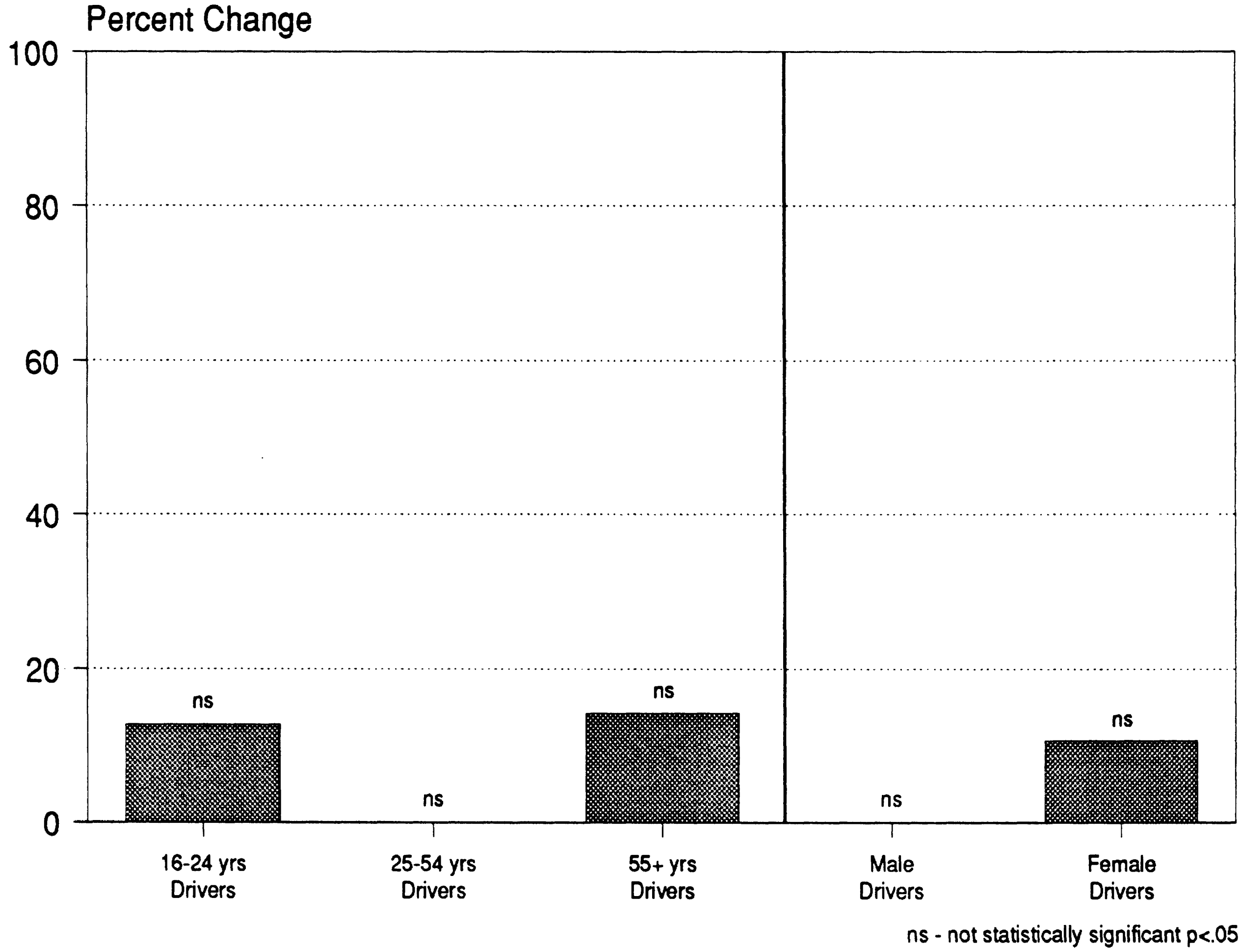
In addition to analyses of speed limit effects by injury severity, we assessed differential effects of the law by the number of traffic units involved in crashes, crash configuration, extent of vehicle damage, age and gender (Figures 2 and 3[3]). These analyses found no significant differential effects on crashes associated with the increased speed limit. It is especially notable that the analysis of traffic unit involvement (i.e., the number of vehicles involved in crashes) found no significant change in the number of vehicles involved in crashes after the 65-mph limit was implemented. This suggests that the 65-mph speed limit has principally affected the severity of injuries resulting from crashes rather than crash incidence itself. This will be discussed in greater detail later.

Figure 2. Effects of Increase in Maximum Speed Limit by Crash Configuration and Vehicle Damage Level (65-mph Highways)



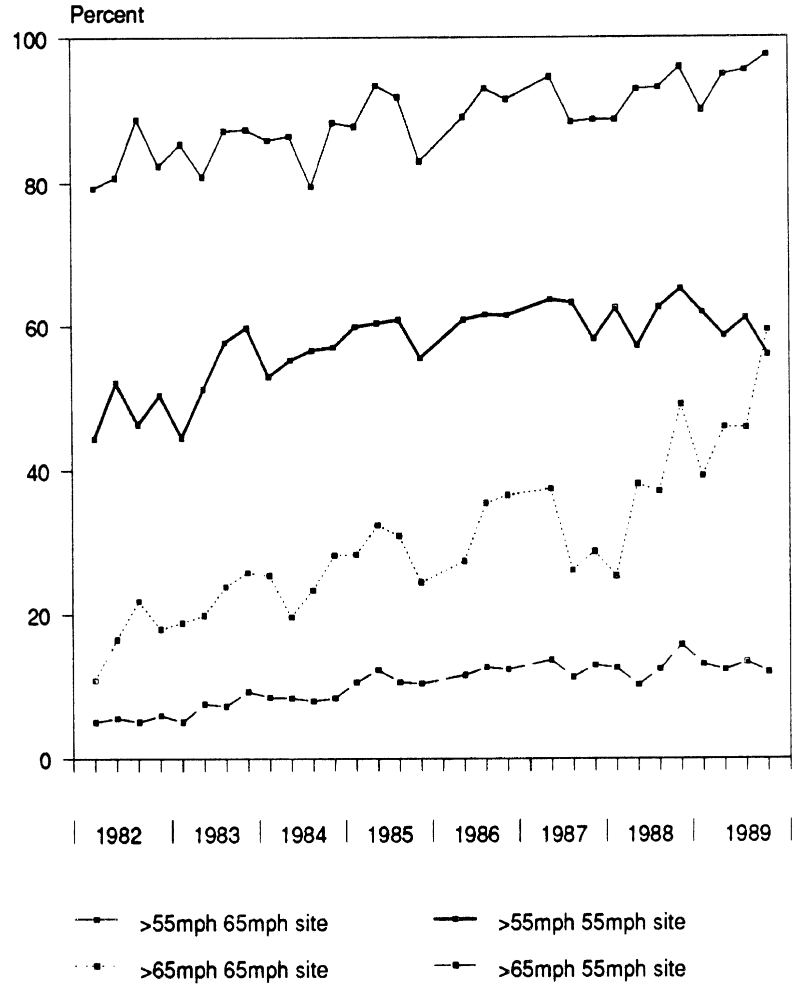
[3]Detailed time-series model results can be found in Appendix C.

Figure 3. Effects of Increase in Maximum Speed Limit by Age and Gender (65-mph Highways)



We also examined available data on travel speeds measured at 55 sites throughout the State of Michigan to assess the effect of the increased speed limit on travel speeds (Figure 4). This figure shows a general upward trend in travel speeds up to 1988 when the 65-mph speed limit was in full effect. The proportion of drivers exceeding 65 mph on roads with 55-mph speed limits appears to have increased slightly after the speed limit change in late 1987. The proportion of drivers exceeding 55 mph on roads with 55-mph speed limits seems have increasing slightly after the speed limit change, but declined since the last quarter of 1988. On the other hand, speeds have increased dramatically on roads with the 65-mph speed limit. With the exception of one quarter, the proportion of drivers exceeding 55 mph on roads with 65-mph speed limits has increased steadily since the first quarter of 1988, reaching almost 100%. The proportion of drivers exceeding 65 mph on roads with 65-mph speed limits has risen precipitously since the first quarter of 1988 (rising from 30% prior to the 65-mph limit to 42% after the 65-limit was implemented).

Figure 4. Travel Speeds Measured on 55 Sites throughout Michigan: 1982-1989



The quasi-experimental research design, including experimental series of road segments where the speed limit was raised and comparison series of road segments where the limit remained unchanged, controlled for many threats to a causal interpretation of observed increases in casualties. To provide further confidence that other major factors influencing crash outcomes could not explain observed effects, we re-estimated each time-series model including a series of covariates that have been demonstrated to influence crash and injury rates (Wagenaar, 1984a; Wagenaar, 1984b; Wagenaar and Streff, 1989; Streff, Wagenaar, and Schultz, 1990). Results of models including covariates revealed larger estimated increases in fatalities, minor, and property-damage-only crashes associated with the 65-mph speed limit than models without these covariates

(Appendix D). Observed increases in casualties since the implementation of the 65-mph speed limit cannot be attributed to other factors such as the compulsory safety belt use law, changes in economic conditions, alcohol consumption, or demographics of the driver population. Estimated effects without these statistical controls appear to underestimate the detrimental effects of the 65-mph limit on crash-trauma outcomes.

DISCUSSION

Increasing the speed limit on rural interstates and other limited-access highways to 65 mph resulted in increased fatal, serious, and moderate injuries resulting from motor-vehicle crashes on those roads. Deaths on roads with the 65-mph speed limit increased 28.4%, severe injuries on these roads increased 38.8%, and moderate injuries on these roads increased 24.0%. These increases translate into an additional 31 deaths, 420 serious injuries, and 491 moderate injuries over the 25 months of experience with higher speed limits studied (Table 1). The estimated societal cost of these casualty increases is nearly $98 million.

Table 1. Estimated Injuries and Costs Attributable to Speed Limit Increase to 65 mph

	Injuries	Cost[4]
Fatal	31	$62,898,442
Serious injuries	420	28,258,860
Moderate injuries	491	6,763,525
TOTAL	942	$97,920,827

Some have suggested that the increased speed limit on the rural interstates will not have a deleterious effect on crashes because the new speed limit will reduce speed variance. Recall that reductions in speed variance have been shown to be associated with decreased probabilities of crashes (Lave, 1985; Garber and Gadirau, 1988). If we accept the hypothesis that the increased speed limit would reduce speed variance, we would expect a corresponding decrease in the number traffic units involved in crashes on the roads with the new speed limit. Our analyses do not support this hypothesis.

We found no significant change in the number of traffic units involved in crashes on the 65-mph highways. From these analyses, we conclude the major effect of the 65-mph speed limit on Michigan highways has been increased severity of injuries among crash-involved persons rather than an increase in crashes themselves. This conclusion is consistent with the current state

[4]Based on 1988 willingness-to-pay values of $2,028,982 per fatality, $67,283 per serious injury, and $13,775 per moderate injury (Streff and Molnar, 1990).

of knowledge of the effects of speed limits on speed variance and crashes, as well as our knowledge of the effects increased speed has on the severity of crashes and related injuries (i.e., injury severity increases exponentially with crash speed, Giamotty, et al., 1980).

While the 65-mph speed limit has unquestionably had a detrimental effect on the safety of rural limited-access highways, we each must decide individually and determine a consensus as a society about what course of action to take. One possible course of action is to decrease the speed limit back to 55 mph. In fact, some have suggested this possibility as a fuel conservation measure in response to the current Iraq-Kuwait crisis. Given the high levels of support the public has expressed for the 65-mph limit in the recent past (e.g., Streff, Wagenaar, Molnar, and Schultz, 1989), this may not be a popular decision. Of course, it is also possible that this course of action will not result in decreased crash trauma. We must recall that the speed limit was increased to 65-mph in part as a response to the general driving behavior of the public. That is, they were frequently disregarding the existing 55-mph limit. Little seems to have changed to suggest that people will be willing to obey a renewed 55-mph limit any more than they were willing to obey the original limit.

However, evidence from analysis of the effects of reducing the National Maximum Speed Limit to 55 in 1974 strongly suggests that reducing the speed limit will result in a decrease in crash casualties. Although many drivers disobeyed the 55-mph limit, many drivers are now disobeying the 65-mph limit. Our survey of public opinion on traffic safety showed that people believe that they do not risk being ticketed until they are travelling 5-10 mph over the posted speed limit, whether the limit is 55 or 65 mph. Self-reports of driving speeds from this survey also indicate that drivers take advantage of the perceived ticket threshold regardless of the posted limit (Streff et al., 1989). These results support the speed reduction and injury preventing potential of returning the speed limit to 55 mph.

A second course of action could be to increase police enforcement of the 65-mph limit with increased patrols or even automated speed enforcement devices. There has been a consensus supporting increased police patrols in Michigan (Streff, et al., 1989). This measure would probably have its greatest effect in reducing the variance on the highways. However, our results indicate that the increases in casualties associated with the speed limit are probably due more to the effects of increased speed on crash and injury severity than the effects of speed variance on crash frequencies.

A third possible course of action is to keep the 65-mph speed limit and accept the increased casualties and their associated societal costs as the price for the increased convenience of the higher speed limit. A fourth course of action is to keep the 65-mph speed limit, but enact new legislation affecting more global traffic safety issues. For example, passing a primary enforcement safety belt use law would better protect not only passengers on the 65-mph roads, but all roads in Michigan. Based on the experience of other states with primary enforcement laws and crash casualty data from Michigan, we estimate that a primary enforcement belt use law would save about 33 lives and prevent nearly 250 serious injuries each year. A second example is tighter laws prohibiting alcohol-impaired driving. These laws could include a reduction of the blood alcohol concentration at which a person is defined "per se" to be guilty of intoxicated driving to 80 mg/dl (.08%) and the level of presumptive impairment to 50 mg/dl (.05%). In fact, Moskowitz and Robinson (1988) found that driving performance is significantly impaired at blood alcohol concentrations of 50 mg/dl, and driving impairment was first observed at concentrations as low as 20 and 30 mg/dl.

A proper course of action on traffic safety and societal mobility must be determined in an informed environment. The results of this study are an important element in any discussion of traffic safety or mobility in the state. This study has shown that the 65-mph speed limit has had a detrimental effect on the safety of our rural limited-access highways. We hope these findings are brought together with other information to develop a unified traffic safety and mobility plan for Michigan.

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APPENDIX A

Time Series Charts[5]

[5]The designation "65 mph" on these charts indicates road segments that changed from 55 to 65 mph speed limit in November 1987 and January 1988. These segments all had a 55 mph limit over the 1978 through 1986 period.

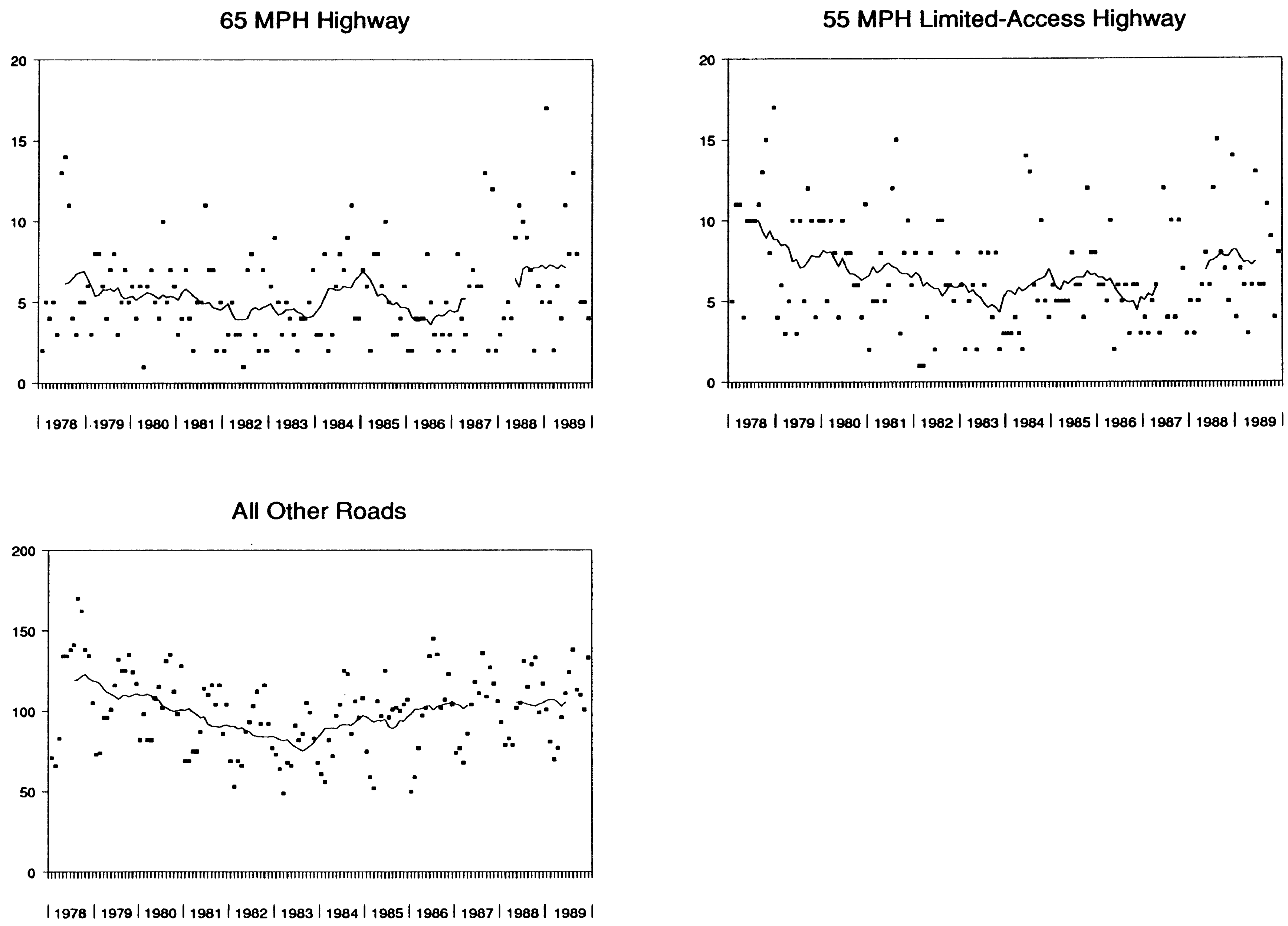


Figure A.1: Fatalities by Highway Type

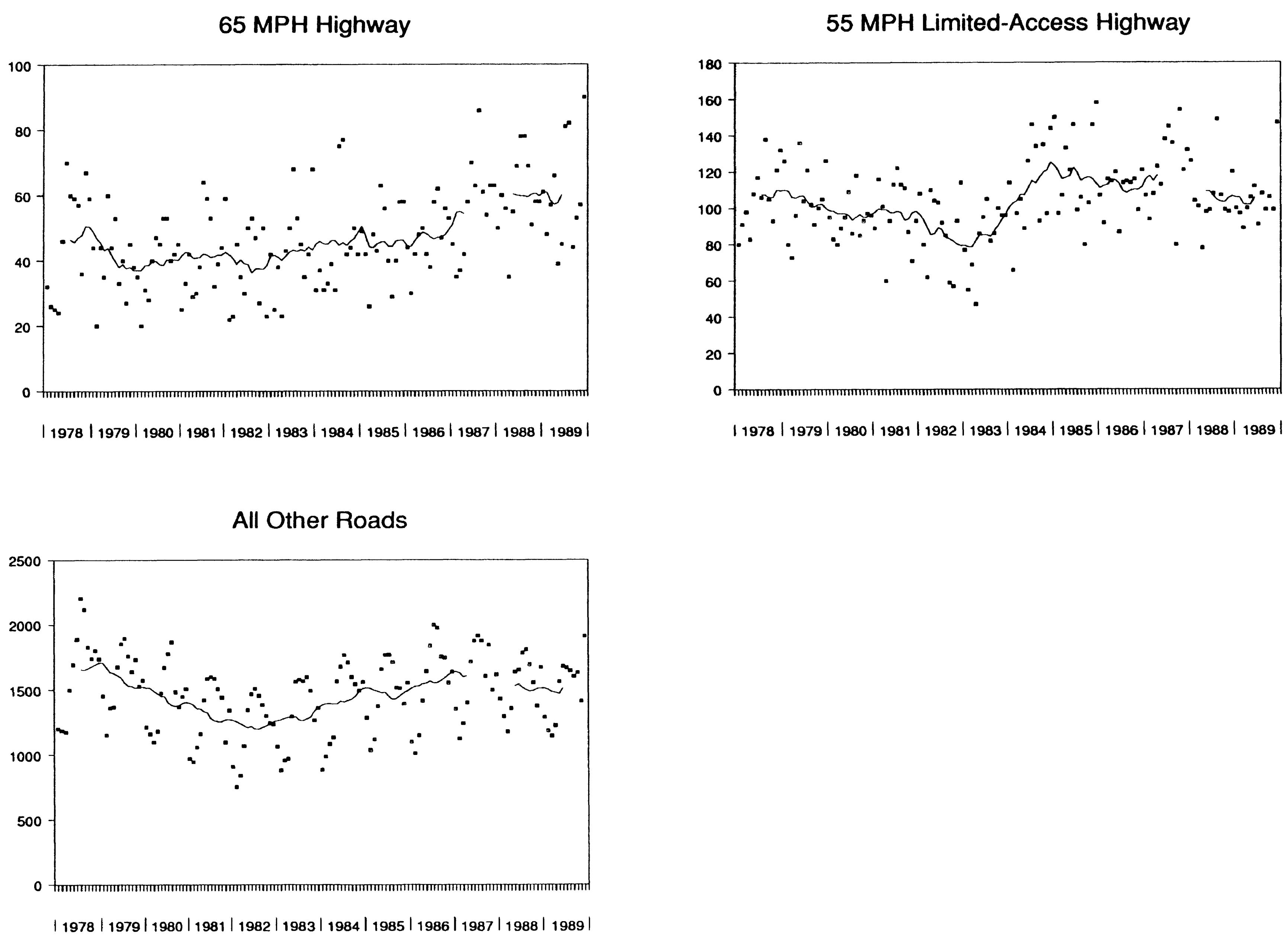


Figure A.2: A-level Injuries by Highway Type

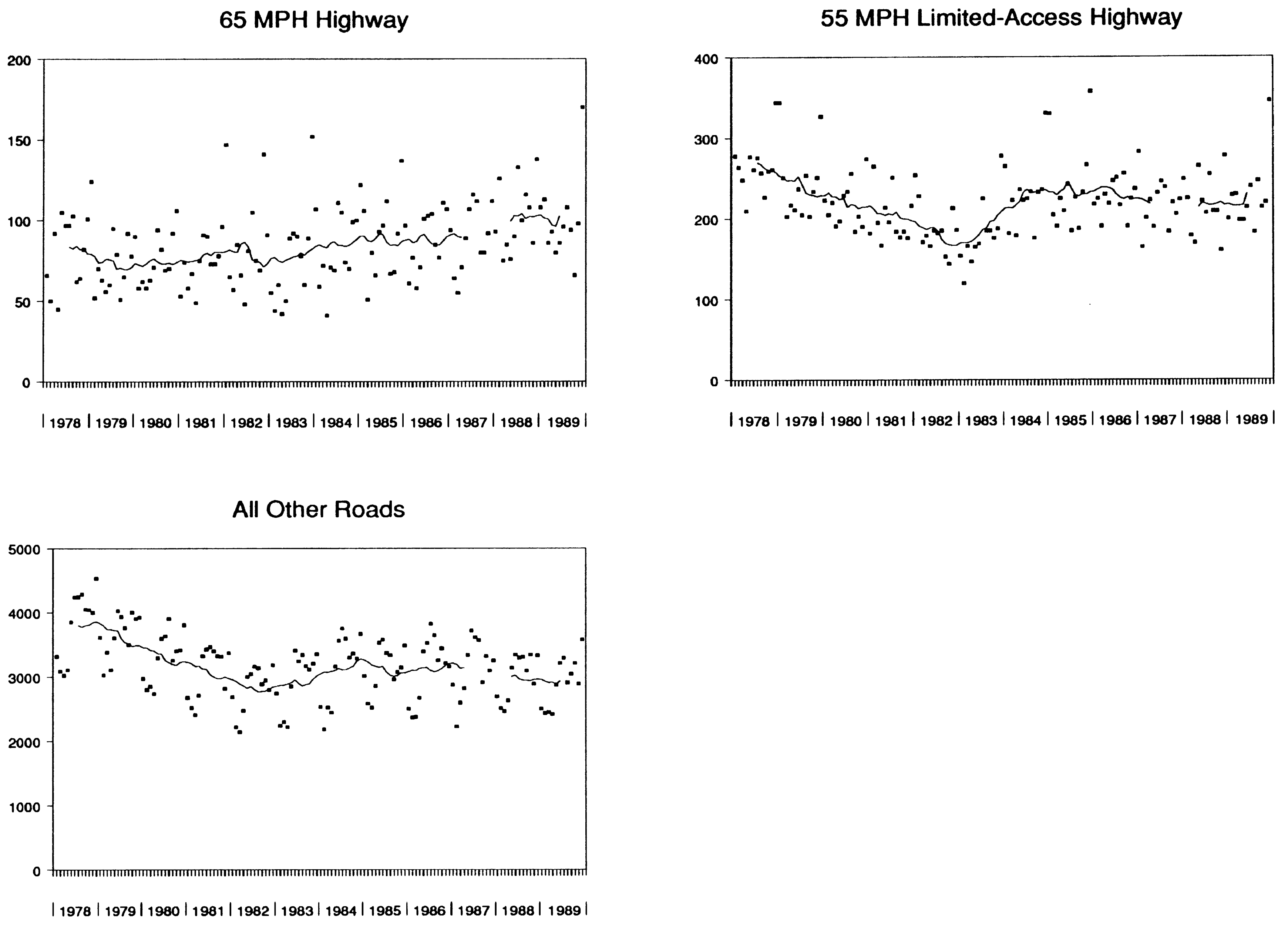


Figure A.3: B-level Injuries by Highway Type

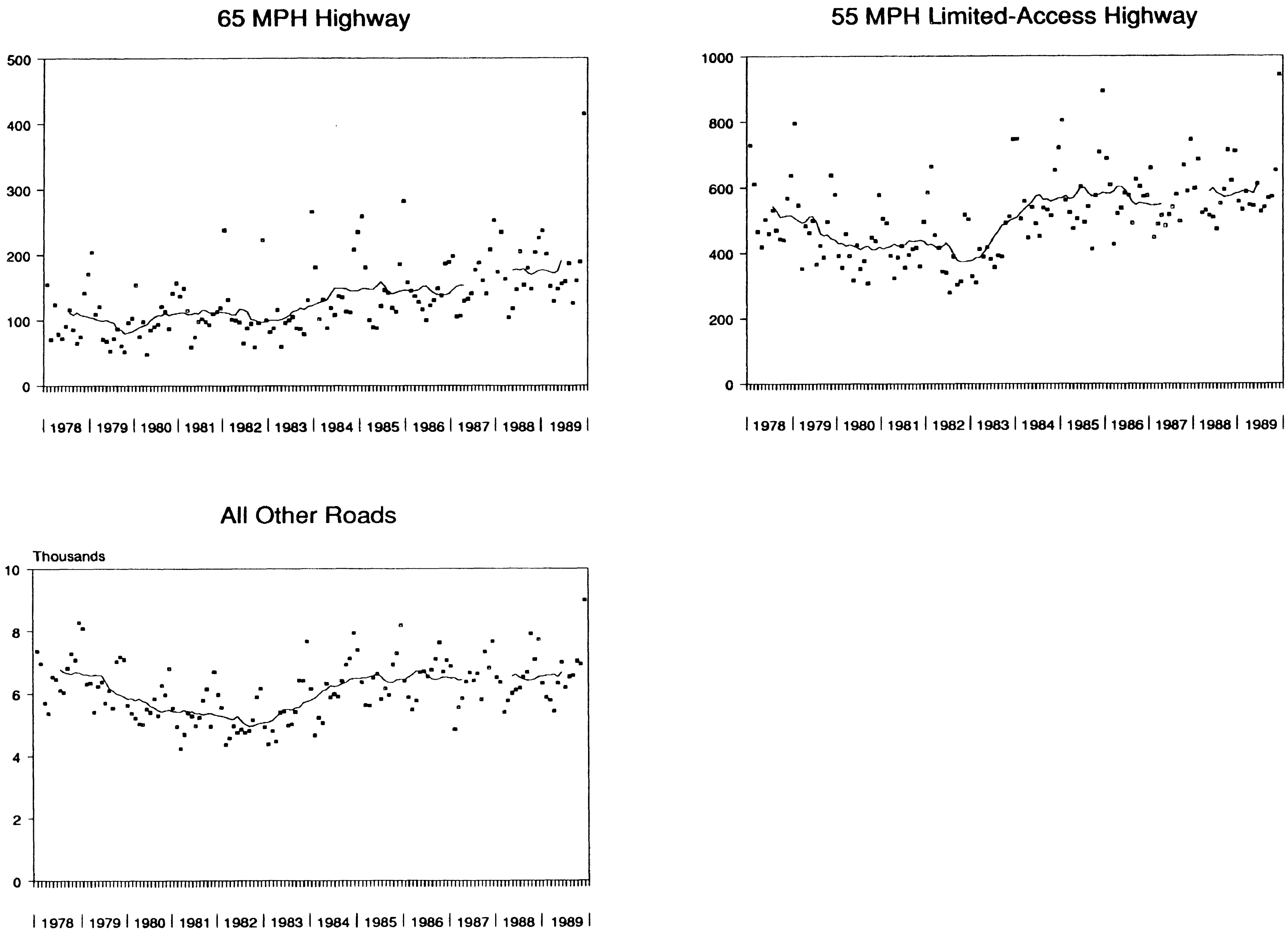


Figure A.4: C-level Injuries by Highway Type

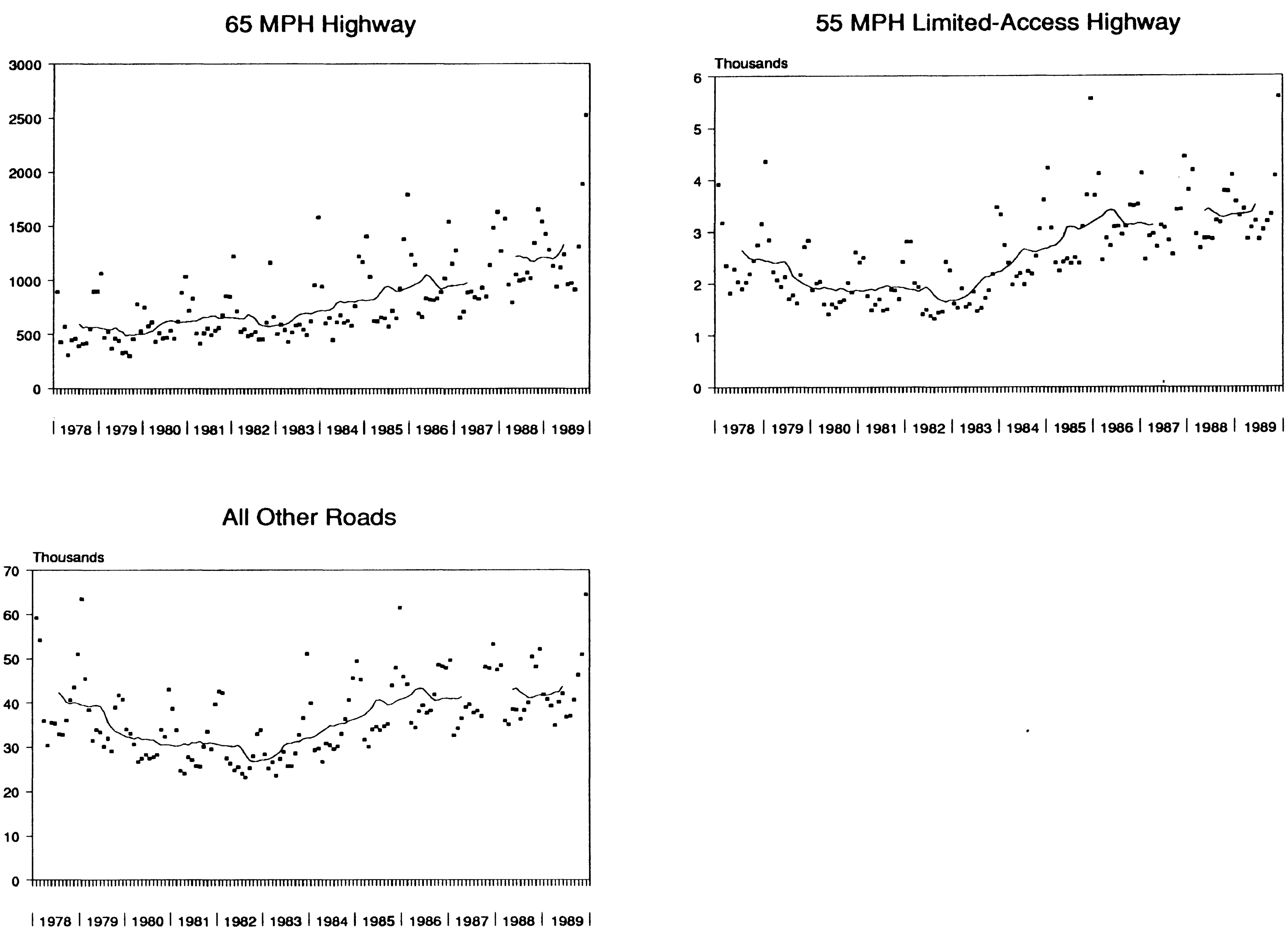


Figure A.5: Property Damage Only Crashes by Highway Type

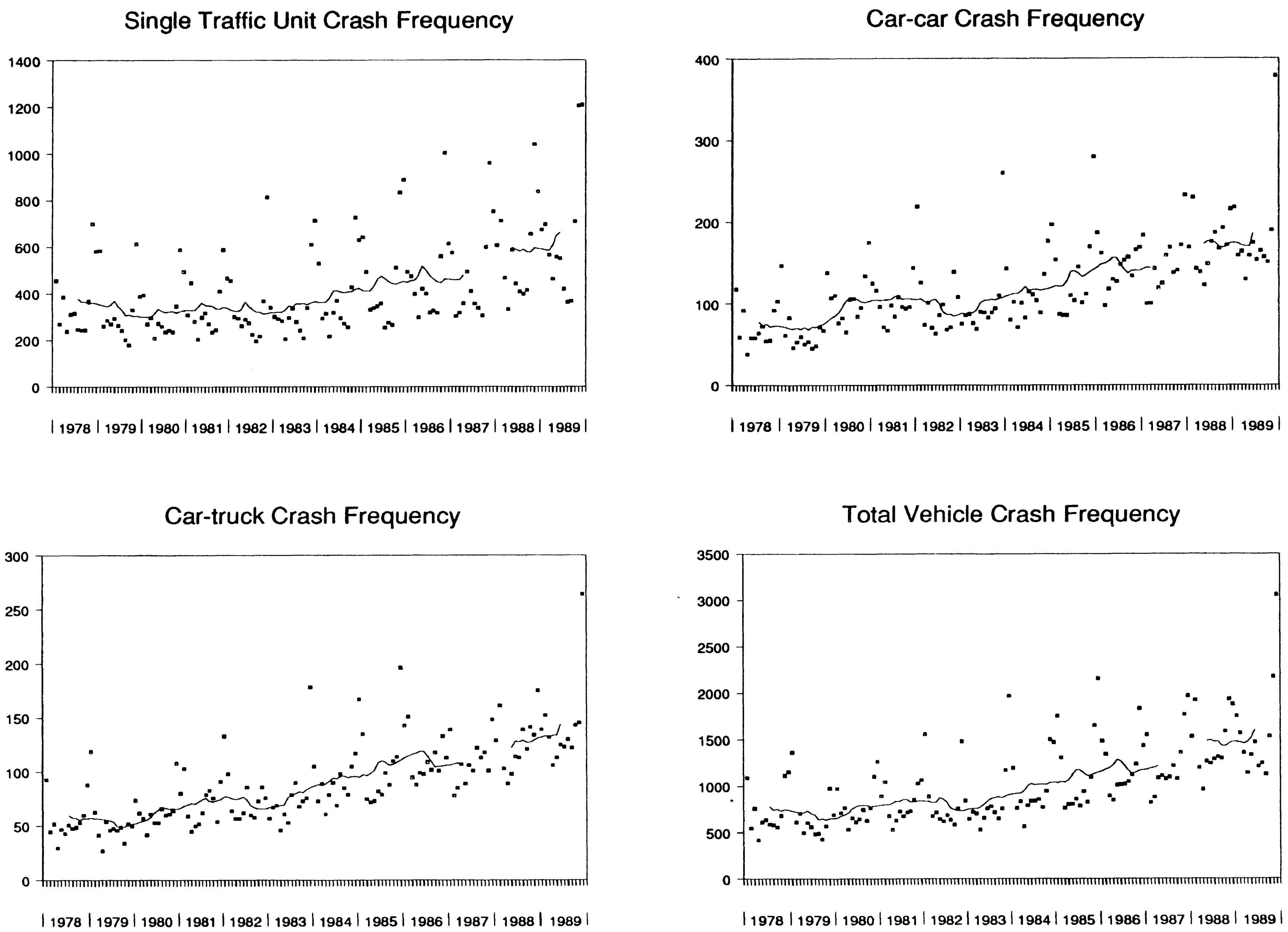


Figure A.6: Crashes on 65-MPH Highways by Vehicle Type

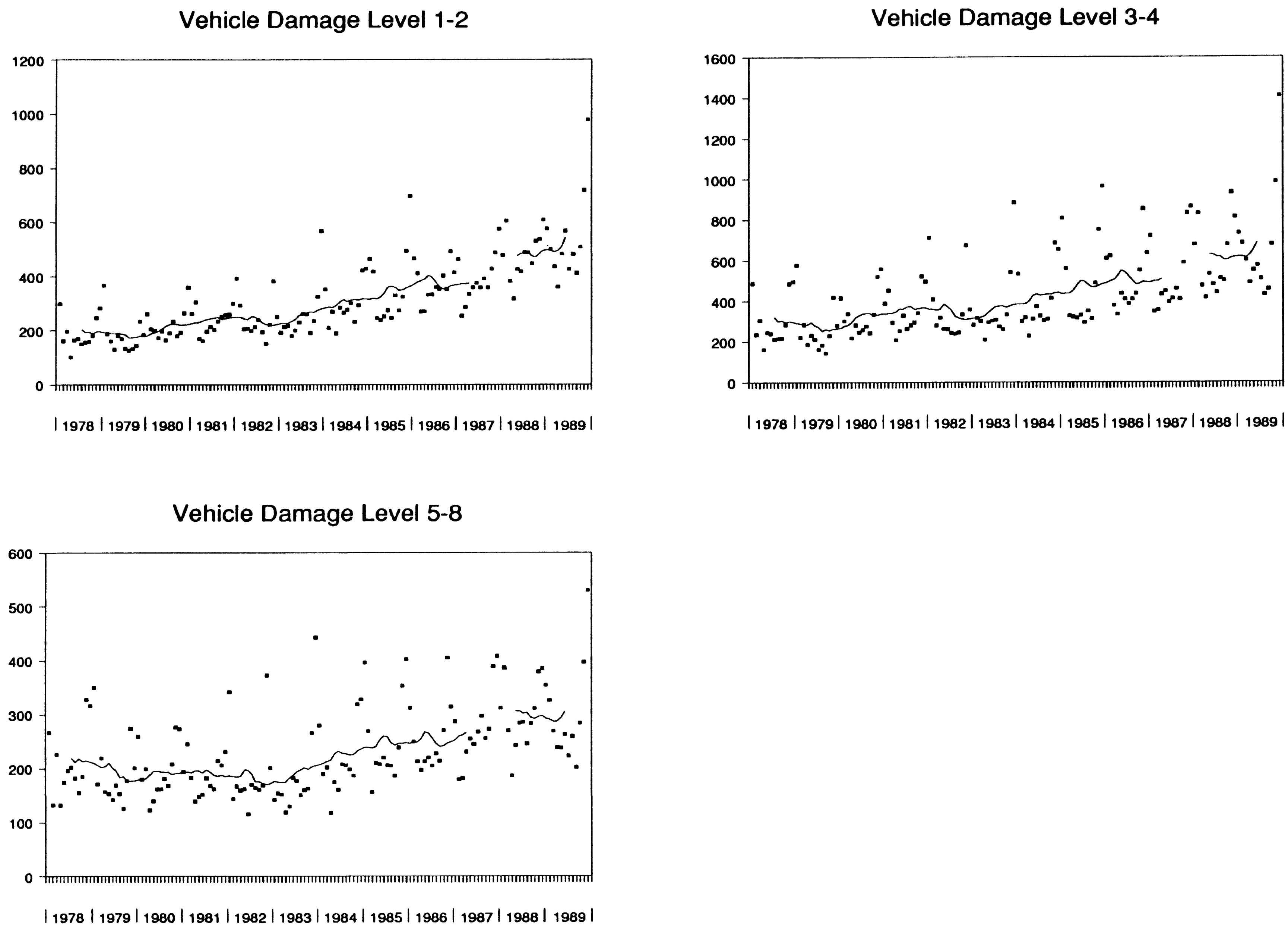


Figure A.7: Crashes on 65-MPH Highways by Vehicle Damage Level

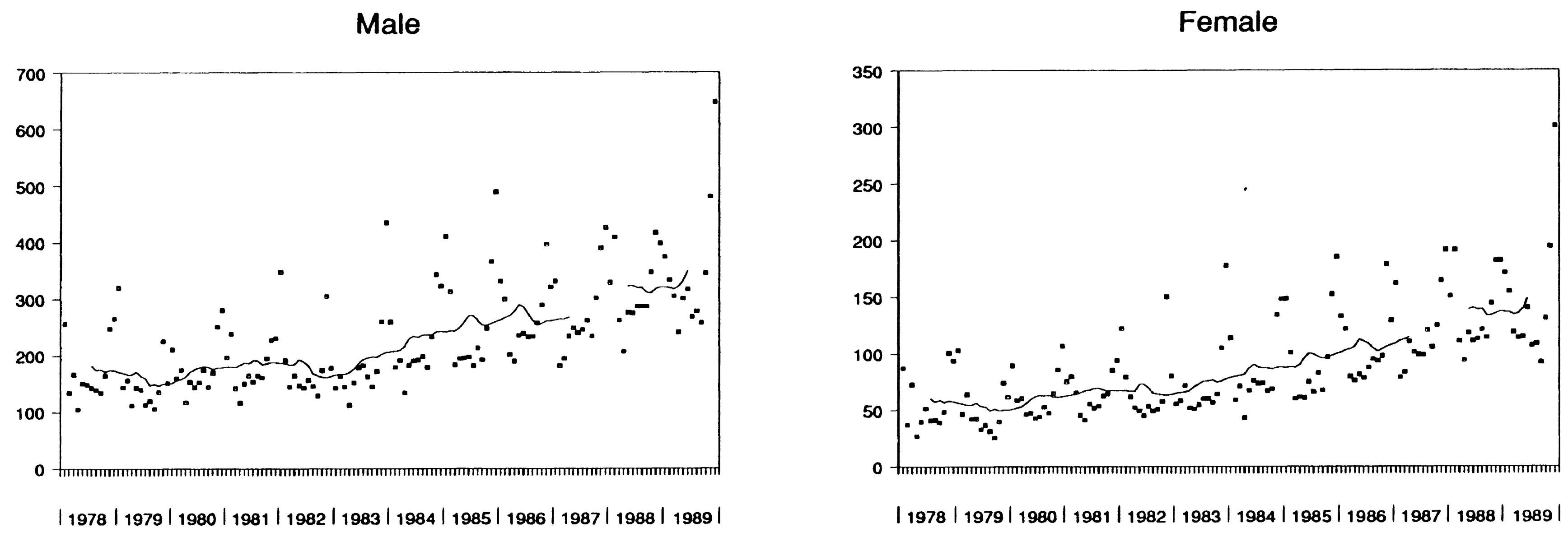


Figure A.8: Rate of Crashes on 65-MPH Highways per Million Licensed Drivers, by Gender

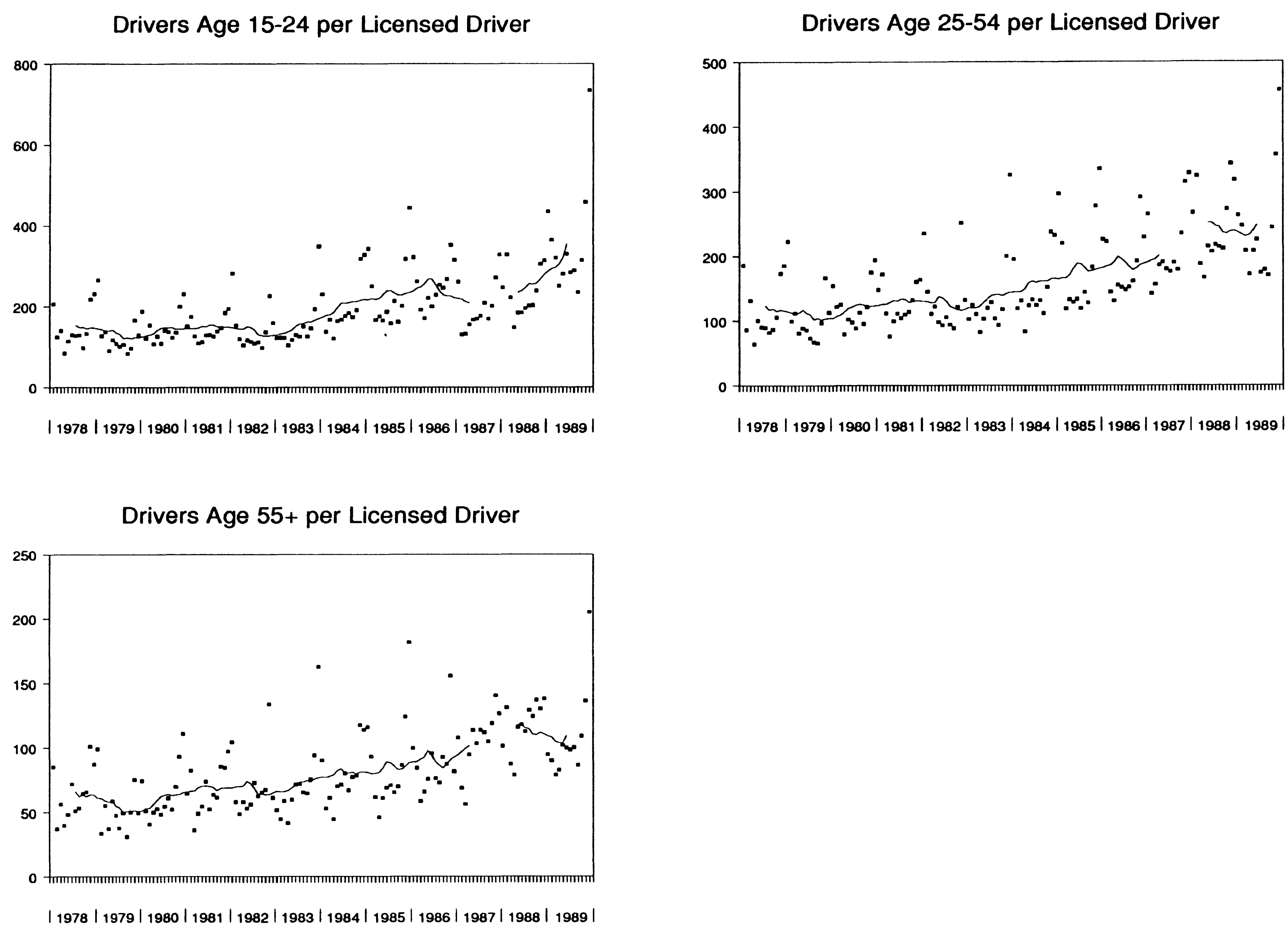
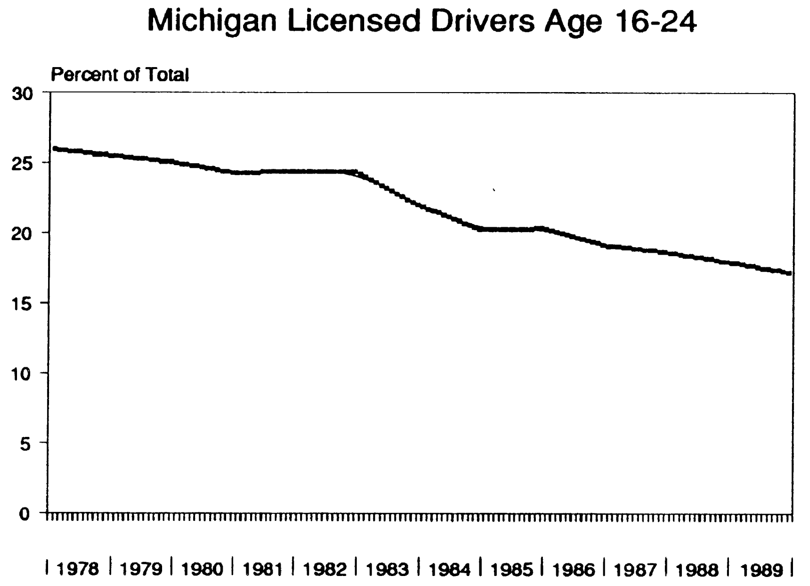
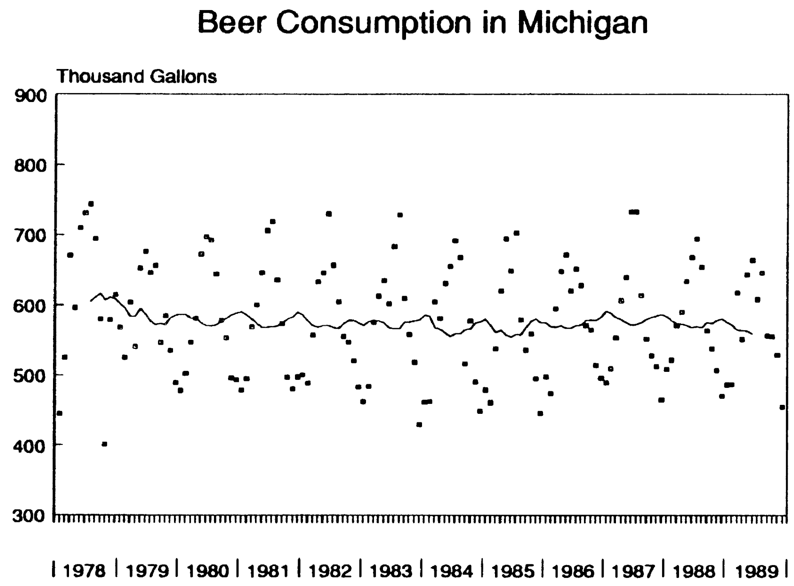


Figure A.9: Rate of Crashes on 65-MPH Highways per Million Licensed Drivers, by Age





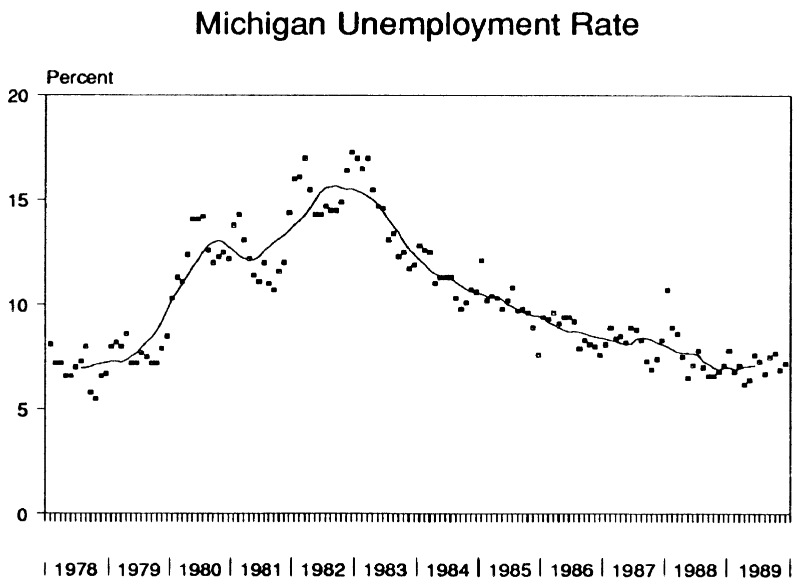


Figure A.10: Covariates Used in Time-series Models

APPENDIX B

Effects of Increase in Maximum Speed Limit: Results from Time-Series Models with Anticipatory and Implementation Effects

Table B.1. Effects of Increase in Maximum Speed Limit: Results from Time-Series Models with Anticipatory and Implementation Effects

	Estimate	Standard Error	Percent Change	90% Confidence Interval Low	90% Confidence Interval High
Fatalities					
65 MPH Highways					
ARIMA (0, 0, 5) $(0, 1, 1)_{12}$					
$R^2 = 0.03$					
Anticipatory Effect	0.2938*	0.3072			
Implementation Effect	0.2502	0.1036	28.4	8.3	52.3
55 Limited-access Highways					
ARIMA (0, 1, 1) $(0, 1, 1)_{12}$					
$R^2 = 0.08$					
Anticipatory Effect	0.3312	0.3719			
Implementation Effect	0.2621	0.2651	30.0	-16.0	101.0
All Other Roads					
ARIMA (0, 1, 1) $(0, 1, 1)_{12}$					
$R^2 = 0.72$					
Anticipatory Effect	0.0898	0.1246			
Implementation Effect	0.0727	0.1048	7.5	- 9.5	27.8
Serious Injuries					
65 MPH Highways					
ARIMA (0, 0, 0) $(0, 1, 1)_{12}$					
$R^2 = 0.48$					
Anticipatory Effect	0.5033*	0.1414			
Implementation Effect	0.3280*	0.0507	38.8	27.7	50.9
55 Limited-access Highways					
ARIMA (0, 1, 1) $(0, 1, 1)_{6}$					
$R^2 = 0.22$					
Anticipatory Effect	0.2590	0.1807			
Implementation Effect	- 0.0026	0.1570	- 0.3	-23.0	29.1
All Other Roads					
ARIMA (0, 1, 5) $(0, 1, 1)_{12}$					
$R^2 = 0.89$					
Anticipatory Effect	0.0521	0.0837			
Implementation Effect	0.0316	0.0857	3.2	-10.4	18.8
Moderate Injuries					
65 MPH Highways					
ARIMA (0, 0, 7) $(0, 1, 1)_{12}$					
$R^2 = 0.50$					
Anticipatory Effect	0.2424*	0.1220			
Implementation Effect	0.2152*	0.0493	24.0	14.4	34.5

Table B.1. Continued

	Estimate	Standard Error	Percent Change	90% Confidence Interval Low	High
55 Limited-access Highways					
ARIMA (0, 1, 1) (0, 1, 6)$_6$					
R^2 = 0.30					
Anticipatory Effect	0.2094	0.1559			
Implementation Effect	-0.0298	0.1392	- 2.9	-22.8	22.0
All Other Roads					
ARIMA (0, 1, 9) (0, 1, 1)$_{12}$					
R^2 = 0.88					
Anticipatory Effect	0.0327	0.0694			
Implementation Effect	0.0069	0.0716	0.7	-10.5	13.3
Minor Injuries					
65 MPH Highways					
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$					
R^2 = 0.65					
Anticipatory Effect	0.2213	0.2142			
Implementation Effect	0.0862	0.1910	9.0	-20.4	49.2
55 Limited-access Highways					
ARIMA (0, 1, 2) (0, 1, 1)$_{12}$					
R^2 = 0.59					
Anticipatory Effect	0.1065	0.1664			
Implementation Effect	0.0581	0.1503	6.0	-17.2	35.7
All Other Roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
R^2 = 0.77					
Anticipatory Effect	0.0709	0.0853			
Implementation Effect	0.0447	0.0851	4.6	- 9.1	20.3
Property Damage Only Crashes					
65 MPH Highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
R^2 = 0.84					
Anticipatory Effect	0.1518	0.1679			
Implementation Effect	0.1370	0.1491	14.7	-10.3	46.6
55 Limited-access Highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
R^2 = 0.82					
Anticipatory Effect	0.1290	0.1677			
Implementation Effect	0.0885	0.1695	9.3	-17.3	44.4
All Other Roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
R^2 = 0.84					
Anticipatory Effect	0.1796	0.1239			
Implementation Effect	0.1051	0.1324	11.1	-10.7	38.1

*Statistically significant at $p < .05$, two-tailed test.

APPENDIX C

Differential Effects of Increase in Maximum Speed Limit to 65 by Crash Configuration, Vehicle Damage Level, Gender, and Age

Table C.1. Differential Effects of Increase in Maximum Speed Limit to 65 by Crash Configuration, Vehicle Damage Level, Gender, and Age

	Estimate	Standard Error	Percent Change	90% Confidence Interval Low	90% Confidence Interval High
Crash Configuration					
Single Vehicle					
ARIMA (0, 1, 1) $(0, 1, 2)_{12}$					
$R^2 = 0.87$					
Anticipatory Effect	0.1858	0.1336			
Implementation Effect	0.2078*	0.1167	23.1	1.6	49.1
Car-car					
ARIMA (0, 1, 5) $(0, 1, 1)_{12}$					
$R^2 = 0.73$					
Anticipatory Effect	0.1196	0.2077			
Implementation Effect	0.0573	0.1739	5.9	-20.4	41.0
Car-truck					
ARIMA (0, 1, 7) $(0, 1, 1)_{12}$					
$R^2 = 0.78$					
Anticipatory Effect	0.0396	0.1778			
Implementation Effect	0.0034	0.1468	0.3	-21.2	27.8
Vehicle Damage Level					
Low					
ARIMA (0, 1, 1) $(0, 1, 1)_{12}$					
$R^2 = 0.83$					
Anticipatory Effect	0.1402	0.1699			
Implementation Effect	0.1290	0.1495	13.8	-11.0	45.5
Medium					
ARIMA (0, 1, 1) $(0, 1, 2)_{12}$					
$R^2 = 0.83$					
Anticipatory Effect	0.1964	0.1822			
Implementation Effect	0.2046	0.1697	22.7	- 7.2	62.2
High					
ARIMA (0, 1, 1) $(0, 1, 2)_{12}$					
$R^2 = 0.71$					
Anticipatory Effect	0.2100	0.1459			
Implementation Effect	0.1452	0.1200	15.6	- 5.1	40.9

Table C.1. Continued

	Estimate	Standard Error	Percent Change	90% Confidence Interval Low	High
Gender					
Male Driver Rate					
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$					
$R^2 = 0.69$					
Anticipatory Effect	0.3220	0.2549			
Implementation Effect	-0.0760	0.2765	- 7.3	-41.2	46.1
Female Driver Rate					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.83$					
Anticipatory Effect	0.1719	0.1544			
Implementation Effect	0.1006	0.1176	10.6	- 8.9	34.2
Age					
Age 15-24 Rate					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.80$					
Anticipatory Effect	0.1146	0.2315			
Implementation Effect	0.1200	0.2396	12.7	-24.0	67.2
Age 25-55 Rate					
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$					
$R^2 = 0.73$					
Anticipatory Effect	0.3309	0.2453			
Implementation Effect	-0.1486	0.2603	-13.8	-43.8	32.3
Age 56+ Rate					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.67$					
Anticipatory Effect	0.2665	0.1861			
Implementation Effect	0.1328	0.1507	14.2	-10.9	46.3
Total Vehicles Crashed					
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$					
$R^2 = 0.82$					
Anticipatory Effect	0.1874	0.1580			
Implementation Effect	0.1905	0.1444	21.0	- 4.6	53.4

*Statistically significant at $p < .05$, two-tailed test.

APPENDIX D

Effects of Increase in Maximum Speed Limit: Results from Time-Series Models with Anticipatory Effects, Implementation Effects, and Controls for Effects of Covariates

Table D.1. Effects of Increase in Maximum Speed Limit: Results from Time-Series Models with Anticipatory Effects, Implementation Effects, and Controls for Effects of Covariates

		Estimate	Standard Error	Percent Change	90% Confidence Interval Low	90% Confidence Interval High
Fatalities						
65 MPH Highways						
ARIMA (0, 0, 5) $(0, 1, 1)_{12}$						
$R^2 = 0.06$						
Anticipatory Effect		0.7971	0.3645			
Implementation Effect		0.3137	0.1254	36.8	11.3	68.2
Adult Belt Law		-0.3678	0.1369			
Unemployment Rate	Lag 0	0.3012	0.5050			
	Lag 1	0.5805	0.6436			
	Lag 2	-1.280	0.6622			
	Lag 3	-0.0405	0.5254			
Beer Consumption	Lag 0	-0.4168	0.7977			
	Lag 1	0.1388	0.7743			
	Lag 2	0.9164	0.7567			
Percent Young Drivers		-0.6279	0.4112			
Child Restraint Law		-0.0015	0.1212			
Serious Injuries						
65 MPH Highways						
ARIMA (0, 0, 8) $(0, 1, 1)_{12}$						
$R^2 = 0.48$						
Anticipatory Effect		0.3927	0.1706			
Implementation Effect		0.2212	0.0595	24.8	13.1	37.6
Adult Belt Law		0.0028	0.0648			
Unemployment Rate	Lag 0	-0.4539	0.2253			
	Lag 1	0.1460	0.2908			
	Lag 2	-0.0226	0.3030			
	Lag 3	0.1240	0.2399			
Beer Consumption	Lag 0	0.5692	0.3495			
	Lag 1	0.1162	0.3432			
	Lag 2	-0.2385	0.3322			
Percent Young Drivers		-0.1272	0.1897			
Child Restraint Law		0.0690	0.0568			

Table D.1. Continued

		Estimate	Standard Error	Percent Change	90% Confidence Interval Low	High
Moderate Injuries						
65 MPH Highways						
ARIMA (0, 0, 5) (0, 1, 1)$_{12}$						
$R^2 = 0.50$						
Anticipatory Effect		0.1452	0.1370			
Implementation Effect		0.1234	0.0462	13.1	4.9	22.1
Adult Belt Law		0.0443	0.0443			
Unemployment Rate	Lag 0	0.0256	0.1894			
	Lag 1	-0.2519	0.2390			
	Lag 2	0.3586	0.2469			
	Lag 3	-0.2168	0.1980			
Beer Consumption	Lag 0	0.2854	0.2994			
	Lag 1	0.0193	0.2948			
	Lag 2	0.0915	0.2835			
Percent Young Drivers		-0.1346	0.1503			
Child Restraint Law		0.0673	0.0450			
Minor Injuries						
65 MPH Highways						
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$						
$R^2 = 0.65$						
Anticipatory Effect		0.3573	0.2226			
Implementation Effect		0.2033	0.1961	22.5	-11.2	69.2
Adult Belt Law		0.0450	0.1355			
Unemployment Rate	Lag 0	0.1898	0.2228			
	Lag 1	-0.0323	0.2631			
	Lag 2	-0.1108	0.2708			
	Lag 3	0.2037	0.2253			
Beer Consumption	Lag 0	0.1609	0.3034			
	Lag 1	0.5905	0.2935			
	Lag 2	0.1171	0.2913			
Percent Young Drivers		-0.4533	0.3076			
Child Restraint Law		-0.1357	0.1416			

Table D.1. Continued

		Estimate	Standard Error	Percent Change	90% Confidence Interval Low	High
Property Damage Only Crashes						
65 MPH Highways						
ARIMA (0, 1, 1) (0, 1, 2)$_{12}$						
$R^2 = 0.84$						
Anticipatory Effect		0.2585	0.1764			
Implementation Effect		0.3094	0.1681	36.3	3.3	79.7
Unemployment Rate	Lag 0	0.0107	0.1618			
	Lag 1	-0.0763	0.1853			
	Lag 2	0.1664	0.1902			
	Lag 3	0.0066	0.1625			
Beer Consumption	Lag 0	0.0692	0.2156			
	Lag 1	0.0129	0.2079			
	Lag 2	-0.3354	0.2071			
Percent Young Drivers		-0.4169	0.2418			