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Age, period, and cohort effects in motor vehicle mortality in the United States, 1980–2010: the role of sex, alcohol involvement, and position in vehicle

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Abstract

Introduction—Although substantive declines in motor vehicle fatalities 1980–2010 have been observed, declines by position in the vehicle and alcohol involvement have not been well elucidated.

Method—Analyses of FARS data use the Intrinsic Estimator (IE) to produce estimates of all age, period, and cohort effects simultaneously by position in the car and by alcohol involvement.

Results—Declines in MVC deaths by position in the car vary for men and women by age and cohort over time. Cohorts born before 1970 had higher risks than those born later. Analyses using proxy indicators of alcohol involvement found highest risks for those aged 16–24. By period, these risks declined more rapidly than non- alcohol related traffic fatalities.

Conclusion—Changes in risk patterns are consistent with evidence regarding the contributions of new technologies and public policy efforts to reduce fatalities, but gains have not been shared evenly by sex or position in the car.

Practical Application—Greater attention is needed to reducing deaths among older drivers and pedestrians. Gender differences should be addressed in prevention efforts aimed at reducing MVCs due to alcohol involvement.

Keywords

motor vehicle crashes; age-period-cohort analysis; alcohol

1. Introduction

Traffic fatalities are a leading cause of death in the United States and occur at rates that have been consistently higher than those in other high-income countries.^{1,2} They are the second

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Conflicts of Interest

The authors have no competing interests that could influence this work.

This study uses public use datasets that include no personal identifiers and is therefore exempt from human subjects review.

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largest contributor to years of life lost before age 75, are the largest single cause of death among youth aged 15–24 years, and result in costs estimated at \$100 billion.^{2,3} Over the last three decades, deaths resulting from motor vehicle collisions (MVC) declined by nearly 25%, although the proportion of deaths associated with alcohol has remained steady since 1994.⁴

Previous studies have identified age as a risk factor for MVC deaths, with the highest death rates reported among younger drivers and those beginning to drink alcohol.^{5,6} Moreover, previous studies highlight the role of sex differences in MVC deaths, where men have experienced 2–3 times higher risk of traffic-related deaths than women, presumably due to male/female differences in total vehicle miles traveled, crash fatality rates, likelihood to exceed speed limits, use of seatbelts, and physical capacity to resist crash impact.^{7–10}

Many other factors have influenced traffic fatality rates over the past 40 years. These include improvements in car engineering (e.g. improved impact design, reduced risk of roll-over, effective air bags); enhanced trauma care; greater use of seatbelts and child protective restraints; reduced drunk, impaired, and inexperienced driving; restrictions on alcohol that reduce impaired driving—especially among younger drivers; and improvements in law enforcement^{11–16}. States (and to a more limited extent, the federal government) have adopted policies to encourage safer driving and occupant protections since the late 1970s. These interventions are strongly associated with decreased traffic fatalities, but the extent of such regulations and their effectiveness differ significantly.¹⁷ Changes in motor vehicle design, road safety, and regulatory environments are set against a backdrop of demographic change, urbanization, and economic cycles that have also affected trends in vehicle ownership, driving behaviors, and motor vehicle crashes and related fatalities over time.¹⁸

Given the complex interplay of factors that have influenced MVC fatalities, we apply age-period-cohort (APC) analysis to elucidate the contribution of changing demographic and social characteristics to observed changes in traffic fatality rates over a 30 year period. APC analysis aids in understanding long-term mortality trends by helping to identify the independent contribution of age-specific risks over time. The analysis also aids in describing period-specific effects arising from secular changes such as new legislation, vehicle design, or other factors that would affect traffic fatalities in specific time periods. Finally, APC analysis allows testing for the presence of differences among birth cohorts who may exhibit differences due to risk perception, social values, and other norms that could affect their risk of traffic-related death.

Only one prior study has applied APC analysis to motor vehicle fatality trends in the US¹⁹. That study demonstrated long-term trends in death rates, confirmed age and period effects, and showed that motor vehicle fatalities peaked during two periods: 1910–34 and 1960–69. The authors suggest these changes may be attributable to the rise in automobile transportation in the first period, and heightened industrial production in the second. Both periods were followed by a period of quick decline, corresponding to economic slowdowns. However, this prior study examined deaths only until 1994 and was thus unable to capture contemporary changes in technology, regulations, and law enforcement or emergence of new risks such as distracted driving due to cell phone use.^{20,21}

The present study has three goals. First, it extends earlier work¹⁹ using APC analysis of traffic fatalities by focusing on the most recent decades (1980–2010)—a period during which major advances were made in motor vehicle and driving safety. Second, it decomposes traffic-related deaths to examine the independent contribution of differences in age, period, and cohort effects related to death rates among drivers, passengers, and pedestrians. Third, it uses APC analyses to compare traffic fatalities where alcohol was involved (using a proxy indicator of single vehicle nighttime deaths) to identify the extent to which age, period, and/or cohort effects explain long-term changes in mortality due to impaired driving observed over the past 30 years.

2. Material and Methods

2.1. Data Analysis

APC analysis is most often used to help identify how the changing demographic composition of the population and time-specific factors affecting different cohorts explain mortality trends.²² Although potentially powerful, all APC analyses suffer from methodological difficulties because of the linear relationship among these three factors (i.e. Cohort = Period – Age).²³ Existing estimation methods generally require equating one or more (age, period, cohort) parameters to be equal.²⁴ While there is no single approach to deal with this limitation, the Intrinsic Estimator (IE) is a fairly recent technique that is able to produce unbiased estimators of the independent effects of age, period and cohort if certain conditions are met.^{25,26} To assess whether our data met these criteria (that there exist distinct age, period and cohort effects and that these effects cannot be adequately captured by using only a one or two factor model), we first used graphical techniques to assess patterns and variation by age, time, and birth cohort.²⁷ Age-specific death rates varied considerably and trends over time differed by age group, suggesting potential cohort effects. We then fit Poisson models using single (i.e. age only, period only, cohort only), two factor (i.e. age-period, age-cohort, period-cohort) and three factor models, assessing fit statistics (AIC, BIC) to determine that all three factors were operating (see appendix A). The results show that the three-part model results in superior fit. Based on these results (and informed by previous studies identifying all three effects in earlier periods) we conduct final analyses using Stata statistical software version 13 with the publicly available add-on file for the IE algorithm²⁸.

Results estimated by the IE algorithm are obtained in the form of Incidence Rate Ratios (IRRs). The statistical model is based on a Poisson link that includes log population size as an offset. Results can be interpreted as the relative risk of death for each age group, year, or cohort relative to the average of the entire age range, time period, or set of birth cohorts, respectively. To facilitate interpretation, we present results in both tabular and graphic form. The tabular format (available as an appendix) provides estimate values and their 95% confidence intervals, while the graphs facilitate identification of patterns and include results for all traffic deaths as a visual reference point.

2.2. Data Source & Variable Definition

Outcome data (numerators) were extracted from the Fatality Analysis Reporting System (FARS), a census of all MVC deaths in the United States. The dataset contains details about the crash and characteristics of the deceased including age, sex, relative position of the deceased in the crash (i.e., was the deceased the driver, an occupant, or a pedestrian), and whether alcohol was involved in the crash. We note that determination of alcohol use in the crash is imperfect (even while using the FARS' imputation methods), so we also present results from a validated proxy measure: deaths from single vehicle nighttime crashes.^{29,30} The FARS dataset contains deaths of drivers aged 5–14, which were excluded from analysis since numbers were very small and may have been errors. The residual category “others” (those involved in crashes who were neither drivers, passengers, nor pedestrians) contained very few deaths. For this reason, these “other” deaths are retained in the analysis of all deaths, but were not analyzed as a separate category. Denominators are official population counts for each 5 year age group and sex made available online by the National Cancer Institute.³¹

3. Results

Figure 1 presents age-specific death rates for females and males for the period 1980 to 2010. As can be seen the figure, death rates declined for all ages, for females (top panel) and for males (bottom panel) with steeper declines in the first decade of the period. Throughout the period, women in all age groups except 0–15 had lower fatality rates than their male counterparts. Among both sexes, those aged 16–30, and those 75+ experienced the highest rates as well as the steepest rates of decline.

Figure 2 displays the total death counts, alcohol and non-alcohol involved deaths, and deaths for drivers, occupants, and pedestrians by sex. For women (top panel), deaths to drivers and to occupants were similar at the beginning of the period, but deaths to drivers rose between the mid-1990s and the mid-2000s, falling to 1980 levels by the end of the period. Deaths in which alcohol was likely to be involved declined slowly and steadily throughout the period, while deaths in which alcohol was not involved fluctuated at higher levels, with sharp declines post-2006. For men, deaths for drivers were substantially higher than deaths for occupants. Beginning in the early 1990s, there was a slow decline in death for men in which alcohol was involved, while deaths in which alcohol was not involved rose steadily beginning in the early 1990s, before declining again in the mid 2000s.

3.1. APC effects and position/role in vehicle

Analyses of age effects by sex and position in the vehicle are shown in Figure 3 (the top graph displays rates for women and the bottom graph shows rates for men). Additional details are presented in the first block of Appendix Table 1. Compared to the average female risk for all ages, the relative risk of death for female drivers was highest at ages 15–24, remained above 1 until age 40, and rose again at 70+ years. IRRs for female passengers peaked at age 15–19, fell below one at age 30, and increased again at age 65. Compared to the average risk for males of all ages, male drivers aged 20–24 had the highest risk and this rate declined but remaining elevated over 1 until age 45, then rise above 1 again only at ages

70 and over. Male passengers followed a similar pattern to females, with ratios highest at ages 15–29, then falling below 1 until age 65, when they rose again. Among pedestrians of both sexes, risks were highest among those aged 70 and over.

Period effects are shown in the middle panel of Figure 3 and in the second block of Appendix Table 1. For female drivers, the highest period effects came during the period 1995–2004, while for female passengers, the ratios were elevated above 1 through 1999, dropping below 1 from 2000 to 2009. Overall, IRRs for deaths due to motor vehicle crashes for men peaked in 1980–1984 and fell below 1 in the period 1995–1999. This pattern remained consistent for male drivers, passengers, and pedestrians. Among all pedestrians, risks were highest in 1980–1984, and showed steady declines from 1995–2009.

Cohort effects are presented in the last panel of Figure 3 and the third block of Appendix Table 1. For female drivers, cohorts born 1920–1939 have the highest IRRs compared to all other female cohorts. Female passengers born in the 1925 cohort experienced the highest relative risks with steady declines over subsequent cohorts. The ratio of deaths to female pedestrians was highest in cohorts born in 1910–1929, and again for those born 1955–1980, with the lowest rates in the most recent birth cohorts. Cohort effects for male drivers were highest among those born 1945–1965, while for male passengers, cohorts born 1960–2000 had rates that were elevated above 1. Patterns of risk for male and female pedestrians were nearly identical and showed similarly strong sustained declines among cohorts born 1995 and thereafter.

3.2. APC effects and alcohol involvement

Using the proxy indicator of single vehicle nighttime crashes for alcohol-involved deaths, age effects appear in the first panel of Figure 4 (women top, men bottom) and the first block of Appendix Table 2. As can be seen from the graphic, the proxy indicator and the FARS estimates of alcohol involvement provide nearly identical results. The exception is the case of women aged 15–19, where the proxy measure shows significantly higher risk than the FARS alcohol measure. Despite the difference in magnitude, both models found that this age group is at highest risk among women for deaths in crashes where alcohol is suspected to have played a role. For these crashes, women's risk is elevated through age 49 and declines significantly from age 50 onwards. In daytime crashes (the proxy measure of non-alcohol involved crashes), risk ratios for women were highest in ages 15–19, decreased in ages 20–24 and dipped below 1 until rising again at age 55. Risks for deaths among men in nighttime crashes increased sharply at age 15–19, and again at ages 20–24 and remained elevated until age 54. In daytime traffic fatalities among men, risk ratios were highest at ages 15–19, remained elevated through age 29, then rose above 1 again beginning at age 50. In daytime crashes, risks increased significantly for both older men and women aged 65 and above.

The middle panel of Figure 4 and second block of appendix table 2 contain analyses of period effects. Women have elevated risks of dying in single vehicle nighttime crashes in the period 1980–1989, with the highest risk at the beginning of the period, 1980–84. In daytime crashes, women's risk was elevated in 1985–1999 and highest from 2000–2004. For men, the risk of death in single vehicle nighttime crashes was elevated from 1980 to the

mid-1990s. Of note, male risk of death during daytime crashes was also elevated 1980–1994, peaking in 1980–1984.

The last panel of figure 4 and the third block of appendix table 2 present cohort effects by alcohol involvement. For women, risks of deaths in single vehicle nighttime crashes were elevated for those born 1925–1974, peaking in 1960, and demonstrating significant declines among those born 1990 and thereafter. For men, risks were elevated for those born 1910–1985, peaking 1960–1964. For both men and women, risk of death in daytime crashes was generally elevated for cohorts born prior to 1980 and declined significantly for cohorts born 1985 and onwards.

4. Discussion

Traffic fatalities have declined over the past 40 years, and overall, women experienced fewer motor vehicle fatalities than men did in this period. However, APC analyses reveal meaningful differences in the risk profiles for men and women by position in the car and alcohol involvement in the crash. Moreover, whether behind the wheel, in the car, or on the street, risks of fatalities due to motor vehicle crashes are elevated for those over 65 years of age, compared to all age groups.

This study confirms and extends earlier work that age, period, and cohort effects are each significant in explaining motor vehicle mortality trends, but also reveals important sex differences by age and cohort that require attention.¹⁹ Taken together, these findings are consistent with evidence that changes in risk patterns that may be associated with the introduction of new technologies (such as air bags), as well as policies and campaigns aimed at increasing seat belt use, decreasing impaired and other risky driving, and other efforts.^{16,32–34}

Differences by sex by both age and cohort may reflect different exposures on the road, differences in changes in behaviors by men and women, as well as different socialization processes that affect perceptions of risk – both when alcohol is and is not involved. For instance, the increase in the number of female drivers and the annual miles driven in the 1960s–1990s may have increased their exposures and contributed to changes in their risk of death.^{35,36} In addition, differences by sex in single vehicle nighttime crashes (a proxy for alcohol-involved crashes) could be at least partially attributed to sex-related differences in alcohol initiation, and behaviors related to binge-drinking and impaired driving. Recent studies have confirmed that ages 20–24 and 25–29 are the ages at highest and second highest risk for heavy episodic drinking, for men and women, respectively.^{37,38}

Period effects in nighttime versus daytime crashes (proxies for alcohol vs. non-alcohol-related deaths) differed sharply, with greater relative declines seen in nighttime deaths after the 1990–94 period. This change most likely corresponds with several important policy developments, such as the implementation by many states of a set of laws that are designed to regulate alcohol-impaired driving among those below the minimum legal drinking age.¹⁴ There is compelling evidence that alcohol use and abuse have also changed over time and differ by sex. For example, Keyes et al.³⁹ concluded that there was reliable evidence of increased lifetime alcohol use in the cumulative proportion of the population in the United

States in cohorts born after WWII, and that the prevalence of alcohol disorders had increased among women. Birth cohorts from the 1980s appear to exhibit higher alcohol consumption than much earlier cohorts, but those born in the 1990s had relatively lower rates of binge drinking than previous cohorts^{37,38}. Consistent with recent analyses of patterns of heavy drinking, we found that the highest risks of death in single vehicle nighttime crashes occurred at ages 20–24 for men and ages 15–19 for women.³⁸ At the same time, while some studies found that the odds of heavy episodic drinking were highest in the periods 2000–2009, we observed steady decreases in the relative risk of death using our proxy measures of alcohol-impaired driving.³⁸ Thus, patterns consistent with reductions in fatalities on the road during a period when drinking behaviors may have worsened could point to the population-level effects of programs and policies intended to reduce impaired driving.

We do not find substantive evidence of sex differences by cohort in daytime (non-alcohol related) fatality risks. This finding underscores changes in the ways newer cohorts may perceive motor vehicle risks and more uniformly conform to safety behaviors such as seatbelt use.³³ Drivers' seat belt use rate has increased from 12% in 1985 to approximately 50% in 1986 (after state seat belt laws went into effect) and to 82% in 2005 and 86% in 2012.^{40,41} Drivers' norms supporting seatbelt use also appear to be stronger in recent years, perhaps in response to increased primary enforcement of seatbelt laws and greater visibility and social desirability of seatbelt use.^{42,43} Given previous research demonstrating a relationship between drivers' seat belt use and front seat passengers' seat belt use, this trend among drivers may have also influenced passenger safety behaviors.⁴²

Like any study, this one has both advantages and limitations. Although we include the census of all MVC deaths, we do not have information on injuries and acknowledge that APC effects for injuries may differ from those related to deaths. To capture the multiple influences of alcohol consumption and driving patterns over time, we analyze the proxy indicator of single vehicle deaths occurring at night. The literature suggests such proxy measures do a good job in estimating overall trends in alcohol-involved crashes that result in deaths--especially when examining larger geographic areas and longer time periods.²⁹ Finally, we use population size as the denominator, but this measure does not control for driving risk as measured by total vehicle miles traveled (VMT). One advantage to using population size is to facilitate comparisons with other APC analyses and to compare the epidemiologic burden of traffic fatalities with other leading causes of death.

There are several implications of these results for public health policy and practice. First, they highlight the importance of age-specific policies among those learning to drive as well as the impact of impaired driving regulations and their enforcement, especially focused on individuals in their 20s. While these policies are gender-neutral, it is clear that risk factors differ substantially by sex, with female drivers and passengers at greatest risk in earlier age groups than men. This implies the need for greater attention to understanding gender roles around driving and drinking behaviors. Second, an area of particular concern is the increased risk of death among pedestrians and passengers aged 65 and over. Despite some state-level restrictions for certain classes of older drivers, there have been only a few initiatives targeted towards this vulnerable population.⁴⁴ Third, period effects likely point to the generally

positive contribution of technologies, emergency response, and greater regulation and uptake of behavior such as seatbelt and child restraint use over time. Nevertheless, motor vehicle crashes remain a leading cause of death. Continued investment in policies and programs to promote safer driving and technologies to promote safer vehicles is still necessary. Fourth, people born after the 1980s exhibit substantially lower risk of traffic related deaths than any prior cohort. Efforts should be made to ensure that this favorable trend does not erode with the uptake of new technologies such as cell phone talking and texting while driving. Finally, cohort effects, while significant, do not appear to have affected passenger/occupant fatalities, suggesting that further targeting of safety messages and “norming” of protective behaviors is needed for these younger cohorts and subsequent ones.

5. Conclusions

This study has found consistent age-specific risks for traffic fatalities with substantial differences by sex. Period effects are also notable and suggest important changes to car safety as well as moderate population-level effects of regulation aimed to decrease the incidence of crashes and lessen the risk of death given a motor vehicle crash. Newer cohorts appear to be less at risk than older ones for traffic fatalities. Results suggest the need for continued attention to young drivers and early drinkers, more targeted sex-specific efforts to enhance driving safety, and the need to develop more effective approaches to enhancing the safety of older drivers and pedestrians—two populations that have historically received less policy attention.

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Appendix A: Goodness of fit statistics for age-period-cohort log linear models of traffic fatalities

		Age	Period	Cohort	Age-Period	Age-Cohort	Period-Cohort	Age-Period-Cohort*
Female	AIC	9253.014	79643.81	49171.48	2761.744	2319.462	48163.77	147.1626
	BIC	9294.043	79659.19	49225.33	2815.595	2411.779	48230.45	125.3003
Male	AIC	32395.8	283723.3	166140.8	9233.265	4102.412	158437.6	270.1435
	BIC	32436.83	283738.7	166194.6	9287.116	4194.729	158504.3	1239.491

The smaller the value of the AIC and BIC, the better the model fit.

* Estimated via constrained generalized linear model (CGLIM) with age 5=age 10 set as a constraint.

Appendix 1. Age-Period-Cohort effects, by sex and role/position of deceased in relation to the vehicle

Age	Total		Drivers		Occupants		Pedestrians	
	Female	Male	Female	Male	Female	Male	Female	Male
<1	0.594*** 0.53,0.66	0.391*** 0.32,0.48	n/a	n/a	1.053 0.95,1.16	1.186*** 1.10,1.28	0.151*** 0.09,0.26	0.105*** 0.06,0.20
1–4	0.591*** 0.56,0.62	0.396*** 0.36,0.43	n/a	n/a	0.847*** 0.80,0.90	0.845*** 0.81,0.89	1.301*** 1.16,1.46	1.004 0.89,1.14
5–9	0.494*** 0.47,0.52	0.379*** 0.35,0.41	n/a	n/a	0.649*** 0.61,0.69	0.662*** 0.63,0.69	1.242*** 1.12,1.38	0.979 0.87,1.10
10–14	0.522*** 0.50,0.55	0.423*** 0.39,0.46	0.0556*** 0.05,0.07	0.0807*** 0.07,0.10	0.810*** 0.77,0.85	0.844*** 0.81,0.88	0.819*** 0.73,0.92	0.599*** 0.53,0.68
15–19	2.202*** 2.14,2.27	2.160*** 2.06,2.26	2.272*** 2.18,2.37	1.810*** 1.73,1.90	2.648*** 2.56,2.74	3.444*** 3.35,3.54	1.012 0.92,1.12	0.928 0.84,1.03
20–24	1.708*** 1.66,1.76	2.501*** 2.40,2.61	2.160*** 2.08,2.25	2.444*** 2.34,2.55	1.608*** 1.54,1.68	2.886*** 2.80,2.97	0.857** 0.78,0.95	1.212*** 1.11,1.33
25–29	1.218*** 1.18,1.26	1.718*** 1.65,1.79	1.584*** 1.52,1.65	1.726*** 1.65,1.80	1.007 0.96,1.06	1.567*** 1.51,1.62	0.780*** 0.71,0.86	1.082 0.99,1.18
30–34	1.025 0.99,1.06	1.329*** 1.27,1.39	1.303*** 1.25,1.36	1.320*** 1.26,1.38	0.774*** 0.73,0.82	1.025 0.98,1.07	0.834*** 0.76,0.92	1.039 0.95,1.13
35–39	1.008 0.97,1.04	1.169*** 1.12,1.22	1.219*** 1.17,1.27	1.124*** 1.07,1.18	0.739*** 0.70,0.78	0.822*** 0.79,0.86	0.96 0.88,1.05	1.090* 1.00,1.18
40–44	0.989 0.95,1.02	1.100*** 1.05,1.15	1.121*** 1.07,1.17	1.022 0.97,1.08	0.749*** 0.71,0.79	0.738*** 0.70,0.78	1.019 0.93,1.11	1.169*** 1.08,1.27
45–49	0.977 0.94,1.01	1.089*** 1.04,1.14	1.038 0.99,1.08	0.98 0.93,1.03	0.774*** 0.73,0.82	0.704*** 0.67,0.74	1.061 0.97,1.16	1.290*** 1.19,1.40

Age	Total		Drivers		Occupants		Pedestrians	
	Female	Male	Female	Male	Female	Male	Female	Male
50–54	0.982 0.95,1.02	1.076** 1.02,1.13	1 0.96,1.05	0.955 0.90,1.01	0.788*** 0.74,0.84	0.640*** 0.60,0.68	1.119* 1.02,1.23	1.350*** 1.25,1.46
55–59	1.004 0.97,1.04	1.057* 1.00,1.11	0.967 0.92,1.01	0.924** 0.87,0.98	0.832*** 0.78,0.88	0.593*** 0.56,0.63	1.244*** 1.14,1.36	1.363*** 1.26,1.48
60–64	1.089*** 1.05,1.13	1.05 0.99,1.11	0.96 0.91,1.01	0.903** 0.85,0.96	0.99 0.94,1.05	0.652*** 0.61,0.70	1.398*** 1.28,1.53	1.340*** 1.23,1.46
65–69	1.238*** 1.19,1.29	1.096** 1.03,1.17	1.019 0.97,1.07	0.936 0.87,1.00	1.224*** 1.16,1.29	0.729*** 0.68,0.78	1.570*** 1.43,1.72	1.362*** 1.24,1.49
70+	1.814*** 1.76,1.87	1.784*** 1.70,1.87	1.324*** 1.28,1.37	1.465*** 1.40,1.54	1.889*** 1.81,1.97	1.451*** 1.38,1.52	2.801*** 2.62,3.00	2.319*** 2.16,2.49
Period								
1980–1984	1.080*** 1.06,1.10	1.233*** 1.20,1.27	0.895*** 0.87,0.92	1.171*** 1.14,1.21	1.190*** 1.16,1.22	1.308*** 1.28,1.34	1.357*** 1.29,1.42	1.464*** 1.40,1.53
1985–1989	1.111*** 1.09,1.13	1.129*** 1.10,1.16	1.033* 1.01,1.06	1.092*** 1.06,1.12	1.168*** 1.14,1.20	1.188*** 1.16,1.21	1.206*** 1.15,1.26	1.246*** 1.20,1.30
1990–1994	1.020* 1.00,1.04	0.964** 0.94,0.99	0.997 0.97,1.02	0.932*** 0.90,0.96	1.058*** 1.03,1.09	1.032** 1.01,1.05	1.026 0.98,1.08	1.03 0.99,1.08
1995–1999	1.035*** 1.02,1.06	0.920*** 0.90,0.94	1.088*** 1.06,1.11	0.912*** 0.88,0.94	1.029* 1.00,1.06	0.963*** 0.94,0.98	0.929** 0.89,0.98	0.907*** 0.87,0.95
2000–2004	0.970** 0.95,0.99	0.935*** 0.91,0.96	1.073*** 1.05,1.10	0.974 0.94,1.00	0.921*** 0.90,0.95	0.923*** 0.90,0.94	0.839*** 0.80,0.88	0.792*** 0.76,0.83
2005–2010	0.813*** 0.80,0.83	0.867*** 0.84,0.89	0.928*** 0.91,0.95	0.945*** 0.92,0.97	0.717*** 0.70,0.74	0.701*** 0.68,0.72	0.764*** 0.73,0.80	0.740*** 0.71,0.77
Cohort								
1910	0.962 0.91,1.02	0.979 0.89,1.08	0.830*** 0.76,0.91	0.846** 0.75,0.95	0.835*** 0.77,0.90	0.670*** 0.61,0.74	1.241*** 1.10,1.41	1.409*** 1.20,1.65
1915	1.061* 1.01,1.11	1.098* 1.01,1.19	1.014 0.94,1.09	1.016 0.92,1.12	0.966 0.91,1.03	0.829*** 0.77,0.90	1.270*** 1.13,1.42	1.380*** 1.19,1.60
1920	1.149*** 1.10,1.20	1.158*** 1.08,1.24	1.193*** 1.12,1.27	1.141** 1.05,1.24	1.061* 1.00,1.12	0.893** 0.83,0.96	1.216*** 1.09,1.35	1.242** 1.08,1.43
1925	1.176*** 1.13,1.22	1.205*** 1.13,1.29	1.278*** 1.21,1.35	1.214*** 1.13,1.31	1.113*** 1.06,1.17	0.945 0.89,1.01	1.088 0.98,1.21	1.183* 1.03,1.36
1930	1.130*** 1.09,1.17	1.153*** 1.09,1.23	1.238*** 1.17,1.31	1.147*** 1.07,1.23	1.063* 1.01,1.12	0.905** 0.85,0.96	1.041 0.94,1.16	1.157* 1.01,1.32
1935	1.083*** 1.04,1.12	1.090** 1.03,1.15	1.185*** 1.13,1.25	1.062 0.99,1.14	1.03 0.98,1.08	0.913** 0.86,0.97	0.952 0.86,1.06	1.071 0.94,1.22
1940	1.094*** 1.05,1.14	1.173*** 1.10,1.25	1.190*** 1.12,1.26	1.157*** 1.08,1.24	0.989 0.93,1.05	0.908** 0.85,0.97	1.019 0.91,1.15	1.125 0.98,1.29
1945	1.074*** 1.03,1.12	1.219*** 1.15,1.29	1.170*** 1.11,1.24	1.203*** 1.12,1.29	0.927* 0.87,0.99	0.913** 0.86,0.97	0.975 0.87,1.10	1.118 0.97,1.28

Age	Total		Drivers		Occupants		Pedestrians	
	Female	Male	Female	Male	Female	Male	Female	Male
1950	1.087*** 1.04,1.13	1.270*** 1.20,1.34	1.111*** 1.05,1.17	1.224*** 1.15,1.30	0.952 0.90,1.01	0.945* 0.89,1.00	1.114 0.99,1.25	1.228** 1.07,1.41
1955	1.133*** 1.09,1.18	1.330*** 1.26,1.41	1.096*** 1.04,1.16	1.240*** 1.17,1.32	1.008 0.95,1.07	1.035 0.99,1.09	1.266*** 1.13,1.42	1.372*** 1.19,1.58
1960	1.181*** 1.14,1.23	1.334*** 1.26,1.41	1.105*** 1.05,1.16	1.208*** 1.14,1.28	1.039 0.98,1.10	1.109*** 1.06,1.16	1.395*** 1.24,1.57	1.448*** 1.26,1.67
1965	1.148*** 1.11,1.19	1.278*** 1.21,1.35	1.031 0.98,1.08	1.137*** 1.08,1.20	1.028 0.98,1.08	1.141*** 1.10,1.19	1.348*** 1.20,1.52	1.383*** 1.20,1.60
1970	1.111*** 1.07,1.16	1.238*** 1.17,1.31	0.972 0.92,1.02	1.078* 1.02,1.14	1.002 0.95,1.05	1.193*** 1.15,1.24	1.193** 1.05,1.35	1.233** 1.06,1.44
1975	1.095*** 1.05,1.14	1.204*** 1.13,1.28	0.901*** 0.85,0.95	1.012 0.95,1.08	1.012 0.96,1.07	1.218*** 1.17,1.27	1.261*** 1.11,1.43	1.248** 1.07,1.46
1980	1.100*** 1.05,1.15	1.141*** 1.07,1.22	0.890*** 0.84,0.94	0.946 0.88,1.01	1.05 1.00,1.10	1.211*** 1.17,1.26	1.211** 1.07,1.37	1.168 1.00,1.37
1985	1.070** 1.02,1.12	1.052 0.98,1.13	0.884*** 0.83,0.94	0.870*** 0.81,0.94	1.065* 1.01,1.12	1.194*** 1.15,1.24	1.093 0.96,1.25	1.043 0.88,1.23
1990	0.928** 0.88,0.98	0.823*** 0.76,0.90	0.717*** 0.66,0.78	0.638*** 0.58,0.71	1.034 0.98,1.09	1.092*** 1.05,1.14	0.907 0.78,1.05	0.861 0.72,1.03
1995	0.798*** 0.74,0.86	0.667*** 0.59,0.76	0.557* 0.32,0.96	0.415** 0.23,0.76	1.042 0.97,1.12	1.118*** 1.05,1.19	0.657*** 0.55,0.79	0.605*** 0.49,0.75
2000	0.710*** 0.65,0.78	0.568*** 0.48,0.67	n/a	n/a	1.042 0.95,1.14	1.111** 1.03,1.20	0.433*** 0.34,0.55	0.444*** 0.34,0.58
2005	0.639*** 0.56,0.73	0.510*** 0.40,0.64	n/a	n/a	0.909 0.80,1.03	0.981 0.89,1.09	0.510*** 0.38,0.68	0.461*** 0.33,0.64
2010	0.629** 0.46,0.86	0.453** 0.25,0.82	n/a	n/a	0.883 0.67,1.17	0.9 0.72,1.13	0.7 0.15,3.21	0.334 0.03,3.52

Results are Incidence Rate Ratios and 95% confidence intervals relative to the average rate over the entire age, period, and cohort, respectively.

* p<0.05,

** p<0.01,

*** p<0.001

Appendix 2: Age-Period-Cohort effects by sex and indicators of alcohol involvement

Age	Nighttime single vehicle		Daytime		FARS - alcohol-related		FARS -alcohol not suspected	
	Female	Male	Female	Male	Female	Male	Female	Male
<1	0.636*** 0.53,0.77	0.385*** 0.29,0.51	0.534*** 0.44,0.65	0.312*** 0.23,0.41	0.627*** 0.55,0.71	0.456*** 0.36,0.57	0.697*** 0.63,0.77	0.624*** 0.52,0.75

Age	Nighttime single vehicle		Daytime		FARS - alcohol-related		FARS -alcohol not suspected	
	Female	Male	Female	Male	Female	Male	Female	Male
1-4	0.477*** 0.43,0.53	0.265*** 0.23,0.31	0.443*** 0.40,0.49	0.244*** 0.21,0.28	0.645*** 0.61,0.68	0.484*** 0.44,0.54	0.552*** 0.52,0.58	0.405*** 0.36,0.45
5-9	0.358*** 0.32,0.40	0.213*** 0.18,0.25	0.342*** 0.31,0.38	0.189*** 0.16,0.22	0.541*** 0.51,0.57	0.475*** 0.43,0.52	0.425*** 0.40,0.45	0.314*** 0.28,0.35
10-14	0.594*** 0.54,0.65	0.335*** 0.30,0.38	0.429*** 0.39,0.47	0.231*** 0.20,0.26	0.552*** 0.52,0.58	0.519*** 0.48,0.56	0.401*** 0.38,0.42	0.391*** 0.36,0.43
15-19	4.044*** 3.84,4.26	3.985*** 3.74,4.25	2.824*** 2.68,2.98	2.851*** 2.68,3.04	2.024*** 1.95,2.10	1.971*** 1.87,2.08	1.668*** 1.61,1.73	1.701*** 1.61,1.80
20-24	2.935*** 2.79,3.09	4.789*** 4.53,5.07	2.891*** 2.75,3.04	4.584*** 4.34,4.84	1.360*** 1.31,1.42	1.734*** 1.64,1.83	1.369*** 1.32,1.42	1.712*** 1.62,1.81
25-29	1.887*** 1.79,1.99	3.075*** 2.91,3.25	2.085*** 1.98,2.20	3.144*** 2.99,3.31	0.987 0.95,1.03	1.213*** 1.15,1.28	1.095*** 1.06,1.14	1.240*** 1.17,1.31
30-34	1.453*** 1.37,1.54	2.154*** 2.04,2.28	1.724*** 1.63,1.82	2.368*** 2.25,2.49	0.870*** 0.83,0.91	0.99 0.93,1.05	0.951** 0.92,0.99	1.032 0.98,1.09
35-39	1.359*** 1.28,1.44	1.723*** 1.63,1.82	1.649*** 1.56,1.74	1.979*** 1.88,2.08	0.895*** 0.86,0.94	0.938* 0.88,0.99	0.949** 0.92,0.98	0.961 0.91,1.02
40-44	1.211*** 1.14,1.29	1.451*** 1.37,1.54	1.488*** 1.40,1.58	1.711*** 1.62,1.80	0.930** 0.89,0.97	0.965 0.91,1.02	0.976 0.94,1.01	0.982 0.93,1.04
45-49	1.041 0.97,1.12	1.271*** 1.19,1.36	1.315*** 1.23,1.40	1.539*** 1.45,1.63	0.965 0.92,1.01	1.024 0.97,1.09	1.023 0.99,1.06	1.047 0.99,1.11
50-54	0.918* 0.85,0.99	1.094* 1.02,1.17	1.075* 1.00,1.16	1.347*** 1.27,1.43	1.031 0.99,1.08	1.084** 1.02,1.15	1.079*** 1.04,1.12	1.139*** 1.08,1.20
55-59	0.777*** 0.72,0.84	0.930 0.86,1.01	0.910* 0.84,0.99	1.098* 1.02,1.18	1.100*** 1.05,1.15	1.157*** 1.09,1.23	1.182*** 1.14,1.22	1.216*** 1.15,1.29
60-64	0.745*** 0.68,0.81	0.775*** 0.71,0.85	0.774*** 0.71,0.84	0.919* 0.85,1.00	1.236*** 1.18,1.29	1.206*** 1.13,1.29	1.337*** 1.29,1.38	1.319*** 1.24,1.40
65-69	0.714*** 0.65,0.79	0.657*** 0.59,0.73	0.685*** 0.62,0.75	0.747*** 0.68,0.82	1.434*** 1.37,1.50	1.323*** 1.23,1.42	1.583*** 1.53,1.64	1.543*** 1.45,1.64
70+	0.731*** 0.68,0.79	0.658*** 0.60,0.72	0.587*** 0.54,0.64	0.583*** 0.53,0.64	2.174*** 2.10,2.25	2.413*** 2.28,2.55	2.508*** 2.44,2.58	3.106*** 2.96,3.26
Period								
1980-1984	1.217*** 1.18,1.26	1.307*** 1.26,1.35	1.378*** 1.33,1.42	1.369*** 1.33,1.41	0.986 0.96,1.01	1.166*** 1.13,1.21	0.910*** 0.89,0.93	1.029 0.99,1.07
1985-1989	1.205*** 1.17,1.24	1.185*** 1.15,1.22	1.347*** 1.31,1.39	1.290*** 1.26,1.33	1.033** 1.01,1.06	1.031 1.00,1.07	1.087*** 1.07,1.11	1.079*** 1.05,1.11
1990-1994	1.018 0.98,1.05	0.948*** 0.92,0.98	1.078*** 1.04,1.11	1.028* 1.00,1.06	1.007 0.98,1.03	0.925*** 0.89,0.96	1.051*** 1.03,1.07	0.960* 0.93,0.99
1995-1999	0.987 0.95,1.02	0.918*** 0.89,0.95	0.874*** 0.84,0.90	0.829*** 0.81,0.85	1.102*** 1.08,1.13	0.981 0.95,1.01	1.150*** 1.13,1.17	1.017 0.99,1.05

Age	Nighttime single vehicle		Daytime		FARS - alcohol-related		FARS –alcohol not suspected	
	Female	Male	Female	Male	Female	Male	Female	Male
2000–2004	0.883*** 0.85,0.91	0.882*** 0.85,0.91	0.787*** 0.76,0.82	0.828*** 0.80,0.85	1.042*** 1.02,1.07	1.004 0.97,1.04	1.054*** 1.03,1.07	1.037* 1.01,1.07
2005–2010	0.769*** 0.74,0.80	0.842*** 0.81,0.87	0.727*** 0.70,0.75	0.802*** 0.78,0.83	0.849*** 0.83,0.87	0.913*** 0.89,0.94	0.794*** 0.78,0.81	0.890*** 0.86,0.92
Cohort								
1910	0.824 0.71,1.01	0.891 0.72,1.10	1.079 0.92,1.26	1.320** 1.11,1.57	1.05 0.98,1.12	0.993 0.89,1.11	1.056 1.00,1.12	1.107* 1.01,1.22
1915	0.970 0.85,1.11	1.057 0.90,1.24	1.140* 1.01,1.29	1.371*** 1.20,1.57	1.141*** 1.08,1.21	1.136** 1.04,1.24	1.198*** 1.15,1.25	1.260*** 1.17,1.36
1920	0.993 0.89,1.11	1.067 0.93,1.22	1.244*** 1.12,1.38	1.256*** 1.12,1.41	1.183*** 1.13,1.24	1.184*** 1.09,1.28	1.303*** 1.26,1.35	1.325*** 1.24,1.42
1925	1.154** 1.05,1.27	1.251*** 1.12,1.40	1.164** 1.06,1.28	1.224*** 1.11,1.35	1.167*** 1.12,1.22	1.178*** 1.10,1.27	1.321*** 1.28,1.37	1.328*** 1.25,1.41
1930	1.161** 1.06,1.27	1.220*** 1.10,1.35	1.094 1.00,1.20	1.138** 1.04,1.25	1.106*** 1.06,1.15	1.117** 1.04,1.20	1.269*** 1.23,1.31	1.220*** 1.15,1.29
1935	1.101* 1.01,1.20	1.147** 1.04,1.26	0.978 0.90,1.07	1.094* 1.01,1.19	1.075*** 1.03,1.12	1.049 0.98,1.12	1.230*** 1.19,1.27	1.115*** 1.05,1.18
1940	1.129** 1.03,1.23	1.203*** 1.10,1.32	0.977 0.90,1.06	1.106* 1.02,1.20	1.071** 1.02,1.13	1.148*** 1.07,1.24	1.148*** 1.10,1.19	1.142*** 1.07,1.22
1945	1.082 1.00,1.17	1.238*** 1.14,1.35	0.948 0.88,1.03	1.159*** 1.07,1.25	1.051* 1.00,1.10	1.183*** 1.10,1.27	1.117*** 1.07,1.16	1.193*** 1.12,1.27
1950	1.057 0.98,1.14	1.307*** 1.21,1.41	0.973 0.90,1.05	1.228*** 1.14,1.32	1.067** 1.02,1.12	1.224*** 1.14,1.31	1.067** 1.03,1.11	1.191*** 1.12,1.27
1955	1.143*** 1.06,1.23	1.331*** 1.23,1.44	1.111** 1.04,1.19	1.301*** 1.21,1.40	1.081** 1.03,1.14	1.285*** 1.20,1.38	1.021 0.98,1.06	1.218*** 1.14,1.30
1960	1.213*** 1.13,1.30	1.341*** 1.24,1.44	1.242*** 1.16,1.33	1.334*** 1.24,1.43	1.102*** 1.05,1.16	1.280*** 1.20,1.37	1.018 0.98,1.06	1.180*** 1.11,1.26
1965	1.176*** 1.10,1.25	1.291*** 1.20,1.39	1.289*** 1.21,1.38	1.322*** 1.23,1.43	1.062* 1.01,1.11	1.218*** 1.14,1.30	0.962 0.92,1.00	1.142*** 1.07,1.22
1970	1.142*** 1.07,1.22	1.243*** 1.14,1.35	1.211*** 1.13,1.30	1.254*** 1.15,1.36	1.085** 1.03,1.14	1.251*** 1.16,1.34	0.961 0.92,1.00	1.120** 1.04,1.20
1975	1.098* 1.02,1.18	1.187*** 1.09,1.30	1.120** 1.04,1.21	1.193*** 1.09,1.31	1.134*** 1.08,1.19	1.274*** 1.18,1.37	0.950* 0.91,0.99	1.075 1.00,1.16
1980	1.071 0.99,1.15	1.073 0.98,1.18	1.141** 1.05,1.24	1.123* 1.02,1.24	1.141*** 1.09,1.20	1.214*** 1.13,1.31	0.945* 0.90,0.99	1.020 0.94,1.10
1985	1.073 0.99,1.16	1.015 0.92,1.12	1.113* 1.02,1.21	1.012 0.91,1.12	1.100*** 1.04,1.16	1.120** 1.03,1.21	0.971 0.93,1.02	0.952 0.88,1.03
1990	0.902* 0.82,0.99	0.716*** 0.63,0.81	0.879* 0.79,0.97	0.688*** 0.61,0.78	0.962 0.91,1.02	0.890* 0.81,0.98	0.862*** 0.82,0.91	0.775*** 0.70,0.85

Age	Nighttime single vehicle		Daytime		FARS - alcohol-related		FARS –alcohol not suspected	
	Female	Male	Female	Male	Female	Male	Female	Male
1995	0.903 0.78,1.04	0.761** 0.62,0.93	0.803** 0.68,0.95	0.671*** 0.54,0.84	0.794*** 0.73,0.86	0.658*** 0.57,0.76	0.830*** 0.77,0.89	0.722*** 0.63,0.83
2000	0.871 0.72,1.05	0.654** 0.50,0.86	0.705** 0.57,0.88	0.546*** 0.41,0.73	0.706*** 0.64,0.78	0.560*** 0.47,0.67	0.784*** 0.72,0.86	0.690*** 0.58,0.82
2005	0.728* 0.57,0.94	0.541** 0.37,0.79	0.699* 0.53,0.92	0.448*** 0.30,0.67	0.625*** 0.54,0.72	0.511*** 0.40,0.66	0.675*** 0.60,0.76	0.558*** 0.44,0.71
2010	0.621 0.35,1.12	0.410* 0.17,0.99	0.544 0.28,1.08	0.416 0.17,1.03	0.644* 0.45,0.91	0.448* 0.23,0.87	0.679** 0.51,0.90	0.447** 0.26,0.77

Results are Incidence Rate Ratios and 95% confidence intervals relative to the average rate over the entire age, period, and cohort, respectively.

*

p<0.05,

**

p<0.01,

p<0.001

Highlights

- We assess age, period, and cohort effects on motor vehicle mortality trends.
- Risk profiles for men and women differ by position in vehicle and by proxy indicators for alcohol involvement in the crash.
- Age-specific risks were highest among young drivers and occupants regardless of sex
- Risks were also significantly higher for drivers, occupants, and pedestrians aged 65 and over, except where alcohol was involved.
- Period effects show important sustained risk reductions since the mid-1990s, but these effects were less pronounced among drivers.
- More recent (post-1980) cohorts exhibited lower risks for all groups except occupant/passengers.

Figure 1.

Age-specific traffic fatality rates per 100,000, by year for females (top) and males (bottom)

Note different scaling on the Y axes. Source: FARS, authors' calculations.

Figure 2.
Death counts by role of deceased in vehicle and alcohol involvement, females (top) and males (bottom)

Figure 3.
Age, period, and cohort effects by role/position of deceased in relation to the vehicle, females (top) and males (bottom)

Figure 4.
Age, period, and cohort effects by indicators of alcohol involvement in crash, females (top) and males (bottom)