Computing Fatality Rates By Make and Series of Passenger Cars

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INSURANCE INSTITE FOR HIGHWAY SAFETY

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INTRODUCTION

This document describes the methods used to compute occupant fatality rates by make and series of passenger car. The computed rates summarize the motor vehicle occupant fatality experience of passenger cars in the United States and are derived from the U.S. Department of Transportation's Fatal Accident Reporting System (FARS) data and R.L. Polk and Company vehicle registration data. Each computed rate is typically based on three recent model years and reflects occupant fatalities and vehicle registration in three calendar years.

A method for computing predicted occupant fatality rates from wheelbase length, the proportion of occupant deaths in cars with drivers under age 30, and the proportion of occupant deaths in cars with male drivers is also presented. The difference between the predicted and actual fatality rates indicates the extent to which factors other than car size, proportion of youthful operators, and proportion of male operators contribute to the fatality experience of particular makes and series. A large positive difference between these two rates indicates that a particular make and series experienced more occupant fatalities than expected based on the vehicle's size and the age and sex of its operators; a negative difference indicates fewer than expected.

In this report, the occupant fatality rates are for model year 1985 through 1987 cars that were registered in calendar years 1986 through 1988. These rates are analogous to those computed by the Highway Loss Data Institute (HLDI), an affiliate of the Insurance Institute for Highway Safety (IIHS), when summarizing the no-fault insurance injury claims experience for individual vehicle series. HLDI uses claim rates adjusted to a common age and sex distribution of insured operators for reporting these data. Such adjusted rates are informative because they reveal differences between makes and series that are not directly related to age and sex distribution differences among the operators. Because the registration data used for the fatality rate computations were not available by operator age and sex, the fatality rates could not be standardized to a common age and sex distribution. However, by using the age and sex distribution for the drivers of passenger cars in which fatalities actually occurred, it was possible to compute a predicted fatality rate for each make and series that reflected the age and sex distribution among its drivers. In the present study, the relative difference between such predicted fatality rates and the observed fatality rates reveals the differences among cars that are not directly related to age and sex distribution differences among drivers.

 ¹⁹⁸⁸ models are not included because the registration counts are taken in mid-year when the current models are still being sold.
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DEFINITIONS

Vehicle Identification Number (VIN) -- An alphanumeric code, 17 characters in length, assigned to each vehicle by its manufacturer. The VIN uniquely identifies the vehicle and also contains coding that identifies the make (e.g., Chevrolet), series (e.g., Corvette), model year, and other characteristics of each vehicle.

Vindicator¹ -- A computer program written and maintained by the Highway Loss Data Institute (HLDI) that decodes VINs.

Vehicle Series -- Family of vehicles, within a vehicle make, with the same wheelbase and a degree of commonality in construction such as chassis design and body style. Examples of series names with associated make names include Chevrolet Celebrity 4-door, Oldsmobile Cutlass Cruiser station wagon, Ford Mustang convertible, Lincoln Mark VII 2-door, Volkswagen Cabriolet, Acura Integra 4-door, and Mercedes-Benz 560 SEL.

Passenger Car Size and Body Style -- Each passenger car is classified by size based on wheelbase (rounded to the nearest inch) as follows:

Small -- Wheelbases less than or equal to 99 inches;

Midsize -- Wheelbases greater than 99 inches and less than or equal to 109 inches; and Large -- Wheelbases greater than 109 inches.

Each passenger car is classified into one of the following body styles:

- e regular two-door models,
- regular four-door models,
- · station wagons and small passenger vans, and
- sports and specialty models.

Sports and specialty models include all two-seater cars, all convertibles, all midsize and large cars with two or fewer designated rear seating positions, and all luxury cars (base retail price over \$16,000 as of the start of the 1986 model year), regardless of body style.

DATA SOURCES

Fatal Accident Reporting System (FARS) -- FARS is an annual census of all fatal motor vehicle crashes that occur on public roads in the United States.² This file is compiled by the U.S. Department of Transportation from police crash reports, state files, and medical reports. Data elements included in FARS describe the nature and environment of the crash, the vehicle(s) involved, and demographic information about the people in the crash. In particular, the VIN is provided and can be decoded by VINDICATOR to obtain the make, series, model year, and wheelbase length of each passenger car.

R.L. Polk Registration Data -- The R.L. Polk and Company National Vehicle Population Profile (NVPP) data provide annual counts of registered passenger cars.³ Vehicles purchased by the federal government were not included in this file. The data are obtained from state registration files and represent counts of registered vehicles as of July 1 of each calendar year. The NVPP does not provide VINs, but the counts are given by make, series, and model year.

COMPUTATION OF FATALITY RATE

To compute the number of fatalities per 10,000 registered vehicles, the data from FARS and NVPP were combined. The number of fatalities for each make and series (e.g., Chevrolet Caprice four-door) obtained from FARS was divided by the sum of the number of vehicles of the same make and series in the NVPP file that were registered during 1986-88. Before this computation could be performed, it was necessary to first reconcile the sometime slightly different make and series designations from the two files. Table 1 lists the resulting makes and series included in this study.

For the fatality rate computations, only data for 1985-87 models were used. Because some car series were discontinued or substantially changed in this period, the computations were further restricted to only the version of each car that existed in the 1987 model year. In other words, if a particular make and series existed as essentially the same car for all three model years then fatality and registration data for the 1985-87 models were used, but if a car was redesigned for the 1987 model year and had the same name as earlier models, then only data for the 1987 models were used. Similarly if a particular make and series was discontinued in the 1986 or 1987 model year, then data for it were not included in the computations. For example, the Mercury Capri was discontinued after the 1986 model year, and the Buick LeSabre was significantly redesigned as of 1986. Therefore, in the analysis of 1985-87 model cars, the Capri was excluded entirely from consideration and only 1986-87 LeSabres were included.

Because the NVPP registration counts are taken as of July 1 each year, they are incomplete for the model year corresponding to the calendar year as new cars are still being sold and registered. For example, in the 1988 calendar year registration data, on July 1, 1988 there is an incomplete count of all 1988 models. This means that in any calendar year studied, the fatality rates for the corresponding model year cannot be computed because the registration counts are incomplete. Thus, the fatality rates for the 1985-87 models in calendar years 1986-88 are computed from data on 1985 model passenger cars in calendar year 1986, data from 1985 and 1986 models in calendar year 1987, and data from 1985-87 models in calendar year 1988.

Beginning the 1987 model year, vehicle manufacturers were required by federal regulation to begin phasing in automatic restraints such as air bags and automatic seat belts. Because this phase-in began part way through the model year in most cases and because NVPP registration data do not separately identify cars with and without automatic restraints, it was not possible to compute separate fatality rates. In a small number of other cases, vehicle manufacturers began equipping some vehicle series with

automatic restraints as standard equipment ahead of the federal regulation and coincident with the model year (e.g., Toyota Cressida and Mercedes Benz SDL/SEL series). In these instances, the computed rates are based only on the cars with the automatic restraints. Fatalities that occurred in vehicles owned by the federal government could not be identified and were included in the study although vehicles purchased by the federal government were not included in NVPP registration counts.

Individual fatality rates are reported for all makes and series with a combined registration count of at least 150,000. In addition to computing occupant fatality rates for individual vehicle series, results were also computed across vehicle series by car size and body style. For these computations the fatality and registration counts were summed for all vehicle series within a vehicle size and body style group, regardless of the individual registration counts.

COMPUTATION OF PREDICTED FATALITY RATE

In addition to calculating the observed fatality rate (R), a predicted fatality fate (R') for each vehicle series was calculated according to equation (1):

$$log(R') = constant + b1*WHLBSE + B2*log(over 30)+ b3*log(female).$$
 (1)

That is, the natural logarithm of the predicted fatality rate was set equal to the sum of a constant plus b1 times the vehicle wheelbase, plus b2 times the natural logarithm of the proportion of occupant fatalities in that vehicle series whose drivers were at least 30 years of age, plus b3 times the natural logarithm of the proportion of fatalities in that series whose drivers were female. The values of the unknown parameters (the constant, b1, b2, and b3) were estimated using ordinary least square weighted multiple regression with log (R), the natural logarithm of the observed fatality rate, substituting for log (R') as the dependent variable. Note that the proportion of males and the proportion of females are mathematically equivalent expressions of the division of drivers between males and females. Similarly, the proportion of drivers under and over age 30 are mathematically equivalent expressions of the division of drivers between these two age groups.

Parameters b2 and b3 in equation (1) relate the variation in occupant death rate to the age and gender distribution of drivers involved in fatal crashes. These divisions are not the same as age and gender divisions in driver exposure and, therefore, parameters b2 and b3 do not specify how occupant death rate depends on the age and gender divisions of the exposed drivers. Nevertheless, the predicted rates obtained from equation (1) do reflect the age and sex distribution of the exposed drivers, as explained in Appendix A. Therefore, the predicted rate for each vehicle series is an estimate of the expected fatality rate for a vehicle of its particular wheelbase length and distribution of young and male drivers.

Because the predicted occupant fatality rates are estimates, there is some statistical uncertainty in each prediction. A 95 percent lower confidence limit can be calculated for the predicted fatality rate (R') of each vehicle series from the standard deviation (SD) of the logscale fatality rate (log R') using the expression R'* (1 - 1.96*SD). Similarly, a 95 percent upper confidence limit can be calculated for each predicted fatality rate using the expression R'*(1 + 1.96*SD).

In these expressions, the quantity R' is the predicted fatality rate, obtained from equation (1). The quantity SD is an estimate for the standard deviation of the residual, defined as the difference between the actual and predicted logscale occupant death rates. The quantity SD was computed using the formula

$$SD = (1/N + VAR(MEAN) + VAR(RANDOM))^{1/2}.$$
 (2)

The right side of equation (2) is the square root of three variance components. The first component, 1/N, is the variance of the actual (logscale) fatality rate under the customary assumption that the fatality count represents a sample from a Poisson population and N is the observed number of deaths.

The second component, VAR(MEAN), is the variance of the mean prediction. This quantity was estimated for the regression equation under the assumption that the covariates were not subject to error. VAR(MEAN) was computed by the regression analysis package used for the analyses.⁴

The third component, VAR(RANDOM), is a correction term for the second component that was needed because two of the covariates in equation (1), log(over30) and log(Female), were, in fact, subject to random error. VAR(RANDOM) was computed, using error propagation, from the variances for the proportions of under age 30 and male drivers.

$$VAR(RANDOM) = (b2^{2}*Under30/Over30 + b3^{2}*Male/Female)/N$$
 (3)

In equation (3), b2 and b3 represent the coefficient estimates from equation (1); the terms Under30, Over30, Male, and Female represent the indicated driver proportions; and N is the occupant fatality count.

REFERENCES

- 1. Highway Loss Data Institute (1988). Vindicator Users Manual. Release No. 2. Washington, D.C.
- 2. National Highway Traffic Safety Administration (1985-87). Fatal Accident Reporting System. U.S. Department of Transportation, Washington, DC.
- 3. National Vehicle Population Profile (1985-87). R.L. Polk and Co., Detroit, MI.
- 4. SAS (1985). SAS User's Guide: Statistic's Version 5. SAS, Inc, Cary, NC.

Table 1 1985-87 Model Cars included in Analysis

Make		Model			
	Series	2-Door	4-Door	S.W./ Pass. Van	Sports/ Specialty
ACURA	Integra**		Small	,	
ACURA	Integra**	Small			9 4 - alt
ACURA ACURA	Legend 4D** Legend 2D*				Medium Medium
ALFA ROMEO	Milano*		Small		Mediaili
ALFA ROMEO	Spider Conv.		Oman		Small
AMERICAN	Eagle		Medium		
AMERICAN	Eagle			Medium	
AUDI	GT Coupe	Medium	A. 415		
AUDI AUDI	4000 4000 Quattro		Medium		Smail
AUDI	5000 4D				Medium
AUDI	5000 Quattro SW**				Medium
AUDI	5000 Quattro 4D**				Medium
AUDI	5000 SW				Medium
BMW	L7**				Large
BMW BMW	M6*				Medium Medium
BMW BMW	3-Series 2D 3-Series 4D				Medium
BMW	325i Conv.*				Medium
BMW	5-Series				Medium
BMW	633CSi/635CSi				Medium
BMW	733i/735i				Large
BUICK	Century		Medium	NA = allouse	
BUICK BUICK	Century	Medium		Medium	
BUICK	Century Electra	Medium		Large	
BUICK	Electra	Large		Laigo	
BUICK	Electra	ŭ	Large		
BUICK	LeSabre**	Large			
BUICK	LeSabre**		Large	1	
BUICK BUICK	LeSabre	Medium		Large	
BUICK	Regal Riviera**	Medium			Medium
BUICK	Skyhawk			Medium	Moduli
BUICK	Skyhawk	Medium			
BUICK	Skyhawk		Medium		
BUICK	Skylark**	14-45	Medium		
BUICK CADILLAC	Somerset	Medium			Small
CADILLAC	Allante Conv.* Brougham 4D				Large
CADILLAC	Cimarron		Medium		Largo
CADILLAC	Eldorado**				Medium
CADILLAC	Fleetwood Limousine				Large
CADILLAC	Fleetwood/DeVille 2D				Large
CADILLAC	Fleetwood/DeVille 4D				Large
CADILLAC	Fleetwood 60 Special*				Large
CADILLAC CHEVROLET	Seville**			Largo	Medium
CHEVROLET	Astro Van Beretta*	Medium		Large	
CHEVROLET	Camaro	Medialit			Medium
CHEVROLET	Camaro Conv.*				Medium
CHEVROLET	Caprice	Large			
CHEVROLET	Caprice			Large	

		Model			
Make	Series	2-Door	4-Door	S.W./ Pass. Van	Sports/ Specialty
CHEVROLET	Caprice/Impala Cavalier		Large Medium		
CHEVROLET	Cavalier		Medicili	Medium	
CHEVROLET	Cavalier	Medium			
CHEVROLET	Cavalier Conv.	NA - diam			Medium
CHEVROLET CHEVROLET	Celebrity Celebrity	Medium		Medium	
CHEVROLET	Celebrity		Medium	Mediam	
CHEVROLET	Chevette	Small			
CHEVROLET	Chevette		Small		
CHEVROLET CHEVROLET	Corsica* Corvette		Medium		Small
CHEVROLET	Corvette Conv.**				Small
CHEVROLET	Monte Carlo	Medium			
CHEVROLET	Nova	0	Small		
CHEVROLET CHEVROLET	Spectrum Spectrum	Small	Small		
CHEVROLET	Sprint	Small	Siliali		
CHEVROLET	Sprint**		Small		
CHRYSLER	LeBaron*	Medium			
CHRYSLER CHRYSLER	LeBaron LeBaron		Medium	Medium	
CHRYSLER	LeBaron Conv.*			Mediam	Medium
CHRYSLER	LeBaron GTS		Medium		
CHRYSLER	New Yorker		Medium		
CHRYSLER/ CHRYSLER/	New Yorker 5th Ave		Large		
PLYMOUTH	Conquest	Small			
DODGE	Aries	Medium	•		
DODGE	Aries		Medium	NA Pro	
DODGE DODGE	Aries Caravan			Medium Large	
DODGE	Colt		Small	Laige	
DODGE	Colt	Small	•		
DODGE	Colt Vista			Medium	
DODGE DODGE	Colt Vista 4WD Charger/Shelby	Small		Medium	
DODGE	Daytona	Smail			
DODGE	Diplomat		Large		
DODGE	Lancer		Medium		
DODGE DODGE	Omni Shadow*		Small Small		
DODGE	Shadow*	Small	Siliali		
DODGE	600		Medium		
FORD	Aerostar**			Large	
FORD FORD	Crown Victoria Crown Victoria	Large	Lorgo		
FORD	Crown Victoria		Large	Large	
FORD	Escort**	Small		-	
FORD	Escort**			Small	
FORD	Escort** EXP**		Small		Small
FORD FORD	Mustang				Medium
FORD	Mustang Conv.				Medium
FORD	Taurus**			Medium	
FORD	Taurus**		Medium		
FORD	Tempo	Medium	Medium		
FORD FORD	Tempo Tempo 4WD*	Medium	Medium		
, 5110	Tampo Tiro		modum		

		Model				
Make	Series	2-Door	4-Door	S.W./ Pass. Van	Sports/ Specialty	
FORD	Tempo 4WD*	Medium				
FORD	Thunderbird	Medium		•		
GMC HONDA	Safari Van Accord**		Medium	Large		
HONDA	Accord**	Medium	Mediaili			
HONDA	Civic	Modiam		Small ·		
HONDA	Civic	Small		<u> </u>		
HONDA	Civic		Small			
HONDA	Civic CRX			O	Small	
HONDA HONDA	Civic 4WD Prelude	Small		Small		
HYUNDAI	Excel**	Small	Small			
HYUNDAI	Excel**	Small	Omail			
ISUZU	I-Mark	Small				
ISUZU	I-Mark		Small			
ISUZU	Impulse	Small				
JAGUAR	XJ-SC**				Medium	
JAGUAR JAGUAR	XJ-S XJ6				Medium	
LINCOLN	Continental				Large Medium	
LINCOLN	Mark VII				Medium	
LINCOLN	Town Car				Large	
MAZDA	RX-7**				Small	
MAZDA	323**	Small				
MAZDA	323**		Small	. "		
MAZDA ·	323*	Conall		Small		
MAZDA MAZDA	626 626	Small	Small			
MERCEDES	SDL/SEL Series		Siliali		Large	
MERCEDES	190D/E **				Medium	
MERCEDES	260E/300D/E**				Large	
MERCEDES	300TD*				Large	
MERCEDES	560SL**				Small	
MERCEDES MERCURY	SEC Series	Medium			Large	
MERCURY	Cougar Grand Marquis	Large				
MERCURY	Grand Marquis	Laige	Large			
MERCURY	Grand Marquis		9-	Large		
MERCURY	Lynx**			Small		
MERCURY	Lynx**	Small				
MERCURY	Lynx**		Small	Mar allinos		
MERCURY MERCURY	Sable** Sable**		Medium	Medium		
MERCURY	Topaz		Medium			
MERCURY	Topaz	Medium	Woolani			
MERKUR	XR4TI	Medium				
MITSUBISHI	Cordia	Small				
MITSUBISHI	Galant		Medium			
MITSUBISHI	Mirage*	0	Small			
MITSUBISHI MITSUBISHI	Mirage Stories	Small				
MITSUBISHI	Starion Tredia	Small	Small			
MITSUBISHI	Wagon		Omail	Small		
NISSAN	Maxima			Medium		
NISSAN	Maxima		Medium			
NISSAN	Pulsar*	Small				
NISSAN	Sentra*	.		Small		
NISSAN	Sentra*	Small	0			
NISSAN	Sentra*		Small	Small		
NISSAN NISSAN	Sentra 4WD* Stanza**			Small		
. HOOAII	Junea			Jillan		

		Model			
Make	Series	2-Door	4-Door	S.W./ Pass. Van	Sports/ Specialty
NISSAN	Stanza*		Medium		
NISSAN	Stanza 4WD**			Small	
NISSAN	200SX	Small			Small
NISSAN NISSAN	300ZX 300ZX 2+2				Small
NISSAN	Van*			Small	J. Tall
OLDSMOBILE	Calais	Medium			
OLDSMOBILE	Calais**		Medium	l arma	
OLDSMOBILE OLDSMOBILE	Custom Cruiser Cutlass	Medium		Large	
OLDSMOBILE	Cutlass	Wiediam	Medium		
OLDSMOBILE	Cutlass Ciera		Medium		
OLDSMOBILE	Cutlass Ciera			Medium	
OLDSMOBILE OLDSMOBILE	Cutlass Ciera Delta 88**	Medium			
OLDSMOBILE	Delta 88**	Large	Large		
OLDSMOBILE	Firenza		Largo	Medium	
OLDSMOBILE	Firenza	Medium			
OLDSMOBILE	Firenza	•	Medium		
OLDSMOBILE OLDSMOBILE	Ninety-Eight	Large	Lorgo		
OLDSMOBILE	Ninety-Eight Toronado**		Large		Medium
PEUGEOT	505		Medium		
PEUGEOT	505			Large	
PLYMOUTH	Caravelle		Medium		
PLYMOUTH PLYMOUTH	Colt Colt	Small	Small		
PLYMOUTH	Colt Vista	Siliali		Medium	
PLYMOUTH	Colt Vista 4WD			Medium	
PLYMOUTH	Gran Fury		Large		
PLYMOUTH	Horizon Reliant	Medium	Small		
PLYMOUTH PLYMOUTH	Reliant	Medium	Medium		
PLYMOUTH	Reliant		Modicini	Medium	
PLYMOUTH	Sundance*		Small		
PLYMOUTH	Sundance*	Small			
PLYMOUTH PLYMOUTH	Turismo	Small		Large	
PONTIAC	Voyager Bonneville*		Medium	Laige	
PONTIAC	Fiero				Small
PONTIAC	Firebird				Medium
PONTIAC	Grand Am**	Manalla and	Medium		
PONTIAC PONTIAC	Grand Am Grand Prix	Medium Medium			
PONTIAC	Parisienne	Mediaiii		Large	
PONTIAC	Sunbird		b	Medium	
PONTIAC	Sunbird	Medium			
PONTIAC	Sunbird		Medium		Medium
PONTIAC PONTIAC	Sunbird Conv. 1000	Small			Medium
PONTIAC	1000	Siliali	Small		
PONTIAC	6000		- Titali	Medium	
PONTIAC	6000		Medium		
PONTIAC	6000	Medium			Small
PORSCHE PORSCHE	911 Coupe 911 Targa/Cabriolet				Small Small
PORSCHE	924 Coupe**				Small
PORSCHE	928 Coupe				Small
PORSCHE	944 Coupe				Small
RENAULT	Alliance Conv.		C11		Small
RENAULT	Alliance/Encore		Smail		

Make	Series	Model			
		2-Door	4-Door	S.W./ Pass. Van	Sports/ Specialty
RENAULT	Alliance/Encore	Small			
RENAULT	GTA*	Small			Small
RENAULT SAAB	GTA Conv.* 900	Small			Siliali
SAAB	900	Oman	Small		
SAAB	900 Conv.**				Small
SAAB	9000**				Medium
STERLING SUBARU	825* DL/GL			Small	Medium
SUBARU	DL/GL **	Small		Silian	
SUBARU	DL/GL Sedan	Oman	Small		
SUBARU	DL/GL 4WD			Small	
SUBARU	GL 4WD		Small		
SUBARU	GL 4WD **	Small			
SUBARU SUBARU	Hatchback Hatchback 4WD	Small Small			
SUBARU	Justy*	Small			
SUBARU	XT Coupe	Small			
SUBARU	XT Coupe DL				Small
SUBARU	XT Coupe 4WD	Small			
TOYOTA	Camry		Medium		
TOYOTA	Camry*		Mediaili	Medium	
TOYOTA	Celica**	Small		MOGIOTITI	
TOYOTA	Corolla		Small		
TOYOTA	Corolla	Small			
TOYOTA	Corolla FX*	Small	Madium		
TOYOTA TOYOTA	Cressida Cressida		Medium	Medium	
TOYOTA	Celica Conv.*			Mediam	Small
TOYOTA	MR2				Small
TOYOTA	Supra*				Medium
TOYOTA	Tercel*		Small	. "	
TOYOTA	Tercel Tercel*	Conall		Small	
TOYOTA TOYOTA	Tercel 4WD	Small		Small	
TOYOTA	Van			Small	
TOYOTA	Van 4WD*			Small	
VOLKSWAGEN	Cabriolet				Small
VOLKSWAGEN	Fox*	Small	• "		
OLKSWAGEN	Fox*		Small	Cmall	
VOLKSWAGEN VOLKSWAGEN	Fox* Golf	Small		Small	
VOLKSWAGEN	Golf	Jillali	Small		
OLKSWAGEN	GTI	Small			
VOLKSWAGEN	Jetta	Small			
VOLKSWAGEN	Jetta		Small		
VOLKSWAGEN	Quantum		No. of the con-	Medium	
VOLKSWAGEN	Quantum Quantum 4MD		Medium	Medium	
VOLKSWAGEN VOLKSWAGEN	Quantum 4WD Scirocco	Small		MINIDAIN	
VOLKSWAGEN	Vanagon	Small		Small	
VOLNOVIAGEN	240		Medium	Omail	
VOLVO	240			Medium	
VOLVO	740/760 4D			Medium	
VOLVO	740/760 SW	• "		Medium	
YUGO	GV**	Small			

^{* 1987} model only ** 1986 and 1987 models only

APPENDIX A

Let m denote the number of occupant fatalities in cars with drivers age 30 and over and let M denote some measure for the exposure of these occupants. Correspondingly, let n denote the occupant fatalities and N the exposure in cars with drivers under age 30. (The units for measuring M and N need not be explicitly specified because both quantities will be algebraically eliminated from the equation for predicting death rates. All that is needed to make these derivations valid is that exposure be measured addictively so that the total exposure is M + N.)

By definition, the overall rate of occupant fatalities per unit of exposure, R, is equal to the ratio of the number of occupant fatalities divided by the combined exposure:

$$R = (m + n)/(M + N).$$
 (A.1)

Also by definition, the fatality rates are R1 = m/M in cars with older drivers and R1' = n/N in cars with younger drivers. The fatality rates were used to express the driver fatality counts for the two driver groups in terms of the exposures, m = R1*M and n = R1*N. (Note that one driver is included here separately for each fatally injured occupant.)

Substituting these expressions for m and n in equation (A.1), it follows, after some algebra, that

$$R = (R1*M + R1*N)/(M + N)$$

$$= R1*[M + (1 + e1)*N]/(M + N)$$

$$= R1*[1 + e1*N/(M + N)]$$

$$= R1*[1 + e1*f], (A.2)$$

where e1 = (R1' - R1)/R1, and f = N/(M + N). The quantity e1 is the relative difference between the fatality rates of occupants in cars driven by younger and older drivers. The quantity f is the proportion of exposure attributable to occupants in cars with older drivers.

To eliminate the unknown exposures, M and N, from explicitly appearing in the expression for f, one multiplies both the numerator and the denominator by R1', replaces R1'*N by n, substitutes the expression (1 + e1)*R1 for R1', and then replaces R1*M by m, to obtain the chain of equalities in (A.3):

$$f = N/(M + N)$$

= R1'*N/(R1'*M + R1'*N)

$$= n/[(1 + e1)*R1*M + n]$$

$$= n/[(1 + e1)*m + n]. (A.3)$$

Equation (A.3) can be simplified by dividing both the numerator and the denominator by n + m and then writing q1 = m/(n+m) for the proportion of fatalities with drivers age 30 and over:

$$f = p1/(1 + e1*q1),$$
 (A.4)

where p1 = 1 - q1.

Substituting for f in equation (A.2) from equation (A.4) and then taking the natural logarithm of both sides gives equations (A.5) and (A.6):

$$log (R/R1) = log [(1 + e1)/(1 + e1*q1)]$$
 (A.5)

or

$$log(R) = log[(1 + e1)/(1 + e1*q1)] + log(R1).$$
 (A.6)

Equation (A.6) shows that the relationship between the occupant fatality rate for a given vehicle series and the proportion of drivers with a certain characteristic (in this case, being older) can be expressed in terms of the proportion of fatalities occurring in vehicles operated by drivers with characteristic (q1), an unknown parameter, e1, and the unknown fatality rate in vehicles operated by those drivers, R1. Before proceeding, it should be noted that additional equations such as (A.6) can be derived relating the occupant fatality rate for the same vehicle series to the proportion of drivers with other characteristics. For example, in equation (A.6), the death rate of occupants with older drivers, R1, could be replaced by the death rate of occupants with female drivers, say R2, and the proportion of older drivers, q1, by the proportion of female drivers, q2. The new equation (A.6) expresses the relationship between the occupant fatality rate and the proportion of female drivers in terms of the proportion of fatalities with female drivers, an unknown parameter, e2, and the unknown fatality rate in cars driven by female drivers.

The specification of equation (A.6) can be completed by noting that the logarithm of R1, the fatality rate in cars driven by older drivers, can be modeled by a linear function of wheelbase; that is,

$$log (R1) = A1 + B1*WHLBSE.$$
 (A.7)

Substituting the value of log (R1) in equation (A.7) for log (R1) in equation (A.6) yields

$$log(R) = A1 + B1*WHLBSE + log[(1 + e1)/(1 + e1*q1)].$$
 (A.8)

Similarly for the characteristic of sex, setting log(R2) = A2 + B2*WHLBSE gives the following equation:

$$log(R) = A2 + B2*WHLBSE + log[(1 + e2)/(1 + e2*q2)].$$
 (A.9)

Taking a weighted average of equations (A.8) and (A.9) gives

$$c*log(R) + d*log(R) = log(R) = A + B*WHLBSE + c*log[(1 + e1)/(1 + e1*q1)] + d*log[(1 + e2)/(1 + e2*q2)],$$
(A.10)

where A = c*A1 + d*A2, B = c*B1 + d*B2, C>0, d>0, and c + d = 1.

Equations (A.8), (A.9), and (A.10) are theoretically estimable using nonlinear regression models. However, such estimation procedures are sensitive to small samples and the fatality counts for some vehicle, age, and sex combinations are quite small. The reason for obtaining predicted deaths rates corrected for age and sex also makes it possible to approximate the nonlinear form of (A.10) with a simpler expression. Specifically, because occupant death rates are quite sensitive to driver age and sex, the parameters e1 and e2 are expected to be large. For such values of e1 and e2, the ratios (1 + e1)/(1 + e1*q1) and (1 + e2)/(1 + e2*q2) approximate the values 1/q1 and 1/q2. Thus, equation (A.10) is approximated by

$$log(R) = A + B*WHLBSE + c*log (1/q1) + d*log (1/q2),$$
 (A.11)

or

$$log(R) = A + B*WHLBSE - c*log q1 - d*log q2.$$
(A.12)

Equation (A.12) is equivalent to equation (1) with b2 = -c and b3 = -d. In estimating the parameters in equation (1) by multiple regression, the relative size of c and d (or b2, b3) were allowed to vary and the constraint that c + d = 1 was dropped. This was done so as to attribute the largest possible amount of variation to the age and gender factors.

APPENDIX B

The parameter and standard error estimates for equation (1) are given in equation (B.1):

$$log(R) = 0.05 - 2.19*WLBSE0 - 0.96*log(Over30) - 0.40*log(Female).$$
 (B.1)
(0.10) (0.61) (0.17) (0.10)

The wheelbase variable (WLBSE0) used in equation (B.1) was computed by mean-centering the length of wheelbase measured in 100 inches,

WHLBS0 = wheelbase length in inches / 100 - 1.02.

Except for the intercept, all coefficients in this regression are significant at the 0.0005 level. The adjusted R² for the regression is 0.61, indicating that the three variables together explain almost two-thirds of the variability of the log-transformed death rate. Replacing WLBSEO in equation (B.1) by the log transform of wheelbase length had virtually no affect on the model. The reason for this is that WLBSEO and log (wheelbase length/102) have nearly identical numerical values for vehicles in the study.

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