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Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks

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16. Abstract

Logistic regressions calibrate crash fatality rates per billion miles for model year 1991-99 passenger cars, pickup trucks, SUVs and vans during calendar years 1995-2000 – by vehicle weight, vehicle type, driver age and gender, urban/rural, and other vehicle, driver and environmental factors – a cross-sectional analysis of the fatality rates of existing vehicles. These analyses suggest that, after controlling for driver age/gender, urban/rural, annual mileage, and other factors:

- The association between vehicle weight and overall crash fatality rates in the heavier MY 1991-99 LTVs (light trucks and vans) was not significant.
- In three other groups of MY 1991-99 vehicles – the lighter LTVs, the heavier cars, and especially the lighter cars – fatality rates increased as weights decreased.
- MY 1996-99 pickup trucks and SUVs had, on the average, higher fatality rates than MY 1996-99 passenger cars or minivans of comparable weight.

Logistic regression analyses of fatalities per billion miles in two-vehicle collisions show that MY 1991-99 LTVs were more aggressive than MY 1991-99 cars when they struck other vehicles. The analyses show correlations between occupants' fatality risk in the struck car and the frontal height-of-force and rigidity of the striking LTV.

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The effort by Drs. Hedlund, Lund and Reinfurt was not "peer review" of the type used by journals, but consultation to identify shortcomings in the draft and help NHTSA strengthen this report. It differed from a peer review in that: (1) We in NHTSA specifically requested and arranged for these three reviewers. (2) The review process is on record – their comments on the draft may be viewed in the NHTSA docket for this report. (3) The publication of this report does not necessarily imply that they "endorsed" it or agreed with its findings. You may read their comments in the docket to see what they agreed or disagreed with in the draft. We have tried to address all of the comments in our revised report (but we did not send it back to them for a second round of review). (4) They went into far more depth and detail than is customary in a peer review.

EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration's (NHTSA) 1997 report on vehicle weight and fatality risk estimated the effects of 100-pound reductions in light trucks and vans (LTVs) and in passenger cars. In the 1997 report, statistical analyses of model year (MY) 1985-93 vehicles in calendar year (CY) 1989-93 crashes found little overall effect for a 100-pound reduction in LTVs, but an increase of about 300 fatalities per year in cars. However, they also produced the doubtful findings that vehicle weight reductions do not increase fatality risk in car-to-car or LTV-to-LTV crashes and even reduce fatality risk in pedestrian crashes.

NHTSA took a good, hard second look at the subject, identified anomalies in the 1997 report, and applied different analysis techniques to more recent crash data. This new statistical analysis of MY 1991-99 vehicles in CY 1995-2000 crashes supersedes NHTSA's 1997 report.

The new study expands the analyses by separately estimating the effects of 100-pound reductions in heavy LTVs, light LTVs, heavy cars and light cars. It compares the fatality rates of LTVs and cars, to quantify differences between vehicle types, given drivers of the same age/gender, etc. In support of NHTSA's research on car-LTV compatibility, it analyzes fatality rates in two-vehicle crashes based on the mass and rigidity of each vehicle and the height mismatch between vehicles.

Effects of 100-pound weight reductions on fatality rates

In MY 1991-99, and earlier, heavy vehicles had lower fatality rates per billion miles of travel than lighter vehicles of the same general type. When two vehicles collide, the laws of physics favor the occupants of the heavier vehicle (momentum conservation). Furthermore, heavy vehicles were in most cases longer, wider and less fragile than light vehicles. In part because of this, they usually had greater crashworthiness, structural integrity and directional stability. They were less rollover-prone and easier for the average driver to control in a panic situation. In other words, heavier vehicles tended to be more crashworthy and less crash-prone. Some of the advantages for heavier vehicles are not preordained by the laws of physics, but were nevertheless characteristic of the MY 1991-99 fleet. Offsetting those advantages, heavier vehicles tended to be more aggressive in crashes, increasing risk to occupants of the vehicles they collided with.

The statistical analysis uses the Fatality Analysis Reporting System (FARS), R.L. Polk registration data, State crash data and the National Automotive Sampling System (NASS). Logistic regressions calibrate crash fatality rates per billion miles for model year 1991-99 vehicles during calendar years 1995-2000 – by vehicle weight, driver age and gender, urban/rural and other factors discussed and quantified in this report: availability of air bags, ABS, or 4-wheel drive; vehicle age; annual mileage; speed limit; day/night; wet/dry road; high/low State fatality rate; and calendar year. "Crash" fatality rates include fatalities to occupants of the case vehicle, occupants of the other vehicles it collides with, and any pedestrians. The key is to compare fatality rates of heavy and light vehicles "on a level playing field" by adjusting for differences in the age and gender of the drivers, the types of roads they travel, and the other factors. In each of six crash modes that, together, account for over 96 percent of the nation's crash fatalities, the analysis calibrates the average increase in the fatality rate for vehicles weighing W-100 pounds relative to vehicles weighing W pounds, after controlling for driver age/gender and the other factors – a cross-sectional analysis of the fatality rates of existing vehicles. (Throughout this study, a vehicle's "weight" is its "curb weight": the actual weight of the vehicle with a full tank of fuel and other fluids needed for travel, but no occupants or cargo.)

Table 1 shows the average fatality increase per 100-pound reduction in LTVs. As stated above, the "fatality increase per 100-pound reduction" does not mean the effect of literally removing 100 pounds from a specific LTV. It is the average increase in the fatality rates of 1991-99 models weighing W-100 pounds relative to other 1991-99 models weighing W pounds, given drivers of the same age/gender and equal values on the other factors. The analysis comprises pickup trucks, SUVs, minivans and full-sized vans. The top half of Table 1 shows the effect in light trucks weighing 3,870 pounds or more (this was the median weight of LTVs in MY 1991-99, but the majority of trucks after MY 1995 were heavier). As curb weight decreased by 100 pounds, fatality rates increased by 2.5 to 3 percent in rollovers and fixed-object collisions. Fatal crashes with pedestrians and heavy trucks were hardly affected. However, in collisions of heavy LTVs with cars (where 83 percent of the crash fatalities were occupants of the cars) or with other, usually lighter, LTVs, the 100-pound reduction resulted in a modest net benefit, because it somewhat reduced risk to the occupants of the other vehicles.

In each crash mode, the percentage effects calibrated for MY 1991-99 vehicles were applied to the baseline of all CY 1999 crash fatalities in the United States (all model years) to estimate the annual net fatality change if the mix of LTVs weighing 3,870 pounds or more on the road that year had averaged 100 pounds lighter – i.e., if the public had purchased fewer of the very heavy LTVs and more of the make-models weighing not so much in excess of 3,870 pounds. The increase in rollovers and fixed-object crashes was partly offset by the reduction in LTV-to-car and LTV-to-LTV fatalities. The point estimate of the net change for all crash modes was an increase of 71 fatalities, not statistically significant, as evidenced by the interval estimate ranging from –156 to +241. The interpretation of these interval estimates will be discussed after the presentation of all the results for LTVs and cars. The point estimate for the percentage change was a nonsignificant increase of 0.48 percent. The results for the heavier LTVs suggest that there may have been some weight above 3,870 pounds beyond which overall fatality rates tended to increase, rather than decrease, as weight increased.

The lower half of Table 1 shows the effect in LTVs weighing less than 3,870 pounds. As curb weight decreased by 100 pounds, fatality rates increased in every crash mode – although the observed increases in collisions with pedestrians (1.24 percent) and with cars (1.13 percent) were small and not statistically significant. In rollovers and collisions with fixed objects, heavy trucks or other (usually heavier) LTVs, fatality rates increased substantially (3.15 to 6.98 percent) as the weight of the "case" LTV decreased. The point estimate of the net change for all crash modes in baseline CY 1999, per 100-pound reduction among the LTVs weighing less than 3,870 pounds, was an increase of 234 fatalities per year (interval estimate: 59 to 296). The point estimate for the percentage change was an increase of 2.90 percent.

TABLE 1

FATALITY INCREASE PER 100-POUND WEIGHT REDUCTION, LIGHT TRUCKS

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Crash Mode	Annual Baseline Crash Fatalities	Effect (%) of 100-Pound Reduction: Point Estimate	Effect (%) of 100-Pound Reduction: Interval Estimate	Annual Net Fatality Change: Point Estimate	Annual Net Fatality Change: Interval Estimate
LIGHT TRUCKS WEIGHING 3,870 POUNDS OR MORE					
Principal rollover	2,183	2.56	.81 to 3.94	56	18 to 86
Fixed object	2,639	3.06	1.41 to 4.34	81	37 to 115
Ped/bike/motorcycle	2,043	.13	- 1.56 to 1.45	3	- 32 to 30
Heavy truck	860	.62	- 1.61 to 2.48	5	- 14 to 21
Car	5,186	- .68	- 1.79 to .06	- 35	- 93 to 3
Light truck < 3,870	1,010	- 1.50	- 3.20 to - .17	- 15	- 32 to - 2
Light truck 3,870 +*	784	- 3.00	- 6.40 to - .34	- 24	- 50 to - 3
OVERALL	**14,705**	**.48**	**- 1.06 to 1.64**	**71**	**- 156 to 241**
LIGHT TRUCKS WEIGHING LESS THAN 3,870 POUNDS					
Principal rollover	1,319	3.15	.64 to 4.30	42	8 to 57
Fixed object	1,687	4.02	1.71 to 4.97	68	29 to 84
Ped/bike/motorcycle	1,148	1.24	- 1.26 to 2.38	14	- 14 to 27
Heavy truck	584	5.91	3.10 to 7.36	35	18 to 46
Car	2,062	1.13	- .92 to 1.82	23	- 19 to 38
Light truck < 3,870*	247	6.98	1.92 to 9.32	17	5 to 23
Light truck 3,870 +	1,010	3.49	.96 to 4.66	35	10 to 47
OVERALL	**8,057**	**2.90**	**.73 to 3.67**	**234**	**59 to 296**

* Assumes both light trucks in the collision were reduced by 100 pounds.

Table 2 shows the average fatality increase per 100-pound reduction in passenger cars. The regression analyses are based exclusively on data for 4-door cars, excluding police cars. During MY 1991-99, only 24 percent of new passenger cars were 2-door models, and fewer than 1 percent of new 4-door cars were police cars. The upper section of Table 2 shows the effect in cars weighing 2,950 pounds or more (close to the median curb weight of cars throughout MY 1991-99). As curb weight decreased by 100 pounds, fatality rates increased strongly in rollovers (4.70 percent), decreased non-significantly in pedestrian crashes (0.62 percent reduction), but increased moderately in all other crash modes (1.59 to 3.18 percent). In absolute terms, though, the largest increase was in collisions with LTVs (83 per year). The point estimate of the net change for all crash modes was an increase of 216 fatalities per year (interval estimate: 129 to 303). The point estimate for the percentage change was an increase of 1.98 percent. Those estimates were somewhat weaker than the effects in light LTVs but much stronger than the effects in heavy LTVs.

The lower section of Table 2 shows moderate-to-strong effects in every crash mode for cars weighing less than 2,950 pounds. In rollovers and in collisions with heavy trucks and LTVs, fatality rates were 5 to 6 percent higher as cars got 100 pounds lighter. Even in pedestrian collisions, fatality rates rose 3.48 percent. No such increase of pedestrian fatalities was seen in the heavier cars or either group of LTVs. The point estimate of the net change for all crash modes was an increase of 597 fatalities per year (interval estimate: 226 to 715), well over double the increase in the heavier cars or the lighter LTVs. The point estimate for the percentage change was an increase of 4.39 percent.

The strong increase in pedestrian fatalities for the lightest cars is surprising. At least at first glance, the weight of the vehicle shouldn't have had much effect on the fatality risk of pedestrians. Perhaps, heavier vehicles were simply driven better, even after adjusting for the drivers' age/gender, urban/rural and other factors. For example, safety-conscious drivers might have selected heavier cars because they considered them safer. Heavier cars, more expensive on the average, might also have attracted higher-income owners with a more health-conscious, less risk-prone lifestyle. This study, however, found that light and heavy 4-door cars, pickup trucks and 4-door SUVs of MY 1991-99 all had remarkably similar incidence of high-risk driving behavior: drinking, speeding, previous crashes, license suspensions, etc. (Two-door cars had substantially higher-than-average incidence of high-risk driving behavior, but they were not included in the data used to calibrate the weight-safety relationships.) NHTSA research suggests that the geometry of small cars might, in fact, have increased the risk of serious injury to pedestrians (shorter hoods, more head impacts with the windshield frame). Finally, small cars, because they felt more maneuverable, might even have induced drivers to weave in traffic or take other risks they would ordinarily have avoided in a larger vehicle.

We do not know how much of the observed effect in pedestrian crashes was due to self-selection – better drivers picking bigger cars – but we are confident that much of the effect, quite possibly even all of it was "real." Thus, the maximum proportion that was self-selection may have been as low as zero, but it was definitely less than 100 percent. In the absence of evidence supporting any specific proportion between zero and 100 percent, this report takes the midpoint and assumes at most half the observed effect in pedestrian crashes was due to self-selection.

TABLE 2

FATALITY INCREASE PER 100-POUND WEIGHT REDUCTION, PASSENGER CARS

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Crash Mode	Annual Baseline Crash Fatalities	Effect (%) of 100-Pound Reduction: Point Estimate	Effect (%) of 100-Pound Reduction: Interval Estimate	Annual Net Fatality Change: Point Estimate	Annual Net Fatality Change: Interval Estimate
CARS WEIGHING 2,950 POUNDS OR MORE					
Principal rollover	715	4.70	2.40 to 7.00	34	17 to 50
Fixed object	2,822	1.67	0.63 to 2.71	47	18 to 76
Ped/bike/motorcycle	1,349	- .62	- 1.83 to .59	- 8	- 25 to 8
Heavy truck	822	2.06	.67 to 3.45	17	6 to 28
Car < 2,950	1,342	1.59	.70 to 2.48	21	9 to 33
Car 2,950 +*	677	3.18	1.40 to 4.96	22	9 to 34
Light truck	3,157	2.62	1.74 to 3.50	83	55 to 110
OVERALL	**10,884**	**1.98**	**1.19 to 2.78**	**216**	**129 to 303**
CARS WEIGHING LESS THAN 2,950 POUNDS					
Principal rollover	995	5.08	.87 to 7.55	51	9 to 75
Fixed object	3,357	3.22	.25 to 4.45	108	8 to 149
Ped/bike/motorcycle	1,741	3.48	.22 to 5.00	61	4 to 87
Heavy truck	1,148	5.96	2.50 to 7.68	68	29 to 88
Car < 2,950*	934	4.96	- .72 to 7.16	46	- 7 to 67
Car 2,950 +	1,342	2.48	- .36 to 3.58	33	- 5 to 48
Light truck	4,091	5.63	2.85 to 6.67	230	117 to 273
OVERALL	**13,608**	**4.39**	**1.66 to 5.25**	**597**	**226 to 715**

* Assumes both cars in the collision were reduced by 100 pounds.

If so, self-selection also played a role in the other crash modes, not just pedestrian crashes. Therefore, the interval estimates of this study include not only sampling error but also an adjustment – up to half of the observed effect in pedestrian crashes – to account for possible effects due to self-selection.

The interval estimates in Tables 1 and 2 (and also Table 4) are defined as follows: the upper bound is the point estimate plus 1.96 standard deviations of sampling error (from various known sources). The lower bound is the point estimate, minus 1.96 standard deviations of sampling error, minus half the observed pedestrian effect (and, in Table 1, minus an additional allowance for some uncertainty in the model formulation). The interval estimates are a tool for gauging uncertainty, but they are not rigorous 95 percent confidence bounds. When the range in the interval estimate includes zero, the point estimate can be called “not statistically significant.” When the interval is entirely positive, or entirely negative, it provides some evidence that the observed effect is “real” – the tighter the interval, the stronger the evidence – but the intervals are not rigorous confidence bounds, as they would be, for example, in a simple, controlled experiment.

Table 2, showing a strong increase in fatality risk per 100-pound reduction in cars weighing less than 2,950 pounds, is based on an analysis including drivers of all ages. When the analysis was limited to drivers age 60 or older, all the size-safety effects became even more severe, in some crash modes more than double. That suggests older drivers had serious problems controlling the lightest cars and/or that the crash environment in light cars in some way amplified older occupants’ general vulnerability to injury.

The point estimates in Tables 1 and 2 are approximately linear and additive. If, in general, vehicles weighing W-100 pounds had on the average 1 percent higher fatality rates than vehicles weighing W, then vehicles weighing W-200 pounds would have had approximately 2 percent higher rates than vehicles weighing W. The effect of reducing all LTVs by 100 pounds would have been close to the sum of the effects of reducing LTVs over 3,870 pounds and under 3,870 pounds by 100 pounds each: 71 + 234 = 305.

This study estimates a substantially larger fatality increase per 100-pound weight reduction than NHTSA’s 1997 report. A review of the 1997 report reveals flaws in the calibration procedure leading to a systematic underestimate of the size-safety effect in every crash mode, for both LTVs and cars. This study’s results supersede the 1997 report and, in particular, correct its findings on car-to-car crashes. Table 2 now shows fatality risk in car-to-car crashes increased as car weight decreased, consistent with intuition and most of the literature. The lighter cars had higher crash involvement rates and higher fatality risk, given a crash, for their own occupants. That more than offset the reduction in fatality risk of occupants in the “other” car.

In summary, Tables 1 and 2 suggest that the association between curb weight and fatality risk in MY 1991-99 vehicles was weakest – in fact, nonsignificant – in the heavier LTVs. It was strongest in the lighter cars.

Fatal-crash and fatality rates by vehicle type, model years 1996-99

LTVs of the 1990's included some models that had high rollover fatality rates per billion miles. They also included models that, when they collided with other vehicles, the occupant fatality rate was high in the other vehicle. These LTV models may be characterized as "rollover-prone and/or aggressive vehicles." The fatal-crash involvement rates and occupant fatality rates of different vehicle types were compared on as "level a playing field" as possible, by adjusting for differences in driver age/gender, annual mileage, vehicle occupancy (where appropriate), distribution of the mileage by urban/rural, speed limit, and other vehicle, driver and environmental factors – but not for vehicle weight.

The statistical approach, based on logistic regressions and data similar to the preceding analyses, was to compare fatal-crash rates per billion vehicle miles for ten groups of model year 1996-99 vehicles during calendar years 1996-2000: four size groups of 4-door cars, three size groups of 4-door SUVs, two sizes of pickup trucks, and minivans. All vehicles were equipped with air bags. Heavy-duty (200/300-series) pickup trucks and full-sized vans were not included in this analysis. A single "prorated fatal-crash rate" per billion vehicle miles, comprising all crash modes, was computed for each vehicle group, after adjustment for driver age/gender, urban/rural, and other factors. The prorated fatal-crash rates included fatalities to occupants of the case vehicle, occupants of the other vehicles it collided with, and any pedestrians. Each crash was weighted by the number of fatalities; however, in order to prevent double-counting, the number of fatalities in multivehicle crashes was divided by the number of cars/LTVs involved in the crash (e.g., in a 2-vehicle crash, each vehicle was assigned half the crash fatalities).

Table 3 compares the average curb weights and the overall fatal-crash rates of the ten groups. Groups that included numerous rollover-prone and/or aggressive vehicles in MY 1996-99 had greater fatal-crash rates. For example, mid-size 4-door SUVs of model years 1996-99 had an average fatal-crash rate of 13.68. Similarly, large SUVs and pickup trucks had higher fatal-crash rates than some groups of cars or minivans. The four vehicle groups with the lowest overall prorated fatal-crash rates in Table 3 were large cars (7.12), minivans (7.97), mid-size cars (9.46) and large (100-series) pickup trucks (9.56). Very small 4-door cars had the highest rate (15.73). However, by 1996-99, these cars only accounted for well under 1 percent of vehicle sales.

TABLE 3

ADJUSTED FATAL-CRASH INVOLVEMENT RATES
PER BILLION CASE VEHICLE MILES, BY VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, and other factors)

Vehicle Type and Size	Average Curb Weight	Prorated* Fatal Crash Involvements Per Billion Miles
Very small 4-door cars	2,105	15.73
Small 4-door cars	2,469	11.37
Mid-size 4-door cars	3,061	9.46
Large 4-door cars	3,596	7.12
Compact pickup trucks	3,339	11.74
Large (100-series) pickup trucks	4,458	9.56
Small 4-door SUVs	3,147	10.47
Mid-size 4-door SUVs	4,022	13.68
Large 4-door SUVs	5,141	10.03
Minivans	3,942	7.97

* Each fatal crash involvement by a case vehicle is weighted by: the number of crash fatalities divided by the number of cars/LTVs involved in the crash.

Furthermore, 1996-99 SUVs had higher fatality risk for their own occupants than large cars or minivans. Here, for example, are drivers' fatality rates per billion vehicle miles (adjusted for driver age/gender, urban/rural, and other factors):

	Driver Fatalities per Billion Vehicle Miles
Very small 4-door cars	11.56
Small 4-door cars	7.85
Mid-size 4-door cars	5.26
Large 4-door cars	3.30
Compact pickup trucks	6.82
Large (100-series) pickup trucks	4.07
Small 4-door SUVs	5.68
Mid-size 4-door SUVs	6.73
Large 4-door SUVs	3.79
Minivans	2.76

The four vehicle groups with the lowest fatality rates for their own drivers were minivans (2.76), large cars (3.30), large SUVs (3.79), and large (100-series) pickup trucks (4.07).

Table 3 shows the fatal-crash rate was lower for small 4-door SUVs (10.47) than for mid-size 4-door SUVs (13.68) in MY 1996-99. The drivers' fatality rate per billion vehicle miles was likewise lower in small SUVs (5.68) than mid-size SUVs (6.73). This was the only exception to the customary trend, where larger size groups of the same vehicle type had lower fatal-crash rates and occupant fatality rates.

A more detailed comparison of the fatality rates of small SUVs, mid-size SUVs and mid-size cars of MY 1996-99 shows that rollovers and occupants of the "other" vehicle in 2-vehicle crashes accounted for the higher risk of the SUVs. The small SUVs had much lower rollover fatality rates than the mid-size SUVs, although still high compared to the cars. Similarly, the fatality rate for occupants of other vehicles, per billion case-vehicle miles, was substantially lower for the small-SUV case vehicles than for the mid-size SUVs, but still high compared to the cars. By contrast, the fatality rates for the vehicles' own occupants in non-rollover crashes, per billion occupant miles, were fairly similar for the three types of vehicles, and actually lowest for the mid-size SUVs:

	Fatalities per Billion Miles (Not Prorated)		
	Small 4-Door SUVs	Mid-Size 4-Door SUVs	Mid-Size 4-Door Cars
Rollovers	1.06	2.71	.50
Occupants of other vehicles	3.44	4.46	2.55
Occupants of case vehicle, in non-rollovers	4.38	3.95	4.63

As stated above, LTVs of the 1990's included numerous rollover-prone and/or aggressive vehicles. However, by 1996-99, several new models of small 4-door SUVs with improved rollover stability had been introduced. For example, one model was measured by NHTSA and rated substantially more stable than most mid-size or large SUVs of the mid-1990's. The above statistics suggest that small 4-door SUVs of 1996-99 may have been the beginning of a new generation of more stable, less aggressive vehicles with lower fatal-crash rates. This trend appears to have continued and expanded since 1999, comprising entirely new designs such as car-based "crossover" SUVs and less sweeping redesigns of existing LTVs. Indeed, rollover-resistance ratings published by NHTSA in 2001 show new models of SUVs in all three size groups with greater stability than the models they superseded. Also, new technologies such as "blocker bars" have been introduced on some LTVs to make them less aggressive in collisions with other vehicles.

Table 3's adjusted fatal-crash rates for the ten groups of MY 1996-99 vehicles can be applied to the baseline of all CY 1999 crash fatalities in the United States (all model years) to estimate the annual change in fatalities if the mix of vehicle types on the road in 1999 had changed – i.e., if the public had purchased more vehicles of one type and fewer of another. Table 4 estimates the reduction in fatalities given nine hypothetical scenarios in which the MY 1996-99 vehicle mix changed to more of one type of car or minivan and fewer of one type of SUV or pickup truck. For comparison purposes, it also considers one more scenario: a change from very small 4-door cars to small 4-door cars. It estimates what might have been the annual effect of a "one percentage point change" in the vehicle mix. For example, during MY 1996-99, mid-size 4-door SUVs accounted for 8 percent of new-vehicle sales, and large 4-door cars, 12 percent. Table 4 assumes MY 1996-99 vehicles constituted the entire on-road fleet and estimates the effect on fatalities in baseline CY 1999 if the vehicle mix had instead consisted of 7 rather than 8 percent mid-size SUVs and 13 rather than 12 percent large cars.

The first nine scenarios in Table 4 all combine a likely reduction in fatalities with a reduction in vehicle weight. The point estimates of the fatality reductions in Table 4 range from 29 to 200 per year, per percentage point change in the vehicle mix. The reductions for the scenarios involving changes from mid-size or full-size SUVs to cars or minivans have wholly positive interval estimates. By comparison, the change from very small cars to small cars is estimated to reduce fatalities by 156 (with a weight increase). Of course, all these estimates are specifically for MY 1996-99, a time when numerous pickup trucks and SUVs were rollover-prone or aggressive.

TABLE 4

CHANGE IN FATALITIES PER YEAR
GIVEN A ONE-PERCENTAGE POINT CHANGE IN THE ON-ROAD FLEET
FROM MY 1996-99 SUVs AND PICKUPS TO CARS OR MINIVANS

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

	Versus	Weight Reduction Per Vehicle	Fatality Reduction Per Year: Point Estimate	Fatality Reduction Per Year: Interval Estimate
Small 4-dr SUVs	Mid-size 4-dr cars	86	29	– 72 to 64
Mid-size 4-dr SUVs	Mid-size 4-dr cars	961	129	79 to 152
	Large 4-door cars	426	200	140 to 220
	Minivans	80	174	130 to 201
Large 4-dr SUVs	Large 4-door cars	1,545	101	27 to 133
	Minivans	1,199	72	17 to 111
Compact pickups	Mid-size 4-dr cars	278	103	– 57 to 163
Large pickups*	Large 4-dr cars	862	127	– 65 to 194
	Minivans	516	82	– 80 to 161
…………				
Very small 4-dr cars	Small 4-dr cars	– 364	156	– 40 to 231

*Large, standard-duty (100 series) trucks. Excludes heavy-duty 200/300 series pickup trucks.

Car-light truck compatibility

NHTSA has been researching car-light truck compatibility since 1993. In collisions between LTVs and cars, approximately 80 percent of the fatalities are occupants of the cars. The objective is to reduce fatality risk in the car, without increasing risk in the LTV. That may require increasing crashworthiness of the car, but it might be easier to accomplish by reducing the aggressiveness of the LTV, or by a judicious combination of both. Of course, MY 1991-99 LTVs usually outweighed cars but, in addition, there were two sources of mismatch between LTVs and cars that made the LTVs extra "aggressive" when they hit the cars:

- Structural incompatibility: the LTV's front was more rigid than any part of the car

- Geometric incompatibility: the LTV's front applied its force at a height above the car's structures designed to withstand force

The databases and logistic-regression analysis methods used to study vehicle weight and fatality risk were also suitable for investigating car-LTV compatibility. Fatality rates in 2-vehicle collisions, per billion miles of each vehicle, were calibrated as a function of the body type and curb weight of each vehicle (MY 1991-99 in CY 1995-2000), the age/gender of each driver, urban/rural location, speed limit, and other vehicle, driver and environmental factors. Once again, the objective was to compare the fatality rates in car-to-car and LTV-to-car collisions on as "level a playing field" as possible. The first goal was to quantify the extra aggressiveness of MY 1991-99 LTVs relative to MY 1991-99 cars of the same weight. The analysis focused on collisions where the struck vehicle was a car, and the striking vehicle was a car, pickup truck, SUV or minivan. Table 5 shows how much the fatality risk of the driver of the struck car increased when the striking vehicle was an LTV.

The first row of Table 5 evaluates left-side impacts to the struck car by the front of the striking vehicle. Left-side impacts are the most dangerous for drivers, because they sit on the left. When the striking vehicle was a passenger car of weight W, let us say the driver of the struck car had fatality risk index 100. When the striking vehicle was a pickup truck of weight W, the fatality risk of the driver of the struck car increased to 177. In other words, it was almost twice as dangerous, on a per-mile basis, to be hit on the left side by a pickup truck as by a car of the same weight as that pickup truck. When the striking vehicle was an SUV, the risk index was 235. Even when the striking vehicle was a minivan, the risk index was 130, higher than when it was a car. The risk indices for MY 1991-99 pickup trucks, SUVs and minivans were all significantly higher than 100 in front-to-left impacts.

The second row of Table 5 considers head-on (front-to-front) collisions. Here, LTVs were much less aggressive. The risk index for the driver of the struck car was significantly higher than 100 only when the striking vehicle was an SUV (132). Impacts by pickup trucks and minivans had risk indices just slightly, and not significantly, above 100. When they hit cars on the right side or rear, the aggressiveness of LTVs was higher than in head-on collisions, but not as high as when they hit the car on the left side. The third row of Table 5 shows that risk indices for pickup trucks and SUVs were both significantly above 100.

TABLE 5

AGGRESSIVENESS OF MY 1991-99 LTVs IN IMPACTS WITH MY 1991-99 CARS
AFTER ADJUSTMENT FOR THE STRIKING VEHICLE'S WEIGHT**

(Fatality risk index of the driver of the struck car, by striking vehicle type;
MY 1991-99 vehicles in CY 1995-2000 crashes)

Striking Vehicle's Front Impacted the Struck Car on the	Driver Fatality Risk Index in the Struck Car by Striking Vehicle Type			
	Car	Pickup	SUV	Minivan
Left side	100	177*	235*	130*
Front (head-on collision)	100	114	132*	104
Right side or rear	100	139*	162*	125
Anywhere	100	139*	171*	116*

*Significantly greater than 100.
**For example, in a front-to-left impact, if the risk for the driver of the struck car was 100 when the striking vehicle was a 3,500 pound car, the risk increased to 177 when the striking vehicle was a 3,500 pound pickup truck.

Combining all of the preceding crash modes, the last row of Table 5 shows that, overall, every type of MY 1991-99 LTV was significantly more aggressive than a passenger car. All of these indices apply specifically to MY 1991-99 vehicles and could change for more recent LTVs as new technologies or designs are introduced to reduce aggressiveness in collisions.

The second analysis goal was to test for association between the aggressiveness of model year 1991-99 LTVs in crashes and physical parameters describing the structural rigidity and geometry of the trucks. Two parameters were readily available, because NHTSA measures them during its frontal crash tests in the New Car Assessment Program (NCAP). They are:

Frontal rigidity: The average slope of the force-deflection profile maintained for at least 150 millimeters during the vehicle's initial crush in an NCAP frontal impact with the barrier.

Height-of-force: The average height-of-force measured by load cells set at various height levels in the NCAP barrier. It is the weighted average of the effective height of the applied force on the barrier face over the duration of the impact.

Association was tested by limiting the preceding logistic-regression analyses to crashes where the striking vehicle was an LTV (and the struck vehicle was a car), and adding the two parameters to the regression. In front-to-left impacts, there was a statistically significant association between the driver's fatality risk in the struck car and the difference in the heights-of-force of the striking and struck vehicles: the greater the height mismatch between the LTV and the car, the greater the fatality risk of the driver of the car. In head-on collisions, the LTV's frontal rigidity was significantly associated with the car driver's fatality risk: the more rigid the LTV, the greater was the fatality risk of the car driver.

The analyses accept as a given that model year 1991-99 LTVs were, on the average, more aggressive than cars. These somewhat exploratory findings suggest that the LTVs with the tallest and most rigid frontal structures were even more aggressive than the other LTVs.

These analyses of car-LTV compatibility are intended to supplement and corroborate, not supersede NHTSA's previous work on that subject. This study's approach, based on fatality rates per billion miles, controlling for each vehicle's weight, each driver's age and gender, urban/rural, and other factors, helps compare fatality rates in car-car and car-LTV collisions "on a level playing field." On the other hand, the per-mile approach does not necessarily separate crash-proneness from crashworthiness effects (a disadvantage here, although it was a plus in the size-safety analyses). It is best to look at these results in combination with NHTSA's previous findings on car-LTV compatibility. In addition, the statistical findings that show an association of these two parameters with extra aggressiveness of LTVs do not, by themselves, guarantee that these two parameters "caused" the aggressiveness, or that they are the parameters that best explain or measure aggressiveness. Crash testing with existing and, eventually, modified vehicles is another essential step in learning what makes LTVs aggressive.

Limitations of the analyses

This study is a cross-sectional analysis of the crash fatality rates per billion miles of real MY 1991-99 vehicles in CY 1995-2000: light, mid-size and heavy passenger cars, pickup trucks, SUVs and vans. Statistical tools calibrated the relationships between vehicle weight and fatality rates – the average increase for vehicles weighing W-100 pounds relative to vehicles weighing W pounds – and the differences between cars and LTVs, after controlling for driver age/gender, urban/rural, and other vehicle, driver and environmental factors. The results specifically describe the performance of MY 1991-99 vehicles; the impact of new designs or technologies in more recent vehicles will be revealed as they now accumulate on-the-road experience.

The analysis is not a "controlled experiment." People are largely free to pick whatever car or LTV they wish. Owner characteristics and vehicle use patterns can and do vary by vehicle weight and type. This study adjusts for differences in age/gender, urban/rural driving, and other factors, and tries to gauge uncertainty due to less tangible variations in "how well people drive." But, ultimately, we can never be sure that a 30-year-old male operating a large LTV on an urban road at 2:00 p.m. in a Western State drives the same way as a 30-year-old male operating a smaller LTV/light car/heavy car at a similar roadway, time and location. The interval estimates in this study try to depict likely ranges of uncertainty in the principal findings, but rigorous "95 percent confidence bounds" do not apply here, as they would, for example, in a simple, controlled experiment.

CHAPTER 1

A NEW STUDY OF VEHICLE WEIGHT AND FATALITY RISK AND CAR-LIGHT TRUCK COMPATIBILITY

1.1 The need for a new NHTSA study

In 1997, the National Highway Traffic Safety Administration (NHTSA) issued seven reports that addressed vehicle weight and safety by statistically analyzing relationships between existing vehicles' curb weights and their fatality and injury rates in crashes.[1] One of the reports, a study of vehicle weight and fatality risk, was NHTSA's first attempt to estimate the effect of a 100-pound reduction in each of the important crash modes, and to do this separately for light trucks and passenger cars.[2] Calibrated from model year (MY) 1985-93 vehicles in calendar year (CY) 1989-93 crashes, the analyses found little overall effect for a 100-pound reduction in light trucks and vans (LTVs), because increased fatalities of truck occupants were offset by a reduction of fatalities in the vehicles that collided with the trucks, whereas a 100-pound reduction in cars was associated with an increase of about 300 fatalities per year.

Unfortunately, the mere fact that the 1997 report addressed all crash modes did not necessarily make its estimates correct. The 1997 report claimed that fatalities in car-to-car and LTV-to-LTV crashes decreased as both cars or both LTVs were reduced in weight. That disagrees with research and empirical data consistently showing that, at least in the past, heavy vehicles tended to be more crashworthy and less crash-prone than light vehicles. The report's conclusion that vehicle weight reductions saved lives in pedestrian crashes is also questionable.

The most important reason for a new study is to take a good, hard second look at the methods of the 1997 report and to revise or supersede them with techniques that more accurately fit the data.

Another reason for a new study is that the vehicle, crash and driver environment has changed in six years. Since MY 1985-93 and CY 1989-93, LTVs have become more numerous and heavier; belt use increased; there are more air bags and older drivers. New models were introduced and old ones phased out.

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[1] Kahane, C.J., *Relationships between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 808 570, Washington, 1997; Partyka, S.C., *Effect of Vehicle Weight on Crash-Level Driver Injury Rates*, NHTSA Technical Report No. DOT HS 808 571, Washington, 1996; Partyka, S.C., *Passenger Vehicle Weight and Driver Injury Severity*, NHTSA Technical Report No. DOT HS 808 572, Washington, 1995; Hertz, E., *The Effect of Decreases in Vehicle Weight on Injury Crash Rates*, NHTSA Technical Report No. DOT HS 808 575, Washington, 1997; Partyka, S.C., *Patterns of Driver Age, Sex and Belt Use by Car Weight*, NHTSA Technical Report No. DOT HS 808 573, Washington, 1995; Partyka, S.C., *Impacts with Yielding Fixed Objects by Vehicle Weight*, NHTSA Technical Report No. DOT HS 808 574, Washington, 1995; *Relationships of Vehicle Weight to Fatality and Injury Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Summary Report No. DOT HS 808 569, 1997.

[2] Kahane (1997), *op. cit.*

The third motivation is to expand the analyses. The 1997 report estimated two numbers: the effect of a 100-pound reduction in LTVs of any weight, and in passenger cars. The new study separately estimates the effects of 100-pound reductions in heavy LTVs, light LTVs, heavy cars and light cars. It compares the fatality rates of LTVs and cars, to quantify the differences in the rates between vehicle types, given drivers of the same age/gender, etc. In support of NHTSA's ongoing research on car-LTV compatibility[3], this study analyzes fatality rates in two-vehicle crashes based on the mass and rigidity of each vehicle and the height mismatch between the vehicles.

This statistical analysis of CY 1995-2000 crash data involving MY 1991-99 vehicles supersedes NHTSA's 1997 report on vehicle size and fatality risk.

1.2 Why heavier vehicles have usually had lower fatality rates

One safety factor, momentum conservation, is a direct consequence of a vehicle's mass. Other parameters, such as a vehicle's length and width are naturally and historically (i.e., during 1968-99), but not inevitably proportional to its mass. Most of those parameters favor the heavier vehicle, making it physically, intrinsically safer than the light vehicle.

Some human factors of drivers are historically, but not intrinsically confounded with vehicle mass. For example, young drivers historically have driven smaller cars[4], but at least in theory, they might at some future time prefer large cars. These factors could give heavy vehicles lower fatality rates, but don't make them intrinsically safer. The analysis should, as much as possible, remove these factors and compare the fatality rates of heavy and light vehicles on a level playing field, leaving only the physical factors that make heavy vehicles safer. Finally, there are in-between factors where it is not so clear if the relationship with mass is intrinsic or coincidental.

<u>Momentum conservation</u>: When a heavy and a light vehicle collide, the heavy vehicle keeps moving forward; its occupants experience a small velocity change. The light vehicle gets pushed backward; its occupants experience a higher velocity change. These are consequences of the laws of physics; nothing can be done to equalize the velocity changes. For example, in a head-on collision, a 1 percent weight advantage corresponds to more than a 5 percent reduction in the driver's fatality risk, relative to the driver of the other vehicle.[5]

What benefits an individual – being in the heavier of the two vehicles – however, does not necessarily benefit society as a whole. Based on momentum considerations alone, the risk reduction in Vehicle 1 as it becomes heavier is cancelled by a risk increase in Vehicle 2. If momentum conservation were the only factor making heavier vehicles safer (it isn't), overall fatalities in multivehicle crashes would neither increase nor decrease if the entire vehicle fleet were reduced in mass.

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[3] Hollowell, W.T., Summers, S.M., and Prasad, A., *NHTSA's Research Program for Vehicle Aggressivity and Fleet Compatibility*, UK IMechE Vehicle Safety 2002 Conference, London, May 2002.

[4] For example, the database generated for this study suggests 34 percent of drivers of 4-door cars weighing less than 3,000 pounds are younger than 30, but only 15 percent of drivers of cars weighing over 3,000 pounds.

[5] See Section 6.1 of this report.

Momentum also enables a heavy vehicle to knock down, displace or brush aside medium-sized fixed objects that would have brought a lighter vehicle to an abrupt stop.

Crashworthiness: Heavier vehicles have historically done a better job cushioning their occupants in crashes. Their longer hoods and extra space in the occupant compartment provide an opportunity for a more gradual deceleration of the vehicle, and of the occupant within the vehicle. In the New Car Assessment Program, crash test results have been consistently better for large cars, given the same 35 mph barrier impact.[6] While it is conceivable that light vehicles could be built with similarly long hoods and mild deceleration pulses, it would probably require major changes in materials and design and/or taking weight out of their engines, accessories, etc.

> Structural integrity: Heavier vehicles have historically provided better protection against intrusion by fixed objects, heavy trucks, etc. Doors, frames, pillars, roof rails, etc. are thicker and stronger. Since the occupant compartment is larger, these structures also have more room to deform.[7]

Rigidity/sill height/aggressiveness: A rigid structure can be helpful in many impacts with fixed objects. High, strong side sills are important protection if the vehicle is struck in the side. But high, rigid structure increases the risk to the occupants of other vehicles (aggressiveness), and rigidity can also make the vehicle's deceleration more abrupt in some impacts. The database created in Section 6.2 of this report shows some correlation of rigidity and height-of-force with curb weight in current vehicles, but a much stronger association these parameters with vehicle type (some of the MY 1991-99 pickup trucks and SUVs were higher and more rigid than cars or minivans of the same mass).

Mass mismatch: There is widespread belief that a collision between vehicles of similar mass is safer than a collision of badly mismatched vehicles. If so, making the heaviest vehicles lighter, and the lightest heavier, could reduce fatalities in crashes between passenger vehicles. (However, analyses in Section 6.6 of this report do not show significantly higher fatality rates per unit of exposure in crashes of 2,000 with 4,000 pound cars than in crashes of two 3,000 pound cars.)

Directional stability/ease of control: The preceding factors affect fatality risk, given that a crash has occurred. There are also physical factors that tend to make heavier vehicles less crash-prone. Heaver vehicles, with their typically longer wheelbases, are less prone to skid or spin out of control in response to braking or steering input, or on an uneven road surface. They are more likely to stay on the road.[8]

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[6] *Effect of Car Size on Fatality and Injury Risk*, NHTSA, Washington, 1991.

[7] For example, Kahane, C.J., *Evaluation of FMVSS 214 Side Impact Protection Dynamic Performance Requirement, Phase 1*, NHTSA Technical Report No. DOT HS 809 004, Washington, 1999, p. 64 shows a steady improvement of side structure integrity as curb weight increases.

[8] Malliaris, A.C., Nicholson, R.M., Hedlund, J.H. and Scheiner, S.R., *Problems in Crash Avoidance and in Crash Avoidance Research*, Paper No. 830560, Society of Automotive Engineers, Warrendale, PA, 1983.

In theory, a sober, alert, expert driver might find a light vehicle more responsive, easier to brake and steer away from trouble. Unfortunately, many drivers in fatal crashes are impaired, unskilled, distracted, or at the very least caught off-guard in a panic situation. The quicker response of light vehicles may give the average driver yet more opportunity to blunder.

Rollover stability: Heavier vehicles, historically, have almost always been wider than light vehicles of the same class. As a result, they have a higher static stability factor[9] and are substantially less prone to rollover. While it is conceivable that light vehicles could be built just as wide as heavy vehicles, it would presumably require new designs, materials and/or cutting weight out of existing structures, accessories, etc.

Availability of safety equipment: During the 1990's, air bags were often installed a year or two earlier in the heavier vehicles (easier to install, possibly more consumer demand). Antilock Brake Systems (ABS) were installed earlier on the larger, more luxurious vehicles and are still infrequent on small, inexpensive cars.[10] Analyses should be able to control for those differences.

The above are physical factors that have historically or intrinsically influenced the fatality rates in small vs. large vehicles. Here are some human factors of drivers that are confounded with vehicle weight:

Driver age and gender: This report will present data showing that, historically, lighter vehicles have somewhat younger drivers; heavier vehicles, especially heavy cars, older drivers. Small 4-door cars are especially popular with female drivers. Large cars, LTVs generally, but pickup trucks especially, are popular with male drivers.

Young and old drivers have far more fatal crashes per million years, or per billion miles than drivers in the 30-50 age bracket (see Figure 3-15). Up to age 60, males have substantially higher fatal crash rates than females. Young drivers' inexperience and aggressiveness, older drivers' vision and vehicle-control problems, and male drivers' aggressiveness/impairment all contribute to high crash rates. The vulnerability of older occupants to injury further increases their fatality rates.

Thus, the higher incidence of young drivers inflates the fatality rates of lighter vehicles, but the higher incidence of female drivers (especially in small 4-door cars) reduces the rates. The popularity of large cars with older drivers, and LTVs (especially pickup trucks) with males inflates their fatality rates. It is imperative that the analyses control or adjust fatality rates to compensate for differences in driver age and gender.

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[9] Half the track width, divided by the center-of-gravity height.

[10] ABS is effective in reducing certain types of crashes, but may be associated with increases of other types of crashes at certain times; see Kahane, C.J., *Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars*, NHTSA Technical Report No. DOT HS 808 206, Washington, 1994.

Urban/rural: Fatality rates per billion miles are higher in rural areas.[11] Pickup trucks are especially common in rural areas (inflating fatality rates), while small cars are more characteristically urban (deflating the rates).

The preceding human and environmental factors are readily measurable and can be controlled in the analyses. However, there is another set of somewhat interrelated human factors, not easily quantified, somehow related with vehicle weight and fatality risk. Briefly stated, **heavier vehicles may be driven better** for a variety of reasons that are not clearly understood. These factors are discussed in Sections 3.6 and 5.6 of this study, and may include:

Vehicle reputation/driver self-selection: Safety-conscious drivers might pick heavier vehicles because they consider them safer. Also, vehicle brands and body-styles with an excellent reputation for safety tend to attract safety-conscious drivers and, primarily because of this, have exceptionally low fatality rates.[12] These are often, but not necessarily, heavier vehicles. Conversely, sporty and high-performance vehicles, especially 2-door cars, attract risk-prone drivers and have high fatality rates. That could create a "self-fulfilling prophecy," partially explaining the lower fatality rates of heavier vehicles.

However, the analyses in Sections 3.6 and 5.6 will show that light and heavy 4-door cars, pickup trucks and SUVs all have remarkably similar incidence of imprudent driving behavior: drinking, speeding, previous crashes, license suspensions, etc. Only 2-door cars have substantially higher-than-average incidence of imprudent driving behavior, and only minivans are lower than average. In this study, 2-door cars will never be included in data used to calibrate the relationships of weight and fatality risk in passenger cars.

Driver income/vehicle price: Heavier cars are usually, but not always more expensive than light cars. Their owners are likely to have higher incomes, on the average. Higher income [and education] has been associated with a more health-conscious, less risk-prone lifestyle. That may include driving more prudently. (See discussion in Section 3.6.)

Smaller vehicles weave in traffic: It is possible that drivers of small vehicles are more likely to weave around in traffic, change lanes, dart ahead of others or even take corners and curves faster. If so, what is the cause and what is the effect? Is it merely less prudent drivers self-selecting smaller vehicles, as suggested above? Or do the smaller vehicles themselves, because they feel more maneuverable, induce drivers to take risks they would ordinarily avoid in a larger vehicle?

The principal estimates of this study include an allowance (in the interval estimates) that some of the observed relationship between vehicle size and fatality rates could be due to better drivers self-selecting larger vehicles, rather than the intrinsic characteristics of the vehicles.

But these driver effects, while they should not be ignored, are probably of limited importance. The relationship of car weight to fatality risk is calibrated from data on 4-door cars (excluding police cars). During the late 1990's, small 4-door cars were especially popular with 30-50 year

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[11] *Accident Facts, 1993 Edition*, National Safety Council, Itasca, IL, 1993, p. 64.
[12] Kahane, C.J., *Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions*, NHTSA Technical Report No. DOT HS 808 061, Washington, 1994, pp. 3-7.

old women. Although there are, of course, individual variations within that group, they are, overall, the safest and most prudent drivers on the road. It is more correct to say that small 4-door cars had high fatality rates despite, rather than because of the people who drove them.

1.3 NHTSA's earlier reports on vehicle weight and fatality risk

NHTSA's 1997 report estimated the percentage increase (or decrease) in crash fatalities (including occupants of other vehicles, and pedestrians) per 100-pound weight reduction, in each of the important crash modes, separately for passenger cars and LTVs:[13]

NHTSA 1997	**Fatality Increase (%) Per 100 Pound Reduction**	
Crash Mode	**Passenger Cars**	**Light Trucks**
Principal rollover	+ 4.58	+ .81 *
Hit object	+ 1.12	+ 1.44
Hit ped/bike/motorcycle	– .46	– 2.03
Hit heavy truck	+ 1.40	+ 2.63
Hit passenger car	– .62 *	– 1.39
Hit light truck	+ 2.63	– .54 *
OVERALL	+ 1.13	– .26 *

* Not statistically significant

The analysis associated a 100-pound reduction in cars with a significant increase of 302 crash fatalities per year, and a 100-pound reduction in LTVs with a reduction of 40 crash fatalities per year (not statistically significant).

The analysis was a regression of fatality rates per million vehicle registration years, based on Fatality Analysis Reporting System (FARS) and Polk registration data for MY 1985-93 vehicles in CY 1989-93 crashes. However, State crash data were used in a quite indirect way to adjust these rates for differences in driver age and gender. Section 4.8 of this study extensively critiques the methods of the 1997 report. In brief, the 1997 report concluded that lighter vehicles are safer than indicated by their raw fatality rates per million years, based on the following implicit (and essentially "hidden") inferences from the adjustment procedure:

- Heavy cars and LTVs are driven fewer miles per year than mid-size vehicles, because they have older drivers, and older people drive fewer miles per year.

[13] Kahane (1997), *op. cit.*, pp. vi-vii.

- Light cars and LTVs are driven more miles per year than mid-sized vehicles, because they have younger drivers, and young people drive more miles per year.

- Therefore, the simple per-year fatality rates understate their per-mile rates of heavy vehicles, but overstate the rates of lighter vehicles. After the adjustment, the safety advantage of heavier vehicles shrinks for cars and vanishes for LTVs

All of these statements are false, except that older people drive fewer miles per year. In fact, odometer readings from the National Automotive Sampling System (NASS) show that light, mid-size and heavy cars are driven almost equal numbers of miles per year, whereas heavy LTVs are driven substantially more miles per year than light LTVs of the same type. It is also untrue that young people drive more miles per year than 25-50 year old adults. (See Section 2.4 of this report.) As a result, the 1997 report underestimated the fatality increases associated with weight reductions – in every crash mode, for both cars and LTVs. An additional source of bias was the inclusion of 2-door cars and police cars in the calibration of the weight-safety effect in passenger cars. High-performance 2-door cars weighing about 3,000 pounds had very high fatality rates in some crash modes and police cars weighing about 3,700 pounds had high rates in other modes, enough to throw the calibration off the real trend lines of fatality rates by vehicle weight.

In most crash modes the true effect was large enough that, even with these biases, the 1997 report still estimated a fatality increase. However in car-to-car, LTV-to-LTV and pedestrian crashes, where the true effect was smaller, the 1997 report associated fatality reductions with weight reductions. As stated above, those results now seem counterintuitive.

How did this problem escape earlier detection at NHTSA? As the critique (Section 4.8 of this study) explains, the implicit assumptions about annual mileage are quite well hidden and are only revealed by scrutiny of some regression coefficients in the 1997 report. But why didn't NHTSA staff look at the car-to-car results and say, "This can't be right, let's keep reviewing the model until we find the problem"? In fact, NHTSA was already conditioned to believe that the effect of weight reductions on car-to-car crash fatalities might be negligible, because its pre-1997 analyses, due to biases or data flaws of their own, produced similar results.

In 1989-91, NHTSA staff analyzed relationships of passenger-car weight and fatality risk in three crash modes: rollovers, fixed-object and car-to-car. All three results are indeed very close to the 1997 report:

NHTSA 1991	**Fatality Increase (%) Per 100 Pound Reduction**
Crash Mode	**Passenger Cars**
Principal rollover	+ 3.5
Hit object	+ .9
Hit ped/bike/motorcycle	*not analyzed*
Hit heavy truck	*not analyzed*
Hit passenger car	Not statistically significant
Hit light truck	*not analyzed*

Klein, Hertz and Borener performed the analyses of fixed-object and car-to-car crashes.[14] Logistic regressions of 1984-87 Texas and 1984-88 Maryland crash data calibrated drivers' fatality risk per 100 towaway crash involvements, as a function of vehicle weight, driver age and gender, crash mode, and other variables (in car-to-car crashes: the case car driver's fatality risk per 100 involvements as a function of both vehicles' weights, both drivers' ages, and other factors). The model finds no significant change in drivers' fatality risk when each car in a 2-car collision is reduced by 100 pounds, but all other variables stay the same. The fatality rate in fixed-object collisions increases by a modest but significant 0.9 percent for each 100-pound weight reduction. (The 1997 report also found no significant effect in 2-car crashes and a 1.12 percent increase in collisions with fixed objects.)

The analysis method based on fatalities per 100 reported towaway crashes, customary at that time and widely used even today, creates a twofold bias in favor of smaller cars and underestimates the fatality increase per 100-pound reduction:

- By considering the probability of fatality given that a crash has already occurred, the method only measures differences in crashworthiness. It ignores the superior directional stability/ease of control of larger cars, that enables them to stay out of crashes entirely (especially run-off-road/fixed object crashes).

- The measure of exposure (denominator of the fatality rate) – reported towaway crash involvements – is itself confounded with vehicle weight. Heavier cars and LTVs have substantially fewer reported towaway crashes per million miles than small cars. As stated above, they have fewer crashes. Because they are more rugged, even if they have a crash, it is less likely to require towaway. An impact that just dents a big station wagon might disable a small, light car. Finally, even if there is a towaway, it is less likely that a police report will be filed – if nobody is injured and the damage is not especially severe (e.g., when the cars are no longer brand-new).

[14] Klein, T.M., Hertz, E. and Borener, S., *A Collection of Recent Analyses of Vehicle Weight and Safety*, NHTSA Technical Report No. DOT HS 807 677, Washington, 1991; summarized in *Effect of Car Size on Fatality and Injury Risk*, NHTSA, Washington, 1991.

Kahane analyzed fatal rollover crashes of MY 1970-82 cars in CY 1975-86 FARS data.[15] The ratios of fatalities in most-harmful-event rollovers to fatalities in frontal impacts with fixed objects were computed for cars of various size groups. The analysis did not control for driver age or gender. The ratio increased by 3.5 percent per 100-pound weight reduction. This report, too, underestimated the size-safety effect because it considered the frontal impacts a control group with equal fatality risk at all car weights. In reality, fatality risk in fixed-object collisions also increases as car weight is reduced. A more correct conclusion of the report would have been: rollover fatalities increase 3.5 percent faster than frontal fixed-object fatalities, per 100-pound weight reduction.

The results of this report, based on MY 1970-82 cars, are remarkably similar to the current study, based on MY 1991-99 cars. Historically, lighter cars have more rollover fatalities because they are also narrower and shorter cars. Of course, there is a natural correlation of mass, width and length, but at least in theory it should be possible to change one and not the others (e.g., by using different materials). The two studies show how little the relationships of mass, width, length and rollover risk have changed in the last 30 years.

NHTSA also sponsored Mengert and Borener's 1989 analysis of fatal crashes, based on MY 1978-87 cars in CY 1978-87 FARS and Polk data.[16] Separate analyses address four crash modes which, together, comprise essentially all fatal crashes involving cars. The measure of risk, crash fatalities per million car years (including pedestrians and occupants of other vehicles in the crash) is similar to this study and NHTSA's 1997 report. It accounts for crash-avoidance as well as crashworthiness effects. However, their analysis did not adjust for driver age, gender, or any other factor that is confounded with vehicle mass and correlated with fatality risk.

Cars were subdivided into six weight groups. In the three crash modes involving a single passenger car, a relative fatality risk was obtained for each of the six weight groups: the proportion of the fatalities F_i in weight group i was divided by that weight group's proportion of car registrations R_i. For example, if cars in the lightest weight group account for $F_1 = 15$ percent of the single-vehicle crash fatalities and $R_1 = 10$ percent of car registrations, the relative risk is 1.5. In the car-to-car crash mode, the relative risk was obtained for each of the 36 pairs of weight groups: the proportion of car-to-car fatalities F_{ij} involving a car of weight group i and a car of group j was divided by $R_i R_j$. For example, if collisions between cars of the lightest weight group and the heaviest weight group account for $F_{16} = 1$ percent of car-to-car fatalities, $R_1 = 10$ percent and $R_6 = 5$ percent of car registrations, then the relative risk is 2.0. With these measures of relative risk, Mengert and Borener could estimate the net effect on total fatalities for any hypothetical future change in the distribution of car registrations among the six weight groups.

[15] Kahane, C.J., "Effect of Car Size on the Frequency and Severity of Rollover Crashes," *Proceedings of the Thirteenth International Technical Conference on Experimental Safety Vehicles*, NHTSA, Washington, 1991, Paper No. 91-S6-W-12.
[16] Mengert, P., *Estimating Relative Safety of Hypothetical Weight Distribution for the National Passenger Car Population*, 1989 SAE Government/Industry Meeting, Washington, May 3, 1989.

If all passenger cars were to be reduced in weight by 100 pounds, while vehicles other than passenger cars remain unchanged, the Mengert-Borener model predicted the following effects on crash fatalities:

Mengert-Borener 1989	**Fatality Increase (%) Per 100 Pound Reduction**
Crash Mode	**Passenger Cars**
Rollover or hit object	+ 2.0
Hit pedestrian/bike	– 2.4
Hit LTV/heavy truck/motorcycle	+ 1.0
Hit passenger car	– .8
OVERALL	+ .5

These results, too, are consistent with the small overall size-safety effect in NHTSA's 1997 report, and in particular show a reduction in car-to-car and car-to-pedestrian crash fatalities as car weight is reduced. The detrimental effects of weight reduction were confined to single-vehicle crashes and collisions with LTVs and heavy trucks.

However, when the analyses were limited to later calendar years of FARS data, all the results shifted substantially in favor of larger cars: the effect of a 100-pound reduction became 1 to 2 percentage points stronger (or less negative) in each crash mode. It is unknown why the full model showed such small size-safety effects, or why the results shifted in later calendar years of FARS. Possible issues include:

- The absence of any control for driver age/gender, urban/rural, etc.
- The inclusion of 2-door cars in the analysis. High-performance cars weighing about 3,000 pounds might have fatality rates high enough to influence overall results.
- The use of only six weight classes might have created unexpected discontinuities.

Section 6.7 of this report updates the Mengert-Borener analysis of car-to-car crashes, applying their model to CY 1995-2000 FARS data on MY 1991-99 cars – but limited to 4-door cars and using ten rather than six weight classes. The effect of a 100-pound reduction is an intuitively much more reasonable 2.74 percent fatality increase, not the 0.8 percent decrease seen by Mengert and Borener. Unfortunately, this new result was not available in 1995-97. Thus, the Mengert-Borener study and NHTSA's 1989-91 analyses may both have conditioned NHTSA staff not to be alarmed when their 1997 analyses did not show a significant increase in car-to-car crash fatalities as car weight decreased.

Of course, NHTSA is not the only organization studying relationships between vehicle size and fatality risk. For example, as early as 1982-84, Evans analyzed a group of car crashes including rollovers, fixed-object impacts and collisions with heavy trucks and LTVs.[17] He calibrated that fatality risk increased by 2.6 to 4.8 percent per 100-pound reduction of car weight. The range is quite consistent with the results of this study, nearly 20 years later. The National Research Council's 1992 analysis of fuel economy issues extensively reviewed the size-safety literature.[18]

1.4 NHTSA's car-light truck compatibility research

The agency has been researching fleet compatibility since 1993.[19] The long-term goal is to develop safety standards that will reduce crash fatalities and injuries for the entire vehicle fleet, while also providing a high degree of safety in each type of vehicle. In collisions between two different types of vehicles, say a large LTV and a small car, the objective is to reduce fatality risk in the car, without increasing risk in the LTV. That may require increasing crashworthiness of the car, but it might be better accomplished by reducing the aggressiveness of the LTV, or by a judicious combination of both. The research has identified three main sources of mismatch between vehicles:

- Mass incompatibility (one vehicle is much heavier than the other)
- Structural incompatibility (one vehicle is much more rigid than the other)
- Geometric incompatibility (one vehicle applies force at a height above the other vehicle's structures designed to withstand force)

Mass is easily measured placing a vehicle on scales. NHTSA's research staff has identified ways to measure vehicles' rigidity and height-of-force using data collected during NHTSA's crash tests.

NHTSA has also sponsored extensive statistical analyses, based on crash data, of the relative aggressiveness and compatibility of various vehicles, and the relationships of vehicles' rigidity and height-of-force to their aggressiveness in actual crashes.[20] Unlike the size-safety analyses, where this study's goal is to supersede all estimates in NHTSA's 1997 report, this study's

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[17] Evans, L., *Car Mass and the Likelihood of Occupant Fatality*, Paper No. 820807, Society of Automotive Engineers, Warrendale, PA, 1982; Evans, L., "Driver Fatalities versus Car Mass Using a New Exposure Approach," *Accident Analysis and Prevention*, Vol. 16, 1984, pp. 19-36; see also Crandall, R.W., and Graham, J.D., "The Effect of Fuel Economy Standards on Automobile Safety," *Journal of Law and Economics*, 1989.

[18] *Automotive Fuel Economy: How Far Should We Go?*, National Academy Press, Washington, 1992, pp. 47-68.

[19] Gabler, H.C. and Hollowell, W.T., "NHTSA's Vehicle Aggressivity and Compatibility Research Program," *Proceedings of the Sixteenth International Technical Conference on the Enhanced Safety of Vehicles*, NHTSA, Washington, 1996, Paper No. 98-S3-O-12; Gabler, H.C. and Hollowell, W.T., *The Aggressivity of Light Trucks and Vans in Traffic Crashes*, Paper No. 980908, Society of Automotive Engineers, Warrendale, PA, 1998; Gabler, H.C. and Hollowell, W.T., "The Crash Compatibility of Cars and Light Trucks," *Journal of Crash Prevention and Injury Control*, Vol. 2, March 2000, pp. 19-31; Summers, S., Prasad, A., and Hollowell, W.T., *NHTSA's Compatibility Research Program Update*, Paper No. 01B-257, Society of Automotive Engineers, Warrendale, PA, 2000; Hollowell, W.T., Summers, S.M., and Prasad, A., *op. cit.*

[20] Joksch, H., Massie, D. and Pickler, R., *Vehicle Aggressivity: Fleet Characterization Using Traffic Collision Data*, NHTSA Technical Report No. DOT HS 808 679, Washington, 1998; Joksch, H., *Vehicle Design versus Aggressivity*, NHTSA Technical Report No. DOT HS 809 184, Washington, 2000.

objective on car-LTV compatibility is merely to complement and, if possible, to corroborate the existing analyses. The size-safety part of this study included setting up crash and exposure databases for analyzing fatality risk in two-vehicle collisions, per billion miles of each vehicle, by various characteristics of the vehicles and their drivers. These databases happen to be just the right thing for also studying the relative aggressiveness of different types of vehicles.

NHTSA researchers have defined an "aggressivity metric" for vehicle-to-vehicle crashes, equal to the number of occupant fatalities in the "other" vehicle per 1000 police-reported crashes involving the case vehicle. For example, per 1000 2-vehicle crashes in which the "case" vehicle is a large pickup truck, there are 2.89 fatalities in the "other" vehicles (which may be cars, LTVs, etc.). When the "case" vehicle is a large car, there are only 0.83 fatalities in the other vehicles. Thus, the aggressivity metric for large pickup trucks is almost 3½ times the metric for large cars.

This aggressivity metric is clearly defined. Since it is based on fatality rates per 1000 crashes, it does not take crash-proneness of various vehicle types into account. That makes sense here; unlike size-safety analyses, crash-proneness should be filtered out in measuring aggressiveness in crashes. However, as stated in Section 1.3, rates that are measured per 1000 police-reported crashes can be biased against the larger vehicles – because large, rugged vehicles often don't have enough damage (if any) to make a crash worth reporting. Rugged, utilitarian vehicles, such as five-year-old full-sized pickup trucks, may have even fewer reported low-level crashes. The truck has a few scratches the owner doesn't care about; the other vehicle's owner agrees to repair his or her own damage; nobody gains by reporting the crash. Since the crashes that are reported are, on the average, fairly severe, the fatality rate per 1000 reported crashes is high.

Therefore, the analyses of this study, based on fatality rates per billion miles rather than per 1000 crashes, and controlling for each vehicle's weight, each driver's age and gender, urban/rural, etc. may in some ways give a more accurate comparison of the intrinsic aggressiveness of different types of vehicles, or at least a comparison that's not biased against the more rugged vehicle types. On the other hand, the per-mile approach in this study does not filter out the differences in crash-proneness. It complements the aggressivity metric. Together, they provide a fuller analysis of aggressiveness, and its correlation with a vehicle's rigidity and height-of-force.

1.5 Scope and limitations of this study

This study computes crash fatality rates per billion miles of different MY 1991-99 vehicles in CY 1995-2000: light, mid-size and heavy passenger cars, pickup trucks, SUVs and vans. Crash fatalities include occupants of all the vehicles involved in a collision, plus any pedestrians. It then adjusts these rates to put them on as "level a playing field" as possible, in order to discover the intrinsic difference in the fatality rates of light vs. heavy vehicles, and of cars vs. LTVs.

For example, since heavy cars had older drivers than light cars, putting heavy and light cars "on a level playing field" requires computing fatality rates for heavy vs. light cars for drivers of any specific age. Since pickup trucks were driven more in rural areas than cars, a fair comparison requires computing both rural and urban fatality rates for each vehicle type. Since light trucks were driven more miles per year than cars, it is appropriate to compare the fatality rates of trucks and cars per mile rather than per year.

This analysis allows comparison of the fatality rate of a MY 1991-99 passenger car and a MY 1991-99 LTV of the same mass, given drivers of the same age and gender, the same urban/rural mileage, etc. It estimates the trend in fatality rates ranging from the heaviest to the lightest vehicles – the average percentage increase per 100 pound reduction. The "percentage fatality increase per 100-pound reduction," in the context of these analyses, does not mean the effect of literally removing 100 pounds from a specific vehicle. It is the average percentage difference in the fatality rate of 1991-99 models weighing W pounds and the fatality rates of other 1991-99 models weighing W-100 pounds, given drivers of the same age/gender, etc – e.g., given 30-year-old male drivers on urban roads.

The analysis is not a "controlled experiment" but a cross-sectional look at the actual fatality rates of MY 1991-99 vehicles, from the heaviest to the lightest. Since most people are free to pick whatever car or LTV they wish (limited only by their budget constraints), owner characteristics and vehicle use patterns can and do vary by vehicle weight and type. This study tries, when possible, to quantify and adjust for characteristics such as age/gender or urban/rural, and at least to give an assessment of uncertainty associated with the less tangible characteristics such as "driver quality." But, ultimately, we can never be sure that a 30-year-old male operating a large LTV on an urban road at 2:00 p.m. in a Western State drives the same way as a 30-year-old male operating a smaller LTV/light car/heavy car on an urban road at 2:00 p.m. in a Western State. We can gauge the uncertainty in the results, but unlike some controlled experiments, there is not necessarily a single, "correct" way to estimate it.

These are descriptive analyses of the fatal-crash experience of actual 1991-99 make-models. Results, of course, could be different for future vehicles. Specifically, some of the LTVs in those years were rollover-prone, aggressive vehicles. A new generation of more stable, less aggressive LTVs, including entirely new designs such as car-based "crossover" SUVs as well as less sweeping redesigns of existing LTVs, could have significantly lower fatality rates.

One area for possible future analysis is to look more closely at "before vs. after" fatality rates of specific make-models that were redesigned, with important changes in materials or structure: using more of a time-series than a cross-sectional approach.

Improvements in the databases might be considered in future analyses. The current study relies on NASS data to obtain estimates of annual mileage. The main purpose is to compare the average mileage of various types of LTVs to cars, and NASS ought to provide an unbiased comparison. Nevertheless, a much larger database of annual inspection readings from various States might be useful for more accurate estimates of absolute mileage, perhaps at the make-model level.

State crash files were used to obtain "induced-exposure" data to subdivide vehicle miles by driver age/gender, etc. This study improves on the 1997 report by returning to the customary, tested definition of "induced-exposure" involvement: the non-culpable vehicle in a 2-vehicle collision. These vehicles are believed to be an essentially random sample of travel through any specific area.[21] The analysis might be further improved if such data could be obtained from more than eight States. Perhaps, traffic-count or survey data indicating the distribution of overall mileage by urban/rural, speed limit, day/night, etc. could be combined with the induced-exposure data to obtain a more accurate subdivision of the vehicle miles, and a more accurate adjustment for those factors.

Geodemographic data on an appropriate sample of vehicle owners, based on their Zip Code of residence or other information, might be useful for analyzing the relationship of driver income or attitudes, the type of vehicle they select, and their fatal crash rates.

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[21] Stutts, J.C., and Martell, C., "Older Driver Population and Crash Involvement Trends, 1974-1988, *Accident Analysis and Prevention*, Vol. 28, pp. 317-327 (August 1992).

CHAPTER 2

DATABASE TO STUDY FATALITIES PER MILLION YEARS OR BILLION MILES

2.0 Summary

The objective of this study is to compare the fatality rates of different vehicles on as "level a playing field" as possible, in order to discover the intrinsic difference in the safety of light vs. heavy vehicles, and of cars vs. light trucks. The data base must include information about drivers' age and gender, and other factors that differ by vehicle weight or type, in order to allow adjustments for those differences. For example, since heavy cars have older drivers, on the average, than light cars, putting heavy and light cars "on a level playing field" requires computing fatality rates for heavy vs. light cars for drivers of any specific age. Since pickup trucks are driven more in [higher-risk] rural areas than cars, a fair comparison of pickup trucks and cars requires computing both rural and urban fatality rates for each. Since light trucks are driven more miles per year than cars, it is appropriate to compare the fatality rates of trucks and cars per mile rather than per year (since truck fatality rates per year would be inflated by their higher mileage).

The Fatality Analysis Reporting System (FARS) provides most of the information about fatal crashes needed for this study: the type of crash and number of fatalities, the age and gender of the driver(s), the time and location. No single database has comparable exposure information for the "denominators" needed to compute fatality rates. R.L. Polk's National Vehicle Population Profiles (NVPP) count the number of vehicles of a given make-model and model year registered in any calendar year. National Automotive Sampling System (NASS) data, with odometer readings for crash-involved vehicles, permit estimates of annual mileage; NASS data also specify the number of occupants per vehicle. State data on nonfatal crashes, specifically, "induced-exposure" crashes, allow classification of the mileage by age, gender, urban/rural and other characteristics corresponding to the FARS data. (Induced-exposure crashes are involvements as the non-culpable vehicle, in a two-vehicle collision. The distribution of such involvements within a particular area is believed to be an essentially random sample of travel through that area.) Accurate estimates of the curb weight of vehicles are assembled from several publications.

This chapter describes how the various sources are merged to generate a single data base for model year 1991-1999 vehicles in calendar years 1995-2000 that parses vehicle miles by vehicle weight, driver age, gender, urban/rural, … and is suitable for direct use in logistic regressions to calibrate fatality risk as a function of these variables.

2.1 Vehicle classification and curb weight

The Vehicle Identification Number (VIN) allows precise classification of vehicles and analysis of their body style and safety equipment. The VIN is known, with few missing data on FARS (fatal crashes), NASS (odometer readings) and eight State files (induced-exposure crashes) available for analysis at NHTSA for calendar years 1995-99: Florida, Illinois, Maryland, Missouri, North Carolina, Ohio, Pennsylvania and Utah. The VIN itself, however, is not coded on Polk registration files, or listed in publications that specify curb weights.

NHTSA staff developed a series of VIN analysis programs in 1991 for use in evaluations of Federal Motor Vehicle Safety Standards and other vehicle safety analyses.[1] The programs are updated periodically and available to the public. They were extended to model year 1999 in preparation for this study. Based entirely on the VIN, the programs identify a vehicle's make-model, model year and body type, and the type of restraint system for the driver and the right-front passenger. Each vehicle is assigned two four-digit codes: a fundamental vehicle group (that includes all of a manufacturer's vehicles of the same type and wheelbase, and runs for several years, until those vehicles are redesigned) and a specific make-model. For example, Chevrolet Cavalier and Pontiac Sunfire, for model years 1995-99 are two make-models that comprise a single car group. Body styles of passenger cars, based on the VIN, are 2-door convertibles, 2-door coupe/sedans, 3-door hatchbacks, 4-door sedans, 5-door hatchbacks, and station wagons. Light-truck types are pickups, SUVs, minivans and full-sized vans.

Whereas Polk data do not include the actual VIN, their VIN-derived variables suffice to define exactly the fundamental vehicle group, specific make-model and body style/truck type as above, and permitted the Polk data to be merged with FARS or State crash data. Polk data specify the number of vehicles registered as of July 1 of every calendar year.

"Curb weight" is the weight of a ready-to-drive vehicle with a full tank of fuel and all other fluids, but no driver, passengers or cargo (as opposed to the "shipping weight," that excludes some fluids, and the "gross vehicle weight rating," that includes the vehicle and its permissible maximum load of occupants and cargo). Curb weight information is originally derived from seven sources:

1. R.L. Polk's National Vehicle Population Profile data base (cars only)
2. 1991-99 *Gasoline Truck Index* and *Import Truck Index*, published by Truck Index, Inc., Santa Ana, CA (light trucks only)
3. 1991-99 *Branham Automobile Reference Books*, Branham Publishing Co., Santa Monica, CA (cars and light trucks)
4. Passenger vehicle specifications data base supplied to NHTSA by the former American Automobile Manufacturers Association (AAMA) (selected cars and light trucks)
5. 1991-99 *Ward's Automotive Yearbooks*, Ward's Publications, Detroit (cars and light trucks)
6. Curb weights listed in NASS data (and generally derived from the preceding sources)
7. Actual curb weight measurements of 1,165 selected 1991-99 cars and light trucks compliance-tested or crash-tested by NHTSA, its contractors or other organizations

[1] Kahane, C.J., *Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions*, NHTSA Technical Report No. DOT HS 808 061, Washington, 1994, pp. 18-19; Kahane, C.J., *Relationships between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 808 570, Washington, 1997, pp. 15-17.

The first six references are in turn all derived from the same original sources: the manufacturers' official weights for vehicles of a specified make-model and subseries (and, perhaps, engine + transmission), with all equipment standard for that subseries [+ engine + transmission], but without any additional, purely optional equipment.

Polk data specify generally complete and reliable curb weights for cars, but none for trucks. Since Polk also specifies the number of registered vehicles in each subseries [+ engine + transmission], a sales-weighted average curb weight can be computed for each fundamental car group, specific make-model, body style and model year ("sales" in model year MY are approximately equal to NVPP's number of vehicles of that MY registered on July 1, MY+1).

The other publications include narrative descriptions of the models and subseries that are generally more than adequate to determine exactly the applicable 4-digit vehicle-group and make-model codes, and the body style. If several weights are specified for the same make-model (e.g., various subseries/engines), the mode (if known) or the median is selected.

Two other potential data sources were not used in this study: the vehicle weights currently listed on the FARS file, because they are not necessarily the curb weights; and the Environmental Protection Agency's file of CAFE test weights, because this file often does not describe models in enough detail to determine the applicable 4-digit vehicle-group and make-model codes.

In contrast to the published, manufacturer-defined weights for vehicles with standard equipment only, NHTSA's compliance and crash test contractors actually put "real" vehicles on a scale and measure their curb weights. The government acquires "typical" vehicles from the stock of retail dealerships near the test laboratories, generally equipped with the standard and optional features customers want (seven cases were not used, where NHTSA tested vehicles specially converted to battery or natural-gas power). This database, by itself, is not suitable for estimating all curb weights (since most make-models are not tested every year), but it is exceedingly useful for identifying and correcting biases in the published weights. Whereas, before 1990, the average discrepancy between measured and published curb weight was often 3 percent or more in passenger cars[2], it has now shrunk to an average of 1 percent in cars and 2 percent in light trucks. That is because automatic transmissions and air-conditioning, once "optional" except on the most expensive cars, are now standard equipment on many make-models, or at least on subseries of those models.

Although the published weights are supposedly derived from manufacturer sources, there are instances where they disagree with one another, are inconsistent from year to year (e.g., the weight for 1993 is substantially higher than for 1991-92 and 1994-95), or are inconsistent for closely related make-models (e.g.: 1. Nearly identical "corporate cousins" have substantially different weights. 2. The differences between 4X2 and 4X4 trucks, or regular-cab and king-cab, are unreasonably small or large). The following procedures were used to reconcile the published and measured weights, and to develop the most realistic tables of curb weights by make-model:

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[2] Kahane (1994 NCAP), pp. 21-27.

- For passenger cars, the starting point was the Polk NVPP weight (averaged by make-model and body style). They were replaced by AAMA or NASS weights if those were more plausible. (E.g., for some foreign-based manufacturers, Polk sometimes specifies the same, lowest weight for all subseries of a make-model, while AAMA shows a plausible variety of weights.) Weights are then compared year-to-year, across closely related models, across body styles, and with the weights measured in compliance and crash tests, and are adjusted, if necessary, to smooth year-to-year trends and eliminate inconsistencies.

- For light trucks, the starting point was the *Truck Index* weight. For nameplates not included in the *Truck Index* and other missing weights, Branham was consulted, and if also missing there, Ward's. These were replaced by AAMA weights if they were more plausible. Weights are then compared year-to-year, across closely related models (corporate cousins, 4X2 and 4X4, regular cab and king cab, etc.), and with the weights measured in compliance and crash tests, and are adjusted, if necessary, to smooth year-to-year trends and eliminate inconsistencies.

Best estimates of curb weight, by fundamental vehicle group, make-model, body style and model year, are shown in Appendix A of this report for cars, and Appendix B for pickup trucks, SUVs, minivans and full-sized vans. They are based on curb weights published by the manufacturers, adjusted where necessary for consistency year-to-year and across closely related models. These are the curb weights used in most of the analyses of this report, where the weight-safety effect is calibrated separately in passenger cars and light trucks.

However, in the statistical analyses that combine data for cars and light trucks, such as those that compare the intrinsic fatality risk of cars and trucks of the same weight, it is especially important that curb weights be directly comparable. As stated above, the actual measured weight of the passenger cars in compliance and crash tests averaged 1 percent higher than the weights in Appendix A, and the actual weight of light trucks in these tests averaged 2 percent higher than the weights in Appendix B. To put cars and trucks on a "level playing field" in these analyses, the weights in Appendices A and B are inflated by the following percentages that depend on the manufacturer and the vehicle type, and represent in each case the average excess of the actual weights of the test vehicles over the "nominal" weights in the Appendices:

	Percent Increase over Weights in Appendices A and B			
	Cars	Pickups	SUVs	Vans
Chrysler, Jeep, Dodge, etc.	1.92	3.76	1.68	2.75
Ford	.88	3.44	1.79	2.39
GM	.54	3.96	2.36	2.41
All overseas-based manufacturers[3]		2.52	1.20	1.56
Japan-based	1.13			
European-based	.85			
Korea-based	2.31			

2.2 Fatal crash involvements: FARS data reduction

The preparation of fatal crash data involves identifying: (1) the vehicle's make-model and body style, and its curb weight, based on VIN analysis, as described in the preceding section; (2) the crash mode, depending on the types of other vehicles and non-occupants involved (if any), and the impact points of the various vehicles; (3) potential dependent variables, such as counts of fatalities in the vehicle or crash; (4) potential control variables, factors that correlate with both vehicle weight and fatality risk, such as driver age, urban/rural, etc.

The 1995-2000 FARS files contain 137,900 records of crash-involved vehicles of model years 1991-99 with VINs that can be decoded and identified as passenger cars or light trucks (pickups, SUVs and vans, including incomplete vehicles and "300-series" pickups and vans with GVWR slightly over 10,000 pounds). A single fatal crash will generate a vehicle record for each MY 1991-99 car or light truck involved in it (but procedures are later developed to avoid "double-counting" the fatalities). These 137,900 "case" vehicle records are assigned to six basic crash modes (that have the same names as in NHTSA's 1997 report, but slightly different definitions):

[3] Separate inflation factors are computed for Japan-based, European-based and Korea-based passenger cars, since there were substantial numbers of each. Among pickup trucks, SUVs and vans, however, there were only a few European-based and Korea-based models, or none at all, during the 1990's; a single inflation factor is computed for all overseas-based manufacturers.

	Cars	Light Trucks
1. Principal rollovers	4,344	6,677
2. Collisions with fixed objects, etc.	16,597	9,986
3. Collisions with pedestrians/bikes/motorcycles	10,301	8,385
4. Collisions with heavy trucks	6,384	3,945
5. Collisions with passenger cars	19,680	20,918
6. Collisions with light trucks	17,053	7,956
Other/unknown crash mode	3,050	2,624
	77,409	60,491

A more detailed classification of crash involvement types, and their FARS definitions, is shown in Table 2-1. Principal rollovers are single-vehicle crashes where the rollover is the first truly harmful event (although FARS may code the tripping mechanism, such as a ditch, as the "first" harmful event). The second mode includes all single-vehicle crashes that are not principal rollovers and were not fatal to pedestrians or bicyclists; the vast majority of these are collisions with fixed or sizable objects (but many involve secondary rollover). Mode 3 includes collisions with pedestrians, bicyclists and motorcyclists, where the fatality is almost always the "other" road user, not a "case" vehicle occupant. Modes 4, 5, and 6 include all 2-vehicle collisions where the case vehicle is a 1991-99 car or light truck and the "other" vehicle is a heavy truck, car, or light truck, respectively – of any model year, not necessarily 1991-99. They also include 3- and 4-vehicle collisions involving only two vehicle types (when the other vehicles are a mix of cars and light trucks, the involvement is assigned to mode 6 if the case vehicle is a car, and mode 5 if it is a light truck). For most crash types, car involvements exceed light-truck involvements, simply because cars outnumbered light trucks in MY 1991-99. Exceptions where light-truck are overrepresented to the extent of exceeding car involvements are rollovers, noncollisions including "falls from a moving vehicle" and frontal impacts to the side of a car.

Potential dependent variables include (1) the number of fatalities in the crash that the case vehicle was involved in (FATALS), (2) the number of occupant fatalities in the case vehicle (DEATHS), (3) the fatality/survival of the driver of the case vehicle, (4) the sum of occupant fatalities in other vehicles involved in the crash (but not the case vehicle).

TABLE 2-1: FATAL CRASH INVOLVEMENT TYPES
(with number of crash involvements by MY 1991-99 vehicles in CY 1995-2000)

	Cars	LTVs
1. PRINCIPAL ROLLOVERS	4,344	6,677
Includes: (1) first-harmful-event rollovers, (2) first harmful event = curb, ditch, pothole, snow, non-collision and most harmful event = rollover, (3) first harmful event = curb, ditch, pothole, snow, rollover = yes, principal damage = top		
2. COLLISIONS WITH FIXED OBJECTS, ETC.	16,597	9,986
Includes all single-vehicle crash involvements except principal rollovers and crashes that resulted in non-occupant or motorcyclist fatalities. Includes:		
10. Hit object (most harmful event 14-48), principal impact frontal	6,548	3,902
11. Hit object, principal impact on the side	3,934	1,171
12. Hit object, most harmful event/impact is subsequent rollover	3,694	3,183
13. Hit object, most harmful event is fire/immersion/noncollision	360	233
14. Hit object, other/unknown principal impact	830	316
15. Collision with train	364	348
16. Collision with animal	119	66
17. Collision with parked vehicle	495	312
18. First harmful event is fire/immersion/fell from veh./noncollision	224	441
19. All other single-vehicle crashes (but not principal rollover/ped/bike)	29	14
3. COLLISIONS WITH PEDESTRIANS/BIKES/MOTORCYCLISTS	10,301	8,385
Includes all crashes fatal to pedestrians/bicyclists/motorcyclists except crashes that (1) involved more than one passenger vehicle and (2) were also fatal to occupants of the passenger vehicles Includes:		
21. 1 passenger vehicle (PV) killed pedestrian(s)	6,019	4,812
22. 1 PV killed bicyclist(s)	821	799
23. 1 PV killed other non-occupant(s) (equestrians, skateboarders, etc.)	4	12
24. 1 PV killed multiple types of non-occupants	0	0
25. 2+ vehicles involved, fatal only to non-occupant(s)	1,538	998
26. 1 PV killed motorcyclist(s)	1,488	1,442
27. 1 PV hit 1 motorcycle, fatal to PV occupant or both	37	14
28. 3+ vehicles involved, fatal only to motorcyclist(s)	394	307
29. 1+ PV, killed non-occupant(s) plus motorcyclist(s)	0	1

TABLE 2-1 (continued): FATAL CRASH INVOLVEMENT TYPES
(with number of crash involvements by MY 1991-99 vehicles in CY 1995-2000)

	Cars	LTVs
4. COLLISIONS WITH HEAVY TRUCKS	6,384	3,945
Includes crashes in which at least one of the other vehicle(s) is a heavy truck or bus(GVWR > 10,000), based on (1) the VIN, if known (2) manufacturer (only builds heavy trucks) or BODY_TYP, if VIN is missing Excludes 3+ vehicle crashes involving more than 3 vehicle types, and all 5+ vehicle crashes. Includes:		
31. 1 PV + 1 heavy truck, frontal impact by PV	2,694	2,159
32. 1 PV + 1 heavy truck, side impact to PV	1,988	828
33. 1 PV + 1 heavy truck, rear impact to PV	268	163
34. 1 PV + 1 heavy truck, unknown impact area on PV	121	94
35. 3-4 vehicles, including 1+ heavy truck(s)	1,313	701
5. COLLISIONS WITH PASSENGER CARS	19,680	20,918
Includes 2-vehicle collisions where the other vehicle is a car; 3-4 vehicle crashes where all the “other” vehicles are cars; 3-4 vehicle crashes where the case vehicle is a light truck and the other vehicles are a mix of cars and light trucks. Includes:		
41. Hit car, front-to-front, case (CV) and other vehicle (OV) going straight	5,530	4,722
42. Hit car, front-to-front, CV going straight, OV turning	562	464
43. Hit car, front-to-front, CV turning, OV going straight	512	293
44. Hit car, front-to-front, other/unknown maneuvers	80	62
45. Front of CV hit side of car, OV turning	1,207	2,120
46. Front of CV hit side of car, OV not turning (e.g., angle collision)	2,973	4,840
47. Front of CV hit rear of car	662	638
48. Front of CV hit car, other/unknown impact area on OV	114	92
49. 3-4 vehicle crash, frontal damage to CV	1,933	3,748
50. Side of CV hit by front of car, CV turning	1,156	202
51. Side of CV hit by front of car, CV not turning (e.g., angle collision)	2,770	1,051
52. Hit car, side-to-side	226	213
53. Side of CV hit by car, other/unknown impact area on OV	66	42
54. 3-4 vehicle crash, side damage to CV	629	796
55. Rear of CV hit by front of car	582	571
56. Rear of CV hit by car, other/unknown impact area on OV	83	69
57. 3-4 vehicle crash, rear damage to CV	319	626
58. Other/unknown impact area on CV, OV is car	182	216
59. 3-4 vehicle crash, other/unknown impact on CV	94	153

TABLE 2-1 (continued): FATAL CRASH INVOLVEMENT TYPES
(with number of crash involvements by MY 1991-99 vehicles in CY 1995-2000)

	Cars	LTVs
6. COLLISIONS WITH LIGHT TRUCKS Includes 2-vehicle collisions where the other vehicle is a light truck or van (LTV); 3-4 vehicle crashes where all the "other" vehicles are LTVs; 3-4 vehicle crashes where the case vehicle is a car and the other vehicles are a mix of cars and LTVs. Includes:	17,053	7,956
61. Hit LTV, front-to-front, CV and OV going straight	3,542	3,018
62. Hit LTV, front-to-front, CV going straight, OV turning	229	155
63. Hit LTV, front-to-front, CV turning, OV going straight	303	131
64. Hit LTV, front-to-front, other/unknown maneuvers	43	31
65. Front of CV hit side of LTV, OV turning	201	291
66. Front of CV hit side of LTV, OV not turning (e.g., angle collision)	874	1,213
67. Front of CV hit rear of LTV	441	355
68. Front of CV hit LTV, other/unknown impact area on OV	108	83
69. 3-4 vehicle crash, frontal damage to CV	3,104	523
70. Side of CV hit by front of LTV, CV turning	1,533	226
71. Side of CV hit by front of LTV, CV not turning (e.g., angle collision)	3,656	1,057
72. Hit LTV, side-to-side	175	120
73. Side of CV hit by LTV, other/unknown impact area on OV	72	42
74. 3-4 vehicle crash, side damage to CV	1,398	131
75. Rear of CV hit by front of LTV	458	305
76. Rear of CV hit by LTV, other/unknown impact area on OV	55	36
77. 3-4 vehicle crash, rear damage to CV	581	97
78. Other/unknown impact area on CV, OV is LTV	137	120
79. 3-4 vehicle crash, other/unknown impact on CV	143	22
OTHER CRASH INVOLVEMENT TYPES	3,050	2,624
92. Crash fatal to PV occupants **and** pedestrians/bicyclists	43	32
93. 3-4 vehicles including motorcycles, fatal to PV occupants or both	16	13
94. PV hit snowmobile, farm vehicle, etc.	98	111
95. PV hit vehicle of unknown type	73	53
96. 3-4 vehicle crash involving vehicles of 3 or more types	1,111	1,183
97. 5+ vehicle crash	1,709	1,232

The following potential control variables for "case" vehicles are defined directly from FARS data:

DRVAGE – Driver age (range 14 to 96)
Based on the person-level variable AGE, for the driver of the case vehicle. Include if 14 to 96. Delete case if AGE=97 (97 or older), 99 (unknown), less than 14, or if no driver record exists.

DRVMALE – Driver male (values 0, 1, missing)
Based on the person-level variable SEX, for the driver of the case vehicle. If SEX=1 (male) then DRVMALE=1, else if SEX=2 (female) then DRVMALE=0, else if SEX=9 (unknown) then DRVMALE = missing

DRVBELT – Driver's belt use (values 0, 0.73, 1)
Based on the person-level variable REST_USE, for the driver of the case vehicle. If REST_USE=0 (not used) then DRVBELT=0, else if REST_USE=1,2,3,8,13 (shoulder; lap; lap-shoulder; used, type unspecified; used incorrectly) then DRVBELT=1, else if REST_USE=99 (unknown if used) then DRVBELT=.73 (since 73% of the people with known values on this variable are belted, for MY 1991-99 in CY 1995-2000[4])

NITE – Crash happened between 7:00 P.M. and 4:59 A.M. (values 0, 1, missing)
Based on the accident-level variable HOUR. If HOUR = 6-18 (i.e., 6:00 a.m. – 6:59 p.m.) then NITE = 0, else if HOUR = 0-5 or 19-24 then NITE = 1, else if HOUR = 99 (unknown) then NITE = missing

RURAL – Crash happened on a rural road (values 0, 1, missing)
Based on the accident-level variable ROAD_FNC, except in Maryland and Utah[5]. If ROAD_FNC = 1-9 (various types of rural roads) then RURAL=1, else if ROAD_FNC = 11-19 then RURAL = 0, else if ROAD_FNC = 99 (unknown) then RURAL = missing

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[4] The assumption that the unknowns currently (1995-2000) have the same distribution of belt use as the knowns is untested. Kahane, C.J., *An Evaluation of Occupant Protection in Frontal Interior Impact for Unrestrained Front Seat Occupants of Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 807 203, Washington, 1988, pp. 129-132 suggests occupants with unknown belt use on 1975-86 FARS have fatality risk corresponding to a population with 29 percent use of 3-point belts, whereas Goryl, M.E., and Bowman, B.L., *Restraint System Usage in the Traffic Population, 1986 Annual Report*, NHTSA Technical Report No. DOT HS 807 080, Washington, 1987, p. 2 shows actual belt use ranging from 11 to 39 percent in those years and perhaps averaging 15 percent. In any case, this is almost a moot point because DRVBELT is not used in any of the analyses of Chapters 3-5 and only one analysis of Chapter 6.

[5] The Maryland State crash file available at NHTSA has no rural/urban variable. The county variable permits a common definition of "rural" in Maryland FARS and State data. If COUNTY = 3,5,27,31,33,510 (Anne Arundel, Baltimore Co., Howard, Montgomery, Prince Georges, Baltimore City) set RURAL=0, else RURAL=1. Utah FARS data have an unreasonably high proportion of "rural" crashes (for a State where much of the population is concentrated in urban areas). The accident-level variable LOCALITY on the State file is merged onto FARS. If LOCALITY = 5,6 (farms & fields, open country) then RURAL = 1; else if LOCALITY = 1,2,3,4,7 (industrial, commercial, residential, school, church) then RURAL = 0, else RURAL = missing.

SPDLIM55 – Crash happened on a road with speed limit 55 or more (values 0, 1, missing)
Based on the accident-level variable SP_LIMIT. If SP_LIMIT = 5-50 then SPDLIM55 = 0, else if SP_LIMIT = 55-75 or (STATE=30 and SP_LIMIT=0: Montana, no speed limit) then SPDLIM55 = 1, else SPDLIM55 = missing

WET – Crash on a wet road, or other adverse nonfreezing condition (values 0, 1, missing)
SNOW_ICE – Crash on a snowy or icy road (values 0, 1, missing)
Based on the accident-level variable SUR_COND. If SUR_COND = 1 (dry) then WET = 0 and SNOW_ICE = 0; else if SUR_COND = 2,5,8 (wet, sand, dirt, oil, other) then WET = 1 and SNOW_ICE = 0; else if SUR_COND = 3,4 (snow, slush, ice) then WET = 0 and SNOW_ICE = 1; else if SUR_COND = 9 (unknown) then WET = missing and SNOW_ICE = missing

CY – Calendar year of the crash, range 1995 to 2000

VEHAGE – Age of the case vehicle, CY-MY, range 0 (for a new vehicle) to 9 (MY 1991 in CY 2000). Exclude if CY-MY = -1.[6]

HIFAT_ST – Crash happened in a State with a higher-than-average fatality rate (values 0, 1)
Based on the accident-level variable STATE. If the State had a higher-than-national-average overall fatality rate per million vehicle years, HIFAT_ST = 1, else 0.

The fatality rate is the sum of 1995-99 traffic fatalities, divided by 1999 registered vehicles, as listed in *Traffic Safety Facts*, 1996-1999, NHTSA. The 25 States with lower-than average rates are Alaska, California, Colorado, Connecticut, Hawaii, Illinois, Indiana, Iowa, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Vermont, Virginia, Washington, and Wisconsin. The 26 jurisdictions with higher-than-average rates are Alabama, Arizona, Arkansas, D.C., Delaware, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Missouri, Montana, Nevada, New Mexico, North Carolina, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Utah, West Virginia and Wyoming.

A possible drawback of HIFAT_ST as a control variable is its similarity to the dependent variables in the analyses of Chapters 3-6 – the fatality rates in specific crash modes. For all practical purposes, however, HIFAT_ST is a geographical variable. The States with HIFAT_ST = 1 are essentially the contiguous area consisting of the entire South, the Mountain States and the adjacent States Kansas and Missouri, all characterized by one or more of the following: short winters (or no winters), substantial non-metropolitan populations, and/or a youthful population. The HIFAT_ST = 0 group is essentially the entire Northeast, the entire Midwest except Kansas and Missouri, and the Pacific States, all characterized by one or more of the following: long winters, highly urbanized, and/or aging populations. The only exceptions are Colorado and Virginia in the HIFAT_ST = 0 group; Delaware, Maine and South Dakota in the HIFAT_ST = 1 group. Except for those, HIFAT_ST could be renamed SOUTH/MOUNTAIN_ST, a control variable that would raise no objections.

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[6] Because corresponding exposure data might not be available. For example, if the new model year started selling October 1, there would be zero registrations in the NVPP file as of July 1.

Four additional control variables pertaining to the case vehicle are based on the VIN and/or tables of "Factory-Installed Optional Equipment" by make-model and year from *Ward's Automotive Yearbooks*.

DRVBAG – Driver air bag equipped (not necessarily deployed), 1 = yes, 0 = no

ABS – Probability that this vehicle is equipped with 4-wheel Antilock Brake Systems (ABS), range 0 to 1 – i.e., 0 = not available on this make-model, subseries or specific vehicle; 1 = standard; decimals = optional, and this was the proportion sold with ABS, according to *Ward's*

RWAL – Probability of Rear-Wheel AntiLock, range 0 to 1 (always 0 for 1991-99 cars)

AWD – Probability of full-time or part-time 4-wheel or all-wheel drive (4wd, awd, or 4x4), range 0 to 1

2.3 Vehicle registration years: Polk data reduction

R.L. Polk's *National Vehicle Population Profile* databases do not include the actual VIN, but their VIN-derived variables such as MAKE_ABR, SERS_ABR, STYL_ABR, MODEL_CD and WHEELS suffice to define exactly the fundamental vehicle group, specific make-model and body style/truck type as described in Section 2.1. Polk data specify the number of vehicles registered as of July 1 of every calendar year, and provide estimates of vehicle registration years by MY, CY, vehicle group, make-model, body style/truck type and, where needed, by State. At this point, Polk data can be merged with FARS and our curb weight tables to provide simple fatality rates per million vehicle registration years for CY 1995-2000 by make-model or, alternatively, by curb weight intervals. Of course, the Polk data have no information on the age or gender of the drivers, or the annual vehicle mileage.

2.4 Annual mileage and vehicle occupancy: NASS data reduction

Fatality rates per hundred million vehicle miles of travel (VMT), rather than per million registration years, are the most widely accepted measure of risk. National Automotive Sampling System (NASS) data have odometer readings as well as VINs for towaway crash-involved vehicles, permitting rather accurate comparisons of average annual mileage for specific classes of vehicles (e.g., full-sized pickup trucks vs. 4-door cars). While it is true that NASS is a file of towaway crash-involved vehicles that might have somewhat higher absolute mileage than the average vehicle on the road (more mileage = more opportunity to have crashes), the NASS ratios of mileage for various types of vehicles relative to 4-door cars ought to be representative of the entire fleet.[7]

Table 2-2 analyzes the odometer readings of MY 1991-99 4-door cars (excluding police cars) in 1993-2001 NASS, by "nominal" vehicle age: CY – MY. For example, cars that were nominally zero years old (i.e., CY = MY) averaged 8,383 miles on the odometer at the time of the crash. That average increases year-by-year, but at a decreasing rate, to 113,825 for 9-year-old cars.

The actual average odometer readings in Table 2-2 suggest that annual mileage (the difference in the reading from one year to the next) steadily declines as the cars get older, but that the rate of decline gradually slows down, in absolute terms, as the cars age. That suggests a cubic, rather than a quadratic regression of odometer reading by vehicle age (because a quadratic regression would have annual mileage decrease by the same absolute amount every year). A cubic regression, on the 11 explicit or implicit data points in Table 2-2, of the actual average odometer reading by the actual average age of the vehicles (assuming that a model year typically runs from October 1 of the preceding calendar year through September 30), shows a remarkably good fit for the equation:

$$\text{odometer} = 19{,}128 \text{ actual age} - 1006 \text{ actual age}^2 + 27.8 \text{ actual age}^3$$

as may be seen in comparing the "actual" and "calibrated" odometer readings in Table 2-2. The annual mileage rate is the derivative of this function:

$$\text{annual mileage rate} = 19{,}128 - 2012 \text{ actual age} + 83.4 \text{ actual age}^2$$

It is shown in the last column of Table 2-2 (a special "annual mileage rate" is calculated for cars with CY = MY, as explained in the footnotes of Table 2-2). These mileage factors may be multiplied by vehicle registration years to obtain estimates of vehicle miles for 4-door cars.

An important characteristic of 4-door cars (excluding police cars) is that there is no correlation between vehicle weight and annual mileage. A regression analysis was performed on 8,323 NASS cases, with the log of the odometer reading as the dependent variable, curb weight as a

[7] Adrian Lund, in his review of this report, recommended investigating the possibility of an additional bias in NASS odometer readings. Could more crash-prone vehicle types (or vehicle types with more crash-prone drivers) have lower average odometer readings on NASS, especially in the first year, essentially because the drivers get into crashes sooner? To address this question, a Monte Carlo simulation considered four fleets of 10,000 vehicles each. Every vehicle in every fleet is in fact driven exactly 10,000 miles per year. However, the vehicles in the first fleet experienced a NASS-reported crash an average of every 30,000 miles, with an exponential distribution of average mileage between crashes; the second fleet crashes on the average every 40,000 miles; the third fleet every 50,000 miles; the fourth every 60,000 miles. Each fleet generated almost exactly the same average NASS odometer readings: the 0-year-old cars had an average of 5,000 miles when they crashed (which is, in fact, the actual mileage they would have halfway thru their first year), the 1-year-old cars, 15,000 miles, etc. Thus, the average NASS odometer readings accurately reflect the actual mileages of the vehicles and are not biased downwards if a vehicle (or its drivers) is more crash prone than usual. While it is true that the more crash-prone vehicles experience their first crash sooner, they also experience proportionately more crashes later on, throughout their lives. Dr. Lund's review is available in the NHTSA docket for this report.

TABLE 2-2

ODOMETER READINGS AND ANNUAL MILEAGE
OF CRASH-INVOLVED 4-DOOR NON-POLICE CARS 0-9 YEARS OLD

(Model year 1991-99 vehicle cases on 1993-2001 NASS files, total N = 8,323)

Vehicle Age		Average Odometer Reading		
Nominal CY – MY	Average Actual[8]	Actual	Calibrated[9]	Annual Mileage[10]
	[0.00]	[0]	0	
0	0.45[11]	8,383	8,406	[18,023][12]
1	1.25	22,316	22,392	16,743
2	2.25	37,575	38,261	15,023
3	3.25	51,848	52,493	13,469
4	4.25	64,279	65,255	12,082
5	5.25	77,796	76,714	10,862
6	6.25	88,054	87,035	9,809
7	7.25	95,290	96,387	8,922
8	8.25	103,233	104,926	8,203
9	9.25	113,825	112,849	7,650

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[8] Assumes a model year typically runs from October 1, MY-1 through September 30, MY. In that case the median car of model year MY is sold on April 1, MY. By mid-calendar year CY (July 1), this car is (CY – MY) + .25 years old. This formula only works when CY > MY (cars more than a year old). However, when CY = MY, the median sold car on July 1 is older than .25 years, because yet-unsold cars are not involved in the calculation. See footnote 9 for computation of average vehicle age when CY = MY.

[9] Regression of odometer reading by average actual age and age ^{2} with no intercept for the 11 data points in Table 2-2. Regression equation: odometer = 19128*age – 1006.136*age ^{2} + 27.7982*age ^{3} (R-squared = .999834)

[10] Derivative of odometer regression equation: d odometer/d actual age = 19128 – 2012.27*actual age + 83.3945*actual age ^{2}

[11] Again assumes a model year runs from October 1, MY-1 through September 30, MY, with a constant sales rate. Working through sales and exposure on a month-by-month basis suggests that cars of model year MY involved in crashes during calendar year MY were 5.4 months (0.45 years) old.

[12] Working with sales, exposure and the regression equation odometer = 19128*age – 1006.136*age ^{2} + 27.798*age ^{3} on a month-by-month basis suggests that cars of model year MY were driven an average of 12,469 miles during calendar year MY. (This number is low because many of the cars were not on the road for the whole calendar year.) However, since only 69.184 percent of the model year MY run has already been sold and registered as of July 1, MY (NVPP 1991-99 average), 12,469/.69184 = 18,023 is the "mileage factor" that translates vehicle years on the NVPP file to VMT for all vehicles of that model year at age 0.

linear independent variable and vehicle age as a categorical independent variable. Vehicle age was, of course, highly significant (F = 1668.48, df = 9), but curb weight was not at all (F = 0.03, df = 1). Inspection of the NASS cases shows that small, mid-sized and large 4-door cars have quite similar average mileage, year after year.

The ratio of mileage in other vehicle classes relative to 4-door cars was estimated by a regression of 17,627 NASS cases, with the log of the odometer reading as the dependent variable and with vehicle type and vehicle age as categorical independent variables. Each of these independent variables has a statistically significant effect, but the interaction term vehicle type x vehicle age is not significant. In other words, different types of vehicles have different mileage, but the ratio of their mileage to 4-door cars stays about the same at all ages. Table 2-3 shows the ratio of the mileage of other vehicle types relative to 4-door cars of the same age. These ratios are the antilogs of the regression coefficients.

For example, the mileage ratio for compact pickup trucks is 1.036. Since a 2-year-old 4-door car is driven an average of 15,023 miles per year (see Table 2-2), a 2-year-old compact pickup truck is driven approximately 1.036 x 15,023 = 15,564 miles per year.

All classes of light trucks, except the smallest SUVs, have significantly higher annual mileage than cars. Moreover, unlike 4-door cars, within each type of light truck (pickups, SUVs vans), there is a clear trend toward higher annual mileage for the bigger trucks.

Table 2-3 shows that, in order to achieve a "level playing field," size-safety analyses of light trucks should be based on fatality rates per mile rather than per year. So should analyses comparing the intrinsic relative risk of cars and LTVs. By contrast, size-safety analyses of 4-door cars alone can be based on fatality rates per year, since annual mileage is about the same for all sizes. Estimates of vehicle miles traveled (VMT) will be obtained by multiplying registration years by the age-appropriate annual mileage of 4-door cars in Table 2-2 and by the ratio of other vehicle groups to 4-door cars in Table 2-3. As stated above, these estimates are not necessarily accurate, but they adequately adjust for the extra mileage of LTVs over cars, and heavy LTVs over light LTVs.

The NASS data were the largest and most representative set of actual odometer readings available to NHTSA in 2002. Future studies of this type could benefit from much larger files of odometer readings, such as census data collected from a number of States when they conduct vehicle inspections, if they accurately record and encode the odometer readings at the inspections.

In addition to the odometer readings, NASS investigators accurately report the number of occupants (driver plus any passengers) riding in a vehicle. Some vehicle types (e.g., passenger vans) tend to carry more occupants than others. Occupancy rates could conceivably also vary by vehicle size, even within vehicles of the same general type. Certain occupant fatality rates should perhaps be analyzed per occupant mile rather than per vehicle mile, because fatality rates per vehicle mile overstate the risk, for an individual, of riding in the higher-occupancy vehicles.

TABLE 2-3

RATIO OF AVERAGE ANNUAL MILEAGE TO 4-DOOR CARS
BY VEHICLE TYPE

(Model year 1991-99 vehicle cases on 1993-2001 NASS files)

	Ratio of Annual Mileage To 4-Door Non-Police Cars	N of NASS Cases
ALL 4-DOOR (non-police) CARS	1.000	8323
Compact pickup trucks*	1.036	1317
Large (100-series) pickup trucks	1.172	731
Large (2/300-series) pickup trucks	1.296	206
Small SUVs	.977**	448
Mid-size SUVs	1.037	1278
Large SUVs	1.208	265
Minivans	1.116	849
Large vans	1.328	132
Police cars	1.328	169
Sporty, small 2-door cars	.949	761
High-performance 2-door cars	.907	543
Economy 2-door cars	1.019**	1667
Other 2-door cars	1.011**	938

* These vehicle classes are defined in Chapter 5.
** Not significantly different from 4-door cars.

The use of NASS data to analyze occupancy rates, and to adjust, where necessary, for differences in occupancy rates by vehicle size or type, is discussed in Sections 3.1, 4.4, 5.3 and 5.4.

2.5 Induced-exposure crashes: State data reduction

The preceding data count the exposure accumulated by vehicles of a specific curb weight in vehicle years (exactly) or miles (approximately) but say nothing about who was driving the vehicles, or on what type of road. Classification of the mileage by age, gender, urban/rural, etc. allow fatality rates to be adjusted for these control variables – i.e., to compare the fatality rates of cars of two different curb weights for drivers of the same age and gender on the same type of road. State data on nonfatal crashes, specifically, "induced-exposure" crash involvements, supply this information. Induced-exposure crash involvements are the non-culpable vehicles in two-vehicle collisions. Those non-culpable vehicles did nothing to precipitate the collision, but were hit merely because "they were there." The involvements are a surrogate for exposure, because they measure how often vehicles "were there" to be hit by other vehicles.[13] "The induced exposure concept assumes that the not-at-fault driver in a two-vehicle crash is reflective of what is 'on the road' at that point in time, and that the sample of all not-at-fault drivers can be used to predict the characteristics of all non-accident involved drivers on the roadway (i.e., exposure characteristics)."[14] Data from the National Personal Transportation Survey will be presented shortly to demonstrate this assumption is accurate to the extent that induced exposure crashes and actual mileage have similar driver-age distributions. (NHTSA's 1997 size-safety analysis used a different definition of "induced exposure," but this report returns to the customary approach, whose efficacy is well established.)

As of mid-2002, NHTSA had access to eight State files for 1995-99 with relatively complete data on the VINs of crash-involved vehicles:

Florida	Illinois	Maryland	Missouri
North Carolina	Ohio	Pennsylvania	Utah

Illinois, Maryland, Ohio and Pennsylvania have lower-than-national-average fatality risk, as defined in Section 2.2, while Florida, Missouri, North Carolina and Utah are higher than average.

Records of induced-exposure crash involvements of MY 1991-99 cars and LTVs with decodable VINs are extracted. In North Carolina, the definition is the same as was used in studies by that State's Highway Safety Research Center: the non-culpable vehicle (as evidenced by an absence of citations or violations) in a 2-vehicle collision where the other vehicle was found "culpable"

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[13]Stutts, J.C., and Martell, C., "Older Driver Population and Crash Involvement Trends, 1974-1988, *Accident Analysis and Prevention*, Vol. 28, pp. 317-327 (August 1992); Haight, F.A., "A Crude Framework for Bypassing Exposure," *Journal of Safety* Research, Vol. 2, pp. 26-29 (1970); Thorpe, J.D., "Calculating Relative Involvement Rates in Accidents without Determining Exposure," *Australian Road Research*, Vol. 2, pp. 25-36 (1964); Van Der Zwaag, D.D., "Induced Exposure as a Tool to Determine Passenger Car and Truck Involvement in Accidents," *HIT Lab Reports*, Vol. 1, pp. 1-8 (1971); Cerrelli, E., *Driver Exposure: Indirect Approach for Obtaining Relative Measures*, NHTSA Technical Report No. DOT HS 820 179, Washington, 1972.

[14] Stutts and Martell, *op. cit*., p. 318.

(as evidenced by at least one citation or violation).[15] The “other” vehicle may be any type or model year, but there should not be any pedestrians, bicyclists, etc. in the crash. Also, the non-culpable vehicle must have a driver, age 14-96, thereby automatically excluding unoccupied, parked vehicles from the study. This definition is quite satisfactory for North Carolina, where police identify exactly one culpable vehicle in 88 percent of the 2-vehicle crashes, whereas in only 12 percent of the crashes do they judge that neither vehicle, or both are culpable.

Similarly, in Maryland, Missouri, Ohio, Pennsylvania, Utah between 80 and 93 percent of 2-vehicle crashes have exactly one culpable vehicle, as evidenced by any one, or more of the following: the vehicle is coded “at fault,” or its driver charged with violation(s) or it has “contributing factor(s)” indicating driver error or a defective vehicle – and exactly one non-culpable vehicle, as evidenced by “not at fault,” no violations, and “did not contribute.” As in North Carolina, take the non-culpable vehicle in the 2-vehicle crashes with exactly one culpable vehicle.

Florida and Illinois investigators are more conservative in assigning culpability. Only 53-64 percent of 2-vehicle crashes have exactly one culpable vehicle, based on “at fault” coding, violations, or contributing circumstances, while 36-46 percent have none. In these two States, the induced-exposure file is augmented by also including crashes where neither vehicle is “culpable” but: (1) there was a front-to-rear collision, and the rear-impacted vehicle was not backing up at the time of impact, or (2) a vehicle in transport hit a parked vehicle (that was occupied by its driver), or (3) one of the vehicles had an impaired driver or a vehicle defect, and the other did not. In these cases, select as “induced exposure” the vehicles that were rear-impacted, parked, or had the unimpaired driver. That increases the “yield” of induced-exposure involvements to 72-74 percent of 2-vehicle crashes.

Control variables are defined for induced-exposure vehicles parallel to those defined in FARS:

DRVAGE – Driver age (range 14 to 96) Each of the States, and FARS, code driver age on a year-by-year basis up to at least 96; since FARS uses code 97 for “97 and older,” and those FARS cases are deleted, so are any ages greater than 96 in the State data. As stated above, since every vehicle must have a driver with known age, unoccupied parked cars are automatically excluded as induced-exposure involvements.

DRVMALE – Driver male (values 0, 1, missing)

NITE – Crash happened between 7:00 P.M. and 4:59 A.M. (values 0, 1, missing)
Straightforward in all States

DRVBELT – Driver’s belt use (values 0, 0.83, 0.87, 0.90, 0.92, 0.93, 0.95, 1)
Belt users include codes such as “lap + shoulder,” “lap,” “shoulder,” “manual belt,” “automatic belt,” “used” and “belts plus bags.” Unrestrained drivers include “not used,” “not installed” and “air bag only.” In six States, drivers with unknown belt use (other codes, missing) are assigned

[15] *Ibid*., p. 318.

the level of reported belt use among drivers where it is known (83% in Florida, 93% in Maryland, 90% in Missouri, 95% in North Carolina, 87% in Pennsylvania, 92% in Utah). In Illinois and Ohio, all unknowns are counted as unbelted, since only 2-4% of all drivers are explicitly coded unbelted while 10-11% are unknown. (Belt use is evidently overreported in some State crash files; partly for that reason, DRVBELT is never actually used in the analyses of Chapters 3-6).

RURAL – Crash happened on a rural road (values 0, 1, missing)
Based on: rural/urban in Florida, North Carolina, Ohio and Pennsylvania (urban also includes "mixed" and "urbanized"); road class in Illinois; county in Maryland (Anne Arundel, Baltimore City & County, Howard, Montgomery, Prince George = urban; others = rural); population group in Missouri (municipality > 2,500 is urban); and locality in Utah (farms, fields, open country = rural; industrial, commercial, residential, school, church = urban). These definitions correspond exactly with the FARS classifications discussed in Section 2.2 (as tested by comparing the FARS and State records for the same fatal crashes).

SPDLIM55 – Crash happened/case vehicle was traveling on a road with speed limit 55 or more (values 0, 0.05, 0.20, 0.37, 0.76, 0.90, 1, .)
Straightforward in all States except Illinois (in Pennsylvania, take the maximum of the speed limits of the various roads involved; in Utah, set SPDLIM55 to 0 when speed limits are unknown, since those are primarily city streets). In Illinois, it is based on the road class. A FARS tabulation of speed limit by road class for Illinois crashes gives the percent of 55 mph roads for each class, ranging from 100 percent on rural interstates down to 5 percent on urban streets.

WET – Crash happened on a wet road (values 0, 1, missing)
SNOW_ICE – Crash happened on a snowy or icy road (values 0, 1, missing)
WET=1 includes wet, slippery, muddy, oily, sand, dirt and other adverse nonfreezing conditions.
SNOW_ICE=1 includes snow, ice, frost, slush, plowed, salted and cindered, ice patches.

The counts of induced-exposure crash involvements in 1995-99 vary from State to State:

Florida	325,447
Illinois	275,300
Maryland	92,749
Missouri	175,141
North Carolina	250,335
Ohio	361,359
Pennsylvania	148,802
Utah	61,907
TOTAL	**1,691,040**

Fewer than one percent of the induced-exposure cases had missing values on any of these variables, as defined above.

There are some important caveats concerning the appropriate use of induced-exposure data. They are not a substitute for exact, clearly defined measures of exposure, such as vehicle years or miles. Rather, they are the best available tool for subdividing the actual years or miles – approximately – by age, gender, etc. It is believed that the induced-exposure involvements within a particular area and time are an essentially random sample of travel through that area at that time. It is not believed that the induced-exposure crashes in a State over a year are a random sample of all travel in that State during that year. In some places and times – e.g., urban places during daylight hours – the rate of induced-exposure involvements per mile of travel is undoubtedly higher than in other places and times. "Induced exposure is more appropriately viewed as a measure of 'opportunities to crash' that takes into account miles traveled but also traffic conditions, vehicle speeds, length of time on the roadway, amount of nighttime driving, and other factors."[16]

Furthermore, since induced exposure is based on reported crashes, it is biased by factors that affect crash reporting. Specifically, Chapter 1 discussed that heavier vehicles, especially light trucks, have low rates of reported crashes: the same hit that would result in reportable damage on a light vehicle might cause no damage at all, or no damage worth reporting on a rugged, heavier vehicle. Any size-safety analysis based purely on fatalities per 100 reported crashes [induced-exposure or any other type] could be biased against heavier vehicles in general and light trucks in particular, underestimating their safety.

A distinction must be made between the primary independent variables of this study, curb weight and vehicle type, and the control variables such as driver age and gender. The goal is to calibrate the fatality rate as a function of curb weight and vehicle type. The exposure data used for these rates cannot be confounded with curb weight, because that would immediately bias the calibration. Here, it is important to have an absolute measure of exposure such as vehicle years or miles. That is why the study relies on Polk's exact counts of vehicle years by curb weight.

Control variables such as driver age and gender, on the other hand, are only tools to adjust the fatality rates. We are not interested here in the fatality rate as a function of driver age, *per se*. We are only interested in adjusting the fatality rate for small cars downward to the extent that small cars have an excess of high-risk young drivers. If induced-exposure data are used to subdivide the vehicle years by driver age, it is not so critical that the age distribution be absolutely correct. It is more important that the relative difference (interaction) in this age distribution for heavy vs. light cars be preserved. First-order errors in the distribution of induced exposure across the control variables might result in second-order errors, at most, in the calibration of the size-safety effect.

In fact, the induced-exposure data from our eight States are quite accurate even in absolute terms on the distribution of the most important control variable, driver age. When these data are

[16] *Ibid*., p. 326.

combined with Polk and NASS results to make a national mileage file, as will be described in the next section, the distribution of the vehicle miles by driver age is quite consistent with the 1983 and 1990 National Personal Transportation Surveys (NPTS)[17], especially considering the long-term demographic trend toward a higher proportion of older drivers:

Percent Distribution of Miles Driven, by Age	NPTS 1983	NPTS 1990	Induced Exposure 1995-2000
16-24 years	17	15	17
25-64 years	78	80	75
65+ years	5	6	8

They are less accurate on the urban/rural distribution of mileage. The Federal Highway Administration's (FHWA) statistics suggest that approximately 34 percent of the mileage of cars and light trucks in our eight States was rural.[18] Only 25 percent of the induced-exposure crash involvements were on rural roads, since 2-vehicle crashes are less frequent per mile in rural areas. Nevertheless, these data are still satisfactory for control-variable use, since both the actual FHWA mileage and the induced exposure crashes show, for example, that pickup trucks are relatively more common in rural areas.

Belt use tends to be overreported in nonfatal crashes: 83-95 percent in our eight States. That limits its utility as a control variable. Fortunately, it will be shown in Chapters 3 and 4 that belt use is nearly uncorrelated with curb weight, and it is not needed as a control variable in the size-safety analyses.

As of mid-2002, most State files were available at NHTSA only through 1999. The CY 1999 induced-exposure data are used to classify the CY 2000 as well as the CY 1999 vehicle years by driver age and gender, urban/rural, etc. The assumption here is that the distribution of those variables would not be likely to change much in one year.

This report relies on induced-exposure data from eight States to represent the United States. Although the absolute distributions of crashes by driver age, rural/urban, etc. differ considerably from State to State, the interactions of these variables with curb weight are remarkably consistent across States. As we shall show in Sections 3.5, 3.7, 4.5 and 5.6 the use of data from just 8 States makes minimal-to-moderate contribution to the uncertainty of the estimated size-safety effects.

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[17] "Status Report Special Issue: Crashes, Fatal Crashes per Mile," *Insurance Institute for Highway Safety Status Report*, Vol. 27 (September 5, 1992), p. 7.

[18] Teets, M.K., *Highway Statistics 1993*, Report No. FHWA-PL-94-023, Federal Highway Administration, Washington, 1994, pp. V-115 – V-116 show 37 percent of total mileage (including heavy trucks) in these 8 States in 1993 was rural. That corresponds to about 34 percent in the later 1990's, excluding heavy trucks.

2.6 Assembling the analysis data files

The critical step in building an exposure data file is to apportion the right number of vehicle years to each induced-exposure crash, so that the induced-exposure crashes in eight States represent all the vehicle years in the United States. The nation's vehicle registration years are apportioned by make-model, body style, model year and calendar year.

For example, in CY 1998, the MY 1997 Ford Taurus 4-door had the following registrations (as of July 1) and counts of induced-exposure crash involvements:

MY 1997 Ford Taurus in CY 1998	Registrations	Induced-Exposure Involvements
Florida	17,426	203
Missouri	9,817	221
North Carolina	8,797	191
Utah	2,683	59
These 4 high-fatality States	38,723	
Illinois	18,507	295
Maryland	5,460	61
Ohio	19,594	177
Pennsylvania	17,784	123
These 4 low-fatality States	61,345	
All 25 high-fatality States + D.C.	132,454	
All 25 low-fatality States	220,577	
Entire Unites States	353,031	

Since there were 203 crash involvements and 17,426 registered cars in Florida, each crash corresponds to

17,426/203 = 85.84 vehicle years within Florida

However, since the 4 high-fatality States in our sample had 38,723 registered vehicles, whereas all 25 high-fatality States plus D.C. had 132,454 registered vehicles, each Florida crash is apportioned

(132,454/38,723) x (17,426/203) = 293.63 high-fatality vehicle years in the United States

Similarly, each of the 295 crash involvements in Illinois is apportioned

(220,577/61,345) x (18,507/295) = 225.58 low-fatality vehicle years in the United States

The apportionment of vehicle years per crash in the eight States is:

MY 1997 Ford Taurus in CY 1998	Induced-Exposure Involvements	Vehicle Years Apportioned Per Involvement
Florida	203	293.63
Missouri	221	151.94
North Carolina	191	157.54
Utah	59	155.55
Illinois	295	225.58
Maryland	61	321.84
Ohio	177	398.04
Pennsylvania	123	519.88

Note that

$$203 \times 293.63 + 221 \times 151.94 + 191 \times 157.54 + 59 \times 155.55 + 295 \times 225.58 + 61 \times 321.84 + 177 \times 398.04 + 123 \times 519.88$$

$$= 353{,}031 \text{ vehicle years in the entire United States}$$

In other words, these weight factors (vehicle years) apportioned to each induced-exposure crash, will add up, over the entire file, exactly to the number of 1997 Ford Taurus 4-door registrations in the United States during CY 1998. (In general, the weight factors are higher in States such as Pennsylvania that have higher crash-reporting thresholds, and relatively fewer reported crashes per vehicle year.)

This process is repeated for all other make-models of cars and light trucks, MY 1991-99 in CY 1995-2000. Low-sales make-models sometimes have registrations, but no induced-exposure crashes in a State(s) in some year(s). In each such case, a single dummy record is created for that State and year. It is given the weight factor that would have been calculated if there had been one induced-exposure involvement. The values for its control variables are the average values of those variables for the induced-exposure crashes in the other States, for that make-model, MY and CY.[19] These dummy cases, accounting for about 1 percent of total vehicle years, are needed to prevent losing portions of the exposure of low-sales make-models.

Vehicle miles of travel are also apportioned to each induced-exposure case, based on the average annual mileage by vehicle age and class in NASS (see Section 2.4). The Ford Taurus is a 1-year-old 4-door car, a vehicle class averaging 16,743 miles per year in NASS. Since each Florida

[19] To represent the driver age distribution, we do not use the average value of DRVAGE, but the average values of the derivative variables M14_30, M30_50, etc. defined in Chapter 3.

crash is apportioned 293.63 vehicle years, it is also apportioned 293.63 x 16,743 = 4,916,247 vehicle miles.

We are now ready to view hypothetical examples of a fatal-crash record and an exposure record (a specific induced-exposure crash), both from Florida, a high-fatality State), both for a 1997 Ford Taurus 4-door in CY 1998:

	Fatal-Crash Record	Exposure Record
Crash mode	Fixed Object	-
Specific crash type	Frontal – Fixed Object	-
N of fatalities in the crash	2	-
N of case vehicle occupant fatalities	2	-
Case vehicle driver fatality?	Yes	-
Vehicle registration years	-	293.63
Vehicle miles of travel	-	4,916,247
Vehicle type	4-door car	4-door car
Curb weight	3,326	3,326
Driver age	24	28
Driver male?	1	1
Driver belted?	0	1
At night?	0	0
Rural?	1	0
Speed limit 55+?	1	0
Wet road?	0	0
Snowy/icy road?	0	0
Calendar year	1998	1998
Vehicle age	1	1
High-fatality State?	1	1
Driver air bag?	1	1
ABS (4-wheel)?	0.51	0.51
Rear wheel antilock?	0	0
All-wheel drive?	0	0

Fatal crash records come from all 50 States and the District of Columbia. Each exposure record is nominally a specific induced-exposure crash involvement in one of the eight States, a discrete unit. But if this record is weighted by its apportioned vehicle years or miles, it becomes a cohort of vehicle years or miles of travel in the United States. Add up all the exposure records and you get a national census of vehicle years or miles. Divide the sum of the fatalities by the sum of the vehicle years, and you get an unbiased fatality rate per vehicle year, just as if you had never used the induced-exposure data, but only FARS and Polk.

These databases will be used for regression analyses in Chapters 3, 4 and 5, and they can also be used for tabular or graphic presentation of fatality rates per million vehicle years or billion miles for specific subgroups – e.g., the fatality rates of 30-50 year old female drivers as a function of a car's curb weight. These simpler presentations are useful for understanding the real trends in the data, and verifying that the regressions fit the trends. That type of checking was generally impossible with the data setup in the 1997 report.

CHAPTER 3

VEHICLE WEIGHT AND FATALITY RISK IN PASSENGER CARS

3.0 Summary

Crash fatality rates per million vehicle years of model year 1991-99 4-door cars in calendar years 1995-2000 are significantly higher for the lighter cars in almost every crash mode, even after adjusting the rates for driver age and gender, urban/rural, etc. However, the size-safety effect is not uniform across all weights. The fatality increase per 100-pound reduction is stronger in the lighter cars.

The analysis is not a "controlled experiment" but a cross-sectional look at the actual fatality rates of cars that are currently on the road, from the lightest to the heaviest. Since most people can pick what car they drive, owner characteristics and vehicle use patterns can and do vary with car weight. Some characteristics are quantifiable, such as age/gender or urban/rural, and the logistic regression technique readily adjusts for them. Others, like "driver quality" or "attitude" are less tangible and increase the uncertainty of the results. Therefore, ranges of possible size-safety effects are estimated in addition to the regression analyses' simple point estimates.

In 1991-99 passenger cars weighing 2,950 pounds or more (the median for 4-door cars), each 100-pound reduction is associated with a 2.0 percent increase in crash fatality risk, adding an estimated 216 fatalities per year relative to "baseline." In cars weighing less than 2,950 pounds, each 100-pound reduction is associated with a 4.4 percent risk increase, amounting to 597 additional fatalities per year. "Crash" fatality risk includes occupants of these vehicles, occupants of other vehicles they collide with, and pedestrians. Both estimates are subject to uncertainty and have interval estimates that include a possibility of considerably smaller effects.

These are descriptive analyses of the fatal-crash experience of actual 1991-99 cars. The percentage "fatality increase per 100-pound reduction," in the context of these analyses, does not mean the effect of literally removing 100 pounds from a specific car. It is the average percentage difference in the fatality rate of 1991-99 models weighing W pounds and the fatality rates of other 1991-99 models weighing W-100 pounds, given drivers of the same age/gender, etc. The absolute increases per year (e.g., 216 or 597 more fatalities) estimate what could have happened if the public, in 1991-99, had bought a different mix of cars – namely, higher shares of various light make-models and lower shares of the heavy ones – that would have reduced the average weight of cars on the road by 100 pounds.

3.1 The calibration data set: 4-door cars, excluding police cars

The passenger-car analysis is limited to 4-door cars, excluding police cars, because this is a fairly continuous spectrum of vehicles and drivers. Heavy and light 4-door cars look quite a bit alike, except the heavier ones have longer wheelbases, wider track, and longer hoods. As the cars get heavier, the average age of their drivers and the percentage of male drivers and rural mileage steadily increase. This is an ideal situation for regression analysis. Four-door cars don't attract too many drivers with risk-prone personalities and high crash rates. In fact, 30-49 year old females, the safest group of drivers on the road (according to the database generated for this report), are overrepresented in small 4-door cars.

The popularity of 2-door cars has declined steadily since the mid-1970's, and they increasingly occupy "niche" markets. By model year 1999, only 20 percent of new cars had two doors. Two specific groups of 2-door cars are well known for risk-seeking drivers with fatal crash rates above and beyond what might be explained by their age and gender: lightweight sports cars and fairly heavy "muscle" cars. Either group, if aggregated with 4-door cars in the regression analyses, would produce misleading size-safety effects. The inclusion of sports cars would exaggerate the size-safety effect by placing high-risk outliers at the light end of the data, whereas the muscle cars would water down the effect by placing high-risk outliers in the middle of the data. But today, even other types of 2-door cars are increasingly niche cars with possibly unusual driver characteristics.

Ford Crown Victoria and Chevrolet Caprice used as police cars[1] should also be excluded from the regressions. While hurrying to crime scenes or pursuing suspects, police have to drive far more dangerously than they would in ordinary personal transportation. In addition, Table 2-3 showed that police cars are driven 33 percent more miles per year than other 4-door cars. Inclusion of these vehicles would place a high outlier at the heavy end of the vehicle weight range and diminish the calibrated size-safety effect, especially for pedestrian and car-to-car crashes (where police cars are most overrepresented). During the 1990's, about 1 percent of new 4-door cars were police cars.

The "Special Use" variables on FARS and State files are not necessarily reliable for identifying police cars. Instead, the determination is based on the VIN, the vehicle age, and the driver's age and gender. All Crown Victoria and Caprice with subseries or engine codes[2] typical of police cars are excluded from the regressions until they are four years old (CY – MY = 0-3). Many police cars are eventually converted to civilian use and sold to civilians. The above cars, from age 4 onwards, are still assumed to be in likely police service if the driver is a male age 23-45, and excluded from the regressions. If the car is 4 or more years old and the driver is female and/or not in the 23-45 age group, it is assumed that the car is probably in civilian use. Of course, the large number of Crown Victorias and Caprices that do not have the VIN codes typical of police cars are always included in the regressions.

Two additional advantages of limiting the regressions to 4-door non-police cars is that neither annual mileage nor average occupancy are significantly correlated with their curb weight. The absence of correlation between curb weight and annual mileage was demonstrated in Section 2.4.

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[1] www.auto.com/reviews/cwire13_20000613.htm and www.members.tripod.com/~rbc2097/cap9196.htm suggest approximately 60,000 to 70,000 Crown Victorias or Caprices per year were sold as police cars.

[2] For Crown Victoria, VIN characters 6-7 are 72 in 1991-92 or 71 in 1993-99 (police interceptor model). For Caprice, VIN characters 5-8 are L537 in 1991-93, L53E in 1992 only, or L52P in 1994-96 (powerful engines). The VIN, vehicle age and driver age/gender determinations are based on Pennsylvania crash data, which are believed to be complete and accurate in distinguishing police cars from civilian cars.

A regression analysis was run on 7,399 National Automotive Sampling System (NASS) vehicle cases, with N of occupants as the dependent variable; curb weight and vehicle age were the independent variables. Average occupancy increased by .0028 per 100-pound reduction of curb weight (ranging from 1.62 in a 2,000 pound car to 1.57 in a 4,000 pound car). This, too, is nonsignificant (t = 1.18) That permits the simpler regression of fatality rates per million vehicle years, rather than per billion vehicle miles or per billion occupant miles.

3.2 Visible trends in the data

Before the regression analyses, it useful to look at simple graphs of fatality rates by curb weight. They may reveal basic trends in the data, help with formulating some of the analysis variables, and provide some idea of what the regression coefficients ought to be if they really fit the data.

The fatality and exposure data bases generated in Section 2.6 are subdivided into 14 class intervals of curb weight, bounded at the top by the following percentiles of curb weight: the 2nd, 6th, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, 94th, 98th, and maximum weight. In these 14 groups, the average curb weight, number of fatal crash involvements of any type, total exposure in vehicle registration years, and the rate of fatal involvements per million vehicle years are as follows:

Cumulative Percent	Average Curb Weight	Fatal Crash Involvements	Vehicle Years	Fatal Involvements Per Million Years
2	2,095	1,431	4,989,201	287
6	2,306	2,310	10,329,516	224
10	2,343	2,043	9,151,358	223
20	2,412	6,192	24,639,031	251
30	2,646	6,217	24,416,066	255
40	2,810	5,950	27,232,807	218
50	2,913	4,475	21,749,962	206
60	3,023	4,960	27,007,625	184
70	3,218	4,234	23,104,575	183
80	3,351	4,448	23,321,384	191
90	3,493	4,225	24,424,940	173
94	3,739	1,971	9,989,808	197
98	3,960	1,954	9,858,320	198
100	4,232	967	4,898,794	197

The involvement rate drops from 287 crashes per million years at 2,095 pounds to 184 at 3,023 pounds, but then levels off or even rises slightly as curb weight increases beyond 3,000 pounds. The trend is clear in Figure 3-1, which graphs the natural logarithm of the fatality rate by curb weight. Logarithms are useful in these types of analyses because they often have more linear relationships to the independent variables. (Throughout this study, “log” or “logarithm” means the natural logarithm.)

The most important lesson of Figure 3-1 is that the size-safety effect is not uniform across the range of car weights, and that curb weight should not be entered in the regression analyses as a single, linear variable. In fact, Figure 3-1 suggests it would be a good idea to make curb weight a 2-piece linear variable, with the "bend" somewhere around 3,000 pounds (although other possible formulations, such as quadratic regression, should still be considered at this point).

Figures 3-2 – 3-7 look at fatality rates or fatal-crash rates in the six individual crash modes defined in Section 2.2: rollover, fixed-object, ped/bike/motorcyle, heavy truck, car-to-car, and light truck. In the last three figures, the x-axis is always the curb weight of the "case" car. The "other" vehicle(s), heavy trucks, cars, or light trucks, respectively, can be any weight or any model year. "Fatalities" include all crash fatalities: occupants of the "case" car, occupants of any other vehicles, and non-occupants such as pedestrians or bicyclists.

Every crash mode shows an unequivocal trend of decreasing fatality risk as car weight increases from under 2,000 pounds to about 3,000 pounds or slightly more. From 3,000 pounds onward, the graphs diverge. Rollovers continue to show a fatality reduction, perhaps even as strong as at the lighter weights (it is hard to tell due to fluctuations in the data points). Fixed-object fatalities also appear to show a continued decline, but not as steep as below 3,000 pounds. Collisions with peds/bikes/motorcycles and with heavy trucks actually reverse the downward trend and rise after cars exceed 3,500 pounds. Car-to-car and car-to-light-truck collision rates basically flatten out once the weight of the "case" car goes beyond 3,000 pounds.

These simple analyses based on drivers of all ages essentially jumble two important, separate effects. One is the genuine size-safety effect, intuitively stronger in some crash modes than in others. The second is the interaction of the most important control variable, driver age, with both curb weight and fatality risk. That interaction also varies between crash modes. The next section will demonstrate that fatal-crash rates are always high for young and old drivers, and lowest for drivers in their middle years (25-55). Light 4-door cars have relatively more young drivers and heavy cars have more old drivers. Thus, the driver age factor can potentially work against both light and heavy cars, and in favor of mid-sized cars. However, rollovers are so much "young people's crashes" that the driver age factor works strongly against light cars and hardly at all against heavy cars. In fact, it even benefits heavy cars because they have so few young drivers. Conversely, collisions with heavy trucks are "old people's crashes" to the point of really biasing the rates against heavier cars.[3]

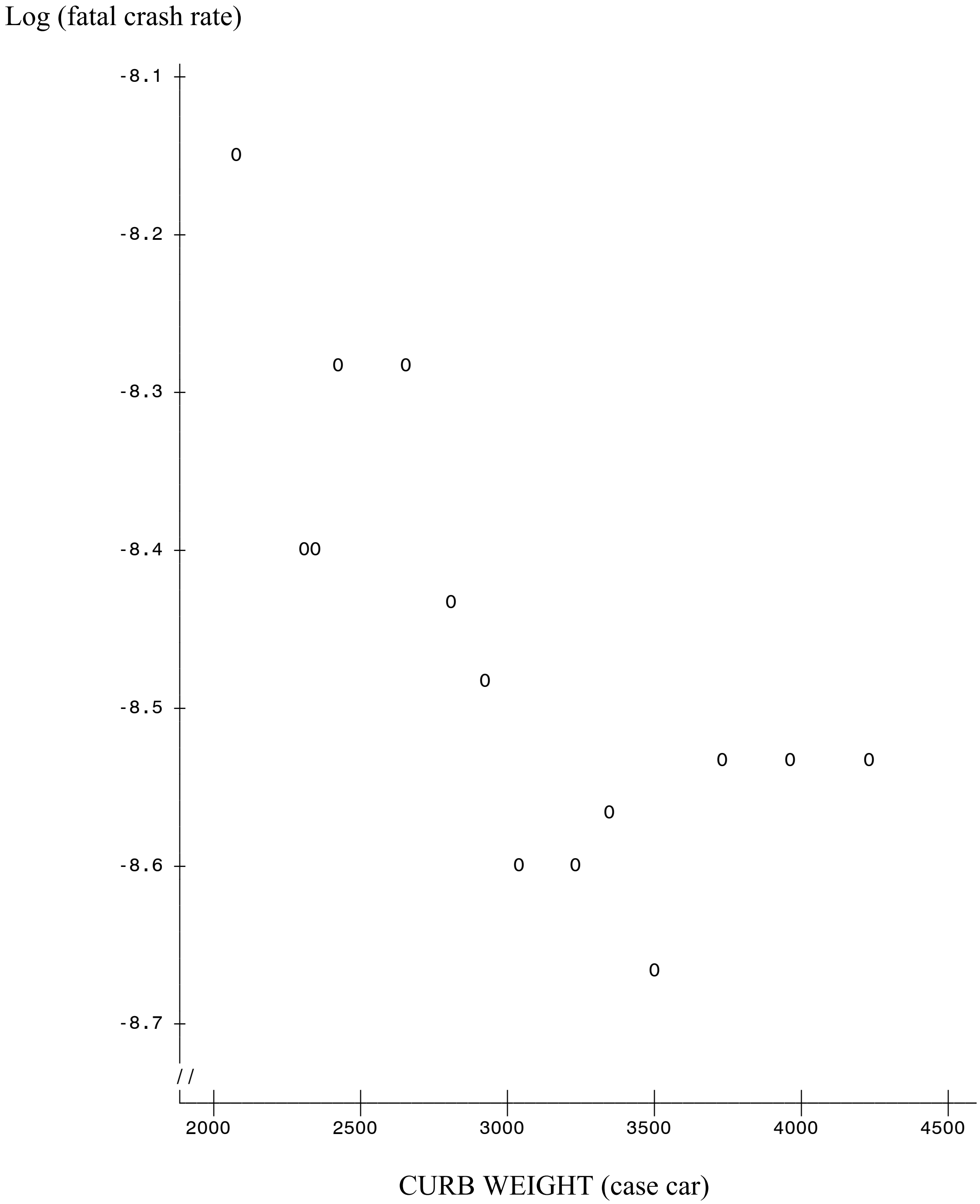
Thus, in rollovers (Figure 3-2), there is a strong weight-safety relationship (although this may be more because heavier cars have wider track width, etc. rather than the direct effect of mass *per se*) and a driver-age effect that works strongly against light cars and even benefits heavy cars. The simple fatality rate per million years drops sharply as car weight increases, from the lightest to the heaviest cars.

[3] See Figure 3-18 later in this chapter.

FIGURE 3-1: ALL CRASH TYPES

LOG(FATAL CRASH INVOLVEMENTS PER YEAR, ANY TYPE) BY CURB WEIGHT*

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)



* Throughout this study, “log” means the natural logarithm.

FIGURE 3-2: ROLLOVERS

LOG(ROLLOVER FATALITIES PER YEAR) BY CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

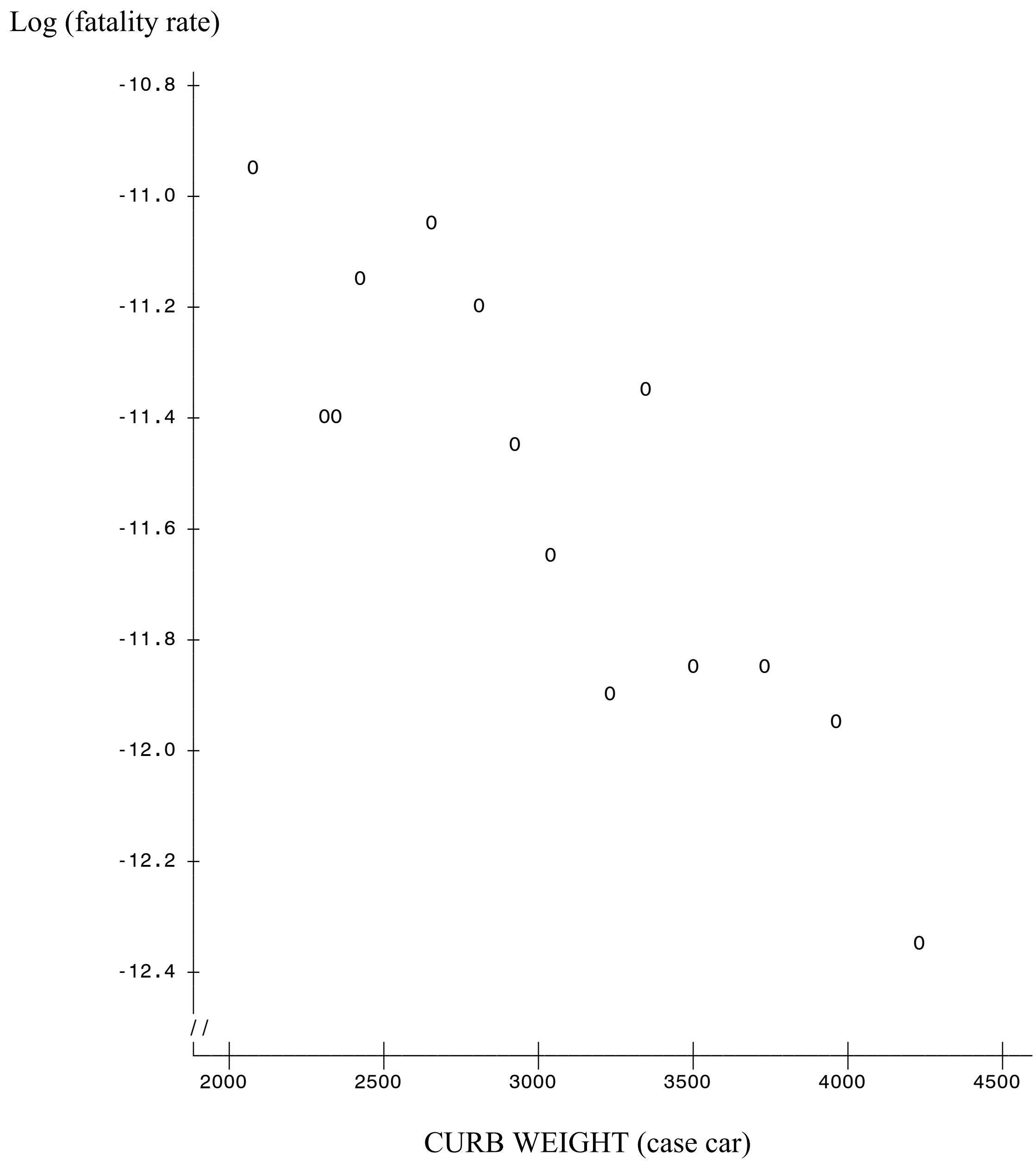


FIGURE 3-3: FIXED-OBJECT COLLISIONS

LOG(FIXED-OBJECT COLLISION FATALITIES PER YEAR) BY CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

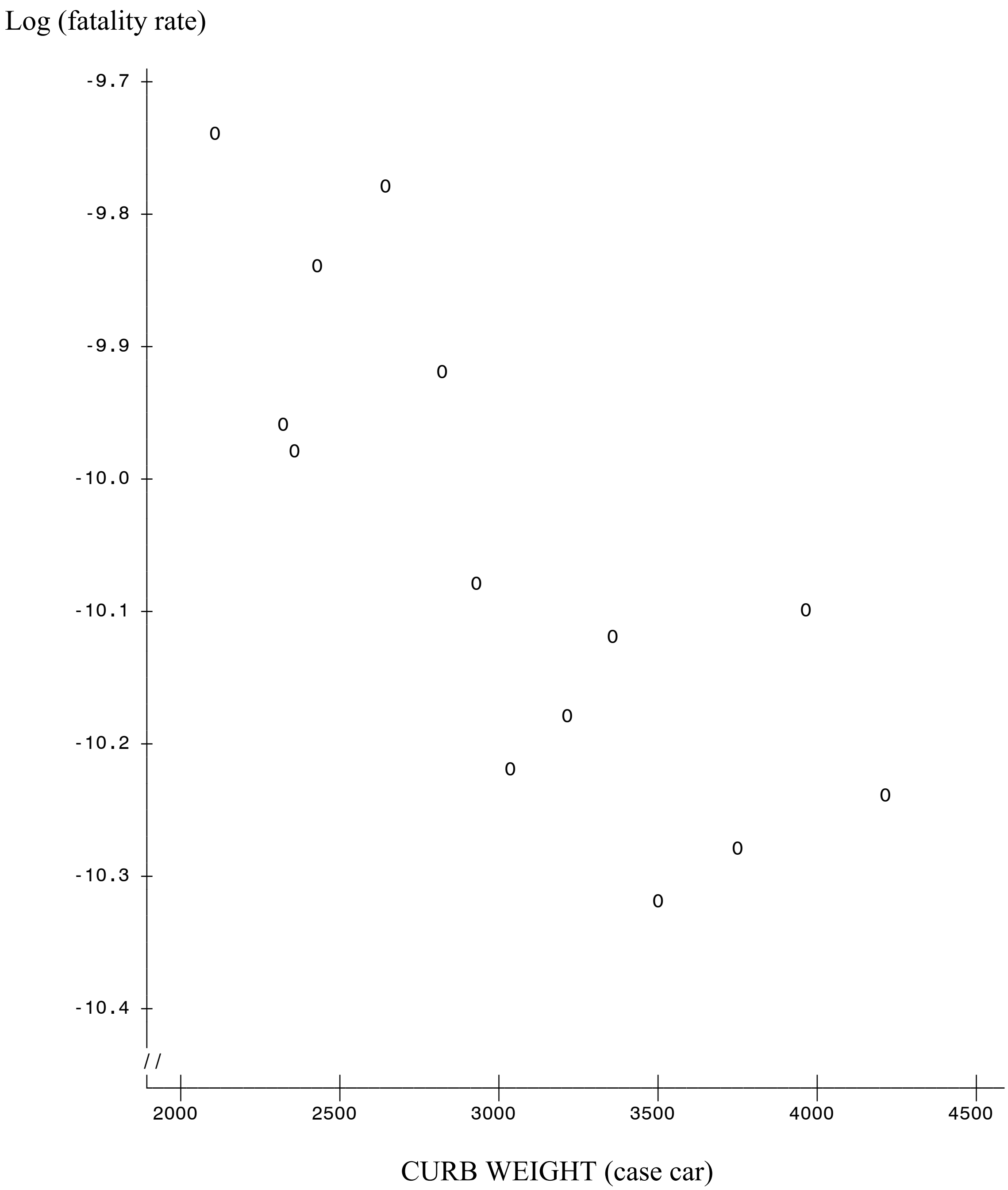


FIGURE 3-4: PEDESTRIANS/BICYCLISTS/MOTORCYCLISTS

LOG(PED/BIKE/MC FATALITIES PER YEAR) BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

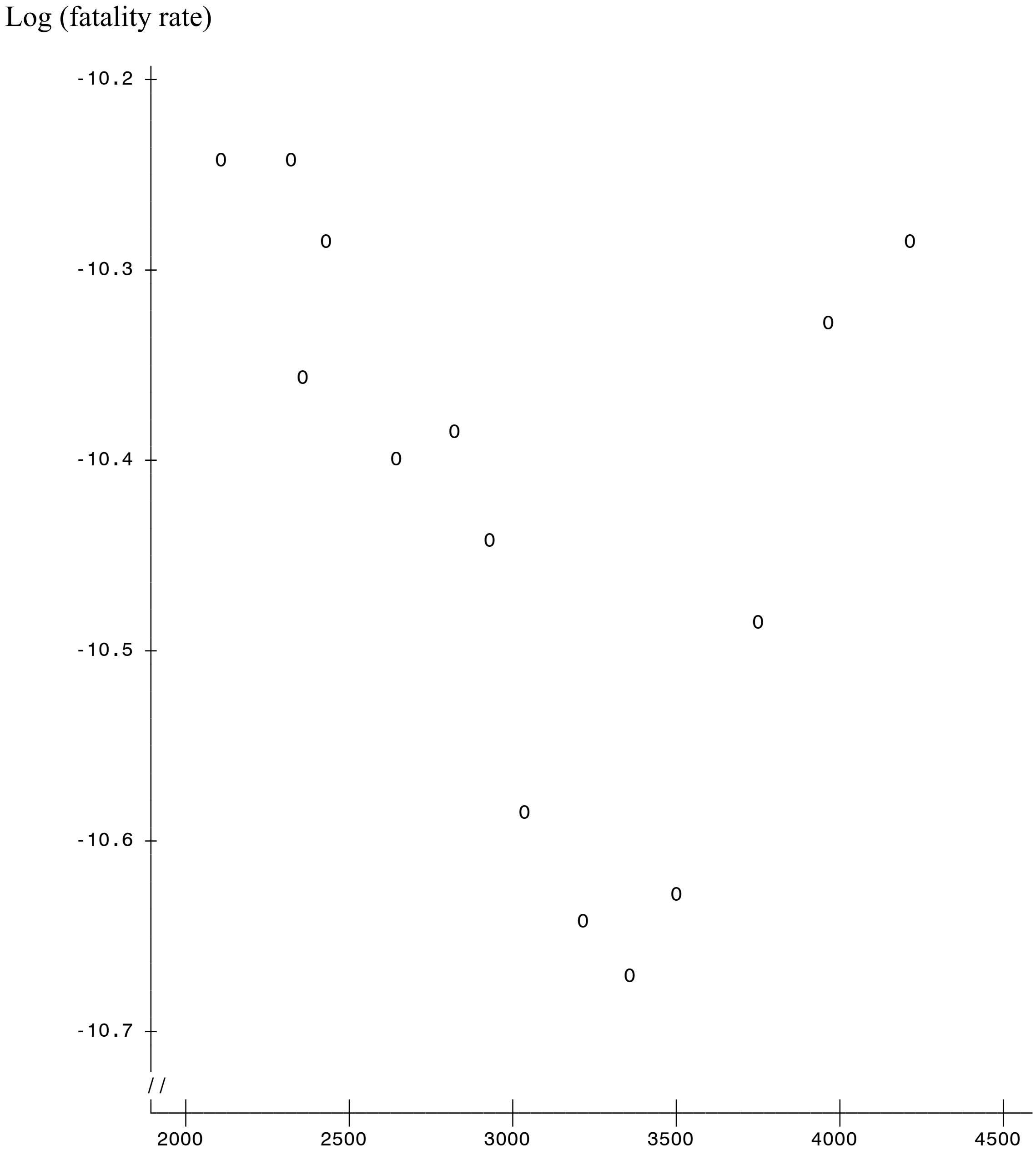


FIGURE 3-5: HEAVY TRUCKS

LOG(FATALITIES PER YEAR IN COLLISIONS WITH HEAVY TRUCKS)
BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

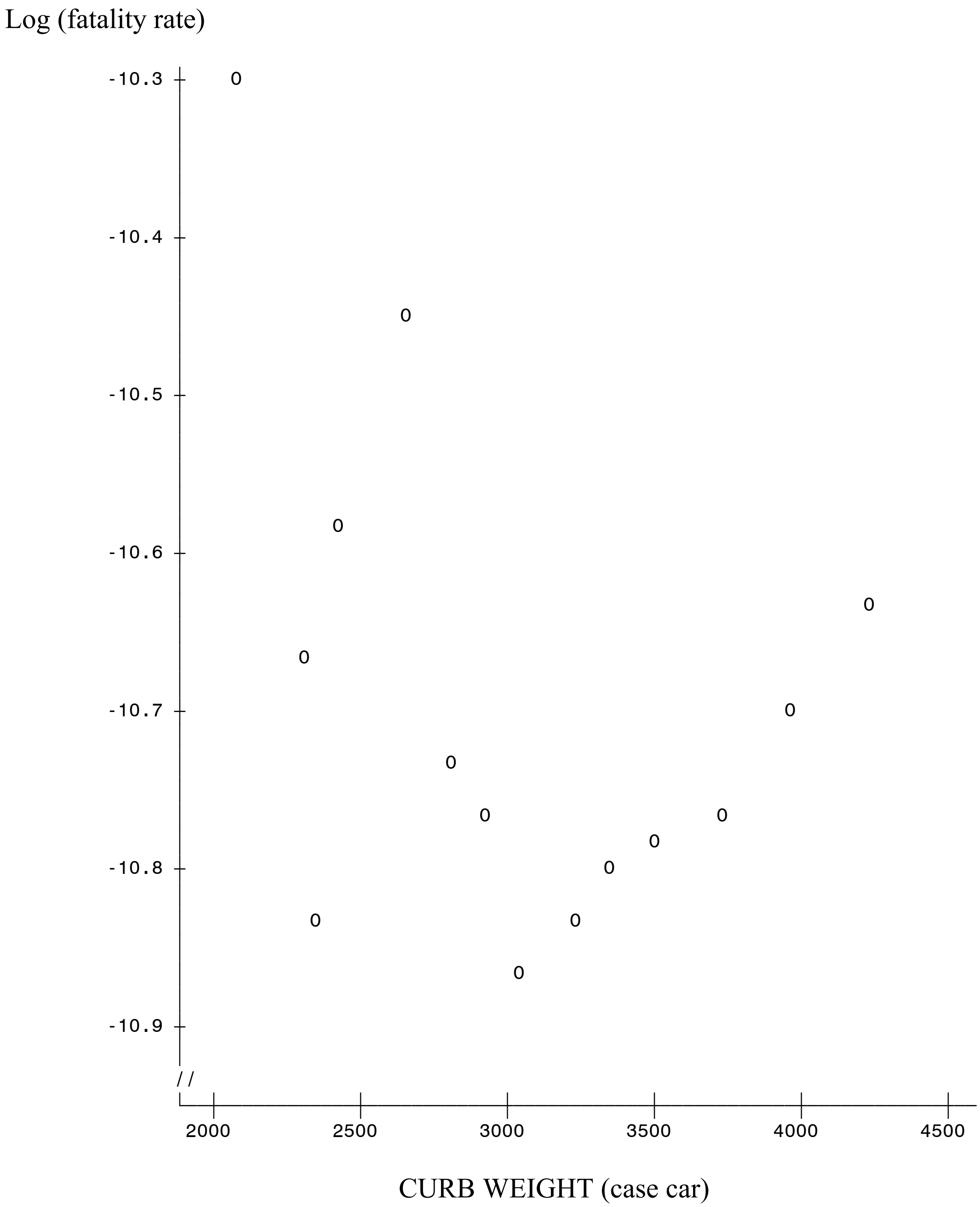


FIGURE 3-6: CAR-TO-CAR COLLISIONS

LOG(FATAL CRASH INVOLVEMENTS PER YEAR WITH ANOTHER CAR(S))
BY THE CASE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

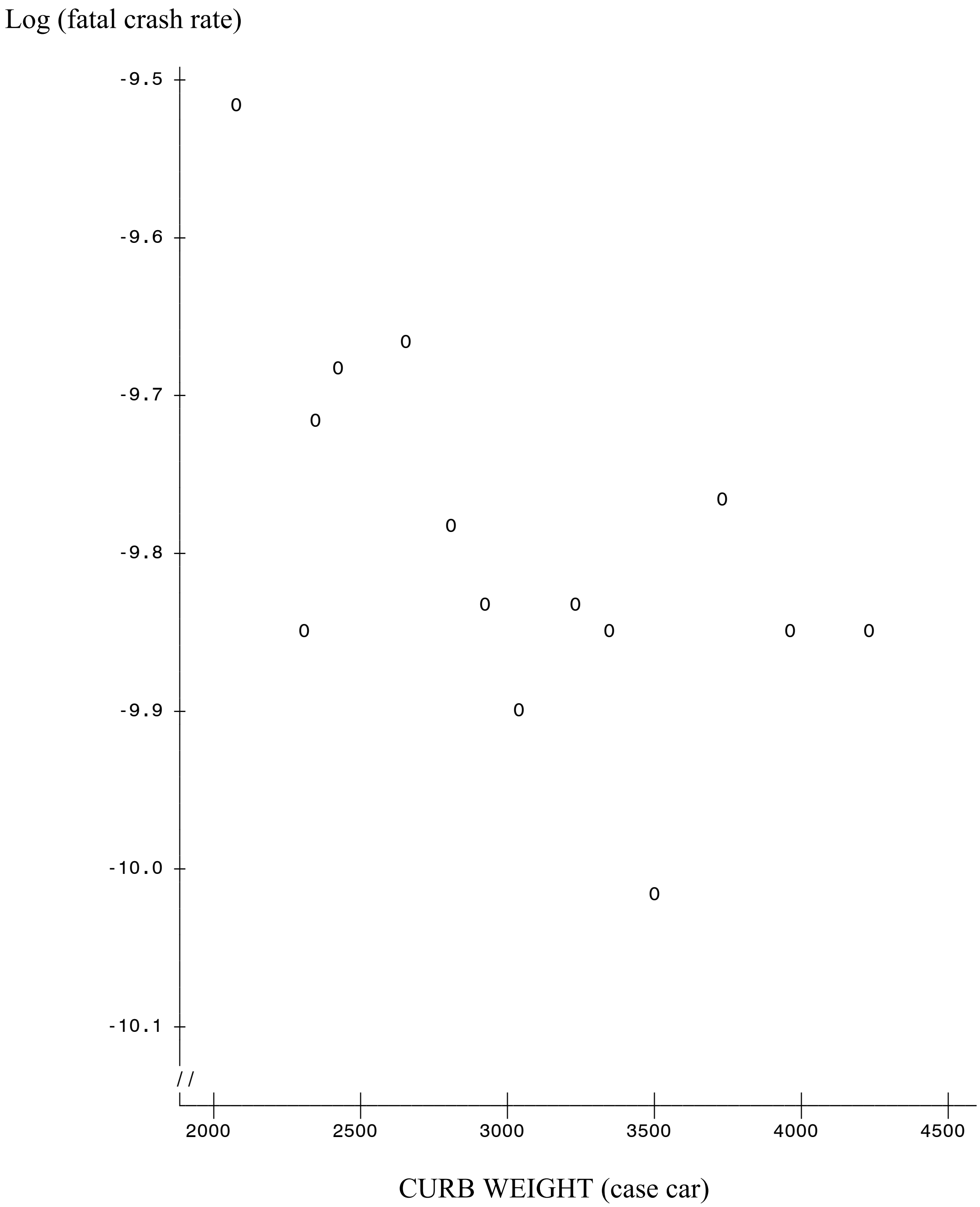
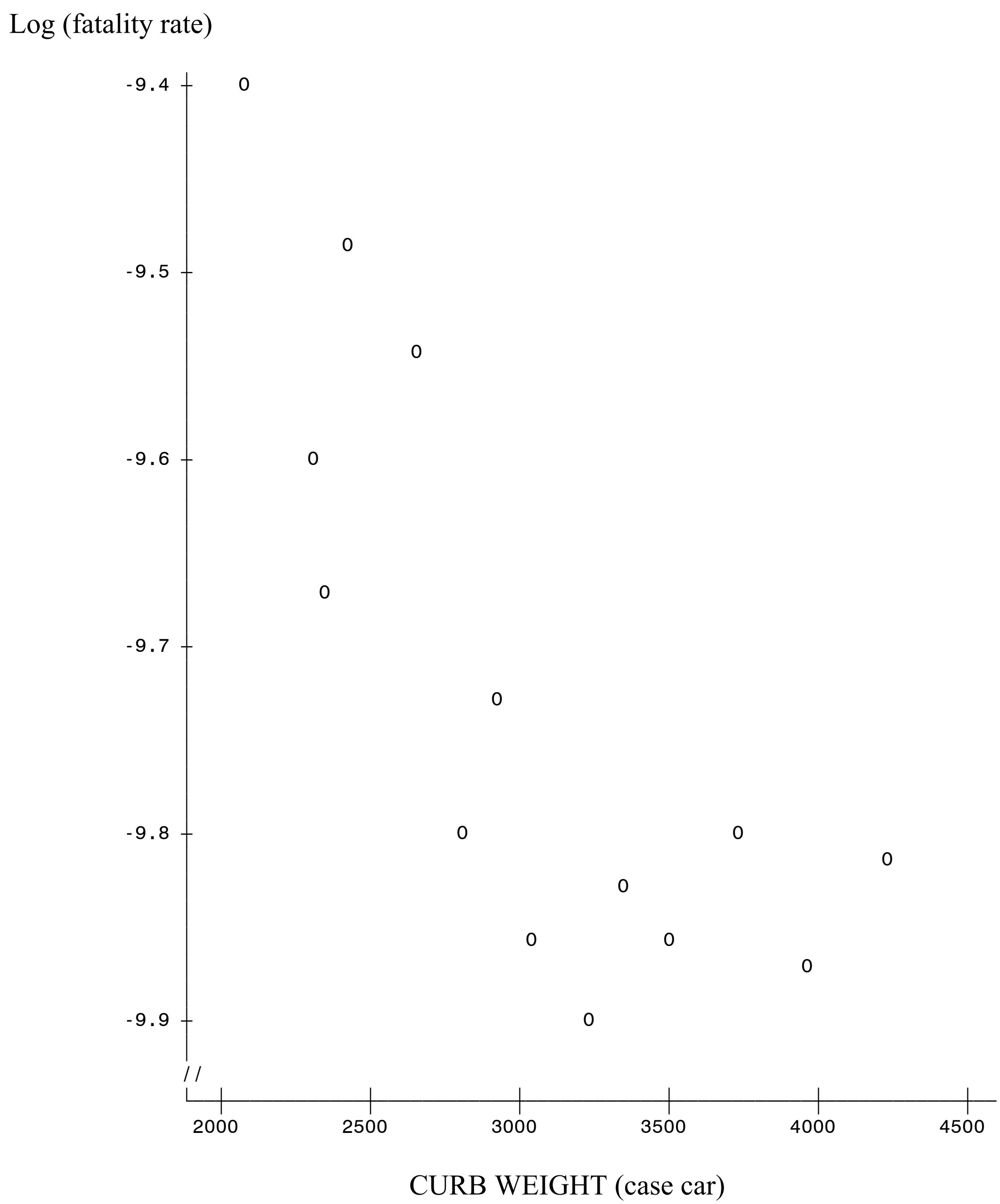


FIGURE 3-7: LIGHT TRUCKS

LOG(FATALITIES PER YEAR IN COLLISIONS WITH LIGHT TRUCKS)
BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)



In collisions with heavy trucks (Figure 3-5), the car weight-safety relationship is also strong, but the tendency of older drivers to get involved in this type of collision is so strong that it overshadows the size-safety effect and produces increasing fatality rates for cars over 3,000 pounds.

In pedestrian collisions, the size-safety effect is presumably weaker than in the other crash modes. The U-shape of the graph in Figure 3-4 may reflect driver age effects, which favor the mid-sized cars relative to light and heavy cars, where young and old drivers, respectively, boost the rates.

In the other three crash modes, fixed-object (Figure 3-3), car-to-car (3-5) and car-to-light truck (3-6), the weight-safety effect may be relatively strong, but not necessarily uniform at all weights. The driver-age effect discriminates about equally against young and old drivers, making the decline steeper up to 3,000 pounds and flattening it out above 3,000. The actual magnitude of the effects can only be determined by more detailed analyses.[4]

The data files assembled in Section 2.6 offer the opportunity to look at fatality rates for subsets of the driving population, specifically for female drivers age 30-49. They have the lowest fatality rate per million registration years of any age-gender group on that database; they also account for a large proportion of the VMT by drivers of 4-door cars (26 percent of 4-door cars weighing less than 3,000 pounds, and 22 percent of 4-door cars weighing 3,000 pounds or more). Figures 3-8 – 3-14 correspond exactly to Figures 3-1 – 3-7, but are limited to fatal crash involvements and vehicle years where the "case" vehicle has a 30-49 year old female driver (but the fatalities in the crash can be any age or gender). However, the data points in Figures 3-8 – 3-14 are based on fewer crash cases, and can be expected to fluctuate more than those in Figures 3-1 – 3-7, because, as stated above, only 24 percent of 4-door-car drivers are 30-49 year old females.

Figure 3-8 (30-49 year old female drivers in all crash modes) has almost the same pattern as Figure 3-1 (all drivers in all crash modes). The rate of fatal crash involvements decreases sharply as curb weight increases from 2,000 to about 3,000 pounds and then essentially levels off. Figure 3-8 demonstrates that the high fatal crash rates in Figure 3-1 were not "merely" a young-driver effect, for even in a group of drivers all about the same age (30-49), the fatality rate is substantially higher in the light cars. Figure 3-8 reemphasizes that the size-safety effect is not uniform across the range of car weights, and that curb weight should not be entered in the regression analyses as a single, linear variable. It suggests a 2-piece linear curb-weigh variable, with the "bend" somewhere around 3,000 pounds.

In rollover crashes, Figure 3-9 demonstrates a strong size-safety trend, and one that persists even at the higher levels of curb weight. The high rollover rates for light (i.e., small and narrow) cars is not merely a young-driver phenomenon, since it appears even within age groups.

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[4] Figures 3-1 and 3-6 graph crash involvement rates, rather than fatality rates, as a hedge against over-weighting cases with multiple fatalities and multiple 1991-99 cars, consistent with the approach in the regression, of car-car fatal crash rates in Section 3.4.

Fatality risk in fixed-object collisions (Figure 3-10) shows a sharp reduction as curb weight increases from 2,000 to about 3,200 pounds. After that, the data points do not indicate a clear trend. The same may be said of ped/bike/motorcycle collisions (Figure 3-11).

Singling out one age/gender group is especially useful for understanding the trend in heavy-truck collisions. Figure 3-12, where the car drivers are 30-49 year old females, shows a strong size-safety effect, including generally low fatality rates for the heavier cars. Gone is the U-shaped pattern from Figure 3-5: among car drivers of all ages, the high fatality rates in this type of crash for the older drivers inflates the rates for the heavier cars, and masks the continuing size-safety effect that emerges in Figure 3-12.

The trends for 30-49 year old female car drivers in collisions with other cars (Figure 3-13) or with light trucks (Figure 3-14) closely resemble the trends for drivers of all ages (Figures 3-6 and 3-7) and assure us that the size-safety effect in the lighter cars is “real” and not just a young-driver phenomenon.

FIGURE 3-8: FEMALE DRIVERS AGE 30-49 IN CASE CARS, ALL CRASH TYPES

LOG(FATAL CRASH INVOLVEMENTS PER YEAR, ANY TYPE) BY CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

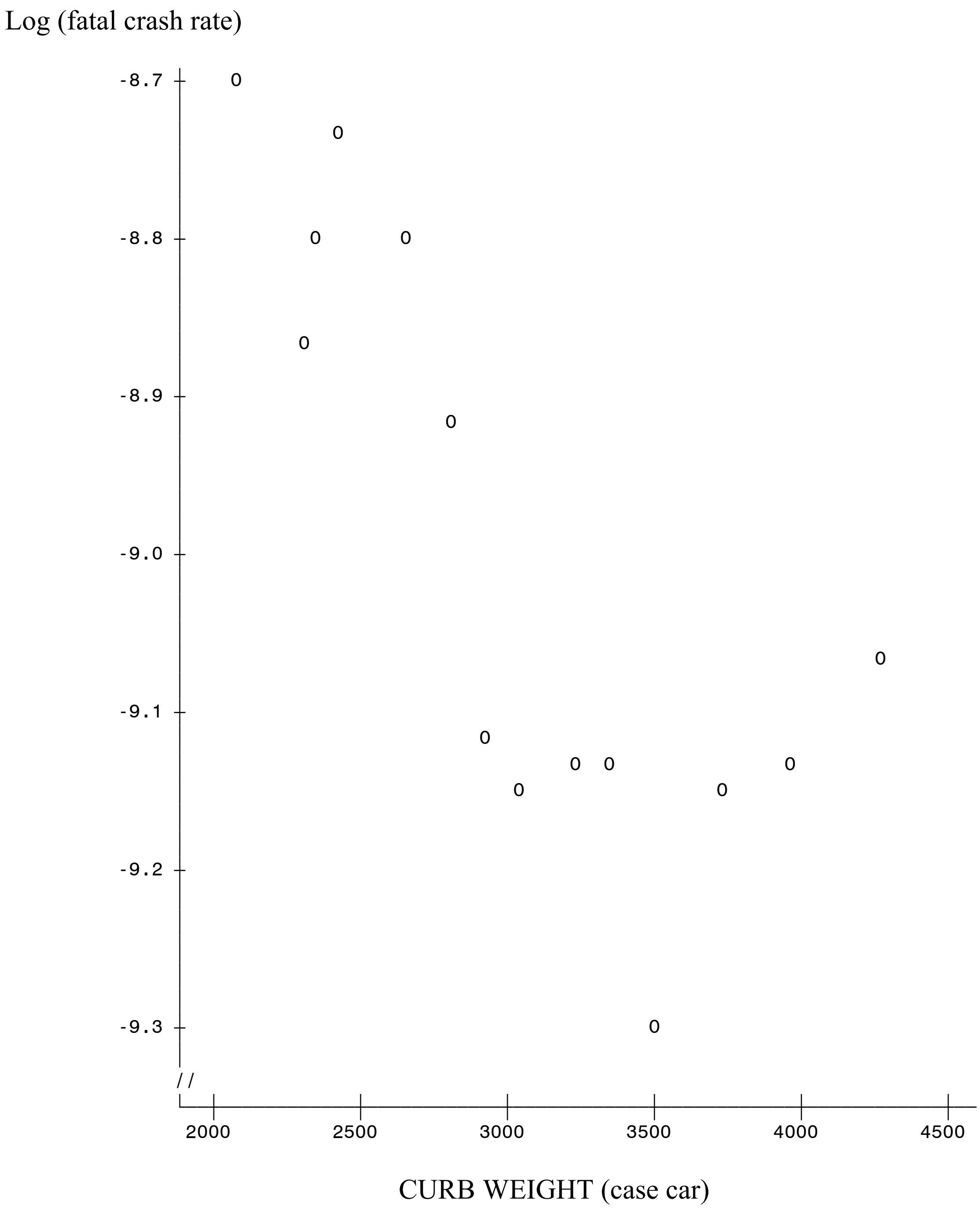


FIGURE 3-9: FEMALE DRIVERS AGE 30-49, ROLLOVER CRASHES

LOG(ROLLOVER FATALITIES PER YEAR) BY CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

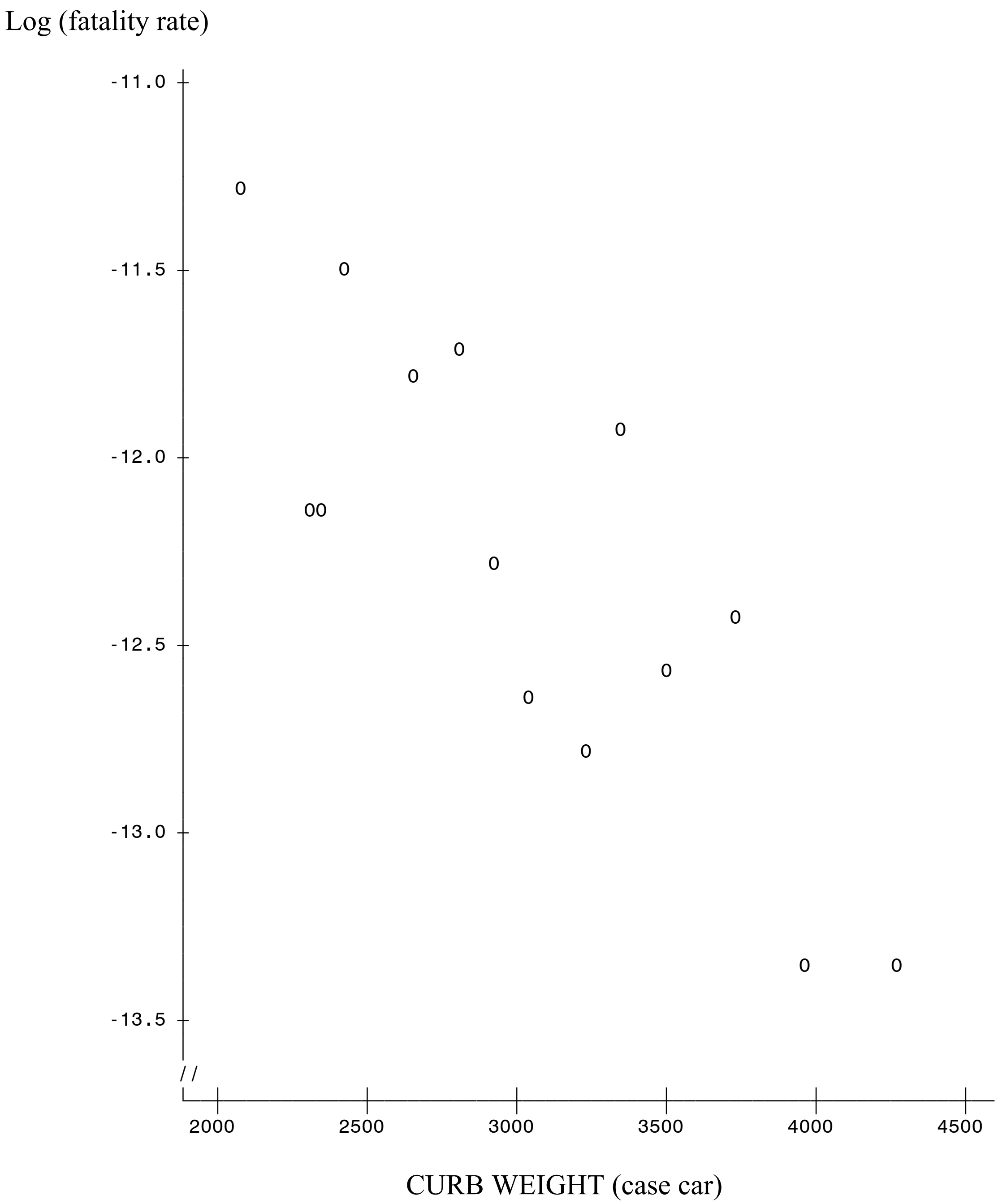


FIGURE 3-10: FEMALE DRIVERS AGE 30-49, FIXED-OBJECT COLLISIONS

LOG(FIXED-OBJECT COLLISION FATALITIES PER YEAR) BY CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

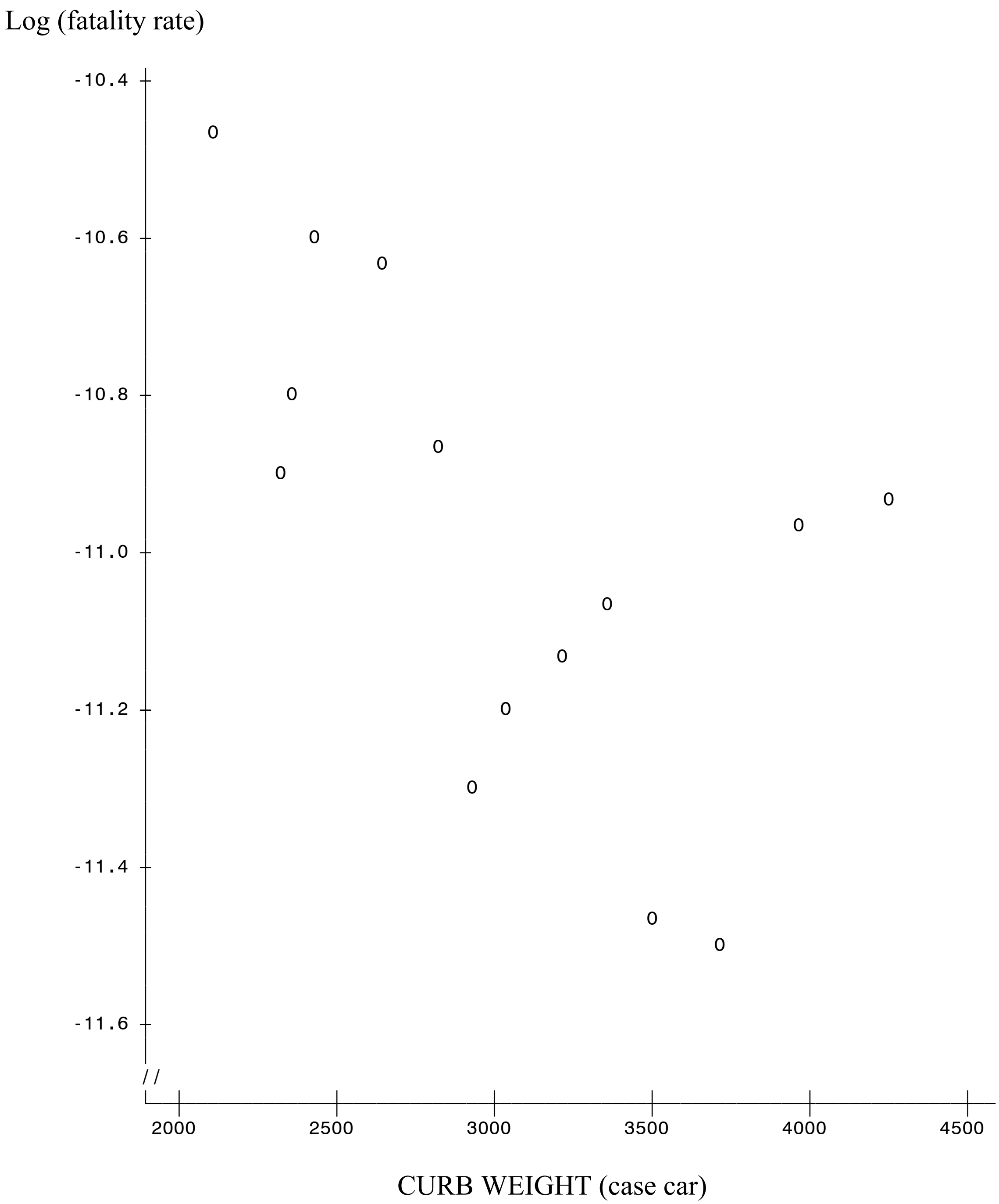


FIGURE 3-11: FEMALE CASE CAR DRIVERS AGE 30-49
COLLISIONS WITH PEDESTRIANS/BICYCLISTS/MOTORCYCLISTS

LOG(PED/BIKE/MC FATALITIES PER YEAR) BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

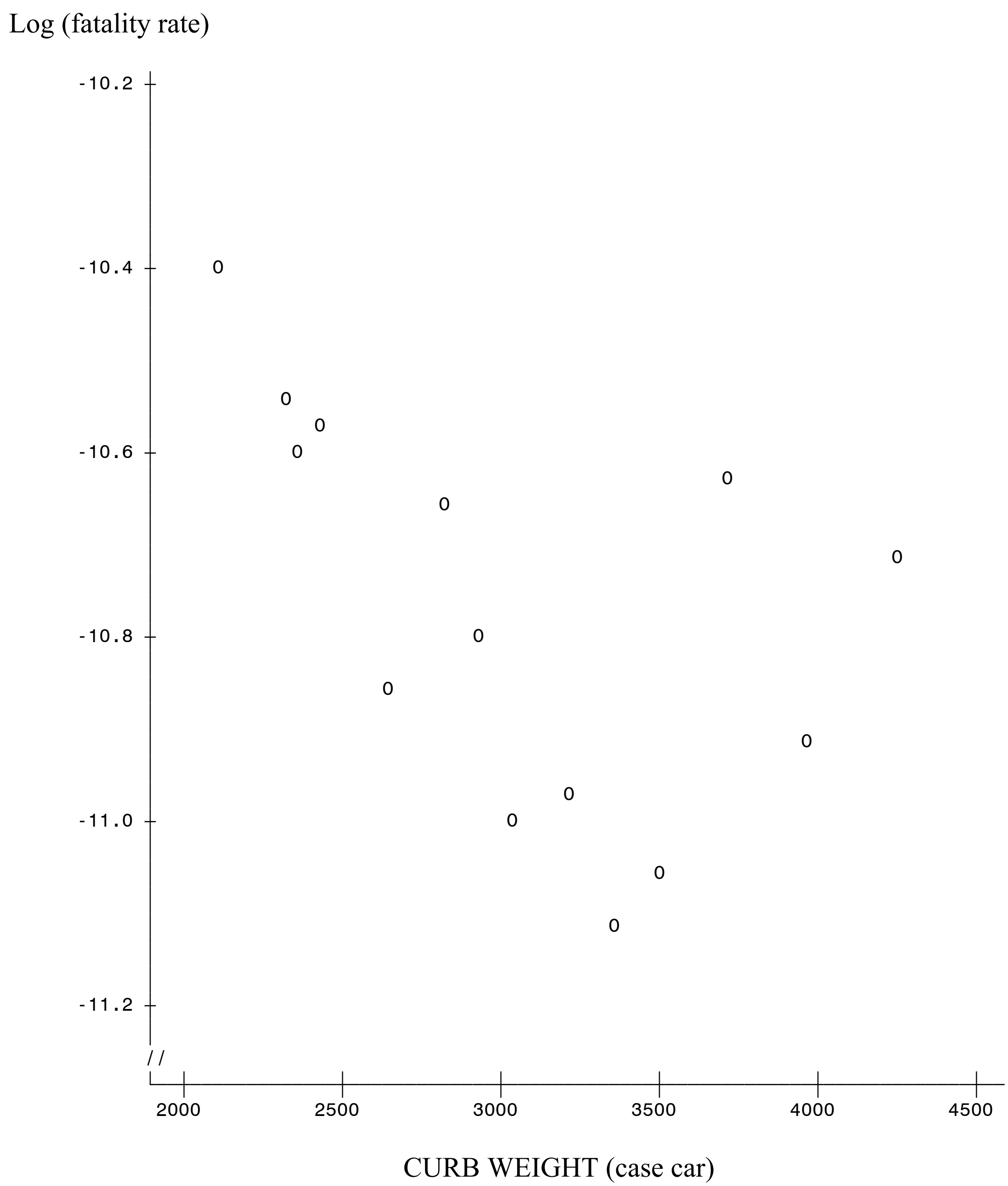


FIGURE 3-12: FEMALE CASE CAR DRIVERS AGE 30-49
COLLISIONS WITH HEAVY TRUCKS

LOG(FATALITIES PER YEAR IN COLLISIONS WITH HEAVY TRUCKS)
BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

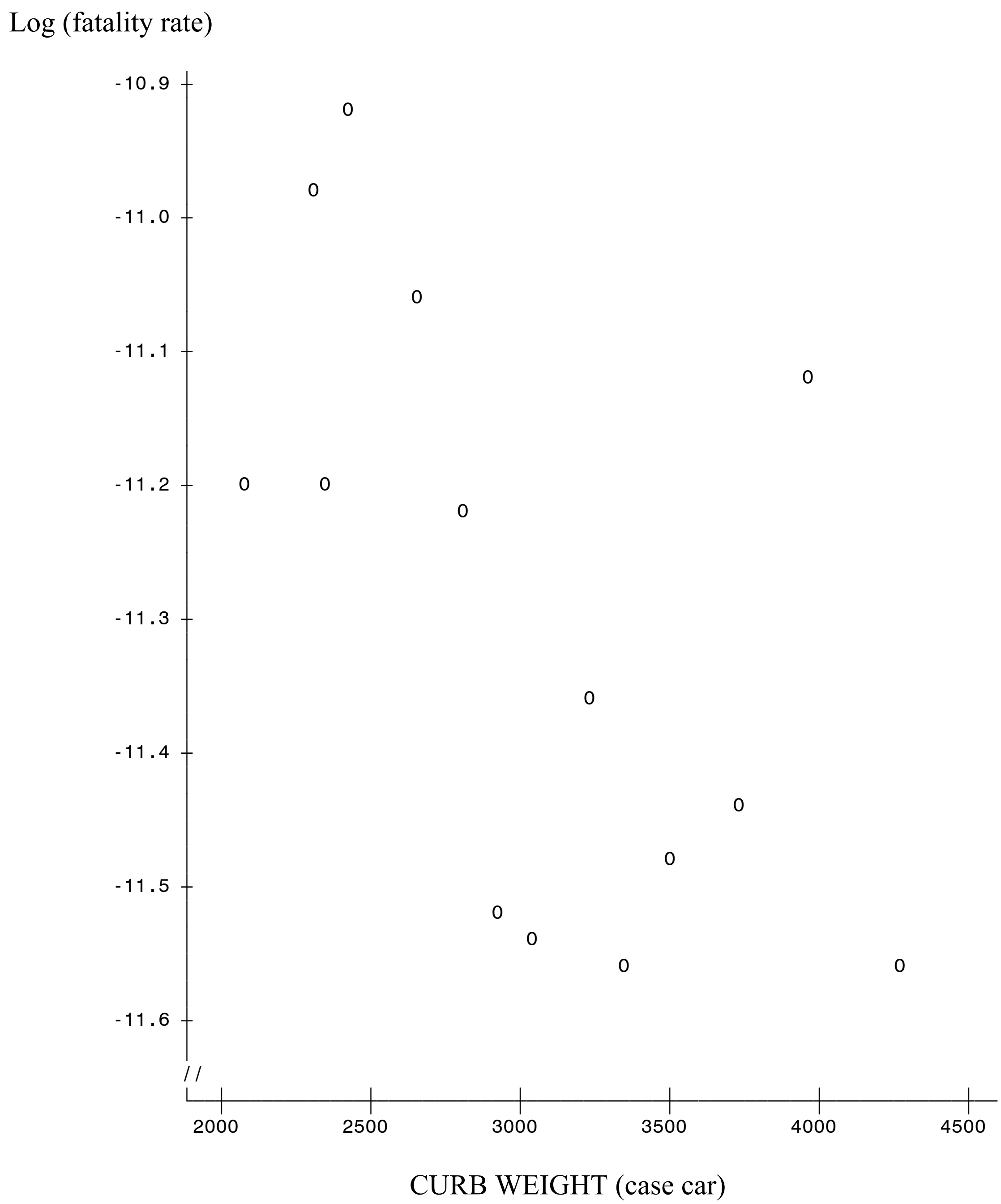


FIGURE 3-13: FEMALE CASE CAR DRIVERS AGE 30-49,
COLLISIONS WITH ANOTHER CAR

LOG(FATAL CRASH INVOLVEMENTS PER YEAR WITH ANOTHER CAR(S))
BY THE CASE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

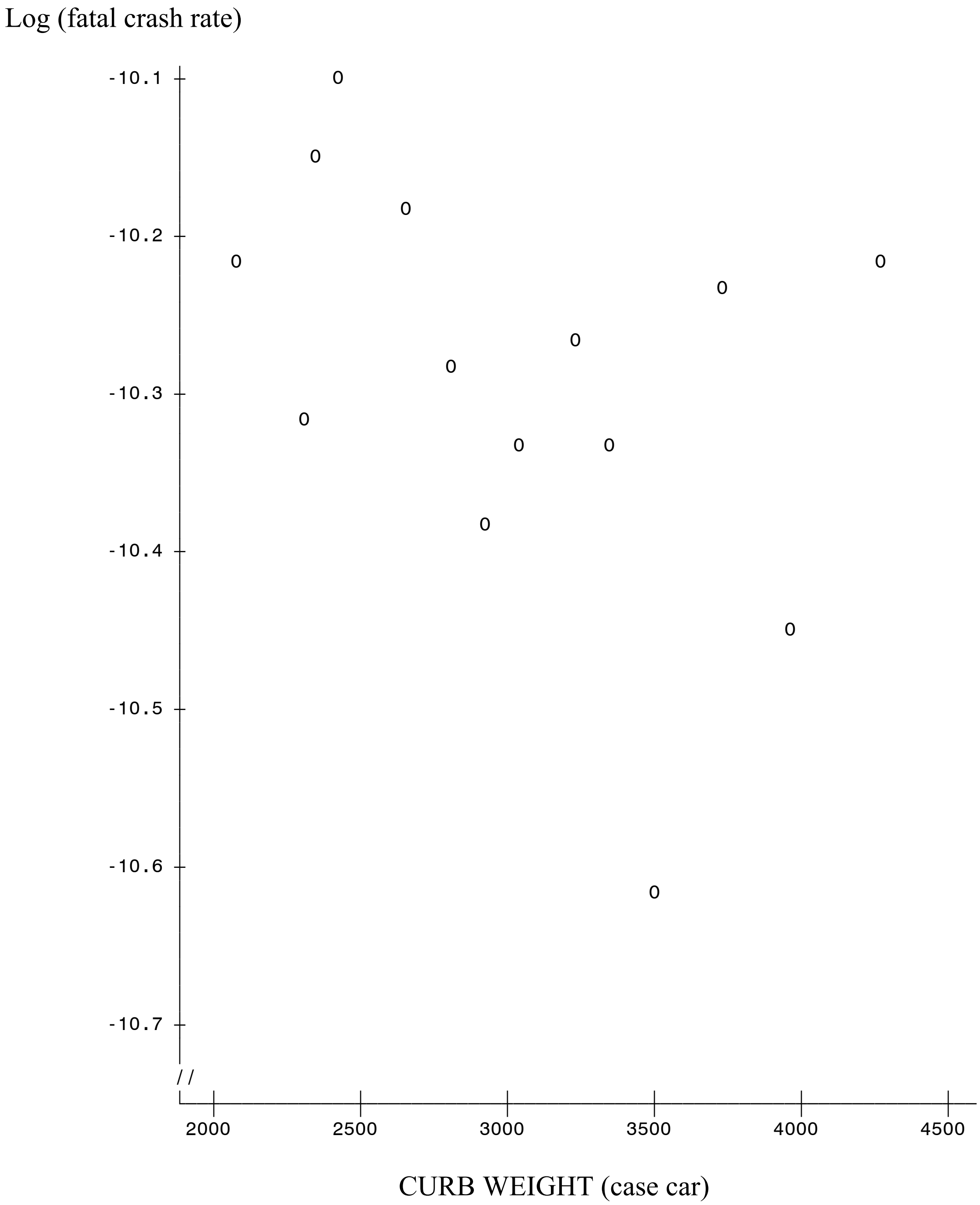
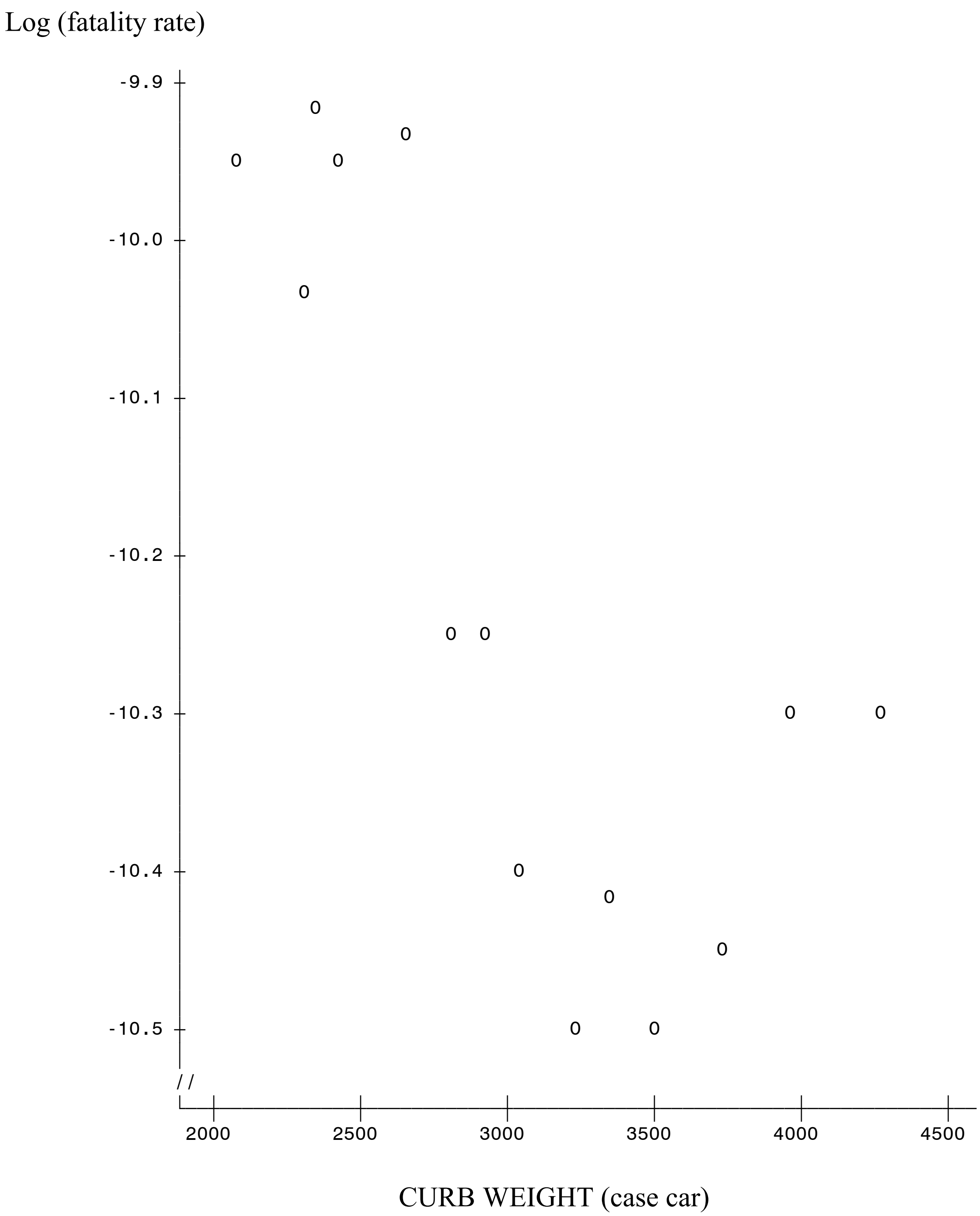


FIGURE 3-14: FEMALE CASE CAR DRIVERS AGE 30-49,
COLLISIONS WITH LIGHT TRUCKS

LOG(FATALITIES PER YEAR IN COLLISIONS WITH LIGHT TRUCKS)
BY THE CAR'S CURB WEIGHT

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)



Figures 3-8 – 3-14 were based on 14 class intervals of curb weight. When the crash cases are subdivided into that many groups, fatality rates may fluctuate too much to show consistent trends. More stable fatality rates can be obtained by considering just four quartile ranges of curb weight. Table 3-1 compares fatality rates of 30-49 year old female drivers of 4-door cars in four curb weight ranges: up to 2,654 pounds, 2,655-2,949, 2,950-3,335 and 3,336+. This table is also limited to cars equipped with air bags, in order to make the results as comparable as possible across weight groups.

The overall rate of fatal crash involvements per million years, for 30-49 year old female drivers, drops from 147 in cars up to 2,654 pounds, to 124 in 2,655-2,949 pound cars, to 105 in 2,950-3,335 pound cars, to 96 in heavier cars. That is a reduction of 35 percent from the lightest to the heaviest quartile. Since the cars in the lightest quartile average 2,374 pounds, and the heaviest, 3,603 pounds, that averages out to a 3.4 percent reduction per 100-pound increase. However, the downward trend is clearly stronger than average in the 2,000-3,000 pound range, then flattens out to some extent beyond 3,000 pounds.

The next two columns in the upper section of Table 3-1 contrast the occupant fatalities in the case vehicle to the other fatalities in the crashes: occupants of other vehicles and pedestrians/ bicyclists. The fatality rate for case vehicle occupants drops from 100 to 45, an especially strong trend (with most of the drop in the lighter weight groups). However, the fatality rate for the "other" vehicle and pedestrians stays about the same, whatever the weight of the "case" car.

The middle section of Table 3-1 concentrates on car-to-car collisions. The crash involvement rate drops from 36 in the lightest cars to 27 in the heaviest, just over 2 percent per 100 pounds. There is a dramatic fatality reduction from 22 to 6 in the case car.

The last section of Table 3-1 shows fatality rates in five other types of crashes. Female drivers age 30-49 have few rollover crashes even in small cars, and very few in large cars. The trend is downwards, too, in the other crash types, most strongly in collisions with fixed objects and light trucks, weakest – but still present – in pedestrian crashes. In all cases, the drop is large below 3,000 pounds, then levels off above 3,000.

Similar tabulations of fatality rates for other age groups of female drivers (14-29, 50-69, 70+), and for four age groups of male drivers all show strong downward trends as vehicle weight increases. Of course, the other age and gender groups all have higher absolute fatal-crash rates than 30-49 year old female drivers – in the case of young males and 70+ year old drivers of either gender, much higher rates.

TABLE 3-1

FATAL CRASHES AND FATALITIES PER MILLION REGISTRATION YEARS
FEMALE DRIVERS AGE 30-49
4-DOOR CARS WITH AIR BAGS, MY 1991-99 IN CY 1995-2000

All Types of Crashes – Rates per Million Years

Car Weight Range	Fatal Crash Involvements	Occupant Fatalities	Fatalities in Other Vehicle & Non-Occupants
Up to 2,654 pounds	147	100	69
2,655-2,949 pounds	124	71	73
2,950-3,335 pounds	105	51	70
3,336 pounds or more	96	45	67

Car-to-Car Crashes – Rates per Million Years

Car Weight Range	Fatal Crash Involvements	Occupant Fatalities	Fatalities in the Other Car
Up to 2,654 pounds	36	22	22
2,655-2,949 pounds	33	14	26
2,950-3,335 pounds	34	10	30
3,336 pounds or more	27	6	25

Other Crashes – Crash Fatalities per Million Years – By Crash Type

Car Weight Range	Rollover	Fixed Object	Ped/Bike Motorcycle	Big Truck	Light Truck
Up to 2,654 pounds	8	22	24	15	45
2,655-2,949 pounds	7	16	21	12	36
2,950-3,335 pounds	4	13	16	10	28
3,336 pounds or more	3	13	18	10	28

Table 3-1 makes two important points. First, this is pretty much "it," except for the fine-tuning. Table 3-1 compares fatality rates for drivers of the same age and gender in cars of different curb weights. In other words, it presents fatality rates by curb weight, already controlling for the two most important factors, age and gender. The regression analyses are going to add some more control variables, and use the data more efficiently, and directly quantify the fatality reduction per 100-pound increase, but they should largely follow the trends in Table 3-1. If the regression equations do not fit the trends in Table 3-1, there's something wrong with those equations. (Specifically, NHTSA's 1997 report that says car-to-car and ped/bike/motorcycle fatalities *increase* as curb weight increases[5] goes against the clear trend of these data.)

Second, these results look pretty "real." In other words, the fatality reductions in the heavier cars to a large extent reflect real vehicle safety differences rather than merely a tendency of notoriously poor drivers to pick small cars. Women 30-49 years old driving late-model (air bag equipped) 4-door cars are usually sober and prudent drivers. These aren't sports cars! Whether the car is light or heavy, very few of these women are drunk, or trying to impress their friends how fast they can go around a curve.[6] There could conceivably be a tendency for the exceptionally careful and defensive drivers to pick the larger (and more expensive) cars, but there certainly is no obvious concentration of bad drivers in the lighter cars.

3.3 Screening the control variables; defining the age/gender variables

Here are the 15 potential control variables on the fatality and exposure files created in Section 2.6:

Driver age	Male driver?	Driver belted?
At night?	Rural?	Speed limit 55+?
Wet road?	Snowy/icy road?	Calendar year
Vehicle age	High-fatality State?	Driver air bag?
ABS (4-wheel)?	Rear wheel antilock?	All-wheel drive?

"Rear wheel antilock" may be dropped from the list immediately, since it was never available on 1991-99 passenger cars, and "all-wheel drive" is also of little value as a control variable, since only 0.7 percent of 1991-99 passenger cars were equipped with all-wheel or 4-wheel drive.

Control variables may also be discarded if they have no association with the dependent variable, fatality risk per million years, and/or the key independent variable, curb weight.[7] Under those circumstances they would not be a source of confounding or bias. Each of the remaining 13

[5] Kahane, C.J., *Relationships between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 808 570, Washington, 1997, p. vi.
[6] In the analysis of driving behaviors (Section 3.6), women have much lower rates of antisocial behaviors than men, including 60 percent lower incidence of drunk driving or DWI history than male drivers.
[7] Reinfurt, D.W., Silva, C.Z., and Hochberg, Y., *A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes [Interim Report]*, NHTSA Technical Report No. DOT HS 801 833, Washington, 1976, pp. 29-31.

potential control variables ought to have some association with fatality risk, at least in some crash modes. On the other hand, not all of them are correlated with curb weight. Table 3-2 shows the correlation of the control variables with curb weight, calculated by one or possibly two methods.

In the first method, the induced-exposure crashes are subdivided into 28 class intervals of curb weight, bounded at the top by the following percentiles of curb weight: the 1st, 2nd, 4th, 6th, 8th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th, 55th, 60th, 65th, 70th, 75th, 80th, 85th, 90th, 92nd, 94th, 96th, 98th, 99th, and maximum weight.[8] In each of these 28 groups, the weighted (by vehicle years) average is computed for curb weight and the 13 control variables. Those average values are linear, continuous variables. For example, the original control variable "driver air bag" can only have values 0 or 1, but its average value for a class interval of curb weight can be anywhere from 0 to 1. The product-moment correlation r of curb weight with each of the control variables can be computed across the 28 class intervals (weighted by total vehicle years in each class interval) and tested for significance, as shown in Table 3-2.

Driver age, driver gender, rural, speed limit 55, driver air bag, and ABS all have a statistically significant ($p < .05$), positive correlation with curb weight. In other words, heavier cars have relatively older drivers, more male drivers, more use on rural and high-speed roads, more air bags and more ABS than light cars. The preference of older drivers for large cars, and young drivers for small cars is well known, and it is the most important factor to control, because fatality rates differ greatly by driver age. Drivers of 4-door cars are, in general, not too young, but average driver age varies from about 35 in under-2,500 pound cars to 55 in cars weighing over 3,500 pounds.

The correlation ($r = .93$) of driver age and vehicle weight across the 28 class intervals, at first glance, seems too high to allow successful regressions with driver age and car weight as independent variables. Therefore, it is important to note that the size-safety regressions in this study (unlike the 1997 report[9]) are on a database where each induced-exposure crash is a separate unit. The right side of Table 3-2 shows that, across the disaggregate database of 976,610 induced-exposure cases, the correlation of age with curb weight is just .313. While statistically significant, this is low enough to allow confident use of both variables in a regression.

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[8] The class intervals at the ends were chosen to contain fewer percentiles than in the middle because: (1) curb weight has more spread at the low and high percentiles; (2) the low and high percentiles are especially important in computing correlation coefficients.

[9] Kahane (1997), pp. 71-80.

TABLE 3-2

CORRELATION OF POTENTIAL CONTROL VARIABLES WITH CURB WEIGHT

Control Variable	Across 28 Class Intervals Of Curb Weight		Across 976,610 Induced-Exposure Crashes	
	r	p <	r	p <
Driver age	.930	.0001	.313	.0001
Driver male?	.962	.0001		
Driver belted?	.043	.83		
At night?	- .829	.0001		
Rural?	.410	.03		
Speed limit 55+?	.818	.0001		
Wet road?	- .718	.0001		
Snowy/icy road?	- .576	.0013		
Calendar year	.205	.30		
Vehicle age	- .086	.66		
High-fatality State?	.348	.070		
Driver air bag?	.605	.0006		
ABS (4-wheel)?	.918	.0001		

The exceptionally strong (r = .96) association of driver gender and car weight reflects several factors.[10] Most directly, men are taller and heavier than women, and need roomier vehicles to feel comfortable. Indirect factors could include trip purpose (women drivers = short, urban trips = small car convenience), income (men can afford bigger cars?), and driver age (in the older generation: men do the driving + big cars). The percentage of drivers that is female ranges from 63 percent in under-2,500 pound cars down to 35 percent in cars weighing over 3,800 pounds. Since female drivers have lower fatal-crash involvement rates, this factor actually makes small cars appear safer than they really are.

The overrepresentation of heavier cars in rural areas and on high-speed roads is no surprise, and reflects trip purpose: use the small car for errands and shopping, the big car for vacations and long business trips.

Manufacturers often installed air bags and ABS earlier in large (i.e., expensive) cars. While air bags were extended to all cars by the mid-1990's, ABS continues to be more often standard, or more popular as an option, on the larger (i.e., more expensive) cars: only about 10 percent of under-2,500 pound cars, but over 90 percent of 3,800 + pound cars have ABS . To the extent that air bags and/or ABS are effective in certain crash modes, this equipment increases the disparity of large- and small-car fatality rates beyond the true size-safety effect, and the analyses must control for it.

A significant negative correlation in Table 3-2 implies that large cars are driven relatively less at night. Driver age and trip purpose appear to be involved. Older drivers (larger cars) may avoid driving at night. Younger drivers are more likely to go at night. Since fatality risk per mile of travel is much higher at night than by day, it is important to keep this as a control variable, even if it partly overlaps with driver age.

Table 3-2 also implies that large cars are driven less on wet and snowy/icy roads. There is no obvious, direct reason why that should be so (if anything, wouldn't some people feel more secure in a big car during a storm?). Two indirect factors explain it: driver age and ABS. Older drivers (larger cars) often avoid driving in bad weather. ABS reduces crash involvements on wet roads, including induced-exposure involvements, and it is more common on large cars.[11] In fact, regressions of the proportion of crashes on wet [snowy/icy] roads by curb weight, driver age and ABS suggest that driver age and ABS fully explain that proportion, while curb weight has little or no effect on it.[12] These road conditions may be dropped from the list of control variables because their association with curb weight is explained by the other control variables, and also

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[10] Here, too, the use of disaggregate data in the regressions, where each induced-exposure crash is a separate unit, allows driver gender to be included as an independent variable without worrying about its strong relationship (at the aggregate level) with curb weight.

[11] Kahane, C.J., *Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars*, NHTSA Technical Report No. DOT HS 808 206, Washington, 1994, pp. 52-57.

[12] These are aggregate weighted linear regressions, with the induced-exposure crashes split up into 111 subgroups based on class intervals of curb weight, driver age and percent of cars with ABS. The dependent variables in one regression is the percent of crashes on wet roads, in the other, on snowy/icy roads. The coefficients for driver age and ABS are always significant (t ranges from 2.96 to 7.28), for curb weight, never (t = .04 and .01, respectively).

because the fatality risk per mile of travel is not that greatly different in dry and adverse road conditions.

The remaining four control variables – driver belt use, calendar year, vehicle age, and high-fatality State – are unnecessary because they do not have a statistically significant interaction with curb weight. Belt use (as reported in the induced-exposure crashes) is the same in small and large cars. The overreporting of belt use in crash data files also diminishes its value as a control variable. The average weight of passenger cars changed little during 1991-99 – thus, no correlation of curb weight with either calendar year or vehicle age. The States with high fatality rates had passenger cars the same size, on the average, as the States with low fatality rates.

Thus, seven control variables that must be included in the analyses of passenger cars:

Driver age	Driver gender	At night?
Rural?	Speed limit 55+?	Driver air bag?
ABS (4-wheel)?		

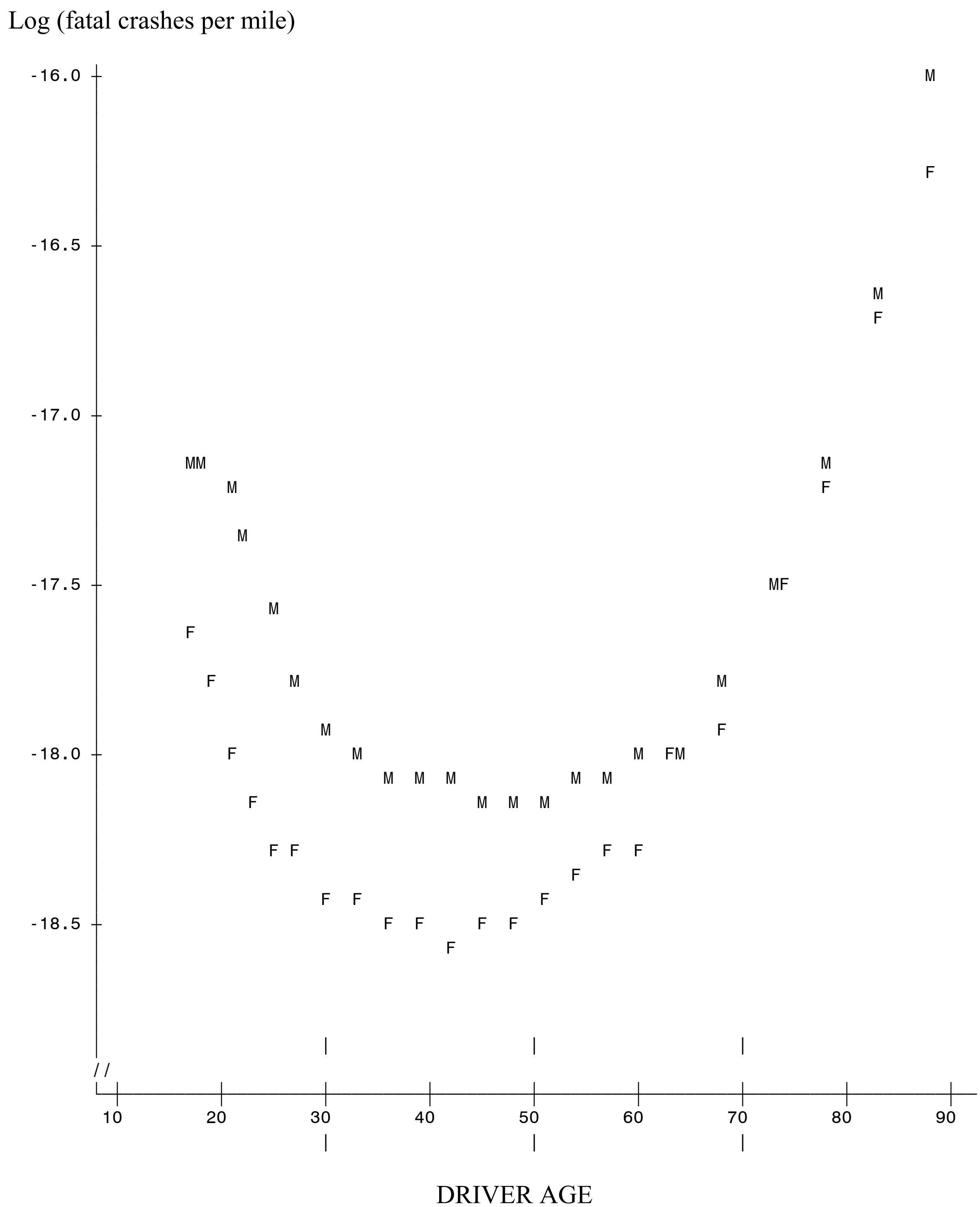
Special care is needed in formulating the independent variables that will be used to describe the driver's age and gender. The effect of driver age is nonlinear, with high fatality rates per mile for young and old drivers, and lower rates in between. The effect of gender is contingent on driver age: the fatal-crash reduction for women, relative to men of the same age, diminishes as both get older.

Figure 3-15 shows the fatal crash involvement rate per mile by driver-age cohorts for males (M) and females (F). (Each induced-exposure crash involvement has a driver of known age and gender, and corresponds to a specified number of vehicle miles, as defined in Section 2.6. The number of fatal crash involvements for a given driver age/gender is divided by the number of miles for that age/gender.)

For men, the rate drops sharply from age 16 to about 30, flattens out or drops slightly from 30 to 50, begins to rise slowly at about 50, at an increasing rate in the 60's, and escalates rapidly from age 70 onward. For women, the fatality rate is initially much lower than for men, drops sharply through the teens and 20's, flattens out with perhaps a slight reduction from 30 to 50 (the safest group of drivers on the road), begins climbing steadily at 50 and catches up to men within 10-20 years, and matches the high rates for men from 70 onward. An 80-year-old driver of either gender has about 7 times the fatal crash rate per mile of a 30-49 year old woman.

FIGURE 3-15: FATAL CRASHES PER MILE BY DRIVER AGE AND GENDER
ALL CRASH TYPES

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)



The net age/gender effects are a composite of several trends:

- Fatality risk from similar physical insults increases steadily by about 2 percent a year, from age 20 (or possibly even younger) onwards. Females have up to 30 percent higher fatality risk than males of the same age, given similar physical insults.[13]
- Young drivers are inexperienced with their vehicles' limits of performance, and are more prone to running off the road.[14]
- Older drivers have increasing difficulty judging speed and distance and are more prone to hitting other vehicles (and also pedestrians, and running off the road).
- Younger and, especially, male drivers are more "aggressive" and less "defensive." They accept risk in order to save time (or avoid annoying delay), on a regular basis, even when they are alert and sober: moving first at a 4-way stop sign, following more closely, taking curves more quickly, taking more chances to pass or change lanes, moving as soon as the light turns green, etc. Figure 3-15 suggests that males' extra "edge" of aggression subsides from age 50 to 65.

Young and, especially, male drivers are more likely to drink and drive, or engage in other antisocial driving behavior that can result in fatal crashes. Drunk driving peaks among young adults (age 21-34), not teenagers.[15] Most of these problems wane after age 40.

In summary, young drivers have many fatal crashes despite their physical resilience, while old drivers have many fatalities to a large extent because of their frailty.

These diverse and important effects need to be formulated as a set of simple variables for use in regression analyses. It is crucial to have enough variables to allow for flexibility in the formulation, since the effects can differ considerably by crash mode. Disaggregate logistic regression allows quite a few independent variables, and this is not the place for parsimony.

The approach used here is to express driver age/gender by one dichotomous and eight continuous variables. The dichotomous variable is already on the file: DRVMALE = 1 if the driver is male, = 0 if female. Driver age is expressed as a 4-piece linear variable, separately for males and females (eight variables in all): four connected straight-line segments, one from age 14 to 30, another from 30 to 50, another from 50 to 70, and the last from 70 and up.[16] The eight variables are:

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[13] Evans, L., *Traffic Safety and the Driver*, Van Nostrand Reinhold, New York, 1991, pp. 25-28.

[14] *Ibid.*, pp. 100-128 discusses young-driver inexperience, perception problems of older drivers, and aggressiveness of young and/or male drivers.

[15] *Traffic Safety Facts 1999*, NHTSA Report No. DOT HS 809 100, Washington, 2000, pp. 112-114.

[16] Actually, the last group is age 70-96. A small number of drivers age 97 or older have been excluded. FARS and the eight State files all identify driver age exactly up to age 96, but some files use codes 97, 98, or 99 for other purposes (e.g., unknown age).

M14_30	= 30 – DRVAGE for male drivers age 14-30, = 0 for male drivers age 31+ and all female drivers
M30_50	= 50 – DRVAGE for male drivers age 30-50, = 20 for male drivers age 14-30, = 0 for male drivers age 51+ and for all female drivers
M50_70	= DRVAGE – 50 for male drivers age 50-70, = 20 for male drivers age 70+, = 0 for male drivers age 14-50 and all female drivers
M70+	= DRVAGE – 70 for male drivers age 70+, = 0 for male drivers age 14-70 and all female drivers
F14_30	= 30 – DRVAGE for female drivers age 14-30, = 0 for female drivers age 31+ and all male drivers
F30_50	= 50 – DRVAGE for female drivers age 30-50, = 20 for female drivers age 14-30, = 0 for female drivers age 51+ and for all male drivers
F50_70	= DRVAGE – 50 for female drivers age 50-70, = 20 for female drivers age 70+, = 0 for female drivers age 14-50 and all male drivers
F70+	= DRVAGE – 70 for female drivers age 70+, = 0 for female drivers age 14-70 and all male drivers

For example, a 40-year-old male driver would have M30_50 = 10, and the other variables set to zero. A 25-year-old male driver would have M30_50 = 20, M14_30 = 5, and the others set to zero. Conversely, a 60-year-old female driver would have F50_70 = 10 and the others set to zero. A 75-year-old female driver would have F50_70 = 20, F70+ = 5, and the others set to zero.

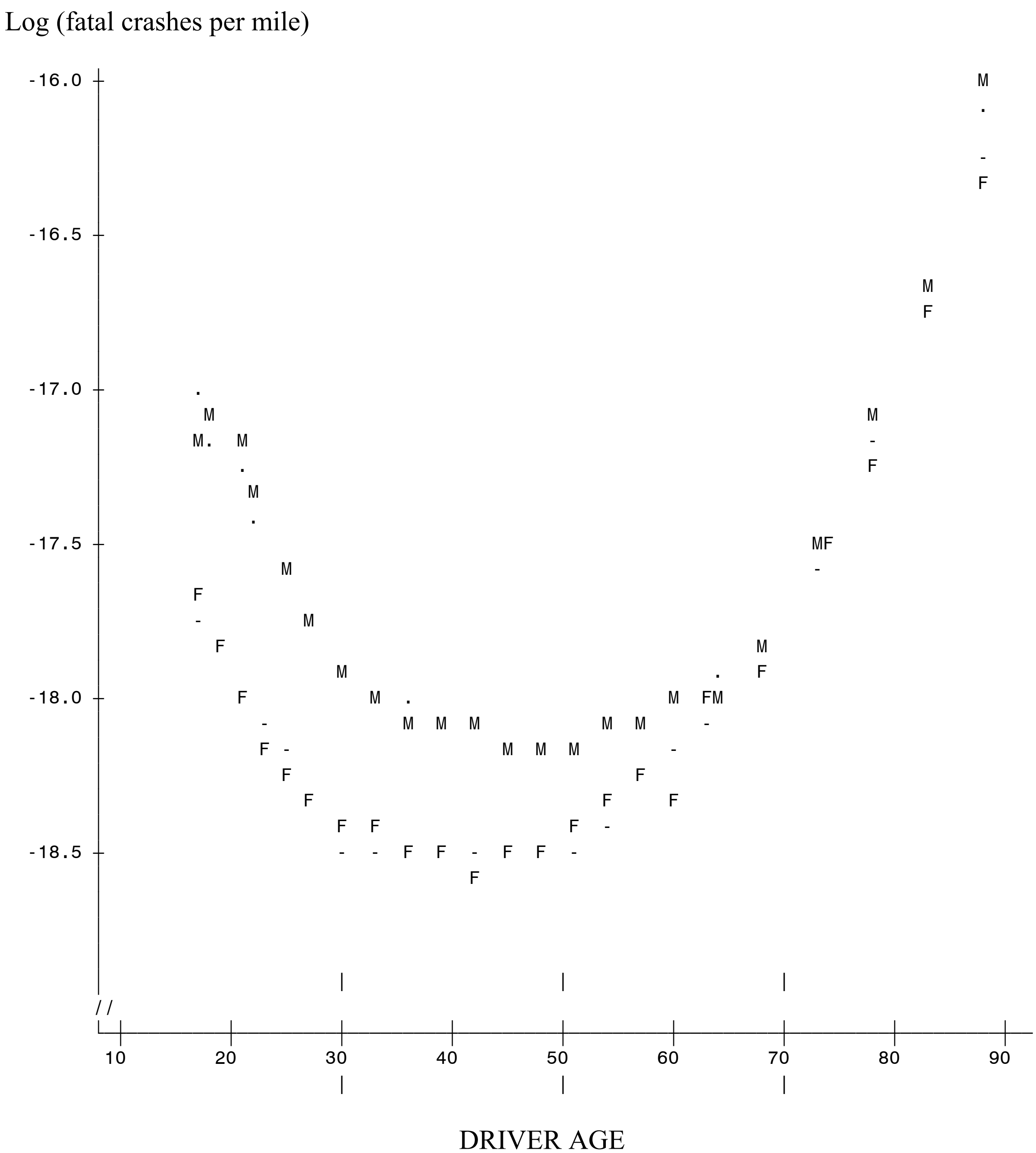
The rationale for defining the variables that way is that it treats 50 years as the baseline age. Each year that a driver is younger than 50 has some effect (usually increasing) on fatality risk, and each year that a driver is older than 50 has another effect (also usually increasing). The effect works like compound interest: the log of the fatality rate [usually] increases for each additional year that a driver's age is younger than 50. A 49-year-old driver will have 1 unit of increase in the log fatality rate (M30_50 = 1), and a 30-year-old driver will have 20 units of increase (M30_50 = 20). Moreover, the rate of increase changes (usually becomes stronger) as drivers get younger than 30 or older than 70. The difference between a 25-year-old and a 50-year-old driver is the 20 units of increase for an age reduction from 50 to 30 (M30_50 = 20) **plus** 5 units of increase, at the new rate, for the age reduction from 30 to 25 (M14_30 = 5).

The data points in Figure 3-15 are used to calibrate a weighted regression with log fatality risk as the dependent variable, DRVMALE, M14_30, M30_50, etc. as the independent variables, and each group's total VMT as its weight factor. Figure 3-16 superimposes the original data points (M = male, F = female) on the regression equations ("." for males, "-" for females).[17] The fit is exceedingly good at all ages ($r^2 = .99$). Indeed, the fit is so good that the "expected" from the regression equation is often hidden directly underneath the "actual" data point.

[17] Figures 3-15 and 3-16 have the same data, but do not appear exactly alike because the SAS PLOT procedure scaled the y-axes differently. A few data points moved up or down one space due to rounding.

FIGURE 3-16: FATAL CRASHES PER MILE BY DRIVER AGE AND GENDER
ALL CRASH TYPES – ACTUAL VS. EXPECTED

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)



Figures 3-17 and 3-18 illustrate the payoff in a flexible formulation of the age/gender variables. Figure 3-17 suggests fatal collisions with fixed objects are generally a young people's crash, although old drivers are hardly immune to it. M14_30 and F14_30 help track the severe increases as drivers get younger. Male and female trends are not parallel here. The rate continues to decrease for 30-50 year old males, while it is already constant for females. The regression follows these nuances almost perfectly.

Collisions with heavy trucks are the older driver's nemesis. Figure 3-18 shows how the regression line ably follows the modest downward trend from age 14 to 30 and the long, alarming increase for older drivers.

The use of nine variables allows for independence in the trends for younger and older people, males and females. The three inflection points in the formulation, ages 30, 50 and 70 are widely viewed as natural "transition points" in a person's life ("don't trust anybody over 30," "life begins at 50," "his biblical threescore and ten years") and Figures 3-15 – 3-18 suggest they may also correspond to ages where actual driving behaviors change in many people. By contrast, the formulation in NHTSA's 1997 report based on just four variables[18] did not track well for the older drivers and forced a parallelism in the rates of younger males and females that did not necessarily exist. Another blunder would be to use quadratic regression because the trends look sort of curvy. That would force the trends for older and younger drivers to be mirror images, and they aren't.

[18] Kahane (1997), p. 38.

FIGURE 3-17: FIXED-OBJECT FATALITIES PER MILE BY DRIVER AGE AND GENDER
ACTUAL VS. EXPECTED

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

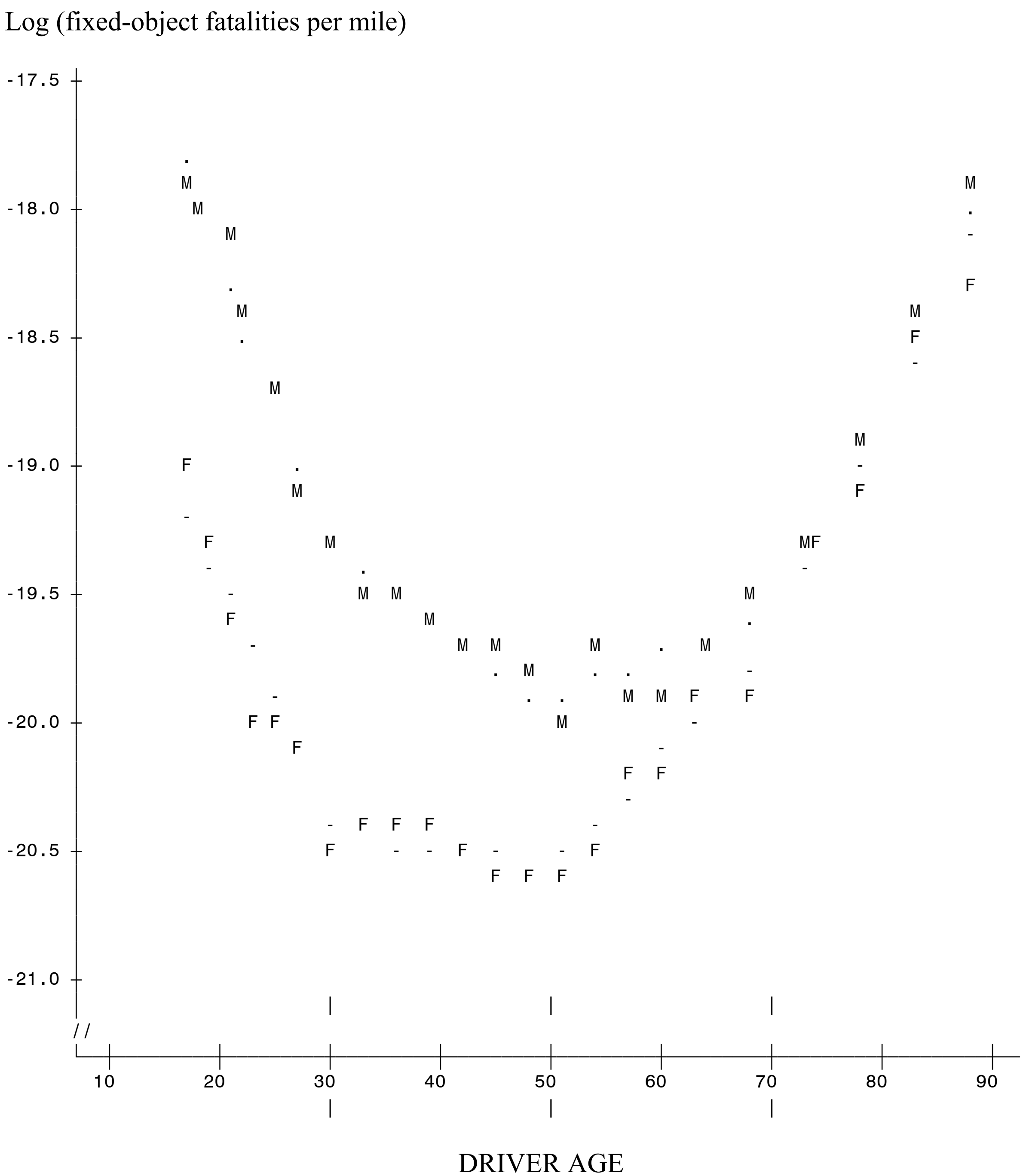
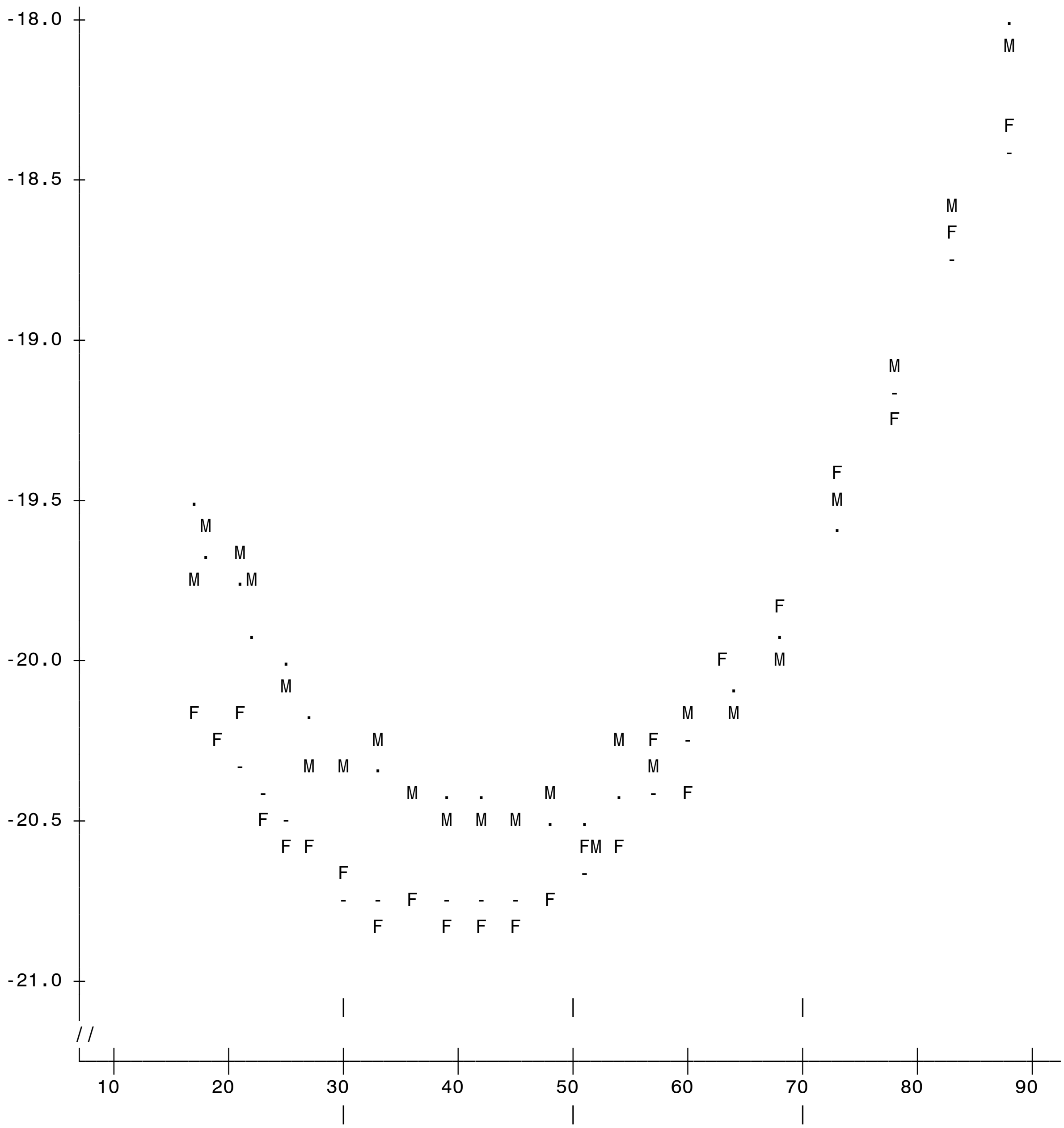


FIGURE 3-18: HEAVY-TRUCK FATALITIES PER MILE BY CAR DRIVER AGE/GENDER
ACTUAL VS. EXPECTED

(4-door passenger cars, excluding police cars, MY 1991-99 in CY 1995-2000)

Log (heavy-truck fatalities per mile)



DRIVER AGE

3.4 Regression analyses of fatality risk by car weight

The data are now almost ready to calibrate the crash fatality rate per year as a function of curb weight for MY 1991-99 cars in CY 1995-2000 crashes, in the six crash modes defined in Section 2.2: principal rollovers, fixed-object, pedestrian-bicyclist-motorcyclist, car-heavy truck, car-car, and car-light truck. Although they are the second crash mode in Section 2.2, fixed-object collisions will be the first regression discussed here, because it is in some ways the most typical analysis.[19] Here, the "crash fatality rate" is the same as the occupant fatality rate, since all fatalities are occupants of the single, case vehicle. Section 2.6 provided examples of typical records on the fatality file and the induced-exposure database, both for a 1997 Ford Taurus involved in a 1998 crash:

	Fatal-Crash Record	Exposure Record
Crash mode	Fixed Object	-
N of fatalities in the crash	2	-
Vehicle registration years	-	293.63
Curb weight	3,326	3,326
Driver male?	1	1
Driver age	24	28
Driver air bag?	1	1
ABS (4-wheel)?	0.51	0.51
At night?	0	0
Rural?	1	0
Speed limit 55+?	1	0

There are 9,537 records of MY 1991-99 4-door passenger cars, excluding police cars, involved in fatal fixed-object collisions during CY 1995-2000, with non-missing values on each of the variables listed above. There are 959,314 induced-exposure cases for these cars, with non-missing values for the variables. Together, they will furnish 968,851 data points to the logistic regression. Over 99 percent of the records had non-missing values for all control variables. Thus, the proportion of records with missing data is small enough that no adjustment is needed for cases with missing data. In addition to the age/gender variables M14_30, M30_50, etc. defined at the end of the preceding section, the file needs four more variables:

FATAL is a flag that indicates whether a data point supplies "failure(s)" (fatalities in collisions with fixed objects) or "successes" (vehicle years of exposure). All records from the fatal crash file have FATAL = 1. All induced-exposure crashes have FATAL = 2.[20]

[19] Includes all single-vehicle crashes that are not principal rollovers and did not result in non-occupant fatalities. See Table 2-1.

[20] *SAS/STAT® User's Guide, Version 6, Fourth Edition*, Volume 2, SAS Institute, Cary, NC, 1989, pp. 1071-1126. The LOGIST procedure in SAS prefers values of 1 for failures and 2 for successes.

WEIGHTFA is the weight factor for each data point. It **counts** the number of failures or successes implied by that data point. The weight factor for fatal crash involvements is (in this regression) the number of fatalities in the crash: a crash that killed two people represents two failures. The weight factor for induced-exposure cases is the number of vehicle years they represent: since the probability of a fatal crash in any single year of driving is negligible, 293.63 vehicle registration years may be considered "293.63 years of driving without a fatality" and that represents 293.63 successes.

UNDRWT00 and OVERWT00: the data in Section 3.2 clearly suggested that the weight-safety relationship is stronger at the lower weights, up to about 3,000 pounds, than at the higher weights, and that curb weight should be entered as a 2-piece linear variable, with the "hinge" somewhere around 3,000 pounds. The median curb weight of 4-door cars in MY 1991-99, 2,950 pounds, can serve as the hinge. If the curb weight is less than 2,950, set

UNDRWT00 = .01 (curb weight – 2,950), OVERWT00 = 0

If the curb weight is 2,950 or more, set

UNDRWT00 = 0, OVERWT00 = .01 (curb weight – 2,950)

Weights are divided by 100 so that the regression coefficient will indicate the effect of a 100-pound weight increase. Other than making the printout easier to read it has no effect on the regressions. The curb weights in this chapter are always the "nominal" weights described in Section 2.1, the best estimates from published material, without the adjustment for the additional weight observed in compliance test vehicles.

Thus, the fatal and induced-exposure crash record described above contribute the following two data points to the regression of fixed-object crash fatality rates (a 24-year-old male driver will set M14_30 to 6, M30_50 to 20, and the other 6 age/gender variables to 0 – for definitions, additional examples and a rationale for these variables, see the discussion in Section 3.3):

	Data Point 1 (fatal crash involvement)	Data Point 2 (induced-exposure involvement)
FATAL	1	2
WEIGHTFA	2 fatalities	293.63 vehicle years
UNDRWT00	0	0
OVERWT00	3.76	3.76
DRVMALE	1	1
M14_30	6	2
M30_50	20	20
M50_70	0	0
M70+	0	0
F14_30	0	0
F30_50	0	0
F50_70	0	0
F70+	0	0
DRVBAG	1	1
ABS	0.51	0.51
NITE	0	0
RURAL	1	0
SPDLIM55	1	0

The LOGIST procedure in SAS is a disaggregate logistic regression analysis. It is performed on 968,851 data points that are crash-involved vehicles: the 9,537 fatal crash involvements plus the 959,314 induced-exposure involvements. However, each of these data points is weighted, and thereby "transformed" by WEIGHTFA. The 9,537 fatal-crash involvements represent 10,569 "failures" (crash fatalities) while the 959,314 induced-exposure involvements represent 243,384,096 "successes" (registration years in the United States). While LOGIST procedure operates on the crash data points, the weighting by WEIGHTFA in effect makes it calibrate the log-odds of a fatality per registration year.[21] These log-odds are calibrated as a linear function of the independent variables, generating the following coefficients:

[21] The text describes the most appropriate way to set up the data for the LOGIST procedure. However, the version of LOGIST used in this study interprets the WEIGHT statement not as a case-weighting but a count of independently-observed cases. It literally treated each registration year as an independent data point. That makes the standard errors of the coefficients about 2-5 percent smaller than they should be, and their chi-squares about 2-5 percent larger (based on sensitivity tests where WEIGHTFA for the induced-exposure cases was divided by 250, in order to have the weights sum up to approximately the original number of crash cases) – i.e., when there are only 10,000 failures, the precision of the regression coefficients is nearly the same when there are 1,000,000 or 250,000,000 successes.

FIXED-OBJECT COLLISIONS (N = 9,537 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0322**	**45.2**	**.0001**
OVERWT00	**- .0167**	**17.1**	**.0001**
DRVMALE	.482	61.9	.0001
M14_30	.1006	901.7	.0001
M30_50	.0279	103.9	.0001
M50_70	.0291	84.2	.0001
M70+	.0973	414.8	.0001
F14_30	.0806	251.5	.0001
F30_50	.0055	2.23	.135
F50_70	.0561	200.9	.0001
F70+	.0928	197.7	.0001
DRVBAG	- .180	53.6	.0001
ABS	.080	6.71	.0096
NITE	1.598	6320.	.0001
RURAL	1.266	3615.	.0001
SPDLIM55	1.599	5465.	.0001
INTERCEPT	- 12.492	48873.	.0001

For cars weighing less than 2,950 pounds, each 100-pound weight reduction is associated with very close to a 3.22 percent fatality increase. In other words, Car A weighing 100 pounds less than Car B has approximately 3.22 percent higher fatality risk per million years than Car B, given the same age/gender driver, ambient conditions (NITE, RURAL, SPDLIM55) and safety equipment (air bags, ABS).[22]

For cars weighing 2,950 pounds or more, each 100-pound weight reduction is associated with close to a 1.67 percent increase in the fatality rate. In other words, the calibrated size-safety effect is about half as severe in the heavier cars as in the lighter cars.

Both of the size-safety effects are statistically significant, as evidenced by chi-square values 45.2 and 17.1, respectively. (For statistical significance at the .05 level, chi-square has to exceed 3.84, and for the .01 level, 6.64.)

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[22] The regression actually calibrates the change in the log-odds of a fatality for a 100-pound weight increase. Since the fatality rate is very low, those log odds are essentially the log of the fatality rate. Thus, a 100-pound weight increase is associated with a 3.22% reduction in the log of the fatality rate, or a 3.17% reduction of the fatality rate itself. A 100-pound weight reduction is associated with a 3.27% increase in the fatality rate itself. The differences in these numbers (3.17, 3.22, 3.27) are trivial compared to the uncertainty in the estimate. From here on, for simplicity, the regression coefficient itself is used as the estimated effect of a 100-pound weight change (in either direction), ignoring the trivial measurement errors this involves.

What does "statistically significant" mean in this context? It means that the specific data set entered into the regression model has a significant association between car weight and fatality risk – the lower the weight, the higher the risk – after controlling for driver age/gender, urban/rural, etc. (It also assumes this data set is a simple random sample of some much larger population). It does not necessarily prove that a future reduction in car weight will significantly increase fatality rates.[23] The following additional sources of uncertainty intervene between the first and second conclusion:

- The data are not a simple, "natural" collection of observations, but have been assembled from various sources (e.g., induced-exposure cases weighted by registration years). It is not clear if statistics such as chi-square have their customary meanings.
- Induced-exposure data were available from just eight States, not randomly selected. It will be shown, however, that this contributes very little to the uncertainty in the estimates.
- It assumes that the list of control variables includes everything important, the variables have been correctly formulated, and the induced-exposure method controls for them correctly.
- Perhaps most important, this is not a "controlled experiment" but a cross-sectional look at the fatality rates of actual MY 1991-99 cars. Since most people can pick what car they drive, the observed size-safety effects could in part be due to intangible characteristics such as "driver quality" or "attitude," possibly confounded with the owner's choice of a small or large car.
- The use of cross-sectional analysis for predictive purposes implicitly assumes that future weight reductions would be accompanied by reductions of track width, wheelbase, hood length, in the proportions that these parameters are related across the current fleet.

The two-piece linear modeling of the size-safety effect, 3.22 percent up to 2,950 pounds and 1.67 percent thereafter, also requires comment. This is a calibration. Obviously, the "real" effect does not abruptly drop in half at exactly 2,950 pounds and it might not be strictly constant above and below that weight. Specifically, a reduction from 3,000 to 2,900 pounds is unlikely to result in either a 3.22 or a 1.67 percent increase, but presumably some intermediate amount.

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[23] James Hedlund expanded on this sentence as follows, in his review of this report: "The study uses these statistical tests as one tool in examining and attempting to quantify the effects of vehicle weight changes. The stronger the statistical test result, the more confidence we have that the effect is real. In particular, effects that are not statistically significant (using the customary 0.05 level) may well not exist. But the study certainly does not use statistical significance as proof that an effect does exist. The study accumulates evidence, by using different analyses, examining how sensitive the results are to changes in data or assumptions, and the like. But the study cannot absolutely prove anything. It's more like a courtroom -- accumulating evidence to demonstrate beyond a reasonable doubt -- than a mathematical proof." Dr. Hedlund's review is available in the NHTSA docket for this report. He also notes that the FARS and State databases are not simple random samples but census files. In NHTSA evaluations and analyses, standard statistical tests are often applied to FARS data on the implicit rationale that the United States is a "sample" of a theoretical population of thousands of countries, each identical to the United States, with the same types of vehicles and drivers, and each with its own fatal crash experience.

Nevertheless, the raw data (Figures 3-1 – 3-14) repeatedly show an effect that is strong and looks quite linear up to about 3,000 pounds, and then flattens out, but with a pattern that cannot be easily deciphered. Clearly, a single, linear effect across all weights would not fit the raw data, while a two-piece linear effect, with the hinge at the median weight, is the next-simplest formulation, and it agrees with the data.

The control variables have appropriate coefficients. There are no "failed regressions" here, as in NHTSA's 1997 report.[24] The 0.48 coefficient for DRVMALE suggests that a 50-year-old male has .48 higher log fatality rate for fixed-object collisions than a 50-year-old female, all else being equal. That is consistent with the actual data points and regression lines in Figure 3-17 (that considered only the effect of age and gender in fixed-object fatality rates). Similarly, the coefficients for M14_30, M30_50, etc. are each quite similar to the regression lines in Figure 3-17. In other words, they say fatality risk increases by 2.79 percent for each year that a male driver is younger than 50, down to age 30, and for each year younger than 30 it increases by 10.06 percent, etc. Young drivers, old drivers and males have high fatality rates, and the regression adjusts the fatality rate of small cars downward to the extent that it is due to a high proportion of young drivers, and it also adjusts the fatality rate of large cars downward to the extent that it is due to a high proportion of male and older drivers. The coefficient for F30_50 is not statistically significant: there is little change in the fatality risk of female drivers between the ages of 30 and 50; however, risk increases significantly for females younger than 30 or older than 50, as evidenced by strongly positive F14_30, F50_70 and F70+ coefficients.

This regression is not a tool to obtain accurate estimates of the effect of air bags and ABS in fixed-object collisions, since it calibrates those parameters by comparing the overall fatality rates for large, non-matching groups of cars with and without air bags, with and without ABS. Nevertheless, the regression coefficients ought at least to be compatible with the estimates from more fine-tuned evaluations of those devices. Indeed, the -.18 coefficient for DRVBAG, suggesting a 1 – log(-.18) = 16.5 percent fatality reduction for air bags, looks quite reasonable for air bags in fixed-object collisions, the majority of which are frontals.[25] The +.08 coefficient for ABS, suggesting a 1 – log(.08) = 8.3 percent fatality increase in these CY 1995-2000 data, is likewise consistent with the literature, which has consistently shown increases in fatal run-off-road crashes with ABS, ranging from about 30 percent in the early 1990's, down to 10 percent or less in late 1990's (the time frame of this size-safety study).[26] The heavier cars of MY 1991-99 were more likely to have air bags and ABS, and the regression adjusts the fatality rates accordingly.

Finally, the regression calibrates strongly positive coefficients for NITE, RURAL and SPDLIM55. Fatality rates per mile (and even more so per reported induced-exposure crash) are

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[24] Kahane (1997), pp. 112-118.

[25] Kahane, C.J., *Fatality Reduction by Air Bags: Analyses of Accident Data through Early 1996*, NHTSA Technical Report No. DOT HS 808 470, Washington, 1996, pp. 36-38.

[26] Kahane (1994 ABS), pp. 92-104; Hertz, E., *Analysis of the Crash Experience of Vehicles Equipped with All Wheel Antilock Braking Systems (ABS) – A Second Update Including Vehicles with Optional ABS*, NHTSA Technical Report No. DOT HS 809 144, Washington, 2000; Farmer, Charles M., "New Evidence Concerning Fatal Crashes of Passenger Vehicles Before and After Adding Antilock Braking Systems," *Accident Analysis and Prevention*, Vol. 33, 2001, pp. 361-369.

substantially higher at night than by day, and on rural, high-speed roads than on city streets.[27] To the extent that heavier cars are driven relatively more on rural and high-speed roads, but relatively less at night, the regression adjusts the fatality rates.

Next is a regression of fatalities in **principal-rollover** crashes per registration year.[28] Here, there are 2,372 records of passenger cars involved in fatal principal-rollover crashes, supplying 2,583 "failures" (crash fatalities). The induced-exposure data are the same as in the fixed-object regression, and will also be the same in the four regressions after this one: 959,314 cases supplying 243,384,096 "successes" (years of travel). The list of independent variables is also the same as in the fixed-object regression, except DRVBAG is omitted: air bags are unlikely to have an effect, and in many cases won't even deploy, in principal rollovers. The regression generated the following coefficients:

PRINCIPAL ROLLOVERS (N = 2,372 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0508**	**27.8**	**.0001**
OVERWT00	**- .0470**	**27.6**	**.0001**
DRVMALE	.119	.97	.326
M14_30	.1000	214.0	.0001
M30_50	.0369	40.4	.0001
M50_70	.0132	3.07	.0798
M70+	.0695	24.0	.0001
F14_30	.0846	99.5	.0001
F30_50	.0152	5.39	.0202
F50_70	.0330	15.3	.0001
F70+	.0445	5.13	.0235
ABS	.392	43.5	.0001
NITE	1.618	1601.	.0001
RURAL	2.128	1610.	.0001
SPDLIM55	2.503	2422.	.0001
INTERCEPT	- 15.203	18343.	.0001

The weight-safety effect is strong, and nearly constant across the range of car weights, consistent with the trends in Figures 3-2 and 3-9. For cars weighing less than 2,950 pounds, each 100-pound weight reduction is associated with close to a 5.08 percent fatality increase; above 2,950 pounds, a 4.70 percent fatality increase. Both coefficients are statistically significant.

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[27] *Accident Facts, 1993 Edition*, National Safety Council, Itasca, IL, 1993, p. 64.
[28] As explained in Section 2.2, principal rollovers are single-vehicle crashes where the rollover is the first truly harmful event (although FARS may code the tripping mechanism, such as a ditch, as the "first" harmful event). Crashes where the first harmful event is a collision with a fixed object (excluding curb, ditch, etc.) are not included, even if a subsequent rollover was the most harmful event.

The control variables have a reasonable relationship to fatality risk. Since rollovers are even less of an "old people's crash" than fixed-object collisions, it is appropriate that M70+ and F70+, as well as M50_70 and F50_70 are weaker than in the preceding regression. The literature shows some persistent fatality increases with ABS in rollovers.[29] Rollover crashes are understandably even more concentrated on rural and high-speed roads than fixed-object crashes.[30]

Next is a regression of **pedestrian/bicyclist and motorcyclist** fatalities per passenger-car registration year. Here, there are 6,875 records of passenger cars that struck pedestrians, bicyclists or motorcyclists, resulting in 7,018 fatalities to the ped/bike/motorcyclists. The induced-exposure data are the same as in the fixed-object regression. Again, the list of independent variables omits DRVBAG, because an air bag in the car will not help the pedestrian, bicyclist or motorcyclist. The regression generated the following coefficients:

PEDESTRIANS-BICYCLISTS-MOTORCYCLISTS (N = 6,875 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0348**	**34.8**	**.0001**
OVERWT00	**+ .0062**	**1.7**	**.1892**
DRVMALE	.270	19.0	.0001
M14_30	.0254	25.5	.0001
M30_50	.0117	13.6	.0002
M50_70	.0138	13.3	.0003
M70+	.0553	60.6	.0001
F14_30	.0136	5.85	.0156
F30_50	.0088	6.44	.0111
F50_70	.0239	29.1	.0001
F70+	.0552	31.3	.0001
ABS	- .059	2.39	.122
NITE	1.579	4156.	.0001
RURAL	.257	89.5	.0001
SPDLIM55	.797	755.	.0001
INTERCEPT	- 11.649	47647.	.0001

Here, the contrast between light and heavy cars is especially strong, consistent with the trends in Figure 3-11. For cars weighing less than 2,950 pounds, each 100-pound weight reduction in the cars is associated with a statistically significant 3.48 percent increase of ped/bike/motorcycle

[29] Hertz, *op. cit.*, Table 5.

[30] Another regression included the DRVBAG variable. It produced an implausible -.188 coefficient for DRVBAG (a significant benefit), while exacerbating the fatality increase for ABS to .436 (possible evidence that the regression confuses the effects of these two devices that were introduced almost simultaneously in many cars). However, the coefficients for UNDRWT00 and OVERWT00 were -.0470 and -.0458, respectively, more or less the same as in the baseline regression without DRVBAG. The baseline regression should be considered more reliable.

fatalities. That is a strong effect, especially considering that the crashworthiness of the car for its own occupants is not at issue here. For cars above 2,950 pounds, the effect is in the opposite direction, but slight (0.62 percent) and not statistically significant. These perhaps surprising results will be given additional analysis in Section 3.6.

Hitting pedestrians is definitely not a "young driver's crash." Appropriately, the M14_30 and F14_30 are much weaker than in the preceding two regressions. The ABS coefficient suggests a possible, but nonsignificant benefit for ABS in pedestrian crashes, consistent with recent literature.[31] Pedestrian crashes are common at night: visibility is a problem, and many of the crashes involve alcohol. Thus, the coefficient for NITE is high. Pedestrian crashes are far less of a problem on rural and high-speed roads. That results in the lowest (but still positive) coefficients for RURAL and SPDLIM55 of any of the regressions. The coefficients are still positive: the probability of a fatality, given a crash, is high on rural/high speed roads. They are smaller than in other crash modes because pedestrians are relatively uncommon on rural and high-speed roads, resulting in low crash rates.

The regression of car occupant fatalities in collisions with **heavy trucks** (GVWR > 10,000 pounds), per car registration year, is based on 4,556 collisions that resulted in 5,467 car occupant fatalities, plus the usual induced-exposure data. In this regression, plus the last two, air bags and ABS are control variables, since both are potentially effective in multivehicle collisions. These are regressions on the weight and safety equipment of the car, the age/gender of the car driver. The weight of the truck is unknown (except that its GVWR is known to exceed 10,000 pounds); the age of the truck driver and the truck's ABS status are not in the regression, either.

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[31] Hertz, *op. cit.*; Farmer, *op. cit*.

COLLISIONS WITH HEAVY TRUCKS (N = 4,556 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0596**	**79.2**	**.0001**
OVERWT00	**- .0206**	**14.6**	**.0001**
DRVMALE	.078	1.10	.294
M14_30	.0564	79.9	.0001
M30_50	.0126	9.5	.0021
M50_70	.0409	103.5	.0001
M70+	.1076	414.7	.0001
F14_30	.0406	33.9	.0001
F30_50	- .0033	.62	.433
F50_70	.0588	195.2	.0001
F70+	.0799	129.2	.0001
DRVBAG	- .246	51.0	.0001
ABS	.051	1.41	.235
NITE	.444	183.	.0001
RURAL	1.214	1596.	.0001
SPDLIM55	2.348	5103.	.0001
INTERCEPT	- 12.690	35143.	.0001

For cars weighing less than 2,950 pounds, each 100-pound weight reduction in the cars is associated with a statistically significant 5.96 percent increase in occupant fatalities per car registration year in collisions with heavy trucks. That is the strongest effect in any of the six basic regressions for passenger cars. For cars above 2,950 pounds, the effect continues to be statistically significant, and in the same direction, but is a weaker 2.06 percent.

Older car drivers are especially prone to collisions with heavy trucks. Here, M70+ and F70+ greatly overshadow M14_30 and F14_30. The high proportion of older drivers in heavy cars inflates their fatality rates; the regression adjusts for that and changes the "wrong direction" trend for heavier cars in the raw data (Figure 3-5) to a significant effect in the direction of higher weight = less risk. Air bags significantly reduce fatality risk in these collisions while ABS does not have a significant effect. The coefficient for SPDLIM55 is especially high because (1) truck traffic is heavy on high-speed roads and (2) crashes are severe.

The last two crash modes include collisions of two to four passenger vehicles, but no heavy trucks, motorcycles or non-occupants. The first one is "**car to car**." The "failures" are the involvements of 1991-99 "case" cars in fatal crashes involving two to four vehicles, and all of them are passenger cars. (Table 2-1 showed that 85 percent of those crash involvements were 2-car collisions, and only 15 percent in 3- or 4-car collisions.) The independent variables include the curb weight, driver age/gender and air bag/ABS status of the case car. No data on the "other" car(s) in the collision are included in the regression; these other vehicle(s) may or may not be MY 1991-99, may or may not be 4-door cars, and their curb weights, driver ages, etc. are not specified in the regression. Section 6.6 will present regression analyses of two-car collision rates based on the curb weights and driver ages for both vehicles, and they will corroborate the findings here.

Note that a collision involving two or more MY 1991-99 cars will contribute multiple data points to this regression, one for each MY 1991-99 car involved. However, the procedure in Section 3.8 for quantifying the societal impact of the size-safety effect is designed to avoid "double-counting" the impacts. As an additional hedge against over-weighting cases with multiple fatalities and multiple 1991-99 cars, this regression, unlike the other five crash modes, gives each crash involvement a WEIGHTFA = 1, even if there was more than one fatality in the crash. Thus, the 13,513 records of 1991-99 passenger cars involved in fatal car-to-car crashes supply 13,513 "failures." The induced-exposure data are the same as usual: 959,314 cases supplying 243,384,096 "successes" (years of travel).

COLLISIONS WITH ANOTHER PASSENGER CAR(S) (N = 13,513 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0248**	**33.5**	**.0001**
OVERWT00	**- .0159**	**20.9**	**.0001**
DRVMALE	.202	19.5	.0001
M14_30	.0526	182.0	.0001
M30_50	.0059	5.53	.0187
M50_70	.0274	113.8	.0001
M70+	.1006	759.2	.0001
F14_30	.0378	78.2	.0001
F30_50	- .0013	.27	.607
F50_70	.0430	237.1	.0001
F70+	.0913	376.5	.0001
DRVBAG	- .180	66.6	.0001
ABS	- .156	32.4	.0001
NITE	.707	1313.	.0001
RURAL	.856	2172.	.0001
SPDLIM55	1.540	6344.	.0001
INTERCEPT	- 11.004	71819.	.0001

For cars weighing less than 2,950 pounds, each 100-pound weight reduction in the cars is associated with a statistically significant 2.48 percent increase in fatal car-to-car collision involvements per registration year. For cars above 2,950 pounds, the effect is also statistically significant, but it is a weaker 1.59 percent in the same direction. Nevertheless, this is the weakest effect for cars up to 2,950 pounds in any of the six regressions, and the weakest, except for pedestrian crashes, for the cars over 2,950 pounds.

Older car drivers and males are especially prone to collisions with other cars. Here, M70+ and F70+ greatly overshadow M14_30 and F14_30. The small coefficients for M30_50 and F30_50 (nonsignificant) suggest there is little change in risk for drivers age 30 to 50. Air bags are quite effective in car-to-car crashes, many of which are head-on collisions. Finally, here is a crash mode where ABS has a substantial benefit, consistent with the literature. The coefficients for NITE, RURAL and SPDLIM55 are considerably lower than in the fixed-object and rollover regressions.

Overall crash fatality risk is the sum of the occupant fatality rate in the case car and the fatality rate in the other car. As might be expected, the weight of the case car has nearly opposite relationships with fatality risk in the case car and in the other car.

COLLISIONS WITH ANOTHER PASSENGER CAR(S) (N = 13,513 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
FATALITY RISK FOR CASE CAR OCCUPANTS			
UNDRWT00	**- .0996**	**353.3**	**.0001**
OVERWT00	**- .0671**	**171.9**	**.0001**
FATALITY RISK FOR OCCUPANTS OF THE OTHER CAR, BY CASE CAR WEIGHT (2-car collisions only)			
UNDRWT00	**+ .0684**	**110.2**	**.0001**
OVERWT00	**+ .0303**	**46.6**	**.0001**

As the weight of the case car is reduced by 100 pounds (i.e., as the fatality rates of 1991-99 cars weighing W-100 pounds are compared to the rates of other 1991-99 cars weighing W pounds), the fatality risk of its own occupants greatly increases: by 9.96 percent in cars weighing less than 2,950 pounds, by 6.71 percent in cars weighing 2,950 pounds or more. But the risk to occupants of the other car in a two-car collision is much reduced: by 6.84 percent if the case car weighs less than 2,950 pounds, by 3.03 if it is heavier than that. Nevertheless, these effects, although opposite, are not of equal magnitude. When the case car is reduced in weight, the additional harm to its own occupants is proportionately greater than the benefit for the occupants of the other car. For example, if the case car weighs less than 2,950 pounds, the 9.96 percent increase in the case car exceeds the 6.84 percent reduction in the other car. That results in a net increase in societal crash fatality risk when curb weight is reduced.

This pattern occurs in all of the crash types involving two or more passenger vehicles (car-to-car, car-to-light truck, light truck-to-car, light truck-to-light truck). Two things are going on at the same time. The first is a trade-off, based on conservation of momentum: when vehicle no. 1 gets lighter, fatalities increase in vehicle no. 1 and decrease in vehicle no. 2. The second is a trend or "gradient" in all the data toward lower fatality risk per million years, or per billion miles, in heavier vehicles, even after controlling for driver age/gender, urban/rural, etc. The gradient may be due partly to the greater crashworthiness and structural integrity of the heavier vehicles, and partly to the lower serious-crash involvement rates of heavier vehicles. The lower crash involvement rates of heavier vehicles could be due to a variety of factors – e.g., greater directional stability, less temptation for drivers to weave and maneuver in traffic, or a tendency of better drivers to choose heavier vehicles ("self-selection" – see additional discussion in Section 3.6). The data and analysis methods of this report do not identify exactly why this gradient is there, but they clearly show it is there.

Thus, when case vehicles are reduced in weight, there is usually a net increase in multivehicle crash fatalities, because the increase of collision involvement rates, and the increased harm to the occupants of the case vehicle overshadow the reduction in harm to the occupants of the other vehicle. The principal exceptions are crashes between cars and the heavier light trucks (see Section 4.3). Here, because 83 percent of the fatalities were occupants of the car, when the truck is reduced in weight the benefits for the car occupants slightly exceed the other effects. But even here, the net fatality reduction when a truck is reduced by 100 pounds is small relative to the net increase when a car is reduced by 100 pounds.

The last crash mode comprises **car-to-light truck** collisions. The case vehicle is a MY 1991-99 passenger car. In 69 percent of these cases, there is only one other vehicle, and it is a light truck (pickup truck, SUV, minivan or full-sized van up to 10,000 pounds GVWR). In 31 percent of the cases, there are two or three other vehicles, at least one of them a light truck, and the others, light trucks or cars. As above, the independent variables include the curb weight, driver age/gender and air bag/ABS status of the case car. No data on the "other" vehicle(s) in the collision are included in the regression. The regression is based on 12,119 records of case cars involved in fatal crashes, resulting in 14,518 crash fatalities ("failures"), plus the usual induced-exposure data. The rationale for counting every crash fatality as a "failure," rather than just every involvement, is that most of the fatalities are the occupants of the passenger cars.

COLLISIONS WITH LIGHT TRUCK(S) (N = 12,119 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0563**	**195.1**	**.0001**
OVERWT00	**- .0262**	**59.1**	**.0001**
DRVMALE	.102	5.13	.0235
M14_30	.0542	185.9	.0001
M30_50	.0036	2.05	.153
M50_70	.0354	203.8	.0001
M70+	.1132	1231.5	.0001
F14_30	.0458	124.8	.0001
F30_50	- .0059	5.49	.0191
F50_70	.0499	368.9	.0001
F70+	.0926	477.3	.0001
DRVBAG	- .162	59.4	.0001
ABS	- .125	22.2	.0001
NITE	.591	925.	.0001
RURAL	1.015	3205.	.0001
SPDLIM55	1.806	9217.	.0001
INTERCEPT	- 11.185	78654.	.0001

For cars weighing less than 2,950 pounds, each 100-pound weight reduction in the cars is associated with a very strong 5.63 percent increase in car-to-light truck collision fatalities per car registration year. Because the effect is large and based on a large number of fatal crash cases, its chi-square, 195.14 is the highest for any curb-weight term in the six regressions. For cars above 2,950 pounds, the effect is also statistically significant, a relatively strong 2.62 percent in the same direction. Here, there is less of a trade-off than in the car-to-car collisions. As cars get lighter, risk increases for their own occupants, but there are so few fatalities in the light trucks that the reduction there will hardly compensate for the increase in the cars. Only in the case of large cars hitting small light trucks is there anything near equal risk in the two vehicles.

The various driver-age coefficients are about the same as in the car-to-car regression. The DRVMALE coefficient is lower. Male aggression has at least a partial payoff. It is, of course, better to drive defensively and not have any collision, but if a car and a light truck do collide at an angle, it is less lethal when the car is the frontally impacting vehicle.[32] Air bags and ABS are almost as effective here as in car-to-car crashes. The coefficients for RURAL and SPDLIM55 are somewhat higher than in car-to-car collisions, reflecting the lower concentration of pickup trucks in city streets.

[32] Unlike front-to-rear collisions, in front-to-side collisions the frontally damaged vehicle is not necessarily the more aggressive (striking) vehicle. But more often than not, it is. In 12,417 2-car, front-to-side collisions of two cars in North Carolina during 1999, where one driver was male and the other female, the male driver was in the frontally damaged vehicle in 6,497 cases (52.3%), the female driver, in only 5,920 cases (47.7%). That's a significant difference.

3.5 Summary and discussion of basic regressions

Here are the calibrated relationships between the curb weights of passenger cars and their fatality rates per million vehicle years, based on six regressions:

	Fatality Increase (%) per 100-Pound Weight Reduction	
Crash Mode	Cars < 2,950 Pounds	Cars 2,950 Pounds +
Principal rollover	5.08	4.70
Fixed object	3.22	1.67
Pedestrian/bike/motorcycle	3.48	- .62 (nonsignificant)
Heavy truck	5.96	2.06
Car-to-car	2.48	1.59
Car-to-light truck	5.63	2.62

In every crash mode, the effect is stronger among cars weighing less than 2,950 pounds than among cars weighing 2,950 pounds or more. In all six crash modes, lower weight is associated with higher fatality risk among the cars weighing less than 2,950 pounds, and in five of the six crash modes among the heavier cars.

The strong trends in **rollover** crashes are no surprise. In MY 1991-99 cars, and for many years before that, curb weight is strongly correlated with track width. Heavier cars are wider, without a comparable increase in center-of-gravity height, and are much less rollover-prone. In addition, larger cars have better directional stability, preventing some of the off-road excursions that lead to rollovers.

The moderate trends in **fixed-object** crashes also seem intuitively reasonable. Heavier cars are typically more crashworthy, with more space to slow down the occupants, a more gradual deceleration in crashes, and an occupant compartment more likely to keep its structural integrity. Greater directional stability can prevent running off the road and hitting fixed objects. Finally, greater mass can in some cases help a car displace or deflect a fixed object, and reduce crash severity to some extent.

The startling result is the strong 3.48 percent increase in **pedestrian** fatality rates per 100-pound weight reduction in cars weighing less than 2,950 pounds, especially considering that the effect in the heavier cars is not statistically significant. At first glance, there is no obvious reason why pedestrians would be at higher risk – or lower risk, for that matter – from lighter cars. On momentum considerations alone, a 150-pound pedestrian has plenty to fear from a 2,000 pound car and little more to fear from a 4,000 pound car. Neither are larger cars endowed with any special crash-avoidance equipment that would reduce pedestrian crashes.

Pedestrian crashes and related issues will be analyzed in Section 3.6, but here are the fundamentals: one possibility is that the dimensions and structure of small cars makes them more hazardous to pedestrians. Another possibility that must be considered is that heavier cars are driven more prudently than light cars. It is widely believed that people who drive small cars are more likely to weave around in traffic, seize opportunities to change lanes or move ahead of other vehicles, and perhaps take corners and curves faster. All of those behaviors increase risk.

If it is true that small-car drivers are more likely to weave in traffic, etc., than large-car drivers of the same age and gender, the important question is: what is the cause and what is the effect? Do good drivers tend to select larger cars, for whatever reason, but if those same good drivers were driving smaller cars (e.g., rent-a-cars), they would still drive just as prudently (driver safety = cause; vehicle weight = effect)? Or does a reduction in car size "tempt" or psychologically induce drivers to weave and take other risks (vehicle weight = cause; driver safety = effect)? Either way, our cross-sectional analysis of fatality rates by car weight will show higher rates for the lighter cars (to the extent that the age/gender variables do not fully capture behavioral differences). But in the first case, the cross-sectional trend would not measure the effect of downward shifts in vehicle weight: if 1991-99 cars had been 500 pounds lighter, good drivers would now have been in 3,500- instead of 4,000-pound cars, but they would have driven these lighter cars as prudently as their former, heavier cars. The cross-sectional trend line would just be displaced to the left. In the second case, the cross-sectional trend would exactly measure the effect of lighter weights. Intuitively, it would seem that reality is neither the purely first case nor the second, but very possibly a blend of the two.

If heavy cars are indeed driven more prudently than light cars, the effect would not be limited to pedestrian crashes. Imprudent driving increases the risk of almost any type of crash. In all the crash modes, the strong size-safety effects among cars weighing less than 2,950 pounds might be at least partly due a trend of less prudent driving in the smaller cars. Specifically, small cars' severe increases of fatality risk in collisions with heavy trucks and light trucks may reflect the mismatch of structural rigidity and sill height in these crashes, but it could also suggest that small cars are driven in a way that increases the likelihood of collisions. The pedestrian crash mode has been singled out only because there are no other obvious factors that ought to make heavier cars safer.

Three other findings merit attention before the detailed analyses of pedestrian crashes and "driver quality" issues.

When the databases are split into two groups based on driver age, 14-59 and 60+, and separate regressions are performed for the younger drivers and the older drivers, the coefficients for curb weight in cars weighing less than 2,950 pounds are consistently greater for the older drivers, indicating a stronger trend to higher fatality risk with lower curb weight in the light cars:

	Fatality Increase (%) per 100-Pound Weight Reduction			
	Cars < 2,950 Pounds		Cars 2,950 Pounds +	
Driver Age:	14-59	**60+**	14-59	60+
Principal rollover	4.58	**10.07**	5.59	1.50 (n.s.)
Fixed object	3.04	**8.15**	.79 (n.s.)	1.04 (n.s.)
Pedestrian/bike/motorcycle	3.48	**5.06**	- 1.47 (n.s.)	.69 (n.s.)
Heavy truck	4.85	**9.28**	1.98	1.59
Car-to-car	1.42	**8.60**	- .65 (n.s.)	2.97
Car-to-light truck	5.56	**7.66**	.54 (n.s.)	3.85

For drivers age 60+ in cars weighing less than 2,950 pounds, the fatality rate increases steeply per 100-pound weight reduction, ranging from 5.06 percent in pedestrian crashes to 10.07 percent in rollovers. They are the strongest weight-safety coefficients found in this study. They suggest older drivers have major problem(s) with small cars.

Several factors are involved here. Of course, the probability of death given the same physical insult rises steadily with age. In the last two crash modes, involving multiple passenger vehicles, the fatality(s) can be in the case vehicle, the other vehicle, or occasionally in both. If the driver of the case vehicle is young, and especially if the case vehicle is also heavy, the fatality will almost certainly have been in the other vehicle. Making the case vehicle lighter might help the occupants of the other vehicle as much or more than it harms the case vehicle occupants. Thus, in the last two crash modes, it is to be expected that the size-safety effect is very strong for older drivers in lighter cars, and weak or even negative for younger drivers in heavier cars.

In rollovers, fixed-object, and heavy-truck crashes, the effect is still very strong for older drivers in lighter cars. Even though the "case vehicle-other vehicle" issue does not apply here, it might be argued that the frailty of older drivers is the main problem, and it is somehow intensified in small cars. But the strong increase in pedestrian fatalities, 5.06 percent, surely cannot be attributed to the frailty of the drivers. It suggests that older drivers, especially, drive small cars poorly, for one or more reasons – and that problem, presumably, must spill over into the other crash modes as well.

Conversely, the preceding table suggests that weight reductions in the heavier cars would have a negligible net effect for younger drivers (the effect is not significant or even negative in 4 of the 6 crash modes).

A second issue is that the preceding analyses are based in part on induced-exposure crashes from eight States, not the entire United States, and that is a source of additional uncertainty in the results. The uncertainty can be quantified by recreating the database using induced-exposure data from just a single State, but continuing to use all the FARS and Polk data from the entire United States, as before. In other words, use data from just a single State, rather than from eight States, to subdivide the nation's VMT or vehicle years by age/gender, urban/rural, etc.

Section 2.6 explained how to assign a quantity of vehicle years to each induced-exposure crash, based on data from eight States. It gave, as an example, MY 1997 Ford Taurus in CY 1998. They accumulated 353,031 vehicle years in the United States and had 203 induced-exposure involvements in Florida. If the database were created using only the induced-exposure crashes from Florida, each of these crashes would simply be apportioned 353,031/203 = 1739.07 vehicle years.

The basic regression for fixed-object collision fatalities per vehicle year is run for the new database that uses only the Florida induced-exposure data to subdivide the nation's vehicle years by age/gender, etc. The process is repeated with six other databases using only the induced-exposure crashes from the six other relatively populous States: Illinois, Maryland, Missouri, North Carolina, Ohio and Pennsylvania. That provides seven comparable "repeated measures" to gauge the uncertainty added by the process. The regression coefficients for curb weight are:

	Fixed-Object Collisions: Fatality Increase (%) per 100-Pound Weight Reduction	
	Cars < 2,950 Pounds	Cars 2,950 Pounds +
Baseline regression (using 8 States)	3.22	1.67
Using only induced-exposure data from:		
Florida	3.13	.69
Illinois	4.91	2.96
Maryland	4.30	1.32
Missouri	4.07	1.54
North Carolina	3.11	1.78
Ohio	2.19	2.47
Pennsylvania	2.45	.24
Average of these 7 results	3.45	1.57
Standard deviation (s)	1.00	.95
Standard error ($s / 7^{.5}$)	.38	.36

Even limiting the induced-exposure data to any single State does not drastically change the estimated weight-safety effects, nor do they differ that greatly depending on what State file is used. The standard error for the seven estimates is just .38% for cars less than 2,950 pounds and .36% for cars weighing 2,950 pounds or more. Those are small uncertainties compared to the point estimates of 3.22% and 1.67%, respectively. In fact, they are smaller than the standard errors SAS calculated in the LOGIST procedure for these parameters in the baseline regression, .48% and .41%, respectively, under the assumption that the calibration data set was a simple random sample.

In other words, the fact that the analysis is based on induced-exposure data from just eight States adds very little to the overall uncertainty in the results. Even though the absolute age/gender, urban/rural, etc. distribution of crashes varies quite a bit from State to State, the interaction pattern of these control variables with curb weight – e.g., the relative overrepresentation of older drivers in heavier cars – doesn't change much from State to State. Induced-exposure data from just one State can be enough to plausibly adjust fatality rates by curb weight for age/gender, etc. – data from eight States are ample.

A third issue is that the results are dependent, to some extent, on the choice of control variables and the way the model is set up. As discussed in Section 3.3, six potential control variables – driver belt use, wet road, snowy/icy road, calendar year, vehicle age, and high-fatality State – are not used because they have little real correlation with car weight. Fatality rates per vehicle year, not vehicle mile, were analyzed. This model included the most important control variables without being cluttered by additional variables. An alternative procedure would be to include those control variables (except driver belt use, whose reporting accuracy in the induced-exposure data is questionable). With vehicle age and calendar year in the model, fatality rates are analyzed per mile rather than per registration year (since annual mileage decreases as a car ages). In general, the alternative model and its variables are defined as in Sections 4.2 and 4.3. It produces regression coefficients for vehicle weight quite similar to the baseline model:

Fatality Increase (%) per 100-Pound Weight Reduction

	Cars < 2,950 Pounds			Cars 2,950 Pounds +		
	Baseline B	Alternate A	A-B	Baseline B	Alternate A	A-B
Principal rollover	5.08	5.07	-.01	4.70	4.97	.27
Fixed object	3.22	3.34	.12	1.67	1.98	.31
Pedestrian/bike/motorcycle	3.48	3.46	-.02	- .62	- .28	.34
Heavy truck	5.96	5.89	-.07	2.06	2.57	.51
Car-to-car	2.48	2.68	.20	1.59	2.11	.52
Car-to-light truck	5.63	5.61	-.02	2.62	3.15	.53

The baseline and alternative models calibrate nearly identical fatality increases in cars weighing less than 2,950 pounds. In the heavier cars, the alternative model calibrates a slightly stronger weight-safety effect, but still essentially the same results in qualitative terms. The differential between the baseline and alternative model is always within the sampling error "noise," as indicated by the 2.57 standard errors column in Table 3-3. While this analysis, of course, does not assess the effects of all conceivable variations in the model setup, it does show that the baseline model is robust and the results are little affected by adding several nonessential control variables to the analysis.

3.6 "Driver quality" issues and pedestrian fatality rates

A possible explanation for the high pedestrian fatality rates in the lightest cars is that people drive light cars less prudently. Do crash data support that hypothesis? One analysis approach is to compare the incidence of specific imprudent driving behaviors, such as drinking, speeding, etc. in light vs. heavy cars, after controlling for driver age, gender and other factors.

The analysis is based on crash involvements of MY 1991-99 4-door cars, excluding police cars, on the 1995-2000 FARS files: the same fatal crash cases as the regression analyses. A driver is assigned one point for each of the following nine indications of imprudent driving in this crash, or on previous occasions[33]:

- Alcohol involvement on this crash (DRINKING = 1)
- Drug involvement on this crash (DRUGS = 1)
- Driving without a valid license at the time of this crash (L_STATUS = 0-4)
- 2 or more crashes during the past 3 years (PREV_ACC = 2-75)
- 1 or more DWI convictions during the past 3 years (PREV_DWI = 1-75)
- 2 or more speeding convictions during the past 3 years (PREV_SPD = 2-75)
- 2 or more license suspensions or revocations during the past 3 years (PREV_SUS = 2-75)
- 2 or more other harmful moving violations during the past 3 years (PREV_OTH = 2-75)
- This crash involves driving on a suspended/revoked license, reckless/erratic/negligent driving, being pursued by police, racing, hit & run, or vehicular homicide (any of DR_CF1, DR_CF2, DR_CF3 or DR_CF4 = 19,36[34],37,46,90,91)

In other words, the dependent variable, BAD_DRIV = 0 for drivers who did not have any of the behaviors listed above, and could theoretically be as high as 9 if they had all of them. The average value of BAD_DRIV is 0.42 in these 51,180 cases of 4-door cars. The GLM procedure in SAS[35] performs a regression of BAD_DRIV by curb weight, driver age and gender (using the

[33] FARS driver history information is generally complete for most of the States. For example, on the 1999 FARS, 50 States appeared to have fairly complete information on previous speeding convictions and other violations; 48 States had fairly complete information on previous suspensions; 37-46 States on previous DWI; and 41-43 States on previous crashes.
[34] In Florida, Kansas, North Carolina, Ohio, and Utah, do not include if DR_CF2, DR_CF3 or DR_CF4 = 36, since that code is applied frequently in those States and does not necessarily mean reckless driving.
[35] *SAS/STAT® User's Guide, Version 6, Fourth Edition*, Volume 2, SAS Institute, Cary, NC, 1989, pp. 893-996.

same nine variables DRVMALE, M14_30, M30_50, etc. as in the size-safety regressions), NITE, RURAL, SPDLIM55, high-fatality State, and vehicle age.

The coefficient for curb weight is close to nil, and not statistically significant (t = 0.28). It says that BAD_DRIV, whose average value is 0.42, increases by .0002 for every 100-pound weight increase. By contrast, the regression calibrated highly significant coefficients for DRVMALE (t = 8.52), M30_50 (t = 26.60), F30_50 (t = 12.27), NITE (t = 35.37), RURAL (t = 4.33), SPDLIM55 (t = -4.96) and vehicle age (t = 5.91). In other words, imprudent driving is more prevalent in males than females, drops very steeply from age 30 to 50 in both genders, but especially males, is much more common at night and in older cars, and somewhat more common in rural areas and low-speed roads. All of those effects are in the expected direction. After controlling for them, curb weight has little or no association with BAD_DRIV.

While there is little or no difference between light and heavy 4-door cars, there are significant differences between 4-door cars and some other vehicle types. Another regression, which will be discussed in Chapter 5, shows all types of 2-door cars have significantly higher values of BAD_DRIV than 4-door cars; sporty and high-performance 2-door cars, much higher. Minivans, full-sized vans and heavy-duty (200 or 300 series) pickup trucks have significantly lower incidence of BAD_DRIV than 4-door cars. These differences are intuitively reasonable and they underscore the lack of differences, by vehicle weight, within 4-door cars.

In the preceding regressions, BAD_DRIV can have values from 0 to 9 and it is treated as a linear dependent variable. A statistically more powerful (but perhaps less descriptive) approach is to define a categorical variable BAD_DRIV' – one or more bad-driving behaviors vs. none – and to run a logistic regression. Here, too, the coefficient for curb weight is close to nil (-0.00046), and not statistically significant (chi-square = 0.04).

Conversely, the presence of **child passengers** age 0-12 in the vehicle can indicate a relatively safe driver, at least to the extent that drivers transporting children are unlikely to be drunk, drugged, or driving recklessly. It is a marker of limited utility, since only about 10 percent of vehicles in fatal crashes have child passengers. Nevertheless, it is possible to perform a logistic regression, with the dependent variable, presence/absence of a child passenger. After controlling for driver age and gender, small 4-door cars are in fact slightly more likely to have a child passenger than large 4-door cars: the coefficient for LBS100 is -0.00803, and it is statistically significant (chi-square = 5.37). By contrast, 2-door cars of all sizes have far fewer child passengers than 4-door cars.

These analyses do not supply any evidence that small 4-door cars are driven less prudently than large cars, after controlling for the age/gender, etc. of the drivers. However, they focus on the more obvious forms of poor driving that tend to get reported – drinking, speeding, bad driver history – or on other simple characteristics, such as the presence/absence of a child passenger. It is still possible that small cars are driven imprudently in more subtle ways that would not necessarily be identified in crash reports or driver records.

Heavier cars are usually, but not always more **expensive** than light cars. Wealthier people can buy heavier cars; people with low income might not be able to afford them. In our primarily urban, industrial society, people with more income [and education] tend to have a more health-conscious lifestyle and fewer behaviors detrimental to health. That presumably includes driving more prudently.[36] Maybe the trend toward lower fatality risk in heavier cars is largely a trend toward lower risk in more expensive cars with wealthier drivers – especially in pedestrian crashes where there are no obvious physical factors that should make heavier cars safer.

The hypothesis is tested by adding the sales price to the database and running the regression for pedestrian/bike/motorcycle fatalities with this additional variable. Sales prices are entered at the make-model level, using the lowest sticker price listed in *Automotive News Market Data Books*.[37] If the model was produced in MY 1998, the 1998 price is used for all model years; otherwise, the price for the model year closest to 1998 is changed to 1998 dollars by the GDP deflator. That procedure makes the price constant across model years and eliminates inflation-related vehicle age effects. As in some other regression analyses of this type[38], the initial choice for an independent variable is the logarithm of the price, LPRICE.

Even the transformed variable LPRICE has a high correlation (r = .89) with curb weight at the make-model level. Heavier cars are unquestionably more expensive, on the average. That level of correlation creates a risk that a regression with both price and curb weight as independent variables might inaccurately sort out their effects. The price variable can be made somewhat more "orthogonal" to curb weight by transforming it to "log price per pound,"

$$L\_PR\_LB = LPRICE/\text{curb weight}$$

L_PR_LB measures the luxury of a car. Its correlation with curb weight is .69, generally "safe" for regressions.

In Section 3.4, the baseline regression for pedestrian/bike/motorcycle fatality rates produced the following coefficients for the curb weight of the car, indicating, among cars weighing less than 2,950 pounds, a strong 3.48 fatality increase per 100-pound weight reduction:

	Coefficient	Wald Chi-Square	P <
UNDRWT00	- .0348	34.75	.0001
OVERWT00	+ .0062	1.72	.1892

Next L_PR_LB is added to the baseline regression. All the independent variables in Section 3.5, such as curb weight, driver age/gender, etc. are retained. L_PR_LB has a statistically significant negative coefficient, indicating that more luxurious cars have lower pedestrian fatality rates.

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[36] Evans, *op. cit.*, pp. 141-148.
[37] Kavalauskas, J.S., and Kahane, C.J., *Evaluation of the American Automobile Labeling Act*, NHTSA Technical Report No. DOT HS 809 208, Washington, 2001, pp. 163-172 tabulates these prices for MY 1994-98.
[38] *Ibid*., pp. 57-69.

Importantly, though, the weight-safety effect in the lighter cars is nearly unchanged from the baseline case:

	Coefficient	Wald Chi-Square	P <
UNDRWT00	- .0324	28.98	.0001
OVERWT00	+ .0125	5.53	.0187
L_PR_LB	- .1822	5.99	.0144

Even the less transformed, more "risky" variable LPRICE, although significant, eats away less than 1/3 of the baseline weight-safety effect in the lighter cars. UNDRWT00 is still statistically significant:

	Coefficient	Wald Chi-Square	P <
UNDRWT00	- .0249	12.04	.0005
OVERWT00	+ .0179	7.46	.0063
LPRICE	- .1863	6.25	.0124

In other words, more expensive cars have lower pedestrian fatality rates, possibly indicating they are driven more prudently, but that effect is fairly orthogonal to, and does not explain the strong weight-safety effect in pedestrian crashes among the lighter cars.

Another approach is to consider the **nameplate** (manufacturer/division) of the car. What you drive is a small part of who you are. Some nameplates have historically had a bold image while others appeal to meticulous types. Price or luxury is not necessarily a factor here. Could it be that the lighter vehicles are hitting more pedestrians because they have a concentration of nameplates that attract the less conscientious drivers?

The hypothesis was tested by identifying nameplates that: (1) had reasonably high sales volume, and (2) offered 4-door cars of at least two sizes, preferably a lineup ranging from small to full-sized cars. A set of dichotomous independent variables representing the various nameplates was added to the baseline regression for ped/bike/motorcycle crashes.

The baseline regression for pedestrian/bike/motorcycle fatality rates produced the following coefficients for the curb weight of the car:

Without Nameplate Variables

	Coefficient	Wald Chi-Square	P <
UNDRWT00	- .0348	34.75	.0001
OVERWT00	+ .0062	1.72	.1892

When all the nameplate variables are added to the baseline regression, the coefficients for curb weight remain virtually unchanged:

With Nameplate Variables

	Coefficient	Wald Chi-Square	P <
UNDRWT00	- .0358	29.78	.0001
OVERWT00	+ .0104	2.77	.0959

Many of the nameplate variables were statistically significant, indicating large differences between nameplates in pedestrian fatality rates. These differences undoubtedly have much more to do with the "image" of the nameplates than any intrinsic quality of the cars. For example, different divisions of the same manufacturer have sharply different rates for essentially identical cars. When it comes to nameplates, there is clearly a self-selection process, with more prudent drivers tending to pick the brands with a reputation for prudent drivers. But this process is also orthogonal to, and does not explain the strong weight-safety effect in pedestrian crashes among the lighter cars. (However, the absence of a weight interaction between nameplates does not preclude the possibility that within any given nameplate, better drivers pick the heavier cars – i.e., in the "jaunty" nameplates, terrible drivers pick the small cars and merely bad drivers pick the big cars, whereas in the "stodgy" nameplates, good drivers pick the small cars and absolutely wonderful drivers pick the big cars.)

The three preceding analyses certainly did not prove that bad driving causes small cars to have high pedestrian fatality rates – although they left enough unanswered questions that the bad-driving hypothesis cannot be summarily rejected.

Next, it is necessary to consider any **physical characteristics of small cars** that could make them intrinsically more harmful than large cars in pedestrian impacts. The literature does not provide unequivocal answers but does hint at geometric features of small cars that could increase serious injury risk of pedestrians.

Large cars have longer hoods than small cars. When the front of a large car strikes a pedestrian, it often sweeps the pedestrian's legs out from under, resulting in a head impact somewhere on the hood. NHTSA research has shown the hood to be one of the softest areas on the car's exterior, especially in the middle.[39] With a smaller car's short hood, the head impact is often located beyond the hood, in the windshield area, not just with the relatively soft laminated glazing but also with its exceedingly rigid metal frame.

This hypothesis is addressed directly in *Pedestrian Injuries and the Downsizing of Cars*, a 1983 NHTSA analysis of the agency's database of pedestrian crashes, the Pedestrian Injury Causation Study (PICS) of 1977-80: "As car curb weight decreased…the proportion of head injures increases….The increase in head injuries seems connected with shorter and lower hoods, which

[39] MacLaughlin, T.F., and Kessler, J.W., *Pedestrian Head Impact Against the Central Hood of Motor Vehicles – Test Procedure and Results*, Paper No. 902315, Society of Automotive Engineers, Warrendale, PA, 1990.

result in more hood top and windshield contacts."[40] One caveat in the report, though, was that "large changes in overall severity are not observed" between light and heavy cars when 'overall severity' is measured by the Injury Severity Score (ISS). Essentially, the excess of dangerous head injuries from windshield frames in small cars is offset by an excess of more common, but less dangerous leg injuries from the fronts of large cars, resulting in about equal average ISS.

However, the report includes tables that focus on life-threatening injuries and clearly show a trend to greater risk in smaller cars: 76 percent of the pedestrians with maximum AIS 5 or 6, and 36 percent of the pedestrians with maximum AIS 4-6 received their most severe injury from the windshield/frame area. Pedestrians were more than twice as likely to contact the windshield or frame in impacts by small cars (< 2,450 pounds) as in impacts by medium (2,450-3,249 pounds) or large cars (3,250-3,949 pounds).[41] Although the data are by now over 20 years old, they are quite consistent with the regression results, that show a strong decline in pedestrian fatalities as car weight increased up to 2,950 pounds, and leveling off above that weight.

Two other hypotheses may be considered for small cars' high pedestrian fatality rate: (1) Even though the regression analyses control for "urban/rural," etc., they may not control enough. For example, large cars in "urban" areas might be concentrated in the suburbs, where there are fewer pedestrians, but small cars in the central city, where there are more. To the extent this hypothesis is true, the high weight-safety coefficients in the pedestrian regressions would be artifacts of the analysis, but the problem would be unique to pedestrian crashes and not spill over into other crash modes. (2) Small cars are less visible, or appear less threatening or further away, and pedestrians are more likely to cut or cross in front of them. If this is true to any extent, it would be a "real" effect, but it would also be unique to pedestrian crash modes and not spill over into the other crash modes.

3.7 Best estimates of the effect of a 100-pound weight reduction

Six regression analyses provided the 12 initial point estimates of the cross-sectional increase in the fatality rate, per 100-pound weight reduction, shown at the beginning of Section 3.5. They are the actual average increases in the fatality rates of existing MY 1991-99 cars in CY 1995-2000 as you move down the scale from current heavy cars to current lighter cars. There are various uncertainties when those results are used to model the relationship of vehicle weight to fatality risk in 1991-99 cars:

- The basic sampling error in calibrating the relationship of vehicle weight to fatality risk, based on the limited, existing fatality and exposure data.
- The additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc.

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[40] Blodgett, R.J., *Pedestrian Injuries and the Downsizing of Cars*, Paper No. 830050, Society of Automotive Engineers, Warrendale, PA, 1983.
[41] *Ibid*., Tables 12 and 13.

- A possible adjustment for self-selection – i.e., to compensate for the extent, if any, to which small-car fatality rates were higher because better drivers selected heavier cars.

The basic sampling error for each of the twelve regression coefficients for curb weight is the "standard error" generated by the SAS logistic regression procedure for that coefficient. In Section 3.5, the additional error due to using data from just 8 of the States was computed for the analysis of fixed-object crashes. The regression coefficient for curb weight up to 2,950 pounds had basic standard error .478 percent and additional standard error .38 percent. The combined standard error is

$$(.478^{2} + .38^{2})^{.5} = .611$$

a modest escalation factor of .611/.478 = 1.28. The regression coefficient for curb weight above 2,950 pounds has basic standard error .405 percent and additional standard error .36 percent. The combined error is .542, and the escalation factor is .542/.405 = 1.34. Thus, the average of the two escalation factors is 1.31. The overall sampling error, using 1.96 standard deviations, would be 1.96 x 1.31 = 2.57 times the basic standard error in the regression printouts.

The influence on the regression results due to better drivers self-selecting heavier cars is, of course, not exactly known and might not even exist. It can't really be measured using statistical theory. The regression results for pedestrian crashes are used to appraise a likely range for this influence. Among cars weighing less than 2,950 pounds, the regression showed a strong 3.48 percent increase in fatality rates of existing cars, per 100-pound weight reduction, after controlling for driver age/gender, etc. A "fault tree" analysis of that 3.48 percent effect suggests it could have one, some, or even all of the following components:

(1) Structural/geometric factors made it more dangerous for pedestrians to be hit by a small car

(2) Pedestrians paid less attention to small cars

Higher fatality rates because small cars were driven less prudently

    (3) Reducing car size tempted or induced the driver to weave more in traffic, etc.

    Small cars driven less prudently only because worse drivers self-selected them

        (4) Self-selection only affected fatality rates in pedestrian crashes

        (5) Self-selection affected rates in other crash modes, too

Only branch (5) of the tree would have inflated the size-safety effect in all crash modes, whereas branches (1), (2) and (3) would be "real" safety effects. In fact, Section 3.6 provides substantive evidence from the Pedestrian Injury Causation Study of a real safety effect on branch (1): the geometry of small cars apparently increased the risk of serious head injuries to pedestrians by the windshield frame. The other analyses of Section 3.6 show little evidence that small 4-door cars were driven less prudently than large cars, let alone that this would be due to self-selection. Those analyses showed that small and large 4-door cars had equal incidence of various unsafe driving behaviors, and that the size-safety effect in pedestrian crashes persisted even after controlling for vehicle price (as a surrogate for driver income) or nameplate (as a surrogate for a car's image or reputation).

The conclusion is that the observed size-safety effect in pedestrian crashes had to be real to quite some extent if not completely, and that it couldn't all have been self-selection. We need to place a lower and an upper bound on the proportion of the pedestrian effect that will be ascribed to self-selection. The lower bound, clearly, is that **none** of the pedestrian effect was self-selection and all of it was real: none of the preceding analyses of imprudent driving behaviors, presence of child passengers, or vehicle price/nameplate showed any evidence supporting the self-selection hypothesis, whereas the Pedestrian Injury Causation Study suggested that small cars are really more dangerous to pedestrians. The upper bound is more difficult to quantify. Even as an upper bound, we cannot assume the entire pedestrian effect was self-selection, because the Pedestrian Injury Causation study clearly indicates the geometry of small cars increased risk for pedestrians. Thus, the upper bound is some proportion, greater than zero but less than 100 percent, of the pedestrian effect. In the absence of evidence supporting any specific proportion, let us split the difference between 0 and 100 percent and use **half** the observed effect in pedestrian crashes is due to self-selection: 1.74 percent for cars up to 2,950 pounds. Since self-selection would also inflate the results in the other crash modes, 1.74 percent are also deducted from the size-safety effects for lighter cars in the other crash modes as well.[42]

The deduction of 0 to 1.74 percent applies only for cars weighing less than 2,950 pounds. In cars weighing 2,950 pounds or more, the observed effect of a 100-pound reduction was a non-significant 0.62 percent increase in pedestrian fatality rates – i.e., no evidence of self-selection that favored the heaviest cars over mid-sized cars.

Combining the three sources of uncertainty generates the interval estimates shown in Table 3-3. Although these interval estimates are derived from exact arithmetic formulas, they are not statistically precise "95 percent confidence intervals." They only convey a sense of the uncertainty in the results, based on 1.96 sigma sampling errors from known sources, plus an allowance for nonsampling errors.

For example, the regression for principal rollovers in Section 3.4 calibrated a 5.08 percent increase in fatality risk per 100-pound weight reduction in cars weighing less than 2,950 pounds. That's the point estimate. Its standard error, as shown on the SAS printout, is .963. Taking 2.57 times this basic standard error is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States). That yields a 1.96 sigma sampling error equal to 2.57 x .963 = 2.47 percentage points.

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[42] James Hedlund and Donald Reinfurt, who reviewed this report, advised the author on describing the process for using half the pedestrian effect as an adjustment factor. Adrian Lund, in his review, described this adjustment as an "an unnecessarily conservative action in the context of the multiple analyses conducted which found no hint that smaller cars were attracting more dangerous drivers. Moreover, several physical explanations were offered that supported the finding that the smallest vehicles may indeed be more harmful to pedestrians because of where their heads would contact the vehicle." The three reviews are available in the NHTSA docket for this report.

The lower bound of the interval estimate is the point estimate, minus the sampling error, minus half the pedestrian effect. In other words, half the pedestrian effect is deducted to adjust for possible self-selection:

$$\text{Lower bound} = 5.08 - 2.47 - \tfrac{1}{2}(3.48) = 0.87$$

The upper bound of the interval estimate is the point estimate plus the sampling error. Here, the entire pedestrian effect is assumed to be "real" and not an indicator of overestimation in the other crash modes:

$$\text{Upper bound} = 5.08 + 2.47 = 7.55$$

For cars weighing 2,950 pounds or more, the regression estimates a non-significant 0.62 percent fatality reduction per 100-pound weight reduction – i.e., no self-selection adjustment is applied. The interval estimate is simply the point estimate plus or minus 2.57 standard errors.

In Table 3-3, the effects in car-to-car collisions have been split into two separate lines: when the "other" car weighs less than 2,950 pounds and when it weighs 2,950 pounds or more. The effect and its errors are doubled in the line where the case and other cars are in the same weight category. The explanation is as follows. In general, as stated earlier, effects are additive. For example, in fixed-object collisions, the effect of a 200-pound reduction would be approximately double the effect of a 100-pound reduction.[43] Similarly, in collisions between cars weighing less than 2,950 pounds with cars weighing more than 2,950 pounds, the societal effect of reducing both vehicles by 100 pounds would be the sum of the effects of reducing first the one and then the other by 100 pounds: 2.48 + 1.59 = 4.07 percent increase. By the same logic, a 100-pound reduction in "all" cars weighing less than 2,950 pounds implies that in collisions between two cars weighing less than 2,950 pounds, both the case and the other vehicle are reduced. The societal effect will be the sum of reducing each one singly – i.e., double the original regression coefficient. (Chapter 6 will present regression analyses of fatality rates in two-car collisions by the weight of each vehicle, and it will confirm that the effect of reducing both vehicles is double the regression coefficient in this chapter.)

[43] Actually $1 - 1.0322^2 = 6.54$ percent increase.

TABLE 3-3

FATALITY INCREASE (%) PER 100-POUND WEIGHT REDUCTION, PASSENGER CARS

Crash Mode	Regression Result	Standard Error	2.57[44] x Std. Error	Interval Estimate Incl. ½ of Ped Effect
CARS WEIGHING LESS THAN 2,950 POUNDS				
Principal rollover	5.08	.963	2.47	.87 to 7.55[45]
Fixed object	3.22	.478	1.23	.25 to 4.45
Ped/bike/motorcycle	3.48	.590	1.52	.22 to 5.00
Heavy truck	5.96	.670	1.72	2.50 to 7.68
Car < 2,950[46]	4.96	.856	2.20	- .72 to 7.16
Car 2,950 +	2.48	.428	1.10	- .36 to 3.58
Light truck	5.63	.403	1.04	2.85 to 6.67
CARS WEIGHING 2,950 POUNDS OR MORE				
Principal rollover	4.70	.894	2.30	2.40 to 7.00[47]
Fixed object	1.67	.405	1.04	0.63 to 2.71
Ped/bike/motorcycle	- .62	.471	1.21	- 1.83 to .59
Heavy truck	2.06	.539	1.39	.67 to 3.45
Car < 2,950	1.59	.348	.89	.70 to 2.48
Car 2,950 +[48]	3.18	.696	1.78	1.40 to 4.96
Light truck	2.62	.341	.88	1.74 to 3.50

[44] As explained in the text, 2.57 times the basic standard error of the regression coefficient is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States).

[45] Lower bound = point estimate – sampling error – half of pedestrian effect = 5.08 – 2.47 – ½ (3.48); upper bound = point estimate + sampling error = 5.08 + 2.47

[46] Assumes both cars in the collision are reduced by 100 pounds: point estimate, standard error and self-selection adjustment are doubled.

[47] Lower bound = 4.70 – 2.30; upper bound = 4.70 + 2.30

[48] Assumes both cars in the collision are reduced by 100 pounds: point estimate, standard error and self-selection adjustment are doubled.

3.8 Effect of weight reductions on the number of fatalities

The percentage changes in the fatality rate, as estimated in Table 3-3, are applied to the absolute numbers of "baseline" fatalities to obtain estimates of the effects of 100-pound weight reductions on the absolute numbers of fatalities. The baseline numbers used in this report are a synthesis of national fatality totals, in single and multivehicle crashes, for CY 1999 and fatality distributions by vehicle type, vehicle weight, and more detailed crash mode based on MY 1996-99 vehicles in CY 1996-2000 FARS.[49] They represent the fatality counts that would likely have been seen if the vehicle mix of 1996-99 had constituted the entire on-road fleet. This baseline is geared for estimating the impact of possible weight reductions that could have occurred in the 1996-99 fleet if consumers had bought a higher proportion of lighter cars.

The starting point for estimating baseline fatalities is the 1999 FARS file that contains records of 41,717 fatalities in traffic crashes in the United States. The vehicle records on this file are classified as passenger cars, light trucks, heavy trucks and buses, motorcycles, other or unknown, based on the VIN where available and BODYTYPE otherwise. Within each crash, the vehicle records are re-sorted by vehicle type (passenger cars first, then light trucks, etc.) and VEH_NO. A new vehicle-oriented file is created, containing one record per crash, with the first vehicle in the crash (after the re-sorting) as the "case" vehicle, and retaining information on the other vehicles involved, the total number of fatalities, etc. This new file, although vehicle-oriented, counts each of the 41,717 fatalities exactly once. The vehicles can be of any model year or even have unknown model year.

The new file is analyzed by crash mode and vehicle mix by the procedure defined in Section 2.2; 3,206 fatalities are excluded because they occurred in crashes that did not involve any cars or light trucks, but only heavy trucks, buses, motorcycles, other and/or unknown vehicle types. Another 857 fatalities are excluded because they do not belong to the basic crash modes 1-6. That leaves 37,654 fatalities in crashes involving at least one passenger car and/or light truck and classifiable in the six basic crash modes (rollover, fixed-object, ped/bike/motorcycle, hit a heavy truck, hit a car, hit a light truck). Of these, 25,412 fatalities are in crash modes 1-4 (most of which involve just a single car or light truck) while 12,242 are in crash modes 5 and 6 (all of which involve at least two cars or light trucks). Two-door cars and police cars are included in the baseline counts, even though they were not used in the regression analyses.

Next, the 25,412 fatalities in crash modes 1-4 are subdivided by vehicle type (car or light truck), vehicle weight, and crash mode, based on the percentage distributions across those variables for MY 1996-99 vehicles in CY 1996-2000 FARS. The percentage distributions can be tabulated

[49] CY 1999 was the latest full year of State and FARS data at the time that work on this report began. Annual fatalities were nearly constant in 1995-2000, ranging from 41,501 to 42,065. The number of fatalities on the 1999 FARS file, 41,717 is near the average for 1995-2000. *Traffic Safety Facts, 2001*, NHTSA Report No. DOT HS 809 484, Washington, 2002, p. 15.

from a subset of the fatal crash file created in Section 2.2.[50] The apportionment of the fatalities is:

Crash Mode	Cars < 2,950	Cars 2,950 +	LTVs < 3,870	LTVs 3,870 +	TOTAL
Principal rollover	995	715	1,319	2,183	5,212
Fixed object	3,357	2,822	1,687	2,639	10,505
Ped/bike/motorcycle	1,741	1,349	1,148	2,043	6,281
Heavy truck	1,148	822	584	860	3,414
TOTAL	7,241	5,708	4,738	7,725	25,412

Similarly, the 12,242 fatalities in crash modes 5-6 are subdivided by the "case" vehicle's type and weight and the "other" vehicle's type and weight, based on the percentage distribution of those variables in **2-vehicle** crashes during CY 1996-2000 in which both vehicles were MY 1996-99 cars or light trucks. First, here is how the 12,242 fatalities would distribute as occupants of the "case" vehicle:

Case Vehicle Occupant Fatalities:	Other Vehicle				
Case Vehicle	Car < 2,950	Car 2,950 +	LTV < 3,870	LTV 3,870 +	TOTAL
Car < 2,950	934	773	891	2,609	5,207
Car 2,950 +	569	677	677	1,707	3,630
LTV < 3,870	226	268	247	709	1,450
LTV 3,870 +	365	505	301	784	1,955
TOTAL	2,094	2,223	2,116	5,809	12,242

In the above table, each crash appears twice (once with vehicle 1 as the case vehicle, and once with vehicle 2 as the case vehicle), but each fatality is counted only once, as an occupant of the case vehicle. Note, for example, that in crashes between small cars and large LTVs, there are 2,609 fatalities in the cars and 365 in the LTVs. Next, the fatalities in the case and the other

[50] Vehicle records for crash modes 1-4 are weighted by FATALS. The few cases that involved more than one passenger vehicle – e.g., 2 vehicles and a pedestrian – are weighted by FATALS divided by the number of passenger vehicles, in order to avoid double-counting. Two-door cars and police cars of MY 1996-99 are included in this analysis, also.

vehicle are added to obtain counts of crash fatalities as a function of the vehicle mix. (The counts add up to more than 12,242, since each fatality appears twice, except in the diagonal entries.) Since the regression analyses calibrate relationships between vehicle weights and crash fatality rates, these are the baseline numbers that will be used to calculate net effects of weight reductions:

CRASH FATALITIES:	Other Vehicle				
	Car		LTV		
Case Vehicle	< 2,950	2,950 +	< 3,870	3,870 +	TOTAL
Car < 2,950	934	1,342	4,091		6,367
Car 2,950 +	1,342	677	3,157		5,176
LTV < 3,870	2,062		247	1,010	3,319
LTV 3,870 +	5,186		1,010	784	6,980

Table 3-4 estimates what would have been the annual net effects of reduced passenger car weights. The upper section of Table 3-4 computes the effect of an average 100-pound downward shift in cars that weighed less than 2,950 pounds, but leaving heavier cars and light trucks unchanged. For example, there are 995 annual baseline fatalities in principal rollovers of cars weighing less than 2,950 pounds. The point estimate from the regression analysis is a 5.08 percent increase in fatalities per 100-pound weight reduction. The point estimate of the net effect is .0508 x 995 = 51 more fatalities per year. The interval estimate of the effect, taking into account both sampling error and possible adjustment for self-selection in the regression results, ranges from 0.87 to 7.55 percent, as computed in Table 3-3. Thus, the interval estimate of the net fatality increase ranges from 9 to 75 additional fatalities per year in rollovers.

For case cars weighing less than 2,950 pounds, each of the crash modes has positive point estimates, indicating more fatalities as weight is reduced, and all except car-to-car have entirely positive interval estimates. In absolute terms, collisions with light trucks (230) and fixed objects (108) show the highest fatality increases per 100-pound weight reduction. The most confident results, however, are for collisions of light cars with heavy trucks and light trucks, where even the lower bound is substantially greater than zero.

Overall, cars weighing less than 2,950 pounds are involved in fatal crashes that result in a total of 13,608 fatalities per year to occupants of these cars, plus occupants of other vehicles, plus non-occupants. A 100-pound reduction would have significantly increased those fatalities: the point estimate based directly on the regression results is 597, and the interval estimate accounting for sampling error and possible adjustment for self-selection is 226 to 715. The overall point estimate is simply the sum of the estimates for the various, mutually exclusive crash modes. The overall interval estimate, on the other hand, is a bit narrower than what would be obtained by just

TABLE 3-4

FATALITY INCREASE PER 100-POUND WEIGHT REDUCTION, PASSENGER CARS

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Crash Mode	Annual Baseline Fatalities	Effect (%) of 100-Pound Reduction: Regression Result	Effect (%) of 100-Pound Reduction: Interval Estimate	Net Fatality Change: Regression Result	Net Fatality Change: Interval Estimate
CARS WEIGHING LESS THAN 2,950 POUNDS					
Principal rollover	995	5.08	.87 to 7.55	51	9 to 75
Fixed object	3,357	3.22	.25 to 4.45	108	8 to 149
Ped/bike/motorcycle	1,741	3.48	.22 to 5.00	61	4 to 87
Heavy truck	1,148	5.96	2.50 to 7.68	68	29 to 88
Car < 2,950*	934	4.96	- .72 to 7.16	46	- 7 to 67
Car 2,950 +	1,342	2.48	- .36 to 3.58	33	- 5 to 48
Light truck	4,091	5.63	2.85 to 6.67	230	117 to 273
OVERALL	**13,608**	**4.39**	**1.66 to 5.25**	**597**	**226 to 715**
CARS WEIGHING 2,950 POUNDS OR MORE					
Principal rollover	715	4.70	2.40 to 7.00	34	17 to 50
Fixed object	2,822	1.67	.63 to 2.71	47	18 to 76
Ped/bike/motorcycle	1,349	- .62	- 1.83 to .59	- 8	- 25 to 8
Heavy truck	822	2.06	.67 to 3.45	17	6 to 28
Car < 2,950	1,342	1.59	.70 to 2.48	21	9 to 33
Car 2,950 +*	677	3.18	1.40 to 4.96	22	9 to 34
Light truck	3,157	2.62	1.74 to 3.50	83	55 to 110
OVERALL	**10,884**	**1.98**	**1.19 to 2.78**	**216**	**129 to 303**

* Assumes both cars in the collision are reduced by 100 pounds

summing the lower bounds and upper bounds of the various crash modes.[51] As stated above, these interval estimates are not statistically precise "95 percent confidence intervals."

In relative terms, the point estimate is a 597/13,608 = 4.39 percent fatality increase per 100-pound weight reduction. The interval estimate ranges from 226/13,608 = 1.66 to 715/13,608 = 5.25 percent.

The lower section of Table 3-4 analyzes case cars weighing 2,950 pounds or more. Each of the crash modes except ped/bike/motorcycle has positive point and interval estimates, indicating significantly more fatalities if weight had been reduced. On the other hand, all of the point estimates are smaller than the corresponding estimates for light cars, in many cases much smaller. Here, too, collisions with light trucks (83) and fixed objects (47) show the highest fatality increases.

Overall, cars weighing 2,950 pounds or more are involved in fatal crashes that result in a total of 10,884 fatalities per year. A 100-pound reduction would have significantly increased those fatalities: the point estimate is 216, and the interval estimate is 129 to 303. As explained in Section 3.7, there does not appear to be a systematic bias that favors the heavier cars within this subgroup. Thus, the interval estimate considers only the uncertainty from the basic regression analyses and the 8-State effect, and it accumulates those two sources of error by the same procedures used for the lighter cars. In relative terms, the fatality increase per 100-pound reduction is 1.98 percent (point estimate), or a range from 1.19 to 2.78 percent (interval estimate).

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[51] The analysis in Section 3.7 considered three sources of uncertainty that accumulate in different ways across crash modes: (1) The basic sampling error in the regression coefficients for vehicle weight. This error derives almost entirely from the finiteness of the FARS data (since the induced-exposure cases outnumber the FARS cases by a factor of 100 or more in the regressions). Since different FARS data are used in different crash modes, the errors are essentially independent across the crash modes and can be accumulated on a root-sum-of-squares basis (except the two car-to-car results are based on the same regression, and their errors need to be added). (2) The additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc. It contributes a .0038 coefficient of variation for the lighter cars. This error is the same in all crash modes and it has to be added across the modes. On the other hand, this error could be in either direction, and it can be accumulated to the preceding error on a root-sum-of-squares basis. (3) The possible adjustment in the cross-sectional results due to better drivers self-selecting heavier cars. This is a systematic adjustment in every crash mode, always in the same direction, and was assessed as 1.74 percent, maximum. It is additive across crash modes and additive to the other errors.

In Table 3-3, the standard error for the regression coefficient in principal rollovers was .963 percent. Table 3-4 shows a baseline 995 fatalities per year in rollovers. The standard error of the absolute effect is .00963 x 995 = 9.58. Similarly, the standard errors of the absolute effect in the other crash modes are: fixed-object, 16.05; pedestrian, 10.29; heavy-truck, 7.69; car-to-car, 13.74 (adding the errors in car-to-light car and car-to-heavy car); and light-truck, 16.49. The square root of the sum of the squares of these six independent errors is 31.22. The standard error for the 8-State effect is .0038. Table 3-4 shows 13,608 baseline fatalities per year in all crash modes. The standard error of the 8-State effect, in absolute terms, is .0038 x 13,608 = 51.71. The overall 1.96 sigma sampling error is $1.96 \times (31.22^2 + 51.71^2)^{.5} = 118.38$. This quantity is added to the point estimate to obtain the upper bound of the interval estimate, which assumes no adjustment for self-selection: 597 + 118 = 715. This quantity and the maximum adjustment for self-selection are both subtracted from the point estimate to obtain the lower bound of the interval estimate. The adjustment is half the pedestrian effect, 1.74 percent in all crash modes except car-to-light-car, where it is doubled to 3.48 percent. The lower bound is 597 – 118 – .0174 x (13,608–934) - .0348 x 934 = 226.

The analyses of this chapter estimate a substantially higher size-safety effect in passenger cars than NHTSA's 1997 study. That report estimated an increase of 302 fatalities per 100-pound reduction,[52] whereas the sum of the point estimates for lighter and heavier cars would be 597 + 216 = 813 here. Although the interval estimates in Table 3-4 do allow room for considerably smaller numbers, even the sum of the lower interval estimates, 226 + 129 = 355, is still higher than the 302 point estimate of the 1997 study. The main difference between the two results, as will be discussed in a critique of the 1997 study in Section 4.8, is a series of analytical procedures in the 1997 study that inappropriately biased its results in favor of lighter cars.

One of the most important findings of this chapter is that the size-safety effect was not uniform, but was very probably weaker in the heavier cars. Table 3-4 suggests an overall 4.39 percent fatality increase per 100-pound reduction in the lighter cars, but only 1.98 percent in the heavier cars (point estimates). Chapters 4 and 5 will expand on those findings. They will suggest that the overall net effect of ostensible downward shifts in vehicle weight could have varied considerably, depending on whether they had been concentrated in certain vehicle groups or occurred across the board.

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[52] Kahane (1997), p. vi.

CHAPTER 4

VEHICLE WEIGHT AND FATALITY RISK IN LIGHT TRUCKS

4.0 Summary

A cross-sectional look at crash fatality rates per billion vehicle miles of model year 1991-99 light trucks (pickup trucks, SUVs and vans) in calendar years 1995-2000, controlling for driver age and gender, urban/rural, etc., shows different trends in the heavier and the lighter trucks. In trucks weighing 3,870 pounds or more (the median for model years 1991-99), a 100-pound reduction had little effect on overall crash fatalities, since increases in rollovers and fixed-object impacts were offset by reductions in collisions with other passenger vehicles: as heavy light trucks became lighter, they did less harm to occupants of other vehicles in multivehicle collisions. In light trucks weighing less than 3,870 pounds, on the other hand, each 100-pound reduction is associated with a 3 percent risk increase, amounting to a point estimate 234 additional fatalities per year, relative to baseline (the interval estimate is a range of 25 to 296 additional fatalities).

These are descriptive analyses of the fatal-crash experience of actual 1991-99 LTVs (Light Trucks and Vans – i.e., pickup trucks, SUVs, and vans). The percentage "fatality increase per 100-pound reduction," in the context of these analyses, does not mean the effect of literally removing 100 pounds from a specific LTV. It is the average percentage difference in the fatality rate of 1991-99 models weighing W pounds and the fatality rates of other 1991-99 models weighing W-100 pounds, given drivers of the same age/gender, etc. The absolute increases per year (e.g., 234 more fatalities) estimate what could have happened if the public, in 1991-99, had bought a different mix of LTVs – namely, higher shares of various light make-models and lower shares of the heavy ones – that would have reduced the average weight of LTVs on the road by 100 pounds.

4.1 Visible trends in the data

Graphs of fatality rates by curb weight, crash mode and, possibly, vehicle type may reveal basic trends in the data, help with formulating some of the analysis variables, and provide some idea of what the regression coefficients are likely to be.

Section 2.6 develops fatality and exposure databases suitable for computing fatality rates of light trucks. A principal difference from the passenger car analyses of the preceding chapter is that, with light trucks, fatality rates should be calculated per billion miles, not per million years, in order to allow comparisons "on a level playing field." As shown in Section 2.4, the heavier the LTV, the more miles it tends to be driven per year (whereas light and heavy 4-door cars had virtually the same annual mileage). Heavier LTVs have higher fatality rates per million years because they are driven more miles, not because they are less safe on a per-mile basis.

Tables 2-2 and 2-3 provide tools for converting vehicle registration years to vehicle miles. For example, the mileage ratio for compact pickup trucks to 4-door cars is 1.036 (Table 2-3). Since a

2-year-old 4-door car is driven an average of 15,023 miles per year (see Table 2-2), a 2-year-old compact pickup truck is driven approximately 1.036 x 15,023 = 15,564 miles per year.

All types of light trucks are included in the analyses except "incomplete" vehicles such as chassis-cabs or partially built vans designed for conversion to recreational vehicles. Incomplete vehicles must be excluded because their final curb weight upon completion is unknown to the original equipment manufacturer and not specified in the literature.

The fatality and exposure data are subdivided into 14 class intervals of curb weight, bounded at the top by the following percentiles of curb weight: the 2nd, 6th, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, 94th, 98th, and maximum weight. In these 14 groups, the average curb weight, number of fatal crash involvements of any type, total exposure in billions of vehicle miles, and the rate of fatal involvements per billion miles are as follows:

Cumulative Percent	Average Curb Weight	Fatal Crash Involvements	Billions of Vehicle Miles	Fatal Involvements Per Billion Miles
2	2,641	1,721	61.89	28
6	2,841	3,679	128.92	29
10	2,986	3,144	120.40	26
20	3,237	6,786	317.72	21
30	3,538	4,863	285.75	17
40	3,732	5,427	298.03	18
50	3,872	5,989	382.57	16
60	3,971	3,922	230.18	17
70	4,102	5,193	298.32	17
80	4,287	5,544	303.36	18
90	4,657	5,302	297.77	18
94	5,081	2,218	124.13	18
98	5,303	1,913	121.67	16
100	5,719	1,303	61.18	21

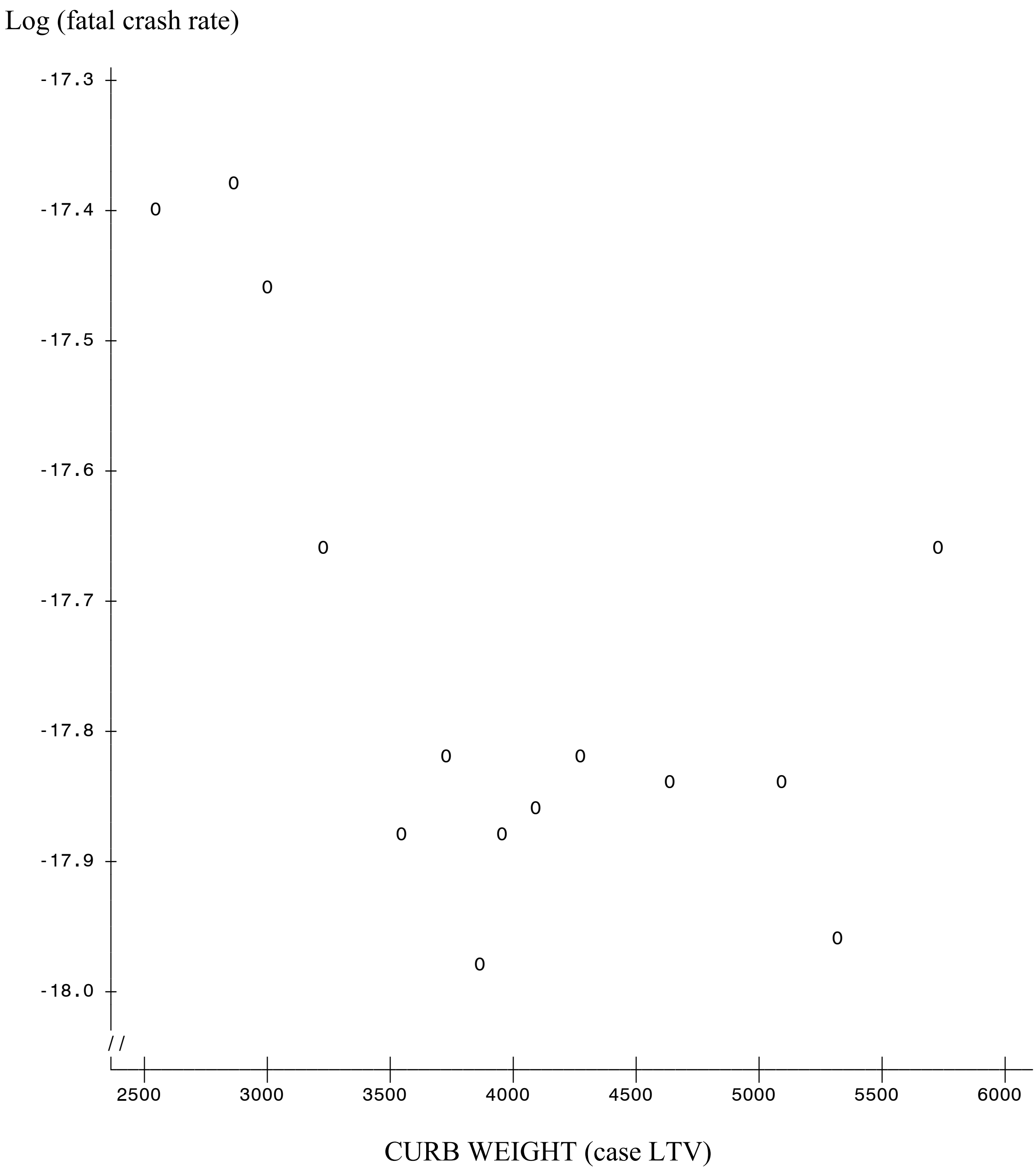
The involvement rate drops from 28-29 fatal crashes per billion miles at 2,641-2,841 pounds to 16-18 at 3,538-3,872 pounds, and changes very little as curb weight increases beyond 4,000 pounds (except for a somewhat higher reading in the very heaviest trucks). The trend is clear in Figure 4-1, which graphs the natural logarithm of the fatality rate by curb weight. As in Chapter 3, logarithms are used because they have more linear relationships to the independent variables.

Figure 4-1 looks a lot like its counterpart for passenger cars, Figure 3-1, except that the range of curb weights is higher for trucks (2,500-5,500) than cars (2,000-4,000). The size-safety effect is not uniform, but again has a 2-piece linear appearance, except here the "bend" is at a higher weight, somewhere between 3,500 and 4,000 pounds.

FIGURE 4-1: ALL CRASH TYPES

LOG(FATAL CRASH INVOLVEMENTS PER MILE, ANY TYPE) BY CURB WEIGHT*

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)



* Throughout this study, "log" means the natural logarithm.

Light trucks are a more diverse group of vehicles than 4-door cars. They include pickup trucks, SUVs and vans, and they are often used for specialized freight- and passenger-hauling tasks in addition to, or even instead of individual personal transportation. Figure 4-1a graphs the overall fatal-crash involvement rates separately for pickup trucks (circles), SUVs (boxes) and vans (V's).

Here, a more complex picture emerges. Pickup trucks show declining fatality rates from 2,500 to about 4,000 pounds, nearly level rates in the 4,000's, and perhaps a slight increase from 5,000 pounds onwards. SUVs are the one group whose fatality rates decline across the full range of curb weight. However, drivers and usage change with weight. For example, the lightest SUVs have a high proportion of young drivers. Vans under 4,000 pounds are primarily minivans and have lower fatality rates than other types of trucks. In fact, the low rate for minivans pulls down the rate for all trucks in the 3,300-4,000 pound range of Figure 4-1, and makes it flatten out sooner. Vans over 4,000 pounds are usually the full-sized type, have use patterns quite different from minivans, and have rising fatality rates.

The information in Figure 4-1a has implications for the statistical analyses: (1) It will be important to include the truck type (pickup, SUV, minivan or full-sized van) as a control variable, and of course to control for driver age and gender, urban/rural, etc., since they vary considerably between and within truck types. (2) It might also be desirable to do a separate set of analyses for pickup trucks only, since they are a more continuous spectrum of vehicles and drivers than other types of trucks: heavy and light pickup trucks look quite a bit alike, except the heavier ones are longer, wider, higher and more rigid. As pickup trucks get heavier, the database used in this report shows that rural mileage increases, as does the average age of the drivers and the percentage of male drivers, but all these increases are at a gradual, steady rate.

Figures 4-2 – 4-7 look at fatality rates or fatal-crash rates in the six individual crash modes defined in Section 2.2: rollover, fixed-object, ped/bike/motorcyle, heavy truck, car-to-car, and light truck. In the last three figures, the x-axis is always the curb weight of the "case" light truck. The "other" vehicle(s), heavy trucks, cars, or light trucks, respectively, can be any weight or any model year. "Fatalities" include all crash fatalities: occupants of the "case" light truck, occupants of any other vehicles, and non-occupants such as pedestrians or bicyclists.

Figure 4-2 examines rollover fatalities per mile of travel, by truck type and curb weight. The most important trend in Figure 4-2 is that SUVs consistently have more rollover fatalities than pickup trucks or minivans of comparable weight. Large vans also have high rollover rates. Within pickups and within SUVs, Figure 4-2 generally shows a fatality reduction as weight increases.

FIGURE 4-1a: ALL CRASH TYPES – BY TRUCK TYPE

LOG(FATAL CRASH INVOLVEMENTS PER MILE, ANY TYPE) BY CURB WEIGHT

(Pickup truck = ‘O’, SUV = ‘■’, van = ‘V’, MY 1991-99 in CY 1995-2000)

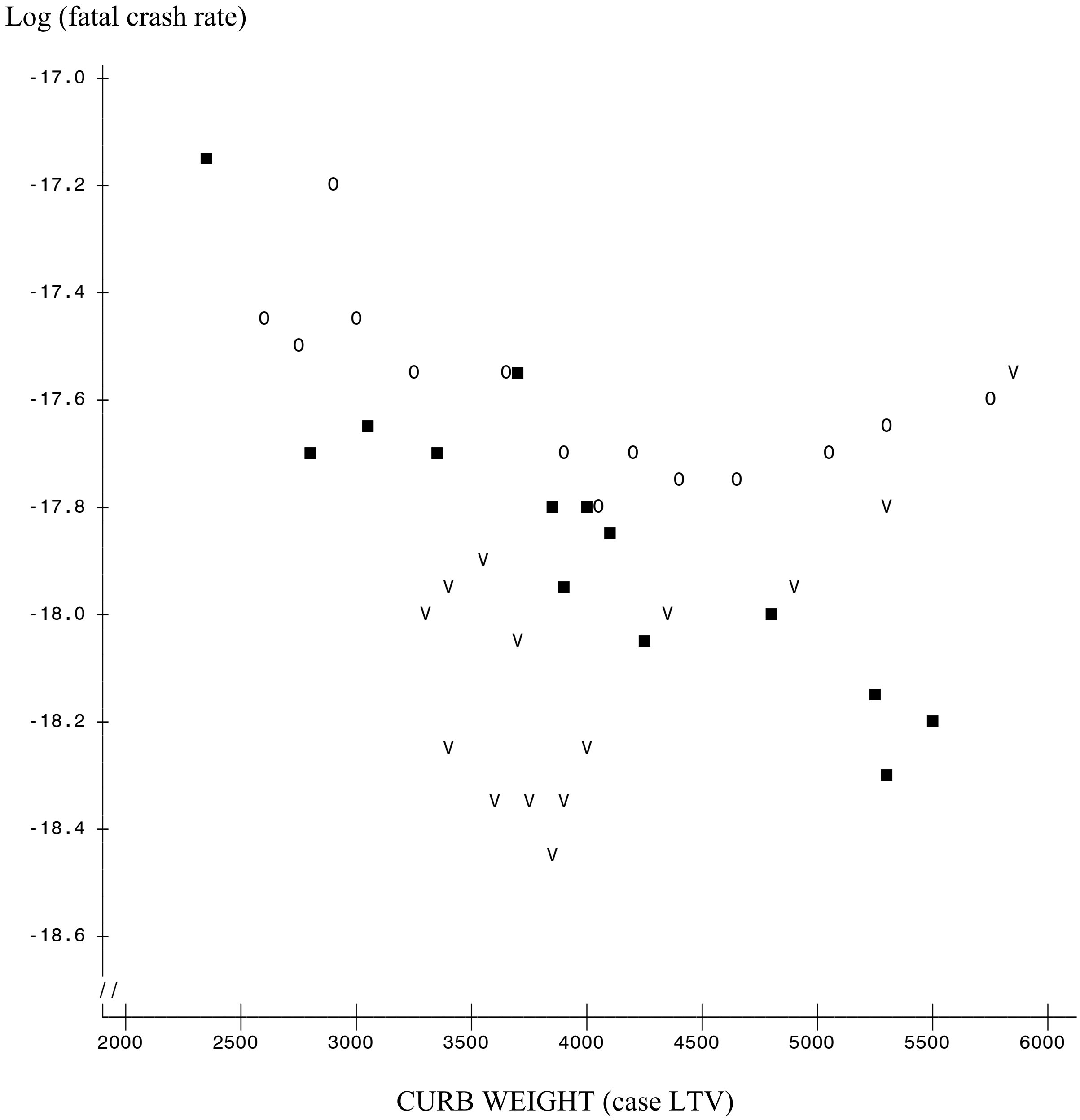


FIGURE 4-2: ROLLOVERS – BY TRUCK TYPE

LOG(ROLLOVER FATALITIES PER MILE) BY CURB WEIGHT

(Pickup truck = ‘O’, SUV = ‘■’, van = ‘V’, MY 1991-99 in CY 1995-2000)

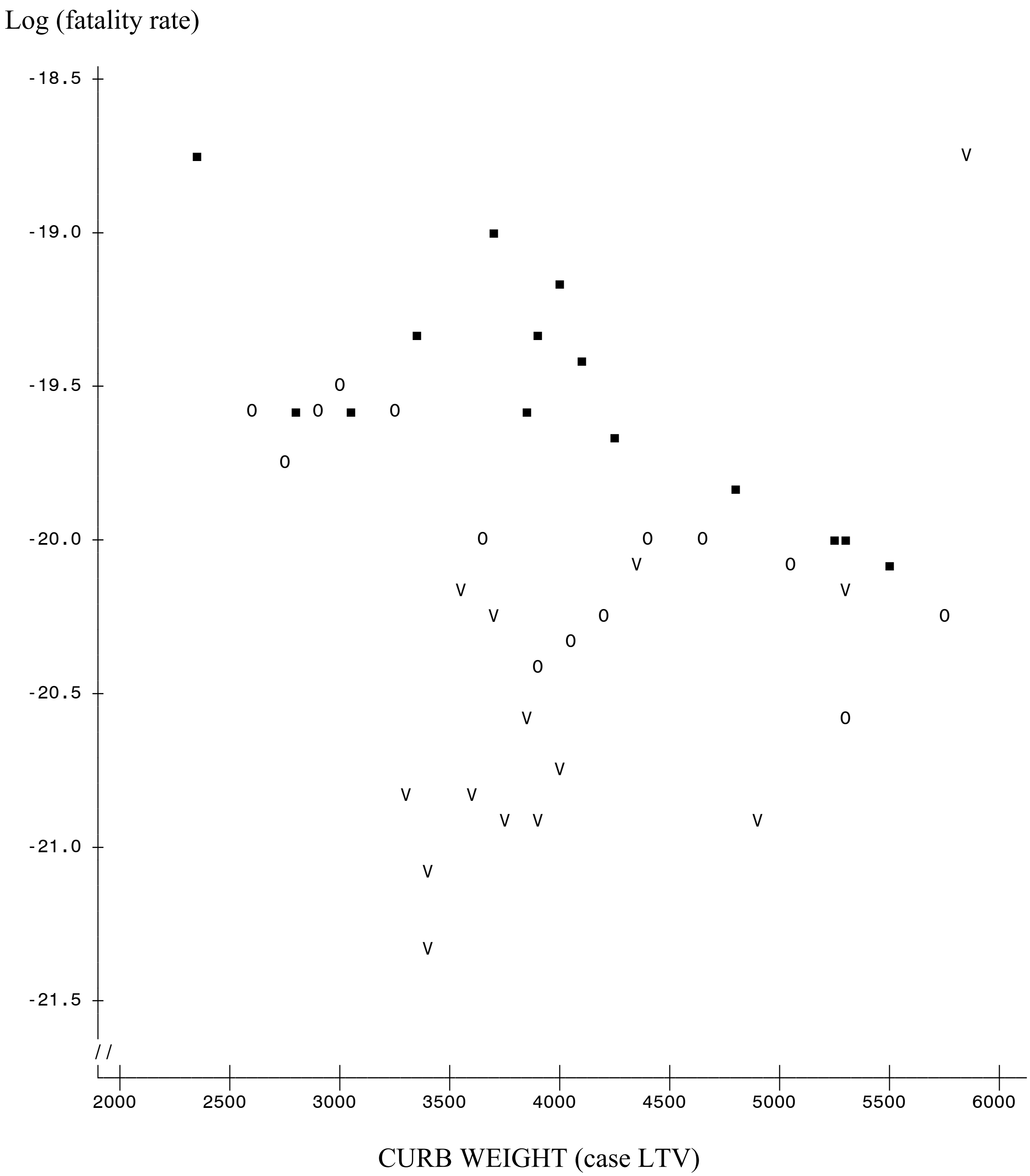


FIGURE 4-3: FIXED-OBJECT COLLISIONS

LOG(FIXED-OBJECT COLLISION FATALITIES PER MILE) BY CURB WEIGHT

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)

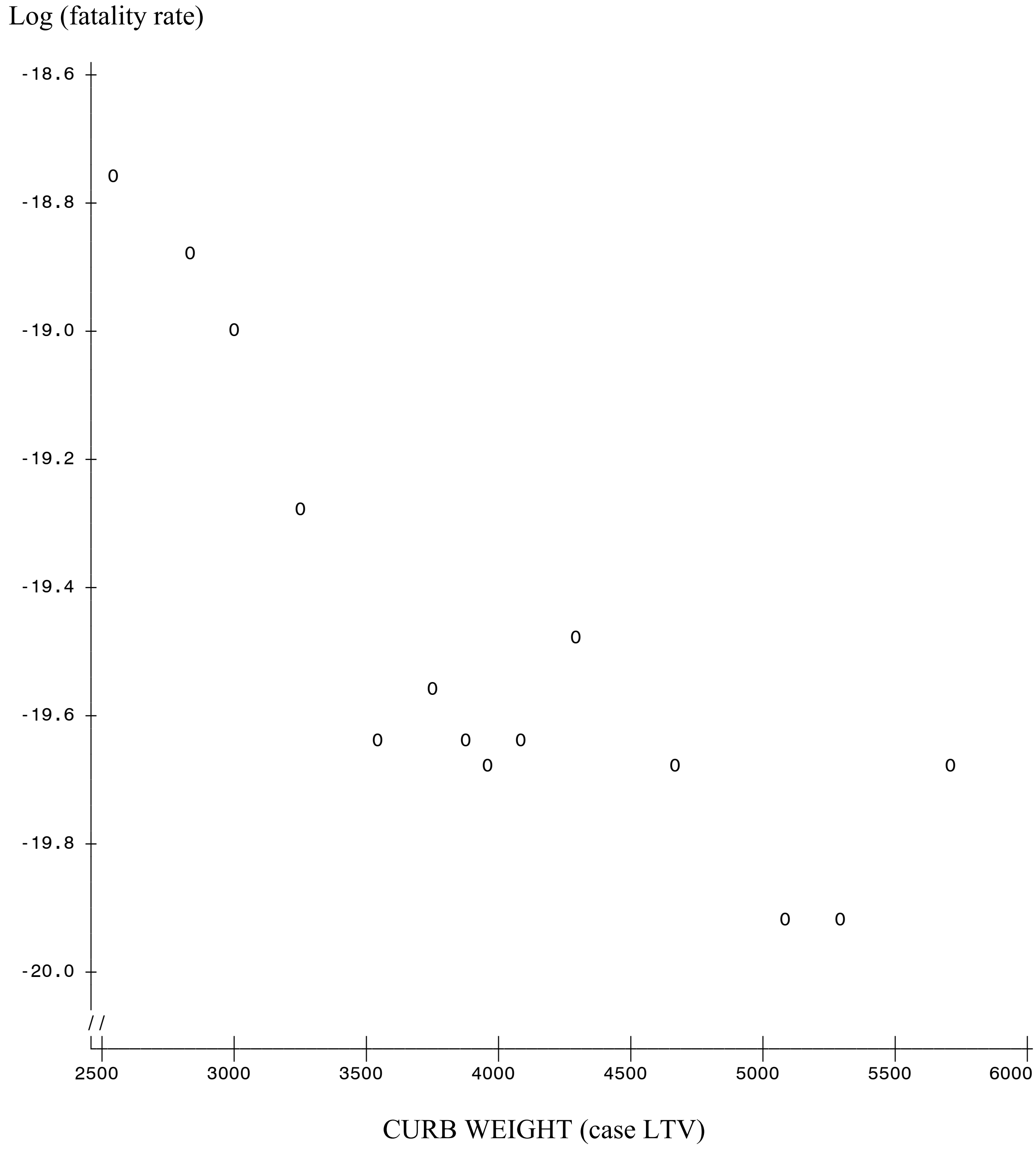


FIGURE 4-3a: PICKUP TRUCKS, MALE DRIVERS AGE 30-49
FIXED-OBJECT COLLISIONS

LOG(FIXED-OBJECT COLLISION FATALITIES PER MILE) BY CURB WEIGHT

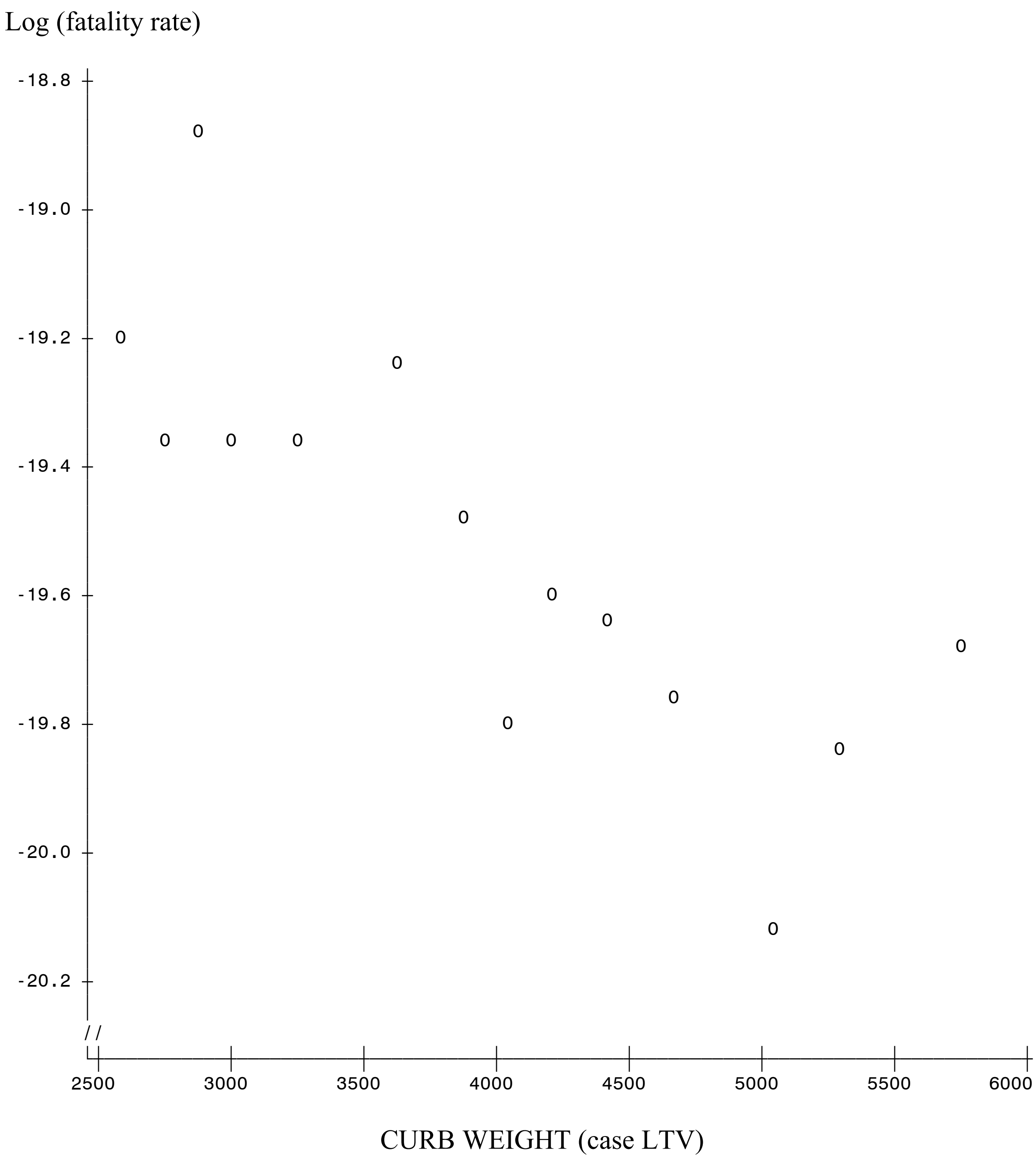


FIGURE 4-4: PEDESTRIANS/BICYCLISTS/MOTORCYCLISTS

LOG(PED/BIKE/MC FATALITIES PER MILE) BY THE LIGHT TRUCK'S CURB WEIGHT

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)

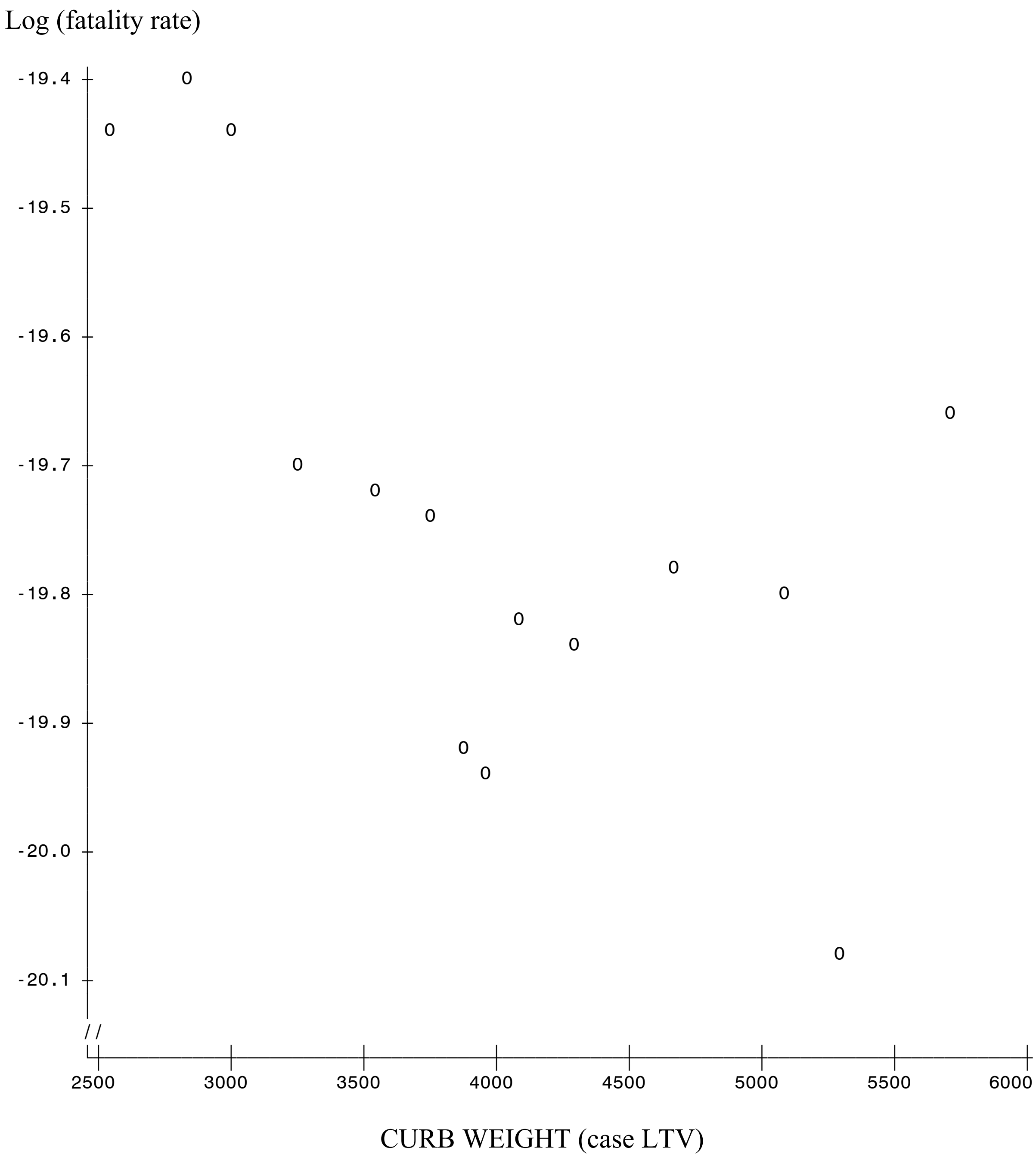


FIGURE 4-5: HEAVY TRUCKS

LOG(FATALITIES PER MILE IN COLLISIONS WITH HEAVY TRUCKS)
BY THE LIGHT TRUCK'S CURB WEIGHT

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)

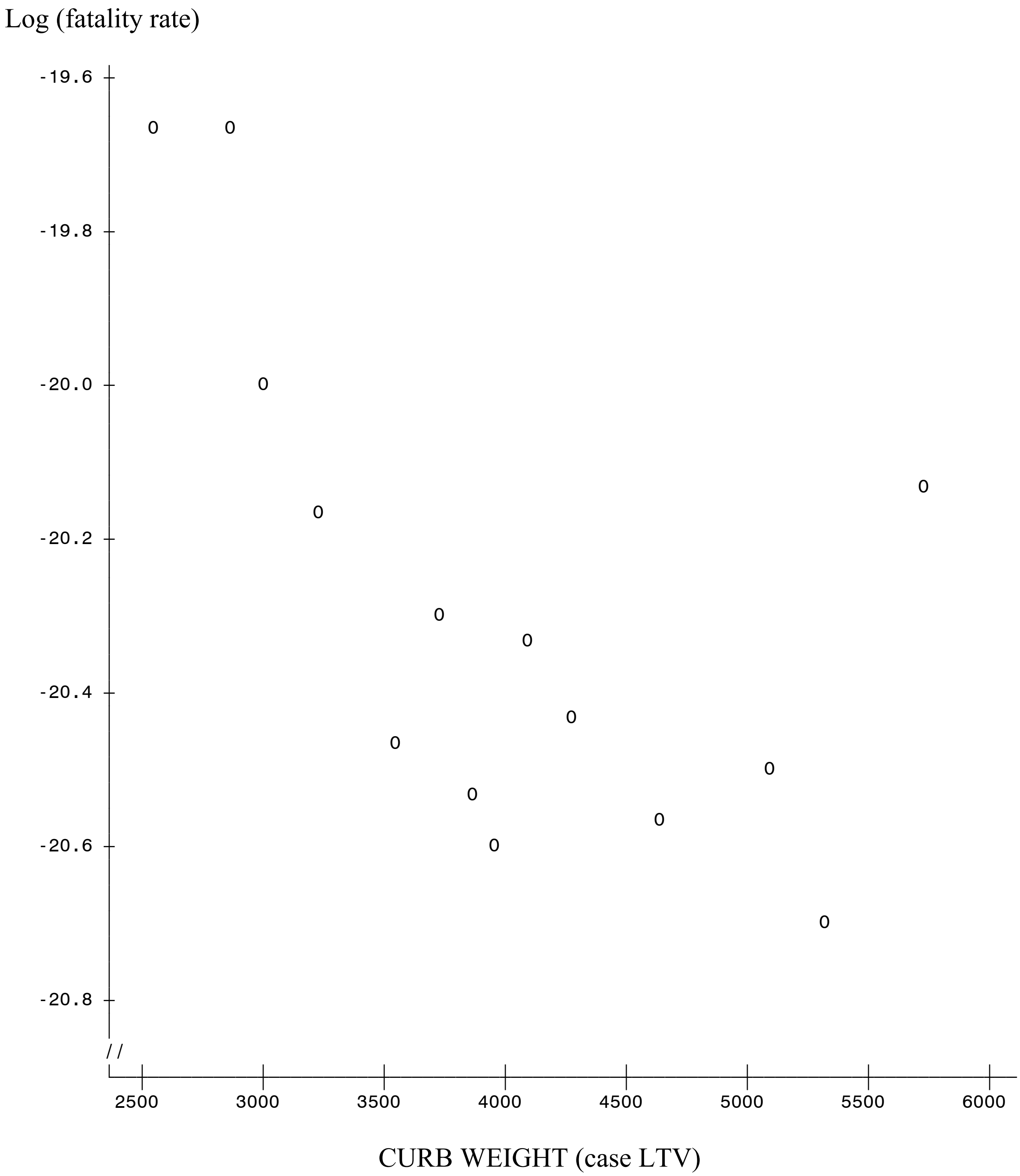


FIGURE 4-6: LIGHT TRUCK-TO-CAR COLLISIONS

LOG(FATALITIES PER MILE IN COLLISIONS WITH A CAR(S))
BY THE LIGHT TRUCK'S CURB WEIGHT

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)

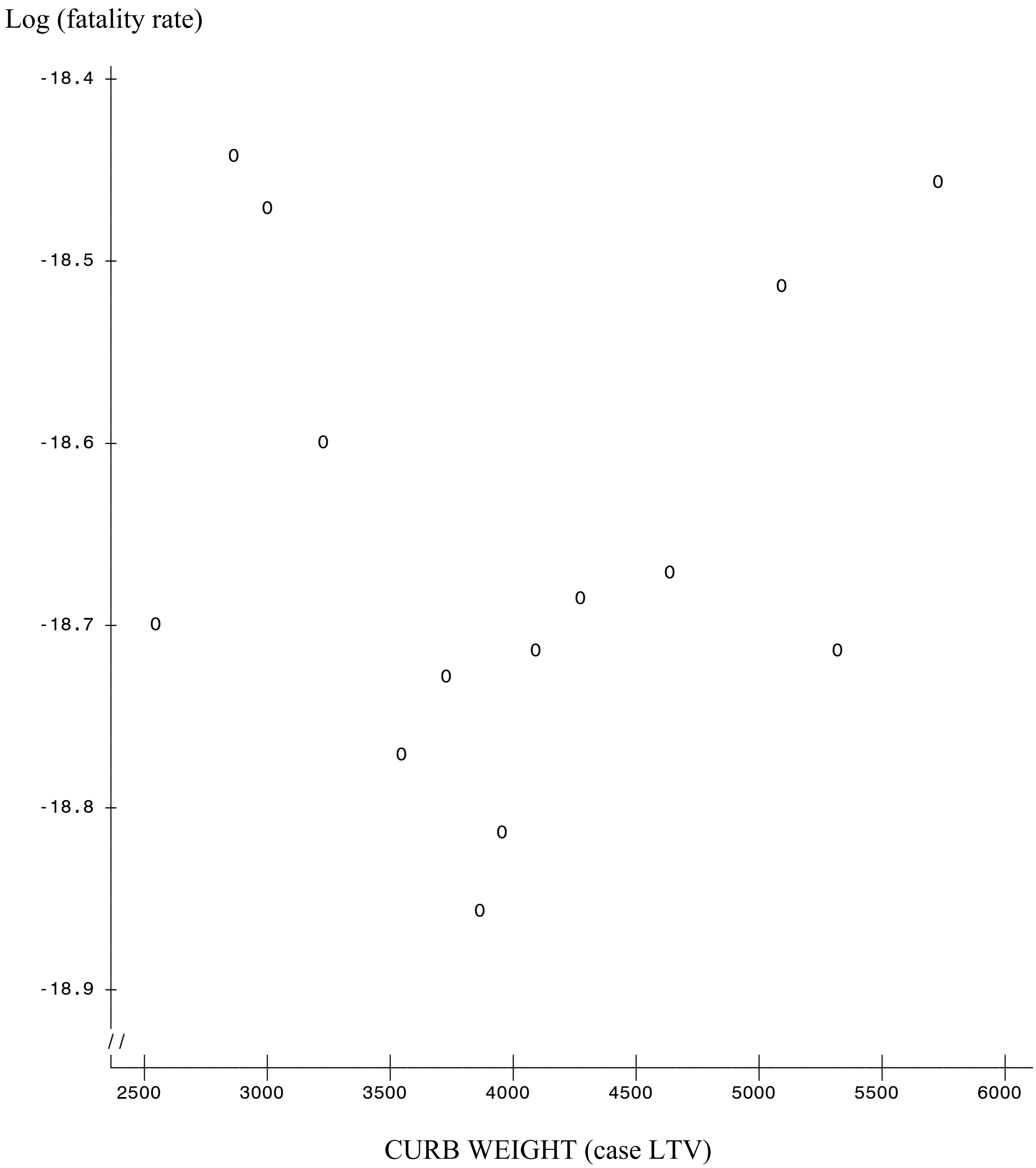


FIGURE 4-6a: PICKUP TRUCKS, MALE DRIVERS AGE 30-49
PICKUP TRUCK-TO-CAR COLLISIONS

LOG(FATALITIES PER MILE IN COLLISIONS WITH A CAR(S))
BY THE PICKUP TRUCK'S CURB WEIGHT

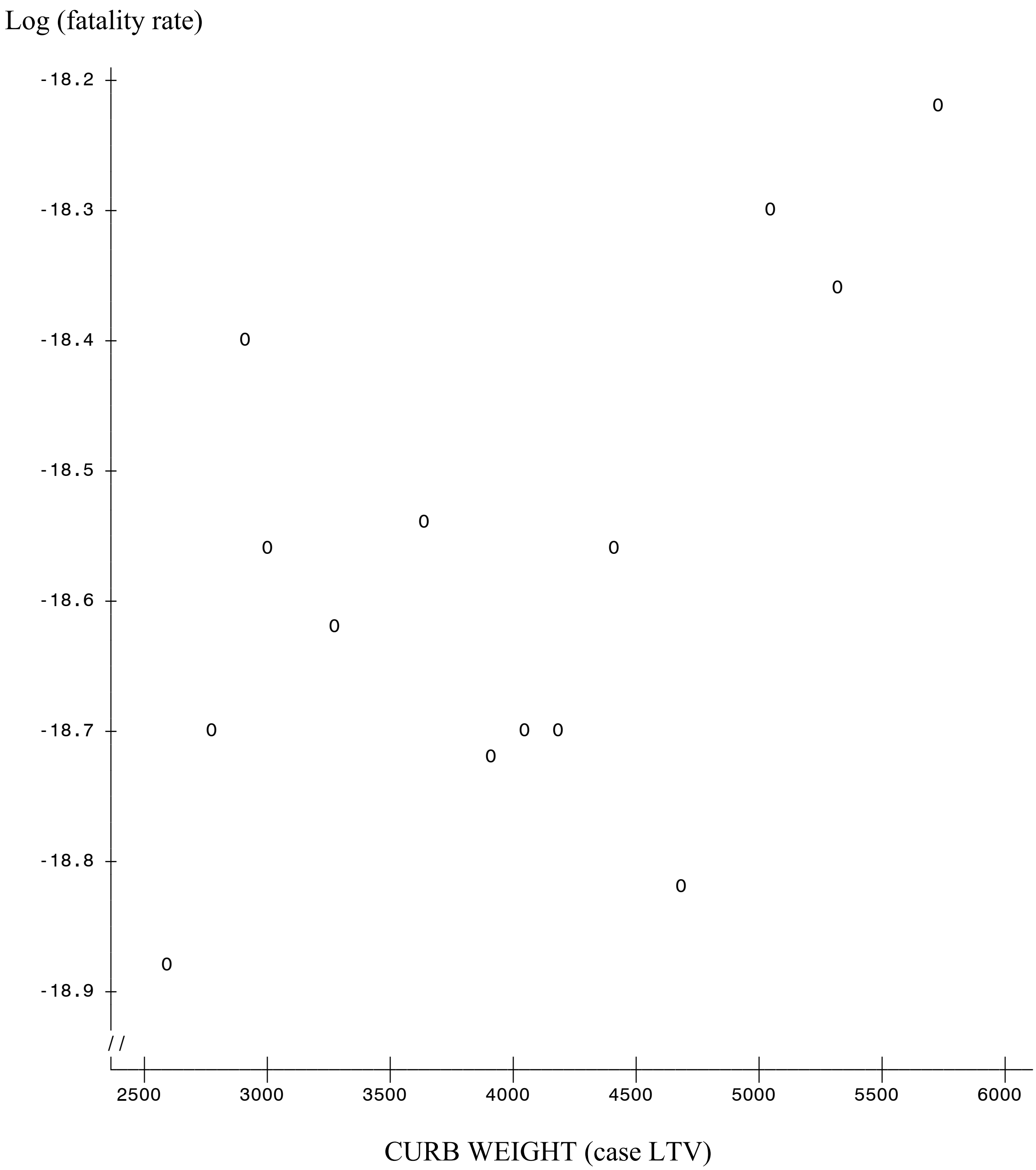
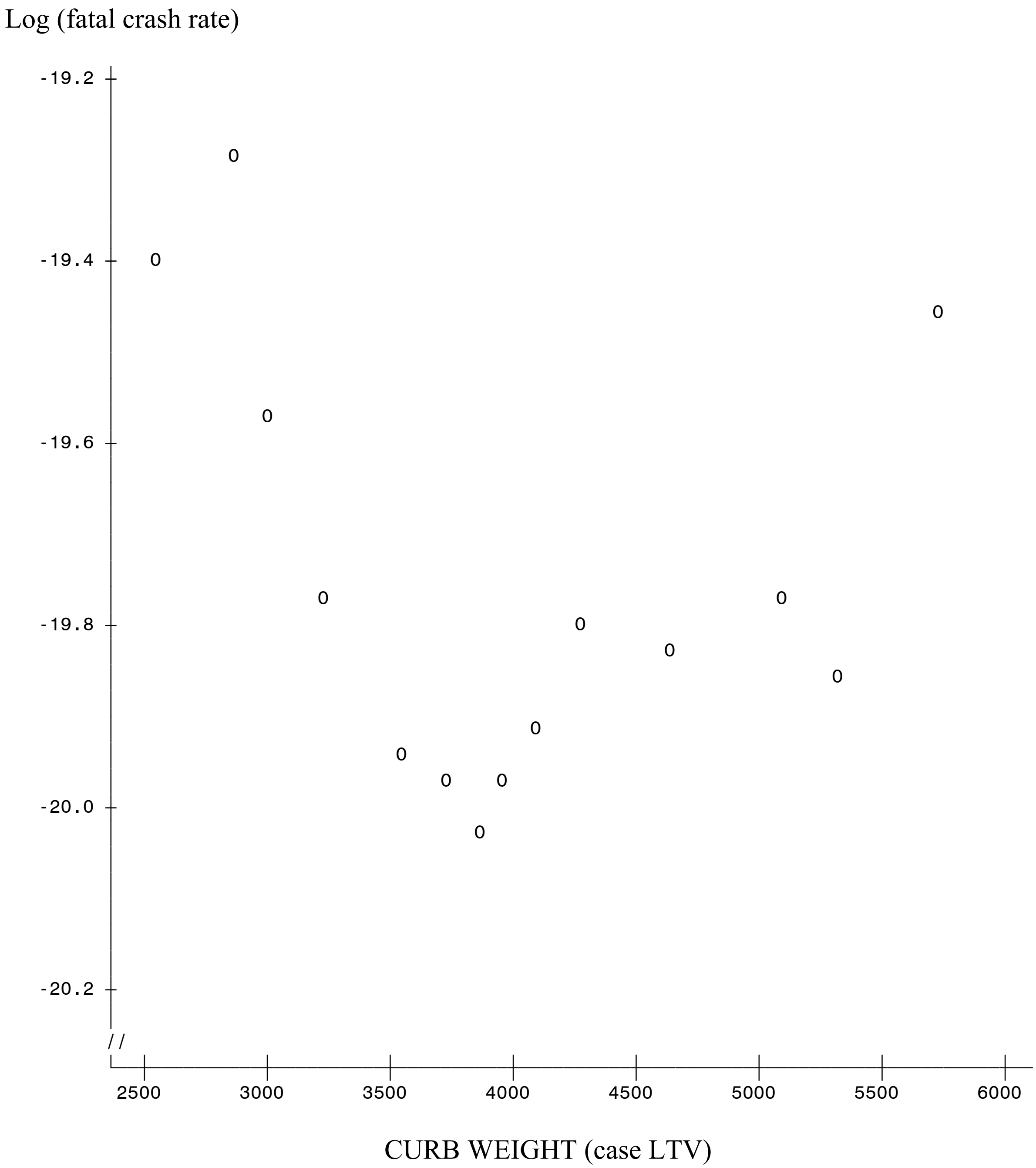


FIGURE 4-7: LIGHT TRUCK-TO-LIGHT TRUCK COLLISIONS

LOG(FATAL CRASH INVOLVEMENTS PER MILE WITH ANOTHER LIGHT TRUCK(S))
BY THE CASE LIGHT TRUCK'S CURB WEIGHT

(Pickup trucks, SUVs and vans, MY 1991-99 in CY 1995-2000)



There are differences among the truck types in the other crash modes, too, but not nearly to the extent seen in rollover crashes. Figures 4-3 – 4-7 show fatality rates by curb weight, but don't separate pickups, SUVs and vans. In fixed-object crashes, Figure 4-3 clearly shows a fatality reduction as vehicle weight increases. It is a rather steady reduction, but appears to be sharper at the lower weights. To demonstrate that the trend in Figure 4-3 is not merely an artifact of the mix of truck types or their drivers' age/gender, Figure 4-3a shows the trend in fixed-object fatality rates exclusively for 30-49 year old male drivers of pickup trucks.[1] The trend is quite similar to Figure 4-3: the fatality rate decreases as weight increases throughout the range, but perhaps not so sharply beyond about 4,000 pounds. Furthermore, the vertical scales in Figures 4-3 and 4-3a are nearly identical (a drop of 1.4 from the highest to the lowest mark), indicating that the effect remains about equally strong even after controlling for truck type, driver age and gender. On the whole, the downward trend looks stronger in Figure 4-3 than in Figure 4-3a, though not a lot. This would suggest that driver factors may account for a bit of the effect.

The data points in Figure 4-4, pedestrian/bike/motorcycle fatalities, are too scattered to reveal a clear trend. The only thing that's clearly visible is high rates for the lightest LTVs, followed by a decline. It is possible that decline as light-truck weight increases from 2,500 to approximately 4,000 pounds, then level off or even rise. Another possibility is that the rates level off as early as 3,000 pounds. Figure 4-5 shows a similar trend in collisions of light trucks with heavy trucks. Up to this point, the graphs of fatality rates in light trucks look quite a bit like their counterparts for passenger cars (Figures 3-2 – 3-5), except LTV trends for collisions with pedestrians (Figure 4-4) and heavy trucks (Figure 4-5) are not as clearly V-shaped as the trends in cars (Figures 3-4 and 3-5). Specifically, in passenger cars, the unadjusted fatality rate for collisions with heavy trucks is especially high for the heaviest cars, because they have the oldest drivers. In LTVs, that trend is not present because the drivers of heavy and mid-sizes LTVs are about equally old, as will be discussed in Section 4.2.

A much different, V-shaped trend appears in Figure 4-6, crash fatalities in light-truck-to-car collisions, per light-truck mile, as a function of the light truck's curb weight. The fatality rate decreases at first, but somewhere under 4,000 pounds it turns around, begins to increase and eventually returns to a high level. To show these trends are no fluke or artifact of the vehicle mix, Figure 4-6a exhibits the same effects when the data are limited to 30-49 year old male drivers of pickup trucks. In collisions between light trucks and cars, most of the fatalities are in the car. Among 1991-99 designs, the heavier light trucks are also more aggressive, and do more harm to car occupants. The same pattern appears in Figure 4-7, fatal crash involvement rates in light truck-to-light truck collisions, as a function of the weight of the case light truck.

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[1] Male drivers were selected for Figures 4-3a and 4-6a, rather than female drivers as in Figures 3-8 – 3-14 (for passenger cars), because 80 percent of pickup-truck drivers in our database are males: the more data, the more likely that trends will be visible in the graphs.

4.2 Screening the control variables

Here are the 15 potential control variables on the fatality and exposure files created in Section 2.6:

Driver age	Male driver?	Driver belted?
At night?	Rural?	Speed limit 55+?
Wet road?	Snowy/icy road?	Calendar year
Vehicle age	High-fatality State?	Driver air bag?
ABS (4-wheel)?	Rear wheel antilock?	All-wheel drive?

Together with "truck type" (pickup, SUV, minivan, full-sized van), that makes 16 control variables.

As explained in Section 3.3, one criterion for discarding potential control variables is if they have no association with curb weight.[2] Table 4-1 shows the correlation of the control variables with curb weight, after the database of induced-exposure crashes, generated in Section 2.6, has been aggregated into 28 class intervals of curb weight[3], and weighted by total vehicle miles in each class interval. Correlation coefficients are computed for all light trucks (left side) and for pickup trucks only.

Driver age, driver gender, rural, speed limit 55, snow/ice, calendar year, ABS and all-wheel/4-wheel drive (designated "AWD" throughout this report, but also includes 4WD or 4x4) all have statistically significant ($p < .05$), positive correlation with curb weight. In other words, heavier LTVs have relatively older drivers, more male drivers, more use on rural, high-speed and snowy/icy roads, more crashes in recent calendar years, more ABS and more AWD than the small LTVs.

The correlation of **driver age** and vehicle weight across the 28 class intervals is much lower for light trucks ($r = .56$; $r = .58$ in pickup trucks only) than for passenger cars ($r = .93$ in Table 3-2). The database shows that the average age of drivers increases from 34 in the lightest trucks to 40 in 3,500 pound trucks, and remains at 40 from that weight onward. If the heaviest light trucks are often used for hauling or van-pooling, that might explain why they have no overrepresentation of older drivers. This contrasts with 4-door passenger cars, where the average age of the driver increases quite linearly from 35 in the lightest cars to 55 in the heaviest. Thus, there is a significant correlation of driver age with vehicle weight in LTVs, but because the relationship is not linear (leveling off after 3,500 pounds), the correlation coefficient is lower

[2] Reinfurt, D.W., Silva, C.Z., and Hochberg, Y., *A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes [Interim Report]*, NHTSA Technical Report No. DOT HS 801 833, Washington, 1976, pp. 29-31.

[3] Corresponding to the 1st, 2nd, 4th, 6th, 8th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th, 55th, 60th, 65th, 70th, 75th, 80th, 85th, 90th, 92nd, 94th, 96th, 98th, 99th, and 100th percentiles of curb weight, as in Section 3.3. The class intervals at the ends were chosen to contain fewer percentiles than in the middle because: (1) curb weight has more spread at the low and high percentiles; (2) the low and high percentiles are especially important in computing correlation coefficients.

TABLE 4-1

CORRELATION OF POTENTIAL CONTROL VARIABLES WITH CURB WEIGHT

(Across 28 class intervals of curb weight)

Control Variable	In All Light Trucks		In Pickup Trucks	
	r	p <	r	p <
Driver age	.558[4]	.0021	.579[5]	.0012
Driver male?	.446	.017	.752	.0001
Driver belted?	.022	.91	- .070	.72
At night?	- .772	.0001	- .470	.012
Rural?	.413	.029	.916	.0001
Speed limit 55+?	.856	.0001	.933	.0001
Wet road?	- .511	.0054	- .377	.048
Snowy/icy road?	.586	.0011	.617	.0005
Calendar year	.770	.0001	.660	.0001
Vehicle age	- .804	.0001	- .694	.0001
High-fatality State?	- .111	.57	- .181	.36
Driver air bag?	.318	.099	.258	.19
ABS (4-wheel)?	.605	.0006	.415	.028
Rear-wheel antilock?	.079	.69	.103	.60
All-wheel drive?	.687	.0001	.715	.0001

[4] Across 694,491 individual induced-exposure crashes, the correlation of curb weight with driver age is just .076.
[5] Across 296,007 individual induced-exposure crashes, the correlation of curb weight with driver age is just .085.

than for cars. When the correlation coefficient is computed across the disaggregate database of 694,491 induced-exposure cases, the correlation of age with curb weight is just .076 (in pickup trucks alone: .085).

The correlation of **driver gender** and vehicle weight in light trucks (r = .44; in pickups alone, r = .75), although significant, is also much weaker than in cars (r = .96). The database shows that pickup trucks of all weights have an overwhelming majority of male drivers, ranging from 80 percent in the smallest trucks to 90 percent in the largest. Minivans and the smallest SUVs have a relatively high proportion of female drivers. It is important to control for driver age and gender here, but not quite as critical as in the analyses of passenger cars.

It is no surprise that the larger trucks, especially pickup trucks are more prevalent on **rural** and **high-speed** roads. That inflates their fatality rates, and the analysis will have to control for it.

Table 4-1 suggests the heaviest light trucks are driven less on wet roads and more on snowy/icy roads. Unlike the situation with passenger cars, these effects are only partially, not fully explained by driver age, ABS and AWD. The road-condition variables will need to remain in the analysis.

The most important difference between Tables 4-1 and 3-2 is that there is a significant positive correlation of calendar year with curb weight in light trucks, and a significant negative correlation of vehicle age with curb weight, but there was neither in passenger cars. Light trucks grew in weight throughout the 1990's, but cars did not. The truck analysis will have to control for calendar year and vehicle age, to adjust for the fact that the older trucks are lighter on the average (and older vehicles have higher fatality rates per mile).

ABS is correlated with curb weight because manufacturers have been slower to install ABS in the smaller pickup trucks and SUVs. AWD is correlated with curb weight to a large extent because AWD, 4WD and especially 4x4 add hundreds of pounds to the weight of a truck.

A significant negative correlation in Table 4-1 implies that large trucks are driven relatively less at night. Trip purpose appears to be involved: larger trucks are more often used for work, smaller trucks for personal mobility.

Driver belt use, the State fatality rate, driver air bags and rear-wheel antilock do not have a statistically significant correlation with truck weight across the 28 class intervals of weight. Questions arise on whether to retain or discard them as control variables. Although the presence of driver air bags does not have a significant linear relationship with curb weight, a graph of the 28 data points does show a clear relationship: fewer air bags in the lightest and the heaviest trucks. It is prudent to retain it as a control variable. Driver belt use, on the other hand, is not so accurately reported in the induced-exposure cases, and that consideration, in combination with the very low correlation with truck weight, suggests not to use it as a control variable.

Rear-wheel antilock (RWAL) and high-fatality State are in an intermediate category. Neither has significant correlation with truck weight, but RWAL is sort of a companion variable of ABS (i.e., two dichotomous variables describing the brake system). High-fatality State is rather correlated with some other control variables such as AWD (because winter weather in the Northern States makes AWD/4WD/4x4 popular there, and in general the Northern States have lower fatality rates than the South). It may be needed to help calibrate their effects better. Regressions will be run with and without RWAL and HIFAT_ST to see which does a better job fitting the data.

Thus, 13 to 15 control variables are included in the analyses of light trucks:

Truck type	Driver age	Male driver?
At night?	Rural?	Speed limit 55+?
Wet road?	Snowy/icy road?	Calendar year
Vehicle age	Driver air bag?	ABS (4-wheel)?
All-wheel drive?	RWAL (optional)	High-fatality State (optional)

Driver age and gender will again be represented by the nine independent variables DRVMALE, M14_30, M30_50, etc. defined in Section 3.3.

Truck type will be represented by three dichotomous variables, SUV, MINIVAN and BIGVAN. For pickup trucks, SUV, MINIVAN and BIGVAN are all set to zero.

Calendar year will be represented by five dichotomous variables, CY1995, CY1996, CY1997, CY1998 and CY2000. If the crash happened in CY 1999, those five variables are all set to zero.

The logarithm of the fatality rate generally has a linear relationship with vehicle age, except that new vehicles sometimes have exceptionally high or low rates (reflecting driver inexperience, different use patterns, etc.). Vehicle age will be represented by two variables, VEHAGE with integer values ranging from 0 to 9; and BRANDNEW = 1 when VEHAGE = 0, BRANDNEW = 0 when VEHAGE = 1-9.

4.3 Regression analyses of fatality risk by light truck weight

The data are now almost ready to calibrate the crash fatality rate per mile as a function of curb weight for MY 1991-99 light trucks in CY 1995-2000 crashes, in the six crash modes defined in Section 2.2: principal rollovers, fixed-object, pedestrian-bicyclist-motorcyclist, light truck-heavy truck, light truck-car, and light truck-light truck. As in Section 3.4, fixed-object collisions, the most “typical” analysis, will be discussed first. Here are records on the fatality and the induced-exposure databases for a 1996 GMC Sonoma pickup involved in a 1998 crash in Ohio:

	Fatal-Crash Record	Exposure Record
Crash mode	Fixed Object	-
N of fatalities in the crash	2	-
Vehicle registration years	-	313.238
Vehicle miles[6]	-	4,875,236
Curb weight	3,000	3,000
Truck type	pickup	pickup
Driver male?	1	1
Driver age	24	28
Driver air bag?	1	1
ABS (4-wheel)?	1	1
AWD	0	0
At night?	0	0
Rural?	1	0
Speed limit 55+?	1	0
Vehicle age	2	2
Calendar year	1998	1998
Wet road?	1	0
Snowy/icy road?	0	1
RWAL	0	0
High-fatality State	0	0

There are 9,252 records of MY 1991-99 light trucks involved in fatal fixed-object collisions during CY 1995-2000, with non-missing values on each of the variables listed above. There are 696,810 induced-exposure cases for these trucks, with non-missing values for the variables. Together, they will furnish 706,062 data points to the logistic regression. Over 97 percent of the records had non-missing values for all control variables (and over 99 percent had non-missing values for all control variables except DRVBAG). Thus, the proportion of records with missing data is small enough that no adjustment is needed for cases with missing data. In addition to the age/gender variables M14_30, M30_50, etc. defined at the end of the preceding section, the file needs four more variables:

FATAL is a flag that indicates whether a data point supplies "failure(s)" (fatalities in collisions with fixed objects) or successes (vehicle miles of exposure). All records from the fatal crash file have FATAL = 1. All induced-exposure crashes have FATAL = 2.[7]

WEIGHTFA is the weight factor for each data point. It **counts** the number of failures or successes implied by that data point. The weight factor for fatal crash involvements is (in this regression) the number of fatalities in the crash: a crash that killed two people represents two

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[6] 2-year-old compact pickup trucks are driven an average of 15,564 miles per year, based on Tables 2-2 and 2-3.
[7] *SAS/STAT® User's Guide, Version 6, Fourth Edition*, Volume 2, SAS Institute, Cary, NC, 1989, pp. 1071-1126. The LOGIST procedure in SAS prefers values of 1 for failures and 2 for successes.

failures. The weight factor for induced-exposure cases is the number of vehicle miles they represent: since the probability of a fatal crash in any single mile of driving is negligible, 4,875,236 vehicle miles may be considered "4,875,236 miles of driving without a fatality" and that represents 4,875,236 successes.

UNDRWT00 and OVERWT00: the data in Section 4.1 clearly suggested that the weight-safety relationship is stronger at the lower weights, up to about 3,500-4,000 pounds, than at the higher weights, and that curb weight should be entered as a 2-piece linear variable, with the "hinge" somewhere between 3,500 and 4,000 pounds. The median curb weight of light trucks in MY 1991-99, 3,870 pounds, can serve as the hinge. If the curb weight is less than 3,870, set

UNDRWT00 = .01 (curb weight – 3,870), OVERWT00 = 0

If the curb weight is 3,870 or more, set

UNDRWT00 = 0, OVERWT00 = .01 (curb weight – 3,870)

Weights are divided by 100 so that the regression coefficient will indicate the effect of a 100-pound weight increase. Other than making the printout easier to read it has no effect on the regressions. The curb weights in this chapter are always the "nominal" weights described in Section 2.1, the best estimates from published material, without the adjustment for the additional weight observed in compliance test vehicles.

Thus, the fatal and induced-exposure crash record described above contribute the following two data points to the regression of fixed-object crash fatality rates (a 24-year-old male driver will set M14_30 to 6, M30_50 to 20, and the other 6 age/gender variables to 0, as explained in Section 3.3):

	Data Point 1 (fatal crash involvement)	Data Point 2 (induced-exposure involvement)
FATAL	1	2
WEIGHTFA	2 fatalities	4,875,236 vehicle miles
UNDRWT00	- 3.87	- 3.87
OVERWT00	0	0
SUV	0	0
MINIVAN	0	0
BIGVAN	0	0
DRVMALE	1	1
M14_30	6	2
M30_50	20	20
M50_70	0	0
M70+	0	0
F14_30	0	0
F30_50	0	0
F50_70	0	0
F70+	0	0
DRVBAG	1	1
ABS	1	1
AWD	0	0
NITE	0	0
RURAL	1	0
SPDLIM55	1	0
VEHAGE	2	2
BRANDNEW	0	0
CY1995	0	0
CY1996	0	0
CY1997	0	0
CY1998	1	1
CY2000	0	0
WET	1	0
SNOW_ICE	0	1
RWAL (optional)	0	0
HIFAT_ST (optional)	0	0

The LOGIST procedure in SAS is a disaggregate logistic regression analysis. It is performed on 706,062 data points that are crash-involved vehicles: the 9,252 fatal crash involvements plus the 696,810 induced-exposure involvements. However, each of these data points is weighted, and thereby "transformed" by WEIGHTFA. The 9,252 fatal-crash involvements represent 9,994 "failures" (crash fatalities) while the 696,810 induced-exposure involvements represent 2.96 trillion "successes" (vehicle miles of travel in the United States). While LOGIST procedure operates on the crash data points, the weighting by WEIGHTFA in effect makes it calibrate the log-odds of a fatality per mile of travel.[8] These log-odds are calibrated as a linear function of the independent variables, generating the following coefficients when RWAL and HIFAT_ST are not included among the control variables:

FIXED-OBJECT COLLISIONS (without RWAL or HIFAT_ST)
(N = 9,252 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0316**	**0.0030**	**113.0**	**0.0001**
OVERWT00	**-0.0269**	**0.0031**	**76.4**	**0.0001**
SUV	0.110	0.029	14.3	0.0002
MINIVAN	-0.531	0.039	181.9	0.0001
BIGVAN	0.122	0.066	3.39	0.066
DRVMALE	0.499	0.071	50.1	0.0001
M14_30	0.0781	0.0032	603.9	0.0001
M30_50	0.0108	0.0023	23.1	0.0001
M50_70	0.0363	0.0031	135.8	0.0001
M70+	0.0889	0.0067	174.4	0.0001
F14_30	0.0612	0.0064	92.0	0.0001
F30_50	0.0151	0.0046	10.8	0.0010
F50_70	0.0742	0.0070	112.2	0.0001
F70+	0.0625	0.021	8.80	0.0030
DRVBAG	-0.074	0.033	4.99	0.026
ABS	0.112	0.032	12.5	0.0004
AWD	-0.069	0.025	7.54	0.0060
NITE	1.915	0.021	8675.	0.0001
RURAL	1.346	0.024	3137.	0.0001
SPDLIM55	1.665	0.023	5205.	0.0001
VEHAGE	0.102	0.0076	179.7	0.0001
BRANDNEW	0.077	0.038	4.01	0.045
CY1995	0.083	0.044	3.70	0.058
CY1996	-0.052	0.039	1.79	0.18
CY1997	-0.015	0.035	0.17	0.68
CY1998	0.056	0.033	2.99	0.08
CY2000	0.021	0.032	0.43	0.51
WET	-0.291	0.029	104.5	0.0001
SNOW_ICE	-0.075	0.048	2.46	0.116
INTERCPT	-22.516	0.088	65636.	0.0001

For light trucks weighing less than 3,870 pounds, each 100-pound weight reduction is associated with very close to a 3.16 percent fatality increase. In other words, Truck A weighing 100 pounds

[8] The text describes the most appropriate way to set up the data for the LOGIST procedure. However, the version of LOGIST used in this study interprets the WEIGHT statement not as a case-weighting but a count of independently-observed cases. It literally treated each mile of travel as an independent data point. That makes the standard errors of the coefficients about 2-5 percent smaller than they should be, and their chi-squares about 2-5 percent larger, as explained in Section 3.4 – i.e., when there are only 10,000 failures, the precision of the regression coefficients is nearly the same whether there are 700,000 or 3 trillion successes.

less than Truck B has approximately 3.16 percent higher fatality risk per billion miles than Truck B, given the same age/gender driver, ambient conditions, truck type, safety equipment, vehicle age and calendar year. Conversely, each 100-pound weight increase is associated with close to a 3.16 percent reduction in the fatality rate.[9]

For light trucks weighing 3,870 pounds or more, each 100-pound weight reduction is associated with close to a 2.69 percent increase in the fatality rate. In other words, the calibrated size-safety effect is less severe in the heavier trucks than in the lighter trucks.

Both of the size-safety effects are statistically significant, as evidenced by chi-square values 113.0 and 76.4 respectively. (For statistical significance at the .05 level, chi-square has to exceed 3.84, and for the .01 level, 6.64.) As in Section 3.4, "statistically significant" means that the specific data set entered into the regression model has a significant association between car weight and fatality risk after controlling for driver age/gender, urban/rural, etc. It does not consider other sources of uncertainty, such as: variation in the results from alternative setup of the model, use of just 8 State data files to compute induced exposure, and self-selection (i.e., safer drivers picking heavier trucks) in this cross-sectional analysis of truck fatality rates.

The control variables, with one possible exception (AWD), have coefficients in the expected direction. The coefficients for SUV, MINIVAN and BIGVAN suggest that SUVs and full-sized vans have a slightly higher fatality rate per mile than pickup trucks, minivans substantially lower. The substantial positive coefficient for DRVMALE suggests that 50-year-old males have much higher fatality rates per mile than 50-year-old females, all else being equal. Similarly, the coefficients for M14_30, M30_50, etc. show the customary pattern, as revealed in Figure 3-17, of low fatality rates per mile at age 30-50 and higher fatality rates for young and old drivers.

Consistent with the literature, the regression shows a moderate reduction of fatality risk with driver air bags in these crashes that are often frontal, and a moderate increase in these run-off-road crashes with 4-wheel ABS.[10] The coefficient for all-wheel-drive (AWD), however, is negative, whereas previous regressions of this type often generated positive coefficients.[11] However, this regression, unlike the procedures in earlier studies, did not include HIFAT_ST or its equivalent as a control variable. As we shall see shortly, including HIFAT_ST will change the sign of the AWD coefficient.

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[9] The regression actually calibrates the change in the log-odds of a fatality for a 100-pound weight increase. Since the fatality rate is very low, those log odds are essentially the log of the fatality rate. Thus, a 100-pound weight increase is associated with a 3.16% reduction in the log of the fatality rate, or a 3.11% reduction of the fatality rate itself. A 100-pound weight reduction is associated with a 3.21% increase in the fatality rate itself. The differences in these numbers (3.11, 3.16, 3.21) are trivial compared to the uncertainty in the estimate. From here on, the regression coefficient itself is used as the estimated effect of a 100-pound weight change (in either direction), ignoring the trivial measurement errors this involves.

[10] Kahane, C.J., *Fatality Reduction by Air Bags: Analyses of Accident Data through Early 1996*, NHTSA Technical Report No. DOT HS 808 470, Washington, 1996, pp. 12-15. Hertz, E., *Analysis of the Crash Experience of Vehicles Equipped with All Wheel Antilock Braking Systems (ABS) – A Second Update Including Vehicles with Optional ABS*, NHTSA Technical Report No. DOT HS 809 144, Washington, 2000.

[11] Kahane, C.J., *Relationships between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 808 570, Washington, 1997, p. 130-135.

The regression appropriately calibrates strong increases in fatality rates at night, on rural roads and on high-speed roads. VEHAGE has a coefficient of .10, indicating that fatality rates per mile increase about 10 percent a year as vehicles age (and annual overall mileage decreases while mileage in high-risk situations does not). BRANDNEW also has a positive coefficient, because drivers are more likely to run off the road when the vehicle is new and unfamiliar. The various CY terms have small coefficients indicating minor year-to-year variations in overall fatality risk. WET and SNOW_ICE have negative coefficients because, as a general rule, adverse conditions force people to slow down, reducing the lethality of crashes while increasing the frequency of lower-speed collisions of the "induced-exposure" type.[12]

When RWAL and HIFAT_ST are added to the control variables, the regression produces somewhat stronger coefficients for vehicle weight:

[12] *Traffic Safety Facts 1999*, NHTSA Report No. DOT HS 809 100, Washington, 2000, p. 47 shows 0.62 percent of reported crashes are fatal under normal weather conditions, but only 0.40 percent in the rain and 0.30 percent in snow and sleet.

FIXED-OBJECT COLLISIONS (with RWAL and HIFAT_ST)
(N = 9,252 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0402**	**0.0033**	**151.3**	**0.0001**
OVERWT00	**-0.0306**	**0.0031**	**97.3**	**0.0001**
SUV	0.120	0.029	16.6	0.0001
MINIVAN	-0.375	0.042	80.7	0.0001
BIGVAN	0.286	0.067	18.3	0.0001
DRVMALE	0.511	0.070	52.5	0.0001
M14_30	0.0776	0.0032	596.6	0.0001
M30_50	0.0100	0.0023	19.5	0.0001
M50_70	0.0350	0.0031	125.6	0.0001
M70+	0.0895	0.0067	178.6	0.0001
F14_30	0.0597	0.0064	86.8	0.0001
F30_50	0.0152	0.0046	10.9	0.0010
F50_70	0.0727	0.0070	107.9	0.0001
F70+	0.0664	0.021	10.0	0.0016
DRVBAG	-0.058	0.033	3.07	0.080
ABS	0.251	0.045	31.4	0.0001
AWD	0.100	0.026	14.2	0.0002
NITE	1.904	0.021	8577.	0.0001
RURAL	1.270	0.024	2742.	0.0001
SPDLIM55	1.701	0.023	5444.	0.0001
VEHAGE	0.104	0.0077	183.9	0.0001
BRANDNEW	0.084	0.038	4.95	0.026
CY1995	0.084	0.044	3.71	0.054
CY1996	-0.056	0.039	2.07	0.15
CY1997	-0.025	0.035	0.51	0.47
CY1998	0.053	0.033	2.68	0.10
CY2000	0.022	0.032	0.48	0.49
WET	-0.265	0.029	86.1	0.0001
SNOW_ICE	0.079	0.048	2.68	0.10
INTERCPT	-23.022	0.098	54750.	0.0001
RWAL	0.165	0.040	16.7	0.0001
HIFAT_ST	0.531	0.022	611.9	0.0001

For trucks weighing less than 3,870 pounds, each 100-pound weight reduction is associated with a 4.02 percent increase in the fatality rate, as compared to 3.16 percent in the preceding regression. For trucks weighing 3,870 pounds or more, the effect is 3.06 percent, up from 2.69 percent. These are not vast changes, but they are more than what happened in a comparable sensitivity test for passenger cars (Section 3.5).

The addition of RWAL did little. It is true that the coefficient for ABS climbed from .11 to .25, but that needs to be carefully interpreted. The first regression says ABS increased fatality risk by 11 percent relative to a combination of RWAL or nothing. The second regression says ABS increased risk by 25 percent relative to nothing, but that RWAL increased risk by 16 percent relative to nothing – i.e., ABS is 9 percent more risky than RWAL. Since, by 1991-99, most trucks had either RWAL or ABS, and relatively few had nothing, the two regressions are saying more or less the same thing.

The addition of HIFAT_ST had more consequences. Of course, HIFAT_ST has a strong association with fatality risk. But it also changed the coefficient for AWD from -.07 to +.10. Here's what happened: AWD is more popular in the Northern States, because they are the ones with bad weather.[13] However, the North also has generally lower crash fatality rates than the South. Without control for HIFAT_ST, it appears that AWD is the choice of low-risk drivers. With HIFAT_ST, a more correct picture emerges: true, AWD is popular in the low-risk States, but within any State, AWD is more popular with the high-risk drivers. Unfortunately, AWD is also organically confounded with curb weight, because the 4x4 systems of 4-wheel drive generally used in 1991-99 pickup trucks and mid-sized SUVs typically added 400 pounds to the weight of those vehicles. When AWD has an erroneous negative coefficient, the regression concludes heavier trucks are safer in part because of AWD, and deducts that "effect" from the coefficient for weight. When AWD has a more correct positive coefficient, the regression concludes heavier trucks are safer despite AWD, and properly adjusts the coefficient for weight upwards. Thus, even though HIFAT_ST had little direct correlation with weight, it is needed as a control variable in order to obtain a correct calibration of the effect of AWD, which is confounded with weight.[14] HIFAT_ST did not have a similar impact in the passenger car regressions (Section 3.5) because AWD was not involved in the analysis.

Thus, the second regression, with RWAL and HIFAT_ST fits the data better and will be considered the "baseline" or "point estimate" in this chapter, for fixed-object crashes as well as the other crash modes. The results without RWAL and HIFAT_ST will be presented in Section 4.4 as alternative estimates. They will be used to help establish interval estimates.

The logistic regression of **principal-rollover** fatalities per mile is based on 6,372 fatal crash involvements, resulting in 7,123 occupant fatalities (failures). The list of independent variables is the same as in the fixed-object regression, except DRVBAG is omitted: air bags are unlikely to have an effect, and in many cases won't even deploy, in principal rollovers. There are 708,353 induced-exposure involvements, corresponding to 3.01 trillion VMT (successes). The induced-exposure file is very slightly larger than in the fixed-object analysis because it additionally includes trucks where it is unknown if they were equipped with air bags. The regression generated the following coefficients:

[13] When HIFAT_ST = 0 (primarily Northern States), 47 percent of all MY 1991-99 LTVs, and 90 percent of SUVs are equipped with 4-wheel or all-wheel drive (AWD = 1). When HIFAT_ST = 1 (primarily Southern States), only 29 percent of all LTVs, and 54 percent of SUVs are equipped with 4-wheel or all-wheel drive.

[14] Similarly, the coefficient for SNOW_ICE changed from -.08 without HIFAT_ST to +.08 with HIFAT_ST, because snow is more common in the generally lower-risk Northern States. This change is not important, though, because SNOW_ICE is not organically confounded with curb weight.

PRINCIPAL ROLLOVERS (N = 6,372 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0315**	**0.0039**	**64.2**	**0.0001**
OVERWT00	**-0.0256**	**0.0033**	**58.7**	**0.0001**
SUV	1.047	0.033	1015.	0.0001
MINIVAN	0.111	0.050	5.04	0.025
BIGVAN	1.023	0.072	203.9	0.0001
DRVMALE	-0.177	0.069	6.56	0.010
M14_30	0.1000	0.0039	656.2	0.0001
M30_50	0.0128	0.0029	19.7	0.0001
M50_70	0.0191	0.0044	18.6	0.0001
M70+	0.0579	0.013	21.1	0.0001
F14_30	0.0902	0.0058	241.4	0.0001
F30_50	0.0001	0.0042	0.001	0.97
F50_70	0.0503	0.0071	50.0	0.0001
F70+	0.0304	0.028	1.22	0.27
ABS	0.275	0.052	27.7	0.0001
AWD	0.182	0.030	36.3	0.0001
RWAL	0.316	0.049	41.3	0.0001
HIFAT_ST	1.001	0.027	1396.	0.0001
NITE	1.561	0.024	4211.	0.0001
RURAL	1.678	0.034	2432.	0.0001
SPDLIM55	2.765	0.034	6722.	0.0001
VEHAGE	0.081	0.0070	132.1	0.0001
BRANDNEW	0.232	0.041	31.4	0.0001
CY1995	-0.050	0.047	1.13	0.29
CY1996	-0.080	0.042	3.61	0.057
CY1997	-0.064	0.040	2.62	0.106
CY1998	-0.029	0.038	0.58	0.44
CY2000	-0.018	0.037	0.23	0.63
WET	-1.047	0.046	511.5	0.0001
SNOW_ICE	0.248	0.051	23.4	0.0001
INTERCPT	-24.463	0.098	62964.	0.0001

Consistent with Figure 4-2, the regression shows a rather steady increase in rollover fatality rates per mile as truck weight is reduced. For trucks weighing less than 3,870 pounds, each 100-pound weight reduction is associated with a 3.15 percent fatality increase; above 3,870 pounds, a 2.56 percent fatality increase. Both coefficients are statistically significant.

SUVs of MY 1991-99 had much higher fatal-rollover rates than pickup trucks, after adjusting for the other control variables, consistent with the low static stability of those SUVs. In the raw data of Figure 4-2, the difference between SUVs and pickups did not seem quite so large. But the unadjusted fatality rates of pickup trucks are inflated because so many of them were driven in rural areas, on high-speed roads, by men. SUVs had even higher unadjusted rates despite the fact that they were extensively driven in urban areas, often by women. After adjustment, the intrinsic difference between pickup trucks and SUVs becomes clear.[15]

The other control variables also have a reasonable relationship to fatality risk. Since rollovers are a "young people's crash" the M14_30 and F14_30 coefficients are much stronger than M70+ and F70+. The near-zero coefficient for F30_50 suggests that fatality rates change little for female drivers from age 30 through 50. The negative coefficient for DRVMALE may reflect two phenomena: women drivers may react to incipient loss of control by excessive steering input, eventually leading to rollover, while males are more likely to hit fixed objects. Also, some of the most rollover-prone small SUVs of MY 1991-99 were popular with young females.[16] ABS and RWAL are associated with increased risk, consistent with the literature. AWD also is associated with more rollovers, probably because it is more popular on vehicles that will be used on hazardous roads. Of course, rollover risk is especially high at night, in rural areas, on high-speed roads, and in the less-urbanized high-fatality States. BRANDNEW has a strong positive coefficient, suggesting high rollover risk while drivers are still unfamiliar with their new vehicles.

The regression of **pedestrian/bicyclist and motorcyclist** fatalities per light-truck mile is based on 7,690 records of light trucks that struck pedestrians, bicyclists or motorcyclists, resulting in 7,900 fatalities to the ped/bike/motorcyclists. The induced-exposure data are the same as in the rollover regression. Again, the list of independent variables omits DRVBAG, because an air bag in the truck will not help the pedestrian, bicyclist or motorcyclist. The regression generated the following coefficients:

[15] On our induced-exposure database, 84% of pickup-truck drivers are males, 33% of the induced-exposure crashes are on rural roads, and 22% on roads with speed limit 55 mph or greater. The corresponding statistics for SUVs are: 55% males, 24% rural, 19% speed limit 55+.

[16] Figure 4-2 shows a high rollover-fatality rate for SUVs weighing less than 2,500 pounds. The induced-exposure database shows drivers of SUVs weighing less than 2,500 pounds are 57% female and have a median age of 32, while drivers of other SUVs are only 45% female and have a median age of 38.

PEDESTRIANS-BICYCLISTS-MOTORCYCLISTS (N = 7,690 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0124**	**0.0039**	**10.1**	**0.0015**
OVERWT00	**-0.0013**	**0.0032**	**0.17**	**0.68**
SUV	0.090	0.034	7.08	0.0078
MINIVAN	-0.064	0.041	2.41	0.12
BIGVAN	0.437	0.057	59.0	0.0001
DRVMALE	0.280	0.066	17.8	0.0001
M14_30	0.0292	0.0041	51.8	0.0001
M30_50	0.0055	0.0024	5.06	0.024
M50_70	0.0146	0.0037	16.0	0.0001
M70+	0.0449	0.011	16.9	0.0001
F14_30	0.0278	0.0072	15.1	0.0001
F30_50	0.0035	0.0044	0.65	0.42
F50_70	0.0314	0.0080	15.6	0.0001
F70+	0.0336	0.029	1.30	0.25
ABS	-0.061	0.051	1.43	0.23
AWD	-0.181	0.031	34.4	0.0001
RWAL	0.050	0.046	1.17	0.28
HIFAT_ST	0.293	0.024	151.9	0.0001
NITE	1.570	0.023	4664.	0.0001
RURAL	0.148	0.025	34.2	0.0001
SPDLIM55	0.859	0.027	1020.	0.0001
VEHAGE	0.100	0.0067	222.9	0.0001
BRANDNEW	0.035	0.042	0.71	0.40
CY1995	0.154	0.044	12.3	0.0005
CY1996	0.046	0.041	1.22	0.27
CY1997	0.108	0.038	8.10	0.0044
CY1998	0.059	0.037	2.57	0.11
CY2000	-0.007	0.036	0.04	0.84
WET	-0.742	0.037	404.9	0.0001
SNOW_ICE	-1.201	0.101	141.9	0.0001
INTERCPT	-21.201	0.090	55499.	0.0001

The analysis calibrates weaker effects in pedestrian crashes than in any other crash mode. For trucks weighing less than 3,870 pounds, each 100-pound weight reduction is associated with a modest but statistically significant 1.24 percent fatality increase; above 3,870 pounds, merely a 0.13 percent fatality increase that is not statistically significant.

The M14_30 and F14_30 coefficients are relatively weak, because hitting pedestrians is not a "young driver's crash." The ABS coefficient suggests a possible, but nonsignificant benefit for ABS in pedestrian crashes, consistent with recent literature.[17] The coefficient for NITE is high because pedestrian crashes are common at night (visibility problems, alcohol). Coefficients are low for RURAL, SPDLIM55 and HIFAT_ST, relative to the other crash modes, because

[17] Hertz, *op. cit.*

pedestrian crashes are predominantly urban.[18] For the same reason, AWD has a negative coefficient: all-wheel or 4-wheel drive is more popular in rural areas, where there are lots of trees and ditches, but few pedestrians.[19] The strong coefficients for CY1995 and CY1997 (relative to baseline 1999) reflect the long-term trend toward fewer pedestrian fatalities. The differences between pickup trucks, SUVs and minivans, after controlling for driver age/gender, urban/rural, etc., are quite small.

The regression of LTV occupant fatalities in collisions with **heavy trucks** (GVWR > 10,000 pounds), per LTV mile, is based on 3,660 collisions that resulted in 4,405 fatalities, plus the usual induced-exposure data. Driver air bags are potentially effective and are included in the control variables. These are regressions on the weight and safety equipment of the LTV, the age/gender of the LTV driver. The weight of the heavy truck is unknown (except that GVWR > 10,000); the age of the heavy-truck driver is not in the regression, either.[20]

[18] *Accident Facts, 1993 Edition*, National Safety Council, Itasca, IL, 1993, p. 67.
[19] In our induced-exposure database, AWD has positive correlation with RURAL and SPDLIM55.
[20] As in all the regressions of Chapters 3-5, only the curb weight, driver age, etc. of the case vehicle are included as variables; moreover, the actual weight of the heavy truck, including cargo, is not specified on FARS or State files, only the GVWR.

COLLISIONS WITH HEAVY TRUCKS (N = 3,660 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0591**	**0.0050**	**141.0**	**0.0001**
OVERWT00	**-0.0062**	**0.0045**	**1.92**	**0.17**
SUV	0.116	0.048	5.88	0.015
MINIVAN	0.169	0.056	9.21	0.0024
BIGVAN	0.503	0.084	35.8	0.0001
DRVMALE	0.274	0.090	9.29	0.0023
M14_30	0.0443	0.0057	59.5	0.0001
M30_50	0.0009	0.0034	0.07	0.79
M50_70	0.0417	0.0040	110.0	0.0001
M70+	0.1091	0.0072	228.7	0.0001
F14_30	0.0129	0.011	1.50	0.22
F30_50	0.0091	0.0060	2.33	0.13
F50_70	0.0713	0.0082	75.3	0.0001
F70+	0.0779	0.021	13.3	0.0003
DRVBAG	-0.084	0.049	2.93	0.087
ABS	0.183	0.068	7.24	0.0071
AWD	-0.105	0.041	6.40	0.011
RWAL	0.195	0.061	10.2	0.0014
HIFAT_ST	0.665	0.032	424.0	0.0001
NITE	0.659	0.035	355.9	0.0001
RURAL	1.041	0.038	772.8	0.0001
SPDLIM55	2.574	0.041	4003.	0.0001
VEHAGE	0.118	0.011	106.9	0.0001
BRANDNEW	-0.0005	0.060	0.0001	0.99
CY1995	0.022	0.067	0.11	0.74
CY1996	-0.092	0.070	2.36	0.12
CY1997	0.054	0.052	1.07	0.30
CY1998	0.105	0.049	4.64	0.031
CY2000	0.015	0.048	0.09	0.76
WET	-0.132	0.042	9.94	0.0016
SNOW_ICE	0.474	0.063	57.08	0.0001
INTERCPT	-23.708	0.140	28792.	0.0001

The regression calibrates a much stronger effect in the lighter LTVs. For LTVs weighing less than 3,870 pounds, each 100-pound weight reduction is associated with a 5.91 percent fatality increase; above 3,870 pounds, only a 0.62 percent fatality increase that is not statistically significant.

In this "older drivers' crash mode," not only M70+ and F70+ but also M50_70 and F50_70 are strong. M14_30 is not weak (but not nearly as strong as M70+, F50_70 or F70+), indicating that young male drivers are also over-involved in crashes with heavy trucks, relative to 30-50 year old drivers. Air bags show a moderate benefit. SPDLIM55 is especially strong because there are many heavy trucks on the major highways.

The last two crash modes include collisions of two to four passenger vehicles, but no heavy trucks, motorcycles or non-occupants. The first one is "**light truck to car**." The fatal-crash data points in the regression are the 19,227 fatal involvements of 1991-99 "case" LTVs in collisions with one to three other light vehicles, at least one of them a passenger car. The "failures" are the 22,934 occupant fatalities in those crashes, most of them car occupants. The induced-exposure data are the same as usual: 696,810 cases supplying 2.96 trillion "successes" (miles of travel by the case light trucks). The independent variables include the curb weight, driver age/gender and air bag/ABS/AWD status of the case LTV. No data on the "other" car(s) in the collision are included in the regression; these other vehicle(s) may or may not be MY 1991-99, and their curb weights, driver ages, etc. are not specified in the regression. Chapter 6 will present regression analyses of LTV-to-car collision rates based on the curb weights and driver ages for both vehicles, and they will corroborate the findings here.

COLLISIONS WITH A PASSENGER CAR(S) (N = 19,227 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0113**	**0.0024**	**22.6**	**0.0001**
OVERWT00	**0.0068**	**0.0018**	**14.2**	**0.0002**
SUV	0.195	0.020	95.8	0.0001
MINIVAN	-0.040	0.026	2.42	0.12
BIGVAN	0.266	0.036	54.8	0.0001
DRVMALE	0.169	0.038	19.8	0.0001
M14_30	0.0378	0.0025	237.6	0.0001
M30_50	0.0050	0.0014	12.0	0.0005
M50_70	0.0150	0.0021	53.1	0.0001
M70+	0.0723	0.0052	193.1	0.0001
F14_30	0.0260	0.0042	38.2	0.0001
F30_50	0.0050	0.0025	4.12	0.042
F50_70	0.0300	0.0045	45.1	0.0001
F70+	0.0304	0.017	3.35	0.067
DRVBAG	0.020	0.021	0.89	0.35
ABS	-0.039	0.031	1.57	0.21
AWD	0.024	0.017	1.89	0.17
RWAL	0.134	0.029	22.2	0.0001
HIFAT_ST	0.453	0.014	1054.	0.0001
NITE	0.749	0.015	2534.	0.0001
RURAL	0.679	0.015	2110.	0.0001
SPDLIM55	1.612	0.015	11287.	0.0001
VEHAGE	0.092	0.0051	331.0	0.0001
BRANDNEW	-0.0014	0.025	0.004	0.95
CY1995	0.170	0.029	34.8	0.0001
CY1996	0.111	0.025	18.7	0.0001
CY1997	0.154	0.023	45.2	0.0001
CY1998	0.113	0.022	27.1	0.0001
CY2000	-0.013	0.022	0.38	0.54
WET	-0.202	0.018	120.1	0.0001
SNOW_ICE	0.067	0.032	4.32	0.038
INTERCPT	-20.715	0.060	120209.	0.0001

For trucks weighing less than 3,870 pounds, each 100-pound weight reduction in the light trucks is associated with a 1.13 percent increase in crash fatalities in light truck-to-car collisions; above 3,870 pounds, a 0.68 percent fatality **reduction**. Both effects, although not large in absolute terms, are statistically significant. Thus, the regression results are consistent with the V-shaped trends in Figures 4-6 and 4-6a.

M14_30 and F14_30 are relatively weak, since this is not a young driver's crash. Driver air bags in the case light truck have a negligible effect, because most of the fatalities are in the cars, and will not be affected by the air bags in the trucks. Trucks with ABS have lower fatality rates than trucks with RWAL.

The results contrast with the regression in which the "case" vehicle was the car and the "other" vehicle was the light truck (Section 3.4). There, reducing the weight of the car by 100 pounds substantially increased fatality risk (by 5.63 percent for cars weighing less than 2,950 pounds and by 2.62 percent for cars weighing 2,950 pounds or more). If this were a strictly symmetrical "zero-sum game," reducing the weight of the truck might have had a benefit on overall crash fatalities (most of which are the car occupants) equal to the harm of reducing the car weight. But it does not: reducing truck weight only has slight benefit when the truck weighs over 3,870 pounds, and it even increases crash fatalities when the truck weighs less than 3,870 pounds. This noteworthy result will be given additional analysis and discussion in Section 4.4 and Chapter 6, but the principal factors would appear to be: (1) Light cars are much more vulnerable to truck impacts than heavy cars, whereas small light trucks are only somewhat less aggressive than heavy trucks when they hit cars. (2) Lighter vehicles have higher crash rates and, as a result, higher fatal-crash rates than heavy vehicles.

In the last crash mode, **LTV-to-LTV**, the "failures" are the involvements of 1991-99 "case" LTVs in fatal crashes involving two to four vehicles, **all** of them LTVs. The independent variables include the curb weight, driver age/gender, etc. of the case LTV. No data on the "other" LTV(s) are included in the regression; they may or may not be MY 1991-99.

Note that a collision involving two or more MY 1991-99 LTVs will contribute multiple data points to this regression, one for each MY 1991-99 LTV involved. However, the procedure in Sections 3.8 and 4.6 for quantifying the societal impact of the size-safety effect is designed to avoid "double-counting" the impacts. As an additional hedge against over-weighting cases with multiple fatalities and multiple 1991-99 LTVs, this regression, unlike the other five crash modes, gives each crash involvement a WEIGHTFA = 1, even if there was more than one fatality in the crash. Thus, the 7,344 records of 1991-99 LTVs involved in fatal LTV-to-LTV crashes supply 7,344 "failures."

COLLISIONS WITH ANOTHER LIGHT TRUCK(S) (N = 7,344 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
UNDRWT00	**-0.0349**	**0.0040**	**75.5**	**0.0001**
OVERWT00	**0.0150**	**0.0032**	**22.0**	**0.0001**
SUV	-0.0006	0.036	0.0002	0.99
MINIVAN	-0.0006	0.045	0.0002	0.99
BIGVAN	0.072	0.070	1.03	0.31
DRVMALE	-0.023	0.067	0.12	0.73
M14_30	0.0603	0.0042	205.6	0.0001
M30_50	0.0027	0.0026	1.03	0.31
M50_70	0.0314	0.0033	88.6	0.0001
M70+	0.1084	0.0064	286.4	0.0001
F14_30	0.0610	0.0074	68.1	0.0001
F30_50	-0.0129	0.0045	8.06	0.0045
F50_70	0.0491	0.0066	54.7	0.0001
F70+	0.0692	0.019	13.6	0.0002
DRVBAG	-0.023	0.038	0.37	0.55
ABS	0.012	0.054	0.05	0.83
AWD	0.050	0.031	2.61	0.11
RWAL	0.104	0.049	4.59	0.0322
HIFAT_ST	0.671	0.025	719.1	0.0001
NITE	0.799	0.026	940.7	0.0001
RURAL	1.068	0.028	1448.	0.0001
SPDLIM55	1.892	0.028	4619.	0.0001
VEHAGE	0.120	0.0088	184.6	0.0001
BRANDNEW	0.060	0.045	1.78	0.18
CY1995	-0.054	0.052	1.07	0.30
CY1996	-0.122	0.045	7.29	0.0069
CY1997	-0.086	0.041	4.52	0.034
CY1998	-0.028	0.037	0.54	0.46
CY2000	-0.094	0.036	6.71	0.0096
WET	-0.156	0.033	22.8	0.0001
SNOW_ICE	0.361	0.051	49.7	0.0001
INTERCPT	-22.322	0.105	44905.	0.0001

Here, there is a stronger V-shaped effect, consistent with the pattern in Figure 4-7. For trucks weighing less than 3,870 pounds, each 100-pound weight reduction in the light trucks is associated with a 3.49 percent **increase** in fatal collisions, per mile, with other light trucks; above 3,870 pounds, a 1.50 percent fatality **reduction**. Both effects are statistically significant. When the case LTV is light, chances are the fatality is one of its own occupants; a weight reduction increases the LTV's vulnerability for its own occupants. When the case LTV is heavy, chances are the fatality was in the other vehicle; a weight reduction for the case LTV could make it less aggressive to the other vehicles (to the extent that aggressiveness is correlated with weight).

4.4 Sensitivity tests and discussion

Here are the calibrated relationships between the curb weights of light trucks and their fatality rates per billion vehicle miles, based on six regressions including the control variables RWAL and HIFAT_ST:

	Fatality Increase (%) per 100-Pound Weight Reduction	
Crash Mode	LTVs < 3,870 Pounds	LTVs 3,870 Pounds +
Principal rollover	3.15	2.56
Fixed object	4.02	3.06
Pedestrian/bike/motorcycle	1.24	.13 (nonsignificant)
Heavy truck	5.91	.62 (nonsignificant)
LTV-to-car	1.13	- .68
LTV-to-LTV	3.49	- 1.50

In every crash mode, the effect is stronger among light trucks weighing less than 3,870 pounds than among light trucks weighing 3,870 pounds or more. In all six crash modes, lower weight is associated with higher fatality risk among the light trucks weighing less than 3,870 pounds. However, among LTVs weighing more than 3,870 pounds, the results diverge: in rollovers and fixed-object collisions, lower weight is associated with higher fatality risk, in ped/bike/motorcycle and heavy-truck collisions the association is not statistically significant, and in collisions with other passenger vehicles, the lighter the big LTV, the lower the crash fatality risk.

Before interpreting these results or comparing them to the findings on passenger cars, it is appropriate to do some sensitivity tests to **see how robust they are**. One alternative modeling approach that was already tried on the fixed-object collisions was to exclude the control variables RWAL (rear-wheel antilock) and HIFAT_ST (State with higher-than-average fatality rate) that did not have a significant product-moment correlation with curb weight, although they did have significant relationships with some of the other control variables. In fixed-object collisions, the regression without RWAL and HIFAT_ST produced weight-safety coefficients that were slightly to moderately lower than in the baseline regression with RWAL and HIFAT_ST, but did not produce fundamentally different results. Here are the regression coefficients for curb weight in all of the crash modes, when the control variables include RWAL and HIFAT_ST (baseline) or exclude them:

Fatality Increase (%) per 100-Pound Weight Reduction

	LTVs < 3,870 Pounds			LTVs 3,870 Pounds +		
	Base-line B	W/o rwal & hifat_st A	A-B	Base-line B	W/o rwal & hifat_st A	A-B
Principal rollover	3.15	1.65	- 1.50	2.56	1.77	- .79
Fixed object	4.02	3.16	- .86	3.06	2.69	- .37
Ped/bike/motorcycle	1.24	.90	- .34	.13	- .05	- .18
Heavy truck	5.91	4.88	- 1.03	.62	.26	- .36
LTV-to-car	1.13	.39	- .74	- .68	- .94	- .26
LTV-to-LTV	3.49	2.77	- .72	- 1.50	- 1.85	- .35

In all crash modes, taking out HIFAT_ST causes the regression to attribute a spurious, additional benefit to AWD, which is a more popular option in the lower-fatality snow-belt States, as explained in the preceding section. Since AWD adds to the weight of a light truck, the regression uses the spurious AWD benefit to explain some of the weight-safety effect. This exchanging of the effects, however, is most prominent in rollover crashes. The baseline regression associates AWD with a 20 percent higher rollover rate, which seems plausible, given the use of AWD-equipped vehicles on the type of rustic roads where rollovers are most likely to occur. Without HIFAT_ST, AWD is associated with a 13 percent reduction in rollovers, counterintuitive given usage patterns. In the other crash modes, especially among LTVs weighing 3,870 pounds or more, it doesn't make too much difference (except, maybe, in the LTV < 3,870-to-car crashes, where it changes a small effect to a really small effect). This sensitivity test suggests that the model is fairly robust, except for rollover crashes, but not as robust as the analyses for passenger cars (where adding quite a few nonessential control variables made even less difference – see Section 3.5).

Another alternative is to **limit the analysis entirely to pickup trucks**. They accounted for about 46 percent of the total mileage of LTVs in our database. Whereas the entire population of LTVs has quite diverse vehicle designs and driver profiles, pickup trucks have a more limited range of characteristics, and they change more gradually as the trucks get heavier. Heavy and light pickup trucks look quite a bit alike, except the heavier ones have longer wheelbases, wider track, more rigid structure, longer hoods and, to a lesser extent, higher sills and centers of gravity. All pickup trucks have a higher percentage of male drivers and rural mileage than other vehicle types, but these percentages keep rising as the pickups get heavier. Pickup trucks don't include many "niche" models with especially high-risk or low-risk drivers. This is an ideal situation for regression analysis – a lot like 4-door cars. Of course, limiting the analysis to pickup trucks has the cost of losing over half the data, and it is not clear that the results for pickup trucks alone would be predictive for other truck types. Here are the regression coefficients for all trucks (baseline) vs. pickup trucks alone:

Fatality Increase (%) per 100-Pound Weight Reduction

	LTVs < 3,870 Pounds			LTVs 3,870 Pounds +		
	Base-line B	Pickups only A	A-B	Base-line B	Pickups only A	A-B
Principal rollover	3.15	8.44	5.29	2.56	3.20	.64
Fixed object	4.02	3.26	- .76	3.06	4.05	.99
Ped/bike/motorcycle	1.24	1.15	- .09	.13	.21	.08
Heavy truck	5.91	5.15	- .76	.62	1.63	1.01
LTV-to-car	1.13	2.29	1.16	- .68	- 1.44	- .76
LTV-to-LTV	3.49	3.58	.09	- 1.50	- 2.69	- 1.19

With the prominent exception of LTVs < 3,870 pounds in rollover crashes, limiting the analysis to pickup trucks doesn't make a great difference. The coefficient for rollovers of lighter LTVs increased from 3.15 (lower than the 5.08 in the passenger car analysis) to 8.44 (even higher than for cars). Clearly, in the more homogeneous group of vehicles, increased weight is more strongly associated with greater static stability, wider track, and other factors that would reduce rollover risk.

The 11 other results are far more consistent for all LTVs vs. pickup trucks alone, at least in qualitative terms. While there are differences up to 1.19 percentage points, they are in both directions. The average of those 11 differences is just .04 percentage points: no systematic bias in either direction. The variation is not excessive considering that the pickup truck analyses use less than half the total database (and the standard error for the weight-safety coefficients in the baseline regressions are around .3 or .4 percentage points). This sensitivity test likewise suggests that the model is fairly robust, except for rollover crashes.

A third sensitivity test[21] is to **exclude 2-door SUVs** from the database used in the regressions. The rationale is to some extent the same as the decision to exclude 2-door cars in all the size-safety regressions for passenger cars (see Section 3.1): 2-door SUVs, like 2-door cars, represent "niche" markets and have higher fatality rates than comparable 4-door models. However, there are two factors that diminish the potential impact of excluding the 2-door SUVs: (1) Whereas 2-

[21] Recommended by Adrian Lund in his review of this report. Dr. Lund's review is available in the NHTSA docket for this report.

door cars still accounted for 24 percent of passenger car sales in MY 1991-99, 2-door SUVs accounted for only 17 percent of all SUVs, and thus only 7 percent of all LTVs, during MY 1991-99. (2) Two-door cars include a large number of "muscle cars" with medium weight and exceptionally high fatality rates that would have produced misleading size-safety effects if it had been included in the analyses; 2-door SUVs of the 1990's did not include any obvious large subgroup analogous to these muscle cars. Here are the regression coefficients for analyses including 2-door SUVs (baseline) vs. excluding the 2-door SUVs:

Fatality Increase (%) per 100-Pound Weight Reduction

	LTVs < 3,870 Pounds			LTVs 3,870 Pounds +		
	Base-line B	Excluding 2-dr SUVs A	A-B	Base-line B	Excluding 2-dr SUVs A	A-B
Principal rollover	3.15	4.82	1.67	2.56	2.26	- .30
Fixed object	4.02	3.38	- .64	3.06	3.08	.02
Ped/bike/motorcycle	1.24	1.41	.17	.13	.17	.04
Heavy truck	5.91	5.57	- .34	.62	.53	- .09
LTV-to-car	1.13	1.55	.42	- .68	- .74	- .06
LTV-to-LTV	3.49	3.17	- .32	- 1.50	- 1.52	- .02

Excluding the 2-door SUVs had some impact on the size-safety coefficients for LTVs less than 3,870 pounds, but it did not have a consistent impact. The coefficients became stronger in three crash modes and weaker in the other three. The average change for the six crash modes is +.16, a negligible amount relative to the sampling error in these estimates (see Section 4.5). Although 2-door SUVs have higher fatality rates than 4-door SUVs, these differences are fairly uniform across curb weights; thus, the basic pattern of declining fatality rates with increasing curb weights stays the same whether the 2-door SUVs are included or excluded. The closest thing to an exception is rollovers: because the rollover rates of mid-sized 2-door SUVs of the 1990's was quite high, removing them from the data actually strengthens the trend of reduced fatality rates as weight increases. Since there are relatively few 2-door SUVs weighing over 3,870 pounds, including or excluding those vehicles has little impact on the size-safety coefficients for curb weight over 3,870 pounds.

A fourth sensitivity test[22] is to analyze fatality rates **per occupant mile** rather than per vehicle mile. This makes sense in the three crash modes where all, or nearly all of the fatalities are

[22] Recommended by James Hedlund in his review of this report. Dr. Hedlund's review is available in the NHTSA docket for this report.

occupants of the case vehicle: principle rollovers, impacts with fixed objects and collisions with heavy trucks. The more passengers, the more people are exposed to potentially fatal injuries, given the same impact. If larger vehicles tend to have more passengers, fatality rates per vehicle mile, but not per occupant mile, would be higher, all else being equal. Thus, the baseline regressions based on fatality rates per vehicle mile could be discriminating against the larger vehicles, and understating the size-safety effects.

In Section 3.1, analyses of National Automotive Sampling System (NASS) data showed no significant differences in the average occupancy of small and large 4-door cars. However, the NASS data show significant differences among LTVs, both by size and, especially, body type. . Here are the average numbers of occupants per vehicle (including the driver) in NASS cases for MY 1991-99 vehicles in CY 1993-2001:

	Average N of Occupants	N of NASS Cases
Compact pickup trucks	1.349	1,256
Large (100-series) pickups	1.462	689
Heavy-duty (2/300-series) pickups	1.366	191
Small SUVs	1.528	426
Mid-size SUVs	1.592	1,218
Large SUVs	1.875	248
Minivans	2.071	802
Large vans	2.098	123

Clearly, SUVs have more occupants than pickup trucks, and vans have the most. The effect of vehicle size is less clear. In pickup trucks, occupancy increases from the compact to the basic (100-series) full-sized type, but then recedes in the heavy-duty types. Among SUVs, occupancy is just slightly higher in the mid-size than in the small vehicles, but substantially higher in the largest vehicles. Minivans and large vans have almost the same occupancy, on the average. Here are the regression coefficients for analyses of fatality rates per vehicle mile (baseline) vs. per occupant mile:

Fatality Increase (%) per 100-Pound Weight Reduction

	LTVs < 3,870 Pounds			LTVs 3,870 Pounds +		
	Base-line B	Per Occupant Mile A	A-B	Base-line B	Per Occupant Mile A	A-B
Principal rollover	3.15	3.63	.38	2.56	3.21	.65
Fixed object	4.02	4.59	.57	3.06	3.47	.41
Heavy truck	5.91	6.49	.58	.62	.93	.31

In all six cases, the size-safety coefficient measured per occupant mile is stronger than the baseline result, measured per vehicle mile. Since, on the whole, heavier LTVs have more passengers, measurement of fatality rates per occupant mile reveals an additional benefit for the heavier vehicles. The difference between the sensitivity test and the baseline ranges from 0.31 to 0.65 percentage points. However these differences are substantially smaller than the sampling error ranges that will be found for the baseline coefficients in Section 4.5. Those sampling error bounds extend from 0.95 to 1.86 percentage points on either side, in these three crash modes, according to Tables 4-2 and 4-3. This sensitivity test suggests that the baseline method may slightly underestimate the size-safety effect in three crash modes, but the difference is well within the "noise range." However, to the extent that back-seat passengers are intrinsically at lower risk than drivers and front-seat passengers, computation of fatality rates per occupant mile may actually overstate the intrinsic safety of vehicles that have many passengers.[23] This report will continue to use the baseline estimates, per vehicle mile, in these crash modes, for simplicity and consistency with the results in the other crash modes.

Here's how the baseline results for light trucks compare to the regression coefficients in the analyses of passenger cars (Section 3.4):

[23] Evans, L., *Traffic Safety and the Driver*, Van Nostrand Reinhold, New York, 1991, pp. 47-49.

	Fatality Increase (%) per 100-Pound Weight Reduction			
Crash Mode	LTVs < 3,870	Cars < 2,950	LTVs 3,870 +	Cars 2,950 +
Principal rollover	3.15	5.08	2.56	4.70
Fixed object	4.02	3.22	3.06	1.67
Ped/bike/motorcycle	1.24	3.48	.13 n.s.	- .62 n.s.
Heavy truck	5.91	5.96	.62 n.s.	2.06
Hit car	1.13	2.48	- .68	1.59
Hit LTV	3.49	5.63	- 1.50	2.62

The individual results, a comparison of the results for heavier and lighter LTVs, across crash modes, baseline vs. sensitivity tests, and LTVs vs. cars suggest the following comments:

The baseline coefficients for **rollovers** are weaker in LTVs than in cars. However, the LTV rollover results were especially sensitive to changes in the model or the calibration data set (all LTVs vs. pickups only). LTVs and cars have one thing in common: rollover risk is highly related to static stability, and track width, a determinant of static stability, has in turn historically been strongly correlated with curb weight. How strongly, though, varies with the type of vehicle (e.g., extra strong in pickup trucks). Also, since the effect of weight is less direct in rollovers than in other crash modes, it may be more sensitive to the presence or absence of control variables in the model. Nevertheless, even if the size of the effect is uncertain in LTVs, its basic direction and rationale is the same as in cars: heavier cars and LTVs tended to be wider than light vehicles of the same body type, without a comparable increase in center-of-gravity height, and they rolled over less. In addition, larger vehicles have better directional stability, preventing some of the off-road excursions that lead to rollovers.

In collisions with **fixed objects**, the weight-safety effect in LTVs was about equal or even somewhat stronger than in cars. Heavier vehicles were typically more crashworthy than light vehicles of the same body type, with more space to slow down the occupants, a more gradual deceleration in crashes, and an occupant compartment more likely to keep its structural integrity. Greater directional stability can prevent running off the road and hitting fixed objects. However, one factor could give LTVs an edge. Greater mass can sometimes help a vehicle displace or deflect a fixed object, especially if the vehicle is a massive, rigid LTV.

The weight-safety effect for LTVs in **pedestrian** crashes was weak, unlike cars. Weak makes sense: there is no obvious reason why pedestrians would be at higher risk – or lower risk, for that matter – from lighter vehicles. The factors discussed in Section 3.6 that might have increased pedestrian fatality rates of light cars – self-selection of small cars by imprudent drivers, tendency of drivers to weave in traffic with smaller cars, short hoods resulting in more pedestrians hitting the windshield frame – may not be as important with LTVs.

In collisions with **heavy trucks**, the lighter cars and LTVs had almost exactly the same, exceptionally strong weight-safety coefficient. It demonstrates the extreme vulnerability of the smallest vehicles in impacts with heavy trucks (underride/override, loss of structural integrity). However, the coefficient for heavy LTVs is lower than the coefficient for heavier cars. Perhaps that reflects the increasing proportions of the heavier LTVs being used for work rather than personal transportation, and having alert drivers who can avoid hitting heavy trucks. Or it could mean that trucks from about 4,000 pounds onwards achieved a threshold of sill height and rigidity that enabled them to withstand all but the most severe heavy-truck impacts.

The first four modes comprise the crashes that involve just one car or LTV. Taken together, it is remarkable how similar the results are for light cars, light LTVs, heavy cars and heavy LTVs. In all cases, the lighter the vehicle, the higher the overall fatality rate. The effect was strongest in the light cars – the lightest of the four vehicle groups – and it was weakest in the heavy LTVs.

The last two modes are all crashes involving multiple passenger vehicles. The weight-safety effect depends not only on the weight and body type of the case vehicle, but also on the other vehicle, and the relative size of the case and other vehicle.

Of course, when a light and a heavy vehicle collide, the fatalities are usually in the light vehicle, because its velocity change is smaller than the heavy vehicle's, inverse to the ratio of their masses ("conservation of momentum"). However, these analyses do not calibrate the fatalities in one vehicle, but the total fatalities in the crash, per case vehicle mile. If momentum conservation were the only factor affecting fatality risk, this would be a zero sum game: crash fatalities would be about the same in collisions between two light vehicles, two heavy vehicles, or a light with a heavy vehicle (in the last case, the high fatality rate in the light vehicle would be offset by the low rate in the heavy vehicle[24]). In turn, the regressions would calibrate, for the heaviest vehicles, negative coefficients of the same magnitude as the positive coefficients for the lightest ones.

Instead, the regressions (and the raw data as well) indicate that crash fatalities increased when both vehicles were reduced in weight. Only the heaviest LTVs had negative coefficients in the last two crash modes, and the magnitude of those coefficients wasn't nearly as large as the positive coefficients for the lighter vehicles.

The following factors, which will be analyzed and discussed in more detail in Chapter 6, make a "gradient" run through the 1991-99 vehicle fleet, giving the heavier vehicles lower crash fatality rates or, in the case of the heaviest LTVs, making the negative coefficients less negative:
(1) Heavier vehicles tended to be more crashworthy than light vehicles; a collision between two heavy vehicles resulted in fewer fatalities than a collision of the same speed between two light vehicles. (2) Heavier vehicles had lower crash involvement rates per mile for various reasons, including some perhaps not intrinsically due to their weight – i.e., better drivers may be selecting heavier vehicles (see Section 3.6). (3) As vehicle weight increased, vulnerability tended to decrease faster than aggressiveness to others increased. In a collision of two mismatched

[24] Exactly if fatality risk were a linear function of Delta V, only approximately otherwise.

vehicles, increasing the weight of the light vehicle helped its occupants a lot, while increasing the weight of the heavy vehicle didn't do that much additional harm to the occupants of the light vehicle; thus, increasing the weight of both vehicles resulted in a net gain.

The gradient is seen especially in collisions between cars and LTVs (crash mode 6 when the car is the case vehicle, mode 5 when the LTV is the case vehicle). The harm of a 100-pound reduction in the cars far exceeded the benefit, if any, of a 100-pound reduction in the trucks.

4.5 Best estimates of the effect of a 100-pound weight reduction

Six regression analyses provided the 12 initial point estimates of the cross-sectional increase in the fatality rate, per 100-pound weight reduction, shown at the beginning of Section 4.4. They are the actual average increases in the fatality rates of existing MY 1991-99 light trucks in CY 1995-2000 as you move down the scale from current heavy LTVs to current lighter LTVs. Four sources of uncertainty will be considered (one more than in the passenger car analysis, Section 3.7):

- The basic sampling error in calibrating the relationship of vehicle weight to fatality risk, based on the limited, existing fatality and exposure data: the "standard error" generated by SAS for the 12 regression coefficients.
- The additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc., computed as an inflation factor over the basic sampling error.
- A possible adjustment for self-selection – i.e., the extent, if any, to which small-LTV fatality rates are higher because better drivers select heavier LTVs. As in Section 3.7, this will be approximated by half the observed regression coefficient in pedestrian crashes.
- Additional uncertainty because the regression coefficients appear to be more sensitive to changes in the model (supplementary control variables) than in the passenger car analyses.

The basic sampling errors of the twelve regression coefficients for curb weight are the "standard errors" generated by SAS and shown for each regression in Section 4.3. They are even smaller than in the passenger car regressions, despite similar fatal-crash counts, because LTV weights are more uniformly spread from the lowest to the highest, whereas 4-door cars tend to cluster in the 2,500-3,500 pound range, with fewer cars at 2,000 or 4,000 pounds.

The additional error due to using data from just 8 of the States can be computed for the analysis of fixed-object crashes by the same procedure as in Section 3.5.[25] In the analysis of fixed-object collisions, the regression coefficient for curb weight up to 3,870 pounds has basic standard error

[25] The basic regression model for fixed-object collisions is run for a new database using all of the fatal crash cases, but only the induced-exposure cases from one State, weighted to give national mileage counts. This is repeated for seven States, and the standard error of the seven results is computed. HIFAT_ST has to be excluded from the list of control variables, since it is not meaningful when induced-exposure data from just one State are used.

.327 percent (as shown in Section 4.3) and additional standard error .361 percent. The combined standard error is

$$(.327^2 + .361^2)^{.5} = .487$$

a moderate inflation of .487/.327 = 1.49. The overall sampling error, using 1.96 standard deviations, would be 1.96 x 1.49 = 2.92 times the basic standard error in the regression printouts.

The regression coefficient for curb weight above 3,870 pounds has basic standard error .310 percent and additional standard error .575 percent. The combined error is .653, and the inflation factor is a stronger .653/.310 = 2.11. The overall sampling error, using 1.96 standard deviations, would be 1.96 x 2.11 = 4.14 times the basic standard error in the regression printouts. The State-to-State variation is stronger in LTVs than passenger cars because the types and uses of LTVs vary considerably with geography, population density, consumer tastes, etc., whereas, at least by comparison, the passenger car fleets of the various States are fairly similar.

The influence on the regression results due to better drivers self-selecting heavier LTVs is, of course, not exactly known and might not even exist. It can't really be measured using statistical theory. In Sections 3.6 and 3.7, the regression results for pedestrian crashes were used to appraise a likely range for this effect in passenger cars. It was concluded that a large proportion of the observed effect in passenger cars was "real" (structural/geometric factors that increase pedestrian injury; small vehicles inducing drivers to weave more in traffic), and that a maximum of half the observed effect could be attributed to self-selection. Here, too, the self-selection adjustment will be assumed to range from zero up to half the pedestrian effect. Since the weight-safety effect in pedestrian crashes is substantially less in LTVs (1.24 percent for LTVs up to 3,870 pounds, 0.13 percent for heavier LTVs) than in cars (3.48 percent for cars up to 2,950 pounds), the adjustment is likewise less.[26]

An additional source of possible uncertainty is that the regression coefficients for curb weight are fairly sensitive to changes in the model – e.g., the deletion of the seemingly nonessential control variables HIFAT_ST and RWAL. By contrast, in passenger cars, the addition of quite a few nonessential control variables plus changing the fatality rates from "per year" to "per mile" had relatively little impact on the regression coefficients for curb weight (Section 3.5).

This uncertainty, too, cannot be rigorously assayed, but the sensitivity tests in Section 4.4 offer an estimate. Deleting HIFAT_ST and RWAL reduced the weight coefficients in all 12 cases. In rollover crashes, it also implausibly reversed the sign of the AWD coefficient. But in the other five crash modes, it generated plausible models. In those five crash modes, the model without HIFAT_ST and RWAL produced coefficients for curb weight that averaged 0.74 percentage points lower than baseline for LTVs < 3,870 pounds and 0.30 percentage points lower for LTVs

[26] A case could be made for using the entire pedestrian effect, not half of it, as an adjustment. There are no crash data, as for cars (Section 3.6), suggesting that small LTV's intrinsically pose a greater threat to pedestrians. In that case, the lower bounds of the interval estimates would be .62 percentage points lower in each crash mode in Table 4-2 (but all estimates that are positive in Table 4-2 would remain positive).

over 3,870 pounds. These will be used as adjustment factors and deducted from the point estimate in the computation of a lower bound.

Combining the four sources of uncertainty generates the interval estimates shown in Table 4-2 for LTVs weighing less than 3,870 pounds. Although these interval estimates are derived from exact arithmetic formulas, they are not statistically precise "95 percent confidence intervals." They only convey a sense of the uncertainty in the results, based on 1.96 sigma sampling errors from known sources, plus an allowance for nonsampling errors.

For example, the regression for principal rollovers in Section 4.3 calibrated a 3.15 percent increase in fatality risk per 100-pound weight reduction in LTVs weighing less than 3,870 pounds. That's the point estimate. Its standard error, as shown on the SAS printout, is .393. Taking 2.92 times this basic standard error, as explained above, is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States). That yields a 1.96 sigma sampling error equal to 2.92 x .393 = 1.15 percentage points.

The lower bound of the interval estimate is the point estimate, minus the sampling error, minus half the pedestrian effect (self-selection adjustment), minus the average effect of deleting the control variables HIFAT_ST and RWAL (model formulation adjustment):

$$\text{Lower bound} = 3.15 - 1.15 - \tfrac{1}{2}\,(1.24) - 0.74 = 0.64$$

The upper bound of the interval estimate is the point estimate plus the sampling error. Here, the entire pedestrian effect is assumed to be "real" and the baseline model is accepted:

$$\text{Upper bound} = 3.15 + 1.15 = 4.30$$

Estimates for LTVs weighing 3,870 pounds or more are computed in Table 4-3. The regression for principal rollovers calibrated a 2.56 percent increase in fatality risk per 100-pound weight reduction. That's the point estimate. Its standard error is .334. Taking 4.14 times this basic standard error, as explained above, is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States). That yields a 1.96 sigma sampling error equal to 4.14 x .334 = 1.38 percentage points. The lower bound of the interval estimate is the point estimate, minus the sampling error, minus half the pedestrian effect, minus the average effect of deleting the control variables HIFAT_ST and RWAL:

$$\text{Lower bound} = 2.56 - 1.38 - \tfrac{1}{2}\,(0.13) - 0.30 = 0.81$$

The upper bound of the interval estimate is the point estimate plus the sampling error:

$$\text{Upper bound} = 2.56 + 1.38 = 3.94$$

TABLE 4-2

LIGHT TRUCKS WEIGHING LESS THAN 3,870 POUNDS
FATALITY INCREASE (%) PER 100-POUND WEIGHT REDUCTION

Crash Mode	Regression Result	Standard Error	2.92[27] x Std. Error	Interval Estimate Including Adjustments
Principal rollover	3.15	.393	1.15	.64 to 4.30[28]
Fixed object	4.02	.327	.95	1.71 to 4.97
Ped/bike/motorcycle	1.24	.391	1.14	- 1.26 to 2.38
Heavy truck	5.91	.498	1.45	3.10 to 7.36
Car	1.13	.237	.69	- .92 to 1.82
LTV < 3,870[29]	6.98	.804	2.34	1.92 to 9.32
LTV 3,870 +	3.49	.402	1.17	.96 to 4.66

[27] As explained in the text, 2.92 times the basic standard error of the regression coefficient is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States).
[28] Lower bound = point estimate – sampling error – half of pedestrian effect - model formulation adjustment = 3.15 – 1.15 – ½ (1.24) – .74; upper bound = point estimate + sampling error = 3.15 + 1.15
[29] Assumes both light trucks in the collision are reduced by 100 pounds: point estimate, standard error and adjustments are doubled.

TABLE 4-3

LIGHT TRUCKS WEIGHING 3,870 POUNDS OR MORE
FATALITY INCREASE (%) PER 100-POUND WEIGHT REDUCTION, LIGHT TRUCKS

Crash Mode	Regression Result	Standard Error	4.14[30] x Std. Error	Interval Estimate Including Adjustments
Principal rollover	2.56	.334	1.38	.81 to 3.94[31]
Fixed object	3.06	.310	1.28	1.41 to 4.34
Ped/bike/motorcycle	.13	.320	1.32	- 1.56 to 1.45
Heavy truck	.62	.450	1.86	- 1.61 to 2.48
Car	- .68	.179	.74	- 1.79 to .06
LTV < 3,870	- 1.50	.321	1.33	- 3.20 to - .17
LTV 3,870 +[32]	- 3.00	.642	2.66	- 6.40 to - .34

[30] As explained in the text, 4.14 times the basic standard error of the regression coefficient is equivalent to 1.96 time the total sampling error (basic error of the regression coefficient plus additional uncertainty from using induced-exposure data from just eight States).
[31] Lower bound = point estimate – sampling error – half of pedestrian effect - model formulation adjustment = 2.56 – 1.38 – ½(.13) – .30; upper bound = point estimate + sampling error = 2.56 + 1.38
[32] Assumes both light trucks in the collision are reduced by 100 pounds: point estimate, standard error and adjustments are doubled. The estimate that a 100-pound reduction of both LTVs will reduce fatality risk in collisions between two heavy LTVs is the only instance in this study where reducing the weight of both vehicles is not estimated to increase net risk. However, this estimate is derived from a regression where only the case LTV has to weigh 3,870 pounds or more, and the other LTV can be any weight. It may not accurately reflect the situation where both LTVs are heavy. To do so would have required methods and data beyond the scope of this report. It is possible that this estimate is too negative and, by compensation, the estimate in the row directly above it (other vehicle is light LTV) is not negative enough.

Analogous to Section 3.7, the effects in LTV-to-LTV collisions have been split into two separate lines: when the "other" LTV weighs less than 3,870 pounds and when it weighs 3,870 pounds or more. The effect and its errors are doubled in the line where the case and other LTVs are in the same weight category.

4.6 Effect of weight reductions on the number of fatalities

The percentage changes in the fatality rate, as estimated in Tables 4-2 and 4-3, are applied to the absolute numbers of "baseline" fatalities to obtain estimates of the effects of 100-pound weight reductions on the absolute numbers of fatalities. The baseline numbers used in this report were developed in Section 3.8 for light trucks as well as passenger cars. They are a synthesis of national fatality totals, in single and multivehicle crashes, for CY 1999 and fatality distributions by vehicle type, vehicle weight, and more detailed crash mode based on MY 1996-99 vehicles in CY 1996-2000 FARS.[33] They represent the fatality counts that would likely have been seen if the vehicle mix of 1996-99 had constituted the entire on-road fleet.

Table 4-4 estimates what would have been the annual net effects of reduced light-truck weights. The upper section of Table 4-4 computes the effect of an average 100-pound downward shift in LTVs that weighed less than 3,870 pounds, but leaving heavier LTVs and all passenger cars unchanged. For example, there are 1,319 annual baseline fatalities in principal rollovers of light trucks weighing less than 3,870 pounds. The point estimate from the regression analysis is a 3.15 percent increase in fatalities per 100-pound weight reduction. The point estimate of the net effect is .0315 x 1,319 = 42 more fatalities per year. The interval estimate of the effect, taking into account both sampling error and possible adjustments (self-selection, model formulation) in the regression results, ranges from 0.64 to 4.30 percent, as computed in Table 4-2. Thus, the interval estimate of the net fatality increase ranges from 8 to 57 additional fatalities per year in rollovers.

For case LTVs weighing less than 3,870 pounds, each of the crash modes has positive point estimates, indicating more fatalities as weight is reduced, and all except ped/bike/motorcycle and LTV-to-car have entirely positive interval estimates. Fixed-object collisions (68) and rollovers (42) show the highest fatality increases per 100-pound weight reduction.

Overall, light trucks weighing less than 3,870 pounds are involved in fatal crashes that result in a total of 8,057 fatalities per year to occupants of these LTVs, plus occupants of other vehicles, plus non-occupants. A 100-pound reduction would have significantly increased those fatalities: the point estimate based directly on the regression results is 234, and the interval estimate accounting for sampling error and possible adjustments is 59 to 296. The overall point estimate is simply the sum of the estimates for the various, mutually exclusive crash modes. The overall

[33] CY 1999 was the latest full year of State and FARS data at the time that work on this report began. Annual fatalities were nearly constant in 1995-2000, ranging from 41,501 to 42,065. The number of fatalities on the 1999 FARS file, 41,717 is near the average for 1995-2000. *Traffic Safety Facts, 2001*, NHTSA Report No. DOT HS 809 484, Washington, 2002, p. 15.

TABLE 4-4

FATALITY INCREASE PER 100-POUND WEIGHT REDUCTION, LIGHT TRUCKS

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Crash Mode	Annual Baseline Fatalities	Effect (%) of 100-Pound Reduction: Regression Result	Effect (%) of 100-Pound Reduction: Interval Estimate	Net Fatality Change: Regression Result	Net Fatality Change: Interval Estimate
LIGHT TRUCKS WEIGHING LESS THAN 3,870 POUNDS					
Principal rollover	1,319	3.15	.64 to 4.30	42	8 to 57
Fixed object	1,687	4.02	1.71 to 4.97	68	29 to 84
Ped/bike/motorcycle	1,148	1.24	- 1.26 to 2.38	14	- 14 to 27
Heavy truck	584	5.91	3.10 to 7.36	35	18 to 46
Car	2,062	1.13	- .92 to 1.82	23	- 19 to 38
Light truck < 3,870*	247	6.98	1.92 to 9.32	17	5 to 23
Light truck 3,870 +	1,010	3.49	.96 to 4.66	35	10 to 47
OVERALL	**8,057**	**2.90**	**.73 to 3.67**	**234**	**59 to 296**
LIGHT TRUCKS WEIGHING 3,870 POUNDS OR MORE					
Principal rollover	2,183	2.56	.81 to 3.94	56	18 to 86
Fixed object	2,639	3.06	1.41 to 4.34	81	37 to 115
Ped/bike/motorcycle	2,043	.13	- 1.56 to 1.45	3	- 32 to 30
Heavy truck	860	.62	- 1.61 to 2.48	5	- 14 to 21
Car	5,186	- .68	- 1.79 to .06	- 35	- 93 to 3
Light truck < 3,870	1,010	- 1.50	- 3.20 to - .17	- 15	- 32 to - 2
Light truck 3,870 +*	784	- 3.00	- 6.40 to - .34	- 24	- 50 to - 3
OVERALL	**14,705**	**.48**	**- 1.06 to 1.64**	**71**	**- 156 to 241**

* Assumes both light trucks in the collision are reduced by 100 pounds

interval estimate, on the other hand, is a bit narrower than what would be obtained by just summing the lower bounds and upper bounds of the various crash modes.[34] As stated above, these interval estimates are not statistically precise "95 percent confidence intervals."

In relative terms, the point estimate is a 234/8,057 = 2.90 percent fatality increase per 100-pound weight reduction. The interval estimate ranges from 59/8,057 = 0.73 to 296/8,057 = 3.67 percent.

The lower section of Table 4-4 analyzes case LTVs weighing 3,870 pounds or more. Only rollovers and fixed-object collisions have positive point and interval estimates, indicating significantly more fatalities if weight had been reduced. LTV-to-LTV collisions have negative point and interval estimates, a significant fatality reduction. The other three crash modes have interval estimates that include zero: a nonsignificant effect on crash fatalities. However, the point estimate is positive (barely) in pedestrian and heavy-truck collisions, but negative in collisions with cars.

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[34] The analysis in Section 4.5 considered four sources of uncertainty that accumulate in different ways across crash modes: (1) The basic sampling error in the regression coefficients for vehicle weight. As explained in Section 3.8, these errors are essentially independent across the crash modes and can be accumulated on a root-sum-of-squares basis (except the two car-to-car results are based on the same regression, and their errors need to be added). (2) The additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc. contributes a .00361 coefficient of variation for the lighter LTVs. This error is additive across crash modes, but it can be accumulated to the preceding error on a root-sum-of-squares basis. (3) The adjustment in the cross-sectional results to account for better drivers possibly self-selecting heavier LTVs. This is a systematic adjustment in every crash mode, always in the same direction, and was assessed as 0.62 percent, maximum. It is additive across crash modes and additive to the other errors. (4) Additional uncertainty because the results are sensitive to how the model was formulated. This was assessed as a systematic adjustment of 0.74 percent for the lighter LTVs, additive across crash modes and additive to the other errors.

In Table 4-2, the standard error for the regression coefficient in principal rollovers was .393 percent. Table 4-4 shows a baseline 1,319 fatalities per year in rollovers. The standard error of the absolute effect is .00393 x 1,319 = 5.16. Similarly, the standard errors of the absolute effect in the other crash modes are: fixed-object, 5.52; pedestrian, 4.49; heavy-truck, 2.91; LTV-to-car, 4.89; and LTV-to-LTV 6.05 (adding the errors in LTV-to-light LTV and LTV-to-heavy LTV). The square root of the sum of the squares of these six independent errors is 12.10. The standard error for the 8-State effect is .00361. Table 4-4 shows 8,057 baseline fatalities per year in all crash modes. The standard error of the 8-State effect, in absolute terms, is .00361 x 8,057 = 29.09. The overall 1.96 sigma sampling error is $1.96 \times (12.10^2 + 29.09^2)^{.5} = 62$. This quantity is added to the point estimate to obtain the upper bound of the interval estimate, which assumes no adjustments for self-selection or model formulation: 234 + 62 = 296. This quantity and the maximum adjustments are both subtracted from the point estimate to obtain the lower bound of the interval estimate. The adjustment equals half the pedestrian effect plus the model sensitivity effect, 1.36 percent in all crash modes except LTV-to-light LTV, where it is doubled to 2.72 percent. The lower bound is 234 – 62 – .0136 x (8,057–247) – .0272 x 247 = 59

Overall, light trucks weighing 3,870 pounds or more are involved in fatal crashes that result in a total of 14,705 fatalities per year. A 100-pound reduction would not significantly change those fatalities: the point estimate is an increase of 71, but the interval estimate ranges from -156 to +241.[35]

In relative terms, the point estimate is a 71/14,705 = 0.48 percent fatality increase per 100-pound weight reduction. The interval estimate ranges from -156/14,705 = -1.06 to 241/14,705 = +1.64 percent.

The size-safety effect was weakest for 1991-99 LTVs weighing 3,870 pounds or more (0.48 percent, not statistically significant) and strongest for passenger cars weighing less than 2,950 pounds (4.39 percent). There were intermediate values for cars weighing more than 2,950 pounds (1.98 percent) and LTVs weighing less than 3,870 pounds (2.90 percent). The heavier cars and the lighter LTVs both averaged approximately 3,400 pounds. Weight-safety effects diminished, or even turned negative in the collisions involving multiple passenger vehicles, as case vehicle weight increased. The effect ostensible downward shifts in vehicle weight could have varied considerably, depending on what vehicle groups shifted.

Table 4-4 is based on a 3,870-pound "boundary" between light and heavy LTVs: 3,870 was the median weight of MY 1991-99 LTVs. One disadvantage of that boundary is it makes Table 4-4 "top-heavy" because LTVs became heavier during the 1990's, and Table 4-4 uses a "baseline" of MY 1996-99 rather than the full MY 1991-99 database used in the regressions. The LTVs weighing 3,870 pounds or more are involved in 14,705 annual baseline fatalities, while the LTVs weighing less than 3,870 pounds are involved in only 8,057 fatalities.

A more even distribution of the baseline fatalities can be obtained by raising the boundary to the median weight for MY 1996-99 LTVs, the baseline years for Table 4-4: precisely 4,000 pounds. Every regression analysis of Section 4.3 can be run with 4,000 pounds rather than 3,870 pounds as the boundary between lighter and heavier LTVs. Similarly, the computation of the baseline fatality distribution in Section 3.8 is repeated with 4,000 pounds as the boundary. The resulting estimates of the relative and absolute effects of 100-pound reductions are shown in Table 4-5 (point estimates only). The baseline fatalities are quite evenly distributed: 10,714 involving the

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[35] The interval estimation uses the same method as for lighter LTVs. In Table 4-3, the standard error for the regression coefficient in principal rollovers was .334 percent. Table 4-4 shows a baseline 2,183 fatalities per year in rollovers. The standard error of the absolute effect is .00334 x 2,183 = 7.29. Similarly, the standard errors of the absolute effect in the other crash modes are: fixed-object, 8.18; pedestrian, 6.54; heavy-truck, 3.87; LTV-to-car, 9.28; and LTV-to-LTV 8.28. The square root of the sum of the squares of these six independent errors is 18.23. The standard error for the 8-State effect is .00575. Table 4-4 shows 14,705 baseline fatalities per year in all crash modes. The standard error of the 8-State effect, in absolute terms, is .00575 x 14,705 = 84.55, far greater than the basic standard error. The overall 1.96 sigma sampling error is $1.96 \times (18.23^2 + 84.55^2)^{.5} = 170$. This quantity is added to the point estimate to obtain the upper bound of the interval estimate, which assumes no adjustments: 71 + 170 = 241. This quantity and the maximum adjustments are both subtracted from the point estimate to obtain the lower bound of the interval estimate. The adjustment is half the pedestrian effect plus the model sensitivity effect, .37 percent in all crash modes except LTV-to-light LTV, where it is doubled to .74 percent. The lower bound is 71 – 170 – .0037 x (14,705–784) – .0074 x 784 = – 156

TABLE 4-5

FATALITY INCREASE PER 100-POUND WEIGHT REDUCTION, LIGHT TRUCKS

BASED ON ANALYSES WITH 4,000 POUNDS
AS THE BOUNDARY BETWEEN LIGHT AND HEAVY LTVs

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Crash Mode	Annual Baseline Fatalities	Effect (%) of 100-Pound Reduction	Net Fatality Change
LIGHT TRUCKS WEIGHING LESS THAN 4,000 POUNDS			
Principal rollover	1,877	3.16	59
Fixed object	2,229	4.10	91
Ped/bike/motorcycle	1,508	1.21	18
Heavy truck	728	5.52	40
Car	2,900	1.14	33
Light truck < 4,000*	441	6.22	27
Light truck 4,000 +	1,031	3.11	32
OVERALL	**10,714**	**2.80**	**300**
LIGHT TRUCKS WEIGHING 4,000 POUNDS OR MORE			
Principal rollover	1,625	2.46	40
Fixed object	2,097	2.82	59
Ped/bike/motorcycle	1,683	.03	1
Heavy truck	716	.33	2
Car	4,348	- .90	- 39
Light truck < 4,000	1,031	- 1.77	- 18
Light truck 4,000 +*	569	- 3.54	- 20
OVERALL	**12,069**	**.20**	**25**

* Assumes both light trucks in the collision are reduced by 100 pounds

lighter LTVs and 12,069 involving the heavier LTVs. The majority of rollover and fixed-object fatalities are in the lighter LTVs, but the heavier LTVs have substantially more crashes with cars that result in fatalities.

For LTVs weighing 4,000 pounds or more, the relative fatality increase in the first four crash modes, per 100-pound weight reduction, was slightly less than for trucks weighing 3,870 pounds or more – e.g., in rollovers, 2.46 percent vs. 2.56 percent. In the last two crash modes, the relative fatality reductions were slightly greater. None of the regression coefficients changed sign. The estimated net absolute effect of a 100-pound downward shift would have been an increase of 25 fatalities in trucks weighing 4,000 pounds or more, vs. an increase of 71 in trucks weighing 3,870 pounds or more. Both of these increases are small, relative to the sampling error in the analyses. Setting the boundary at 4,000 rather than 3,870 pounds does not qualitatively change the results.

However, in trucks weighing less than 4,000 pounds, the estimated net absolute effect of a 100-pound downward shift would have been an increase of 300 fatalities, vs. an increase of 234 in trucks weighing less than 3,870 pounds. Thus, according to Table 4-5, the effect of shifting the mix of 1991-99 LTVs in a manner that would have reduced their average weight by 100 pounds is an increase of 325 (300 + 25) fatalities, while in Table 4-4 the estimated increase is 305 (234 + 71). These two estimates ought to be about the same, and they are. The difference between 325 and 305 is small compared to the sampling error in either estimate. That demonstrates the regression analysis procedure is robust, at least to the extent that changing the boundary between light and heavy LTVs doesn't have much impact on the estimated net effect of a 100-pound downward shift in the overall LTV fleet.

4.7 The "crossover weight": crash fatality rates increase for heavier LTVs

The net increase in fatalities would have been small if all 1991-99 trucks over 3,870 pounds had averaged 100 pounds lighter (Table 4-4), and even smaller if just the trucks over 4,000 pounds had averaged 100 pounds lighter (Table 4-5). There must have been some "crossover weight" above 4,000 pounds where fatality rates stop decreasing and start increasing as LTVs get heavier, because the decrease for other road users would have more than offset the increase for the truck occupants.

The crossover weight can be estimated by a logistic regression with a quadratic, rather than a 2-piece linear weight-safety effect. By using the terms LBS100 = CURBWT and $LBS100^2$, the effect of a 100-pound reduction will vary continuously as curb weight increases. At some point, the net effect will cross zero and change signs.

Instead of separate regressions on the six crash modes, the analysis is simplified by performing a single regression of overall, prorated crash fatalities per billion miles. "Prorated crash fatalities" are defined in Section 5.4 to provide a single measure of overall fatality risk, appropriately weighted between single- and multivehicle crashes.[36]

The regression is based on 53,332 records of MY 1991-99 LTVs that were case vehicles in fatal crashes during CY 1995-2000, accounting for 42,768 prorated crash fatalities, plus the same 696,810 induced-exposure records used in other analyses of this chapter. The regression produced the following coefficients for curb weight:

PRORATED CRASH FATALITIES PER BILLION MILES

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
LBS100	- 0.0838	0.00625	179.6	0.0001
LBS100 SQUARED	+ 0.000824	0.000077	115.6	0.0001

These coefficients have the appropriate signs. They say fatality risk increases substantially when a light LTV is reduced by 100 pounds, but the increase gradually diminishes for the heavier LTVs. At any specific curb weight, the effect of a 100-pound reduction can be found by taking the derivative of the regression equation with respect to curb weight, and it is a fatality increase of

$$\text{D\_RATE} = 8.38 - 2 \times .000824 \times \text{CURBWT percent}$$

When CURBWT = 5,085 pounds, D_RATE = 0. This was the crossover weight in MY 1991-99. At any weight lower than 5,085 pounds, the effect of a 100-pound reduction was an increase in prorated crash fatalities, while at any weight greater than 5,085 pounds the effect was a net benefit. Figure 4-8 graphs the percent fatality increase per 100-pound weight reduction as a function of the case LTV's curb weight. For a very light LTV weighing 2,000 pounds, a 100-pound reduction would have increased fatality risk by 5 percent (similar to the weight-safety effect in small cars, see Table 3-4).

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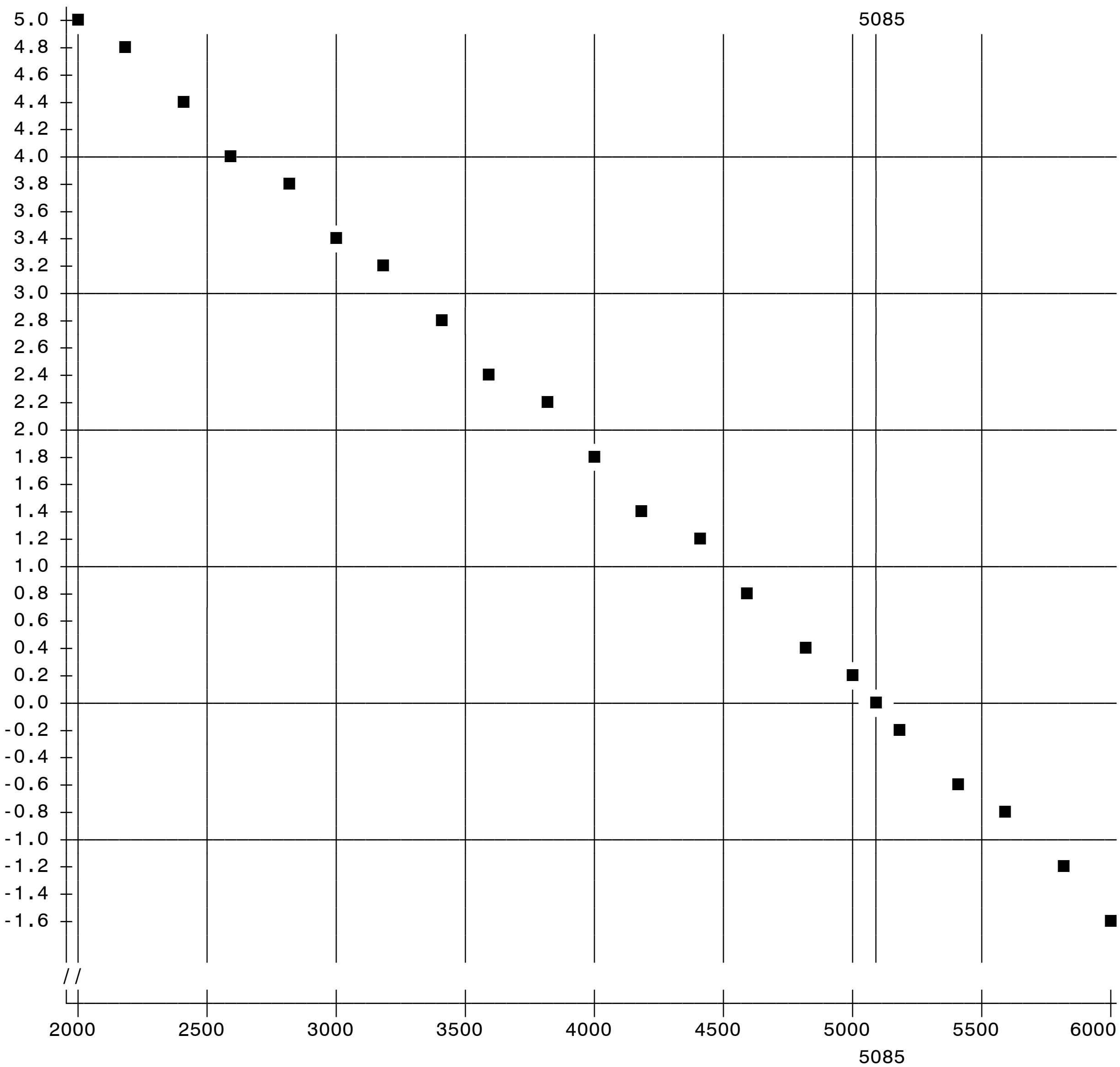
36 "Crash fatalities" include occupants of the case vehicle and the other vehicle, plus non-occupants. However, in cases involving two or more cars/LTVs, there could be double-counting since the same crash might appear twice, once with Vehicle 1 as the case vehicle, once with Vehicle 2 as the case vehicle. "Prorated crash fatalities" for the case vehicle are defined to equal crash fatalities divided by the number of passenger vehicles (cars or LTVs) involved in the crash. The total number of fatalities in the crash is equally apportioned among the light vehicles involved. For example, in a three-car crash that results in two fatalities, each vehicle, when and if it is a case vehicle in the regression, is apportioned a WEIGHTFA = 2/3 prorated crash fatalities (regardless of what vehicle(s) the fatally injured people were occupying). This eliminates double-counting and prevents giving too much weight to the multivehicle crashes. Of course, in crashes that involved only car/LTV – viz., single-vehicle crashes, collisions of one car/LTV with a heavy truck or motorcycle, WEIGHTFA = FATALS as in most of the preceding regressions.

FIGURE 4-8

PERCENT FATALITY-RISK INCREASE PER 100-POUND WEIGHT REDUCTION

(Prorated crash fatalities per billion miles, with quadratic curb-weight terms)

D_RATE (Percent Risk Increase)



CURB WEIGHT

The effects of 100-pound reductions at other curb weights ranged from a substantial increase in the 2,500-3,500 pound range, little net change in the 4,000-5,000 pound range, to a moderate benefit for the heaviest LTVs:

LTV Curb Weight	Percent Fatality Increase Per 100-Pound Reduction
2,500	4.26
3,000	3.44
3,500	2.61
4,000	1.79
4,500	.96
5,085	0.00
5,500	- .68
6,000	- 1.51

An interval estimate for the crossover weight can be obtained by repeatedly performing the regression using induced-exposure data from just one State at a time, for seven States, as in Sections 3.5 and 4.5 (the other component of the sampling error, the "basic" errors of the regression coefficients, is negligible relative to the State-to-State error[37]). The point estimate of the crossover weight is 5,085, and its log is 8.534. The log of the crossover weight in these seven regressions has standard deviation s = .250, and standard error $s / 7^{.5} = .0946$. The interval estimate for the crossover weight ranges from

$$\exp(8.534 - 1.96 \times .0946) = 4{,}224 \text{ pounds}$$

to

$$\exp(8.534 + 1.96 \times .0946) = 6{,}121 \text{ pounds}$$

The range suggests considerable uncertainty regarding the exact location of the crossover weight in MY 1991-99.[38]

[37] The crossover weight is a linear function of the coefficients for LBS100 and LBS100 SQUARED. The "basic" standard error of LBS100 SQUARED is .000077, while its standard error based on State-to-State variation is .000900, over ten times as large.

[38] The principal difference between State crash files is in the proportion of crashes on roads classified as "rural" and/or speed limit 55+. That makes more of a difference here than in the other analyses because the heaviest LTVs (curb weights over 4,500 or even 5,000 pounds) accumulate an exceptionally high proportion of their VMT on rural, high-speed roads, and the fatality rates of these heavy LTVs (after adjustment for RURAL and SPDLIM55) strongly influence the coefficient for LBS100 SQUARED.

4.8 Comparison with NHTSA's 1997 report

This study estimates a substantially higher size-safety effect in passenger cars and light trucks than NHTSA's 1997 report, which was based on MY 1985-93 vehicles in CY 1989-93 crashes.[39] That report estimated an increase of 302 fatalities in crashes involving passenger cars per 100-pound reduction in the cars, whereas the sum of the point estimates for lighter and heavier cars would be 597 + 216 = 813 here (although the interval estimates do allow room for considerably smaller numbers). The 1997 report point-estimated 40 **fewer** fatalities per 100-pound reduction in light trucks, while this study point-estimates 234 + 71 = 305 more. (Both studies are cross-sectional analyses of actual fatal-crash experience. The "fatality increase per 100-pound reduction," in both analyses, is the average difference between models weighing W pounds and other models weighing W-100 pounds, given drivers of the same age/gender, etc.)

This study's point estimates of the weight-safety effects for lighter and heavier vehicles can be averaged, by crash mode. For example, the effect of a 100-pound reduction on passenger-car rollover fatalities is a 5.08 percent increase for cars weighing less than 2,950 pounds and a 4.70 percent increase in cars weighing 2,950 pounds or more. That averages out to 4.89. Now this study's results can be compared to the 1997 report's:

Fatality Increase (%) per 100-Pound Weight Reduction

	Passenger Cars			Light Trucks		
	Average, This Study B	1997 Report A	A-B	Average, This Study B	1997 Report A	A-B
Principal rollover	4.89[40]	4.58	- .31	2.85	.81	- 2.04
Fixed object	2.44	1.12	- 1.22	3.54	1.44	- 2.10
Ped/bike/motorcycle	1.43	- .46	- 1.89	.68	- 2.03	- 2.71
Heavy truck	4.01	1.40	- 2.61	3.26	2.63	- .63
Collision with car	2.03	- .62	- 2.65	.22	- 1.39	- 1.61
Collision with LTV	4.12	2.63	- 1.49	.99	- .54	- 1.53

In all 12 cases, this study calibrates a larger fatality increase as weight is reduced. The differences are quite consistent across crash modes, and average out to 1.73 percentage points. That is because the 1997 report has analysis problems resulting in a systematic bias in favor of smaller vehicles in every crash mode.

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[39] Kahane (1997), pp. vi and vii.

[40] 4.89 = (5.08 + 4.70)/2, the average of the effect in cars weighing < 2,950 and in cars weighing 2,950 +.

A principal tool in this study is a database of induced-exposure crash cases, weighted by registration years, whose case weights add up to the total registration years of cars and light trucks in the United States. The 1997 report did not develop that analytic tool. Instead, it found other ways to wrestle with induced-exposure and registration data, producing biased results, although the biases were not always recognized in 1997.

The first analysis in the 1997 report did not use registration data at all, and simply performed regressions of the fatalities per 1000 induced-exposure crashes, by curb weight, controlling for age/gender, urban/rural, etc.[41] The regressions produced obviously counterintuitive results for light trucks: fatalities substantially increased in every crash mode as weight increased.[42] The 1997 report concluded that this method was unsatisfactory because heavy LTVs have a low rate of induced-exposure crashes, per mile or per year, apparently because they are rugged and hard to damage. That biases the fatality rates per reported crash in favor of the lighter LTVs. In fact, the same bias was present, just not quite as strongly, in passenger cars. The 1997 report did not recognize it. The regressions for cars generated weight-safety coefficients that were too low, but they seemed plausible at the time, probably because earlier analyses in the literature were also based on fatalities and injuries per 100 reported crashes, and had similar biases, and likewise underestimated the weight-safety effect.[43]

Next, the 1997 report tried to analyze fatality rates per million registration years, using the induced-exposure data only indirectly.[44] Data were aggregated and fatality rates per million years were computed by make-model, model year and calendar year. At that level of aggregation, the induced-exposure data provided information about the percentage of young drivers, old drivers, female drivers, rural crashes, etc. That allowed aggregate regressions of the fatality rate per million years by make-model, MY and CY, with independent variables curb weight, percent young drivers (in the induced-exposure crashes), etc. This approach was theoretically unbiased but the regressions failed quite noticeably because, at this level of aggregation, "percent young drivers" and "percent old drivers" were too highly correlated with the key independent variable, curb weight. The telltale signs were: (1) implausible coefficients for curb weight: heavy cars have the same fatality risk as light cars in rollovers, and higher fatality risk than light cars in the other crash modes; (2) implausible coefficients for the driver age variables – e.g., a coefficient of .184 for "young driver" in the rollover regression, almost double what it ought to be, and -.137 for "older male driver," in the wrong direction and far too large a magnitude.[45]

The 1997 report concluded that fatality rates should be computed per million years, but that these fatality rates also needed to be adjusted somehow for driver age, based on induced-exposure data. Lacking this study's technique of weighting induced-exposure crashes by vehicle years, the

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[41] *Ibid*., Chapters 2 and 3. Another issue was that the 1997 report did not use the conventional definition of induced exposure crashes.
[42] *Ibid*., pp. 49-54.
[43] *Ibid*., pp. 12-13.
[44] *Ibid*., pp. 89-118.
[45] *Ibid*., p. 116 presents the rollover regression in the 1997 report. See Section 3.4 of this study for appropriate driver age coefficients in the rollover regression: +.10 for each year that a male driver is younger than 30, +.07 for each year that he is older than 70.

1997 report developed "exogenous driver-age coefficients," a more cumbersome method that essentially could not be checked if it really fit the data.[46]

The centerpiece of that method was a regression analysis in 11 States, again aggregated by make-model, CY and MY, of induced-exposure crash involvements per thousand registration years.[47] One independent variable was curb weight. The others were the percentage of young drivers, old drivers, female drivers, rural crashes, etc., again derived as averages from the induced-exposure data.

The rationale was: this regression would measure the effect of driver age on induced-exposure crashes per thousand registration years. The first regression analysis in the 1997 report, described above, already measured the effect of driver age on fatalities per thousand induced-exposure crashes. Add the driver-age coefficients from the two regressions together, and they should equal the effect of driver age on fatalities per million registration years. That would be the "exogenous driver-age coefficient" and it would simply be forced into the regression of fatalities per million vehicle years.

This approach, too, was theoretically unbiased and might have produced accurate results if the regression of induced-exposure crashes per thousand registration years had been successful.[48] However, that regression also failed, just like the aggregate regressions of fatalities per million years, **but the failure was not detected in 1997**, because the errors in the coefficients were not so extreme, and were even consistent with scenarios that seemed plausible at the time. The coefficients for the five key variables were[49]:

1997 REPORT: LOG(INDUCED-EXPOSURE CRASHES PER REGISTRATION YEAR)

	Coefficient	t	P <
CURBWT00	- .0027	- 2.26	.0241
YOUNGDRV	+ .0278	7.18	.0001
OLDMAN	- .0374	- 7.21	.0001
OLDWOMAN	- .0397	- 5.94	.0001
DRVMALE	- .0301	- .50	.6157

These coefficients don't scream, "failed regression," even though that's what they are. They say the induced-exposure crash rate increases by 2.78 percent for each year-of-age that a driver is younger than 35, decreases by 3.74-3.97 percent per year-of-age for older drivers, and is about

[46] *Ibid*., pp. 118-135.
[47] *Ibid*., Chapter 4.
[48] *Ibid*., pp. 71-80.
[49] *Ibid*., p. 74. The dependent variable is log(induced exposure crashes / vehicle years). CURBWT00 = .01 x curb weight; YOUNGDRV = 35 – age, for drivers younger than 35, 0 otherwise; OLDMAN = age – 50 for males > 50, 0 for all others; OLDWOMAN = age – 45 for females > 45, 0 for all others.

the same for males and females. **After** controlling for driver age/gender, etc., the rate of induced-exposure crashes per thousand years is almost the same for light and heavy cars (only a 0.27 percent reduction per 100-pound weight increase). The numbers are not implausible, and the near-zero effect for curb weight is conceptually reassuring.

The 1997 report went on to infer that, in passenger cars, induced-exposure crashes are essentially equivalent to mileage (or, at least, the mileage per induced-exposure crash is the same for light and heavy cars). Younger people drive more, older people drive less, and, for drivers of the **same age**, heavy and light cars would have nearly the same annual mileage. Since, on the average, lighter cars have younger drivers, they must be driven more miles per year than heavy cars. The high fatality rates per year of light cars are partly due to their high mileage. After adjusting for the extra mileage attributable to young drivers (by using the exogenous driver age coefficients) the 1997 report concludes that light cars are not that much less safe than heavy cars.

That is a false conclusion based on a false premise. Odometer readings from NASS demonstrate that light and heavy 4-door cars of MY 1991-99 had almost the same average annual mileage, despite the differences in driver age (see Section 2.4). A regression of annual mileage of 1-5 year old 4-door cars by curb weight, driver age and gender can be performed on the NASS data, on a disaggregate, case-by-case level, where there is no danger that it might fail:

1993-2001 NASS: LOG(MILEAGE PER YEAR)
(MY 1991-99 passenger cars)

	Coefficient	t	P <
CURBWT00	+ .0079	5.22	.0001
M14_30	- .0015	- .48	.6297
M30_50	+ .0035	1.73	.0829
M50_70	- .0128	- 5.26	.0001
M70+	- .0227	- 5.02	.0001
F14_30	+ .0018	.62	.5369
F30_50	+ .0029	1.60	.1095
F50_70	- .0195	- 8.37	.0001
F70+	- .0191	- 3.41	.0006
DRVMALE	+ .0659	1.85	.0641

Annual mileage did not increase for young drivers and was in fact almost level up to age 50. Mileage decreased beyond age 50, but only by 1½ - 2 percent per year-of-age, not the 3½ - 4 percent suggested by the 1997 report. After controlling for driver age/gender, annual mileage was significantly higher in heavy cars (a 0.79 percent increase per 100-pound weight increase). Even though they had older drivers, heavy cars were driven just as many miles per year as light cars.

In other words, the regression in the 1997 report failed, and it generated a substantial positive coefficient for YOUNGDRV where it should have had close to zero, and coefficients for OLDMAN and OLDWOMAN that were twice as negative as they should have been. These values, in turn, were added to the "exogenous driver age coefficients" and skewed the regression results in every crash mode in favor of lighter cars, as described above.

There are two other important differences between the 1997 report and the current study in the way the studies calibrated the weight-safety relationship for passenger cars: (1) The 1997 report included 2-door cars in the calibration database. As explained in Section 3.1, sporty and high-performance 2-door cars have exceptionally high fatality rates compared to other cars of similar weight. The sports cars exaggerate the size-safety effect by placing a high outlier at the light end, while the muscle cars water down the effect with a high outlier in the middle. (2) The 1997 report also included police cars in the calibration. They are high-mileage vehicles, sometimes driven under emergency conditions. Inclusion of these vehicles places a high outlier at the heavy end of the vehicle weight range and diminishes the calibrated size-safety effect, especially for pedestrian and car-to-car crashes (where police cars are most overrepresented).

Fortunately, it is possible to revise the 1997 model by sequentially omitting 2-door cars and police cars and correcting the exogenous driver-age coefficients. The NASS regression described above is used to correct the driver-age coefficients.[50] Here is how the 1997 calibration responds[51]:

[50] *Ibid*., p. 120 provides a table of driver-age coefficients. The coefficient for "fatalities per 1000 induced-exposure crashes" (varies by crash mode) is added to the coefficient for "induced-exposure crashes per 1000 vehicle years" (always the same) to obtain the exogenous coefficient for a specific crash mode. The correction is to replace the "induced-exposure crashes per 1000 vehicle years" coefficient by the NASS results: 0 for YOUNGDRV and FEMALE (because the NASS coefficients are not significant), -.0178 for OLDMAN (average of the NASS M50_70 and M70+ coefficients), and -.0193 for OLDWOMAN (average of the F50_70 and F70+ coefficients).

[51] Since police cars were not separately identified in the 1997 database, all Caprice and Crown Victoria are excluded here.

Fatality Increase (%) per 100-Pound Weight Reduction

	1997 Report				This Study	
	Base-line	4-Door Only	+ Excl Police	+ Correct Drv Age A	Average B	A-B
Principal rollover	4.58	5.80	4.28	5.39	4.89	.50
Fixed object	1.12	2.20	2.22	3.40	2.44	.96
Ped/bike/motorcycle	- .46	- .50	.11	1.24	1.43	- .19
Heavy truck	1.40	1.45	2.08	3.16	4.01	- .85
Car-to-car	- .31[52]	- .12	.64	1.80	2.03	- .23
Car-to-LTV	2.63	2.79	3.94	5.06	4.12	.94

For example, the 1997 report found a 4.58 percent increase in rollover fatalities per 100-pound weight reduction in cars. Removing 2-door cars from the database and repeating the regression increases the coefficient to 5.80. Additionally removing Caprice and Crown Victoria cases reduces it back to 4.28. Additionally correcting the driver-age coefficients produces 5.39. That is very close to the 4.89 produced in this study (average of the coefficients in lighter cars and heavier cars, 5.08 and 4.70, respectively). The difference between the revised 1997 estimate and the current one is just .50.

In each crash mode, the revised 1997 estimate is more positive than the original estimate, and it is always within one percentage point of the current estimate. In three crash modes, the revised 1997 estimate is higher than the current estimate, in three lower. The average discrepancy between the revised 1997 estimates and the current estimates is just 0.19 percentage points.

Omitting 2-door cars from the 1997 database has an important effect in rollovers and fixed-object collisions, where medium-weight 2-door high-performance cars had high fatality rates, contrary to the general trend of lower fatality rates with increasing weight. Omitting police cars eliminates the 1997 report's paradoxical negative results in pedestrian and car-to-car collisions: police cars are heavy, and had high rates in these collision types due to emergency use. Correcting the exogenous driver-age coefficients adds about 1.1 percentage points in every crash mode.

The current results are different from the 1997 report because the analysis method has changed, not the vehicles. Even retaining the basic overall approach of the 1997 report, but just correcting three features in the model generates weight-safety coefficients very close to the current study.

[52] This is the actual regression coefficient. It is doubled to assess the effect of weight reduction in car-to-car collisions.

The overall relationship of vehicle weight and fatality risk was probably almost the same in MY 1985-93 cars during CY 1989-93 as in MY 1991-99 cars during CY 1995-2000.

The 1997 report's analysis of light trucks has an additional flaw. It implicitly assumes that, given drivers of the same age and gender, light and heavy LTVs would be driven the same number of miles per year. Since heavier LTVs have somewhat older drivers than light LTVs, the [erroneous] exogenous driver-age coefficients imply that heavier LTVs are driven fewer miles per year than light LTVs. In fact, the NASS data in Table 2-3 of this study show the exact opposite: heavier LTVs are driven more miles per year than light LTVs, in some cases substantially more, in spite of having older drivers. The 1997 report inflates the per-mile fatality rates of heavier LTVs when they should be deflated. This is the primary reason that the 1997 report associates a net fatality reduction with weight reductions in light trucks, rather than a fatality increase like the current study.

Three things the 1997 report got right were: (1) The overall relationship of vehicle weight and fatality risk is stronger (in the direction of lower weight = higher fatality rates) in passenger cars than in light trucks. (2) It is stronger in rollover, heavy-truck and fixed-object crashes, weaker in pedestrian crashes. (3) Reductions in the weight of the passenger car are associated with sizeable increases in fatality risk in collisions with light trucks. Nevertheless, the 1997 report substantially underestimated the overall relationship of vehicle weight and fatality risk, and its findings that lower vehicle weight might reduce fatality risk in pedestrian, car-to-car and LTV-to-LTV collisions were counterintuitive.

Additionally, by calibrating a linear, uniform effect for vehicle weight across the entire spectrum of light to heavy, the 1997 report missed one of the important findings of this study: the effect is weaker in the heavier vehicles. Because the 1997 report did not obtain directly comparable curb weights for cars and light trucks, it was unable to compare the fatality rates of LTVs and passenger cars "on a level playing field" – as this study will attempt to do in the next chapter.

CHAPTER 5

FATALITY RATES PER BILLION MILES IN 4-DOOR CARS VS. SUVs, PICKUP TRUCKS AND MINIVANS

5.0 Summary

Crash fatality rates per billion vehicle miles were compared for 4-door cars, SUVs, pickup trucks and minivans of model year 1996-99 in calendar years 1996-2000, controlling for driver age and gender, urban/rural, etc. Large 4-door cars and minivans had the lowest crash fatality rates, taking into account fatality risk for their own occupants as well as occupants of other vehicles and pedestrians. Small cars had higher-than-average risk for their own occupants in most types of crashes. Some of the pickup trucks and SUVs of these model years had high fatality rates for their own occupants in rollovers, and in collisions with other vehicles, there were high fatality rates for occupants of the other vehicle.

These are descriptive analyses of the fatal-crash experience of actual 1996-99 vehicles. They try to compare the fatality rates in different types of vehicles "on a level playing field": for drivers of the same age/gender, for the same mix of rural/urban driving, etc. The results of this chapter apply specifically to model year 1996-99 vehicle designs. Results can change as new designs or technologies are introduced, such as new designs for LTVs with improved rollover resistance, or with equipment to reduce hazards to other vehicles in collisions.

5.1 The calibration data set: MY 1996-99 personal-transportation vehicles

The analysis is based on regressions of fatality rates per billion miles, by vehicle type, driver age/gender, urban/rural, etc. Unlike Chapters 3, 4 and 6, vehicle weight *per se* is not a regression variable. However, the basic vehicle types (cars, pickup trucks, SUVs, vans) are subdivided into two or more "size groups" partially based on weight. The objective here is to compare the fatality risk of, say, a mid-sized SUV and a mid-sized car [lighter, on the average, than the mid-sized SUV], rather than an SUV and a car of exactly the same weight.

Since the analysis combines cars and light trucks, there are plenty of data. It can be limited to more recent vehicles and still have statistical power: model year 1996-99 vehicles in calendar years 1996-2000. The few 1996-99 vehicles without driver air bags are also excluded. The MY and CY range corresponds exactly to the "baseline" vehicle fleet used throughout this report for estimating the effects of weight reductions on fatalities. By contrast, the weight-safety regressions of Chapters 3 and 4, in order to obtain an adequately large database, extended to MY 1991-99 in CY 1995-2000 and included many vehicles without air bags.

The analysis is limited to ten groups of vehicles that are extensively used for personal transportation by "typical" drivers. As in Chapter 3, 2-door cars and police cars are excluded. By the late 1990's, 2-door cars increasingly occupied niche markets with unusual driver characteristics (sporty cars, high-performance cars). Unlike Chapter 4, 2-door SUVs, extra-heavy duty pickup trucks (200 or 300 series) and all full-sized vans are also excluded. The 2-door SUVs can be considered niche vehicles parallel to 2-door cars, while the heavy-duty pickups and vans may be extensively used for specialized tasks such as farm work, household contractors (plumbers, roofers, etc.) or van-pooling.[1] The analysis in Section 5.6 will demonstrate that drivers of 4-door cars, 4-door SUVs and pickup trucks (up to 100-series size) have quite similar incidence of high-risk driving behaviors; drivers of 2-door cars and 2-door SUVs, substantially more; drivers of 200- and 300-series pickup trucks and full-sized vans, substantially less.

Four-door cars were subdivided by make-model into four size groups generally based on their mass, occupant space, and/or market slot relative to other models produced by the same manufacturer or competitors. The classification is for the purpose of this analysis and does not necessarily correspond to "official" groups defined by the government or others. Ranges of curb weight for the different groups sometimes overlap. Pickup trucks were divided into two groups and 4-door SUVs, three. Along with minivans, that makes ten groups of light vehicles, whose constituent 1996-99 make-models are listed in Table 5-1:

	Curb-Weight Range
• Very small 4-door cars	1,950 to 2,274
• Small 4-door cars	2,208 to 2,878
• Mid-size 4-door cars	2,566 to 3,567
• Large 4-door cars	3,035 to 4,690
• Compact pickup trucks	2,625 to 4,178
• Large (100-series) pickup trucks	3,404 to 5,268
• Small 4-door SUVs	2,636 to 3,437
• Mid-size 4-door SUVs	3,476 to 4,484
• Large 4-door SUVs	4,332 to 5,899
• Minivans	3,354 to 4,819

[1] The 1995 National Personal Transportation Survey (NPTS) estimates 80% of trips in passenger cars are for personal transportation (family/personal business, school, church, social, recreational), as are 84% of trips in vans, 77% in SUVs, and 69% in pickups. Thus, pickups have a substantially higher percentage of trips for "earning a living" than the other types, but still are used primarily for personal transportation (*1995 NPTS Databook*. Federal Highway Administration Report No. ORNL/TM-2001/248, Washington, 2001). However, NPTS does not provide separate statistics for small and large pickups or vans or for 2-door vs. 4-door vehicles.

TABLE 5-1: "SIZE GROUPS" OF MY 1996-99 MAKE-MODELS

Very Small 4-Door Cars
Ford Aspire
Chevrolet/Geo Metro
Toyota Tercel
Mitsubishi Mirage
Hyundai Accent

Small 4-Door Cars
Dodge/Plymouth Neon
Ford Escort
Mercury Tracer
Chevrolet Cavalier, Corsica, Prizm
Pontiac Sunfire
Saturn (all)
Nissan Sentra
Honda Civic
Mazda Protege
Subaru Impreza
Toyota Corolla
Suzuki Esteem
Hyundai Elantra
Kia Sephia
Daewoo Lanos, Nubira

Mid-Size 4-Door Cars
Chrysler Cirrus
Dodge Stratus
Plymouth Breeze
Eagle Summit wagon
Ford Taurus, Contour
Mercury Sable, Mystique
Buick Century (96), Regal (96), Skylark
Chevrolet Malibu, Lumina
Oldsmobile Achieva, Alero, Ciera, Supreme
Pontiac Grand Am, Grand Prix (96)
VW Jetta, Golf, Passat
Audi A4
BMW 300
Nissan Altima
Honda Accord
Mazda 626
Mercedes C Sedan
Saab 900, 9-3
Subaru Legacy
Toyota Camry
Mitsubishi Galant
Acura Integra
Hyundai Sonata
Infiniti G20
Lexus ES
Daewoo Leganza

Large 4-Door Cars
Chrysler Concorde, LHS, New Yorker, 300
Dodge Intrepid
Eagle Vision
Ford Crown Victoria
Lincoln Town Car, Continental
Mercury Grand Marquis
Buick LeSabre, Park Avenue, Roadmaster
Buick Century (97-99), Regal (97-99)
Cadillac (all)
Chevrolet Caprice
Oldsmobile 88, 98, Aurora, Intrigue
Pontiac Bonneville, Grand Prix (97-99)
Audi A6, A8
BMW 500, 700
Nissan Maxima
Jaguar (all)
Mazda Millenia
Mercedes E, S
Saab 9000, 9-5
Toyota Avalon
Volvo (all)
Mitsubishi Diamante
Acura TL, RL
Infiniti Q45, J30, I30
Lexus LS, GS

TABLE 5-1: "SIZE GROUPS" OF MY 1996-99 MAKE-MODELS (Continued)

Compact Pickup Trucks
Dodge Dakota
Ford Ranger
Chevrolet S/T
GMC Sonoma
Nissan (all)
Isuzu Hombre
Mazda (all)
Toyota Tacoma

Large (100) Pickup Trucks
Dodge Ram 1500
Ford F150
Chevrolet C/K10
GMC Sierra C/K1500
Toyota T100

Small 4-Door SUVs
Jeep Cherokee**
Chevrolet/Geo Tracker*
Subaru Forester
Toyota RAV4*
Suzuki* Sidekick, X-90, Vitara, Grand Vitara
Honda CR-V
Kia Sportage*

Mid-Size 4-Door SUVs
Jeep Grand Cherokee
Ford Explorer*
Mercury Mountaineer
Chevrolet S/T Blazer*
GMC Jimmy*
Oldsmobile Bravada
Nissan Pathfinder
Isuzu Rodeo
Toyota 4Runner
Mitsubishi Montero
Honda Passport
Lexus RX300
Infiniti QX4

Large 4-Door SUVs
Dodge Durango
Ford Expedition
Lincoln Navigator
Chevrolet Tahoe*, Suburban
GMC Yukon*, Suburban
Cadillac Escalade
Isuzu Trooper
Toyota Land Cruiser
Acura SLX
Lexus LX450, LX470
Land Rover* (all)
Mercedes (all)

Minivans
Dodge Caravan, Grand Caravan
Plymouth Voyager, Grand Voyager
Chrysler Town & Country
Ford Aerostar, Windstar
Mercury Villager
Chevrolet Astro, Lumina, Venture
GMC Safari
Oldsmobile Silhouette
Pontiac Trans Sport, Montana
VW Eurovan
Nissan Quest
Isuzu Oasis
Mazda MPV
Toyota Previa, Sienna
Honda Odyssey

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* Two-door models excluded.
** Due to coding problems, all MY 1996-99 Jeep Cherokees are included. In MY 1997-99, 95% of Jeep Cherokees had four doors.

5.2 Unadjusted fatality rates

Section 2.6 develops fatality and exposure databases for computing fatality rates of cars and light trucks. As in Chapter 4, fatality rates are calculated per billion vehicles miles, not per million years, because light trucks and vans (LTVs) are driven more miles per year than cars, and the heavier LTVs more miles than the small LTVs.[1] Here are the average curb weights, numbers of involvements in fatal crashes of any type, total exposure in billions of vehicle miles, and rates of involvements in fatal crashes of any type per billion miles in the ten vehicle type/size groups, MY 1996-99 in CY 1996-2000. A crash is "fatal" if it resulted in at least one fatality, in the case vehicle, in other vehicles and/or pedestrians. "Curb weight" throughout this chapter has been adjusted by the procedure discussed in Section 2.1, and it is directly comparable for cars and LTVs. The "nominal" weights listed in Appendices A and B have been inflated by the percentages (averaged by manufacturer and vehicle type) whereby actual curb weights measured before NHTSA crash and compliance tests exceeded the nominal weights:

ALL DRIVERS, ALL ROADS, MY 1996-99 IN CY 1996-2000

	Average Curb Weight	Involvements in Fatal Crashes	Billions of Vehicle Miles	Unadjusted Fatal Involvements Per 10^9 Miles
Very small 4-door cars	2,105	279	13.03	21.4
Small 4-door cars	2,469	4,220	294.22	14.3
Mid-size 4-door cars	3,061	6,757	583.84	11.6
Large 4-door cars	3,596	3,387	344.95	9.8
All 4-door cars		*14,391*	*1236.04*	*11.6*
All 2-door cars		*5,587*	*335.29*	*16.7*
Compact pickup trucks	3,339	3,543	177.14	20.0
Large (100-series) pickups	4,458	4,571	276.72	16.5
Compact & 100 pickups		*8,105*	*453.86*	*17.9*
Small 4-door SUVs	3,147	657	54.46	12.1
Mid-size 4-door SUVs	4,022	3,404	231.33	14.7
Large 4-door SUVs	5,141	1,407	127.84	11.0
All 4-door SUVs		*5,468*	*413.63*	*13.2*
All 2-door SUVs		*888*	*44.82*	*19.8*
Minivans	3,942	2,236	248.60	9.0

[1] Vehicle mileage is estimated using annual miles of travel on the National Automotive Sampling System (NASS), as explained in Sections 2.4 and 2.6. Later in this chapter, some occupant fatality rates are calculated per billion occupant miles, because occupancy rates differ by vehicle type and size.

The two groups of small cars, all pickup trucks, and mid-size 4-door SUVs of MY 1996-99 had relatively high unadjusted fatal-crash rates in CY 1996-2000. In MY 1996-99, sales of very small 4-door cars were relatively low (they accumulated 13 billion miles, as compared to 294 billion for small 4-door cars). Mid-size and large cars, small and large 4-door SUVs and minivans had lower rates. Two-door cars and SUVs (not included in the remaining analyses of this chapter) had substantially higher rates than 4-door cars and SUVs. However, the unadjusted rates are definitely not a "level playing field." Above all, pickup trucks had high rates because of their extensive use on rural roads. Young drivers pushed up the rates for smaller cars and SUVs, while old drivers pushed up the rates for large cars. A high proportion of female drivers lowered the rates for cars relative to LTVs.

A more equitable comparison and a better preview of the results of this chapter are obtained by limiting the data to 30-49 year old male drivers on urban roads:

FATAL-CRASH INVOLVEMENTS PER 10^9 VEHICLE MILES
30-49 YEAR OLD MALE DRIVERS, URBAN ROADS, MY 1996-99 IN CY 1996-2000

	Involvements in Fatal Crashes	Billions of Vehicle Miles	Fatal Involvements Per 10^9 Miles
Very small 4-door cars	24	1.30	18.5
Small 4-door cars	314	34.31	9.2
Mid-size 4-door cars	640	90.81	7.1
Large 4-door cars	315	53.43	5.9
Compact pickup trucks	343	41.52	8.3
Large (100-series) pickups	596	79.94	7.5
Small 4-door SUVs	76	9.22	8.2
Mid-size 4-door SUVs	391	47.48	8.2
Large 4-door SUVs	240	28.89	8.3
Minivans	236	44.62	5.3

All rates dropped for this relatively safe group of drivers on safe roads, but especially in pickup trucks. Here, the rate for the larger pickup trucks was just a bit more than mid-size cars, and for the compact pickups, between small and mid-size cars. Small cars had high rates. Large cars and minivans had very low rates. Four-door SUVs of all sizes had rates somewhere between small and mid-size cars. Furthermore, the trend for SUVs differs from cars and pickup trucks in that fatality rates did not decrease as curb weight increases.

Additional insight is obtained by looking at fatality rates in selected crash modes, using data for all drivers on all roads (to provide a large N of cases):

FATALITIES PER 10^9 VEHICLE MILES, ALL DRIVERS, ALL ROADS

	Principal Rollovers	2 Light Vehicle Crashes: In Case Veh.	2 Light Vehicle Crashes: In Other Veh.
Very small 4-door cars	1.4	6.9	2.4
Small 4-door cars	.9	4.2	2.1
Mid-size 4-door cars	.7	2.7	2.4
Large 4-door cars	.4	2.4	2.0
Compact pickup trucks	2.5	2.3	5.6
Large (100-series) pickups	1.6	1.5	6.4
Small 4-door SUVs	1.5	1.8	3.1
Mid-size 4-door SUVs	3.8	1.7	4.1
Large 4-door SUVs	1.7	1.0	3.8
Minivans	.8	1.6	2.6

Pickup trucks and SUVs had much higher rollover fatality rates than passenger cars. However, mid-size MY 1996-99 SUVs had higher rollover fatality rates than small or large SUVs. The rate for small 4-door SUVs, while higher than for cars of comparable size, was less than half the rate for mid-size SUVs and slightly less than the rate for large SUVs. In collisions between two passenger vehicles, small cars had a high fatality rate for their own occupants. Involvement of pickup trucks and SUVs resulted in high fatality rates for the occupants in the other vehicle. Although unadjusted, the preceding data already indicate the two factors that elevate overall crash fatality rates of some pickup trucks and SUVs: rollover proneness and aggressiveness. The adjustment process will quantify the added risk.[2]

Adrian Lund, in his review of this report, noted that 4-door SUVs with 2-wheel drive (4x2) have substantially higher unadjusted fatal-crash rates than 4-door SUVs with 4-wheel drive (4x4) or all-wheel drive (AWD). He inquired whether 4-door 4x2 SUVs ought to be excluded from the analyses of this chapter, similar to the exclusion of all 2-door SUVs and 2-door cars, as discussed above.[3] Indeed, the databases generated for this report show small 4x2 4-door SUVs had 58 percent higher unadjusted fatal-crash rates per mile than small 4x4 4-door SUVs; the corresponding increase was 54 percent in mid-size SUVs, although in large SUVs, the 4x2 vehicles had a 7 percent lower fatality rate. However, the difference between 4x2 and 4x4 SUVs turns out to be largely geographic: 4x4 SUVs were much more popular in the Northern States, where traction on snow and ice is an issue, while 4x2 SUVs were primarily sold in the Sun Belt.

[2] The unadjusted rates, surprisingly, show more fatalities in large cars (2.4) than in the vehicles they collide with (2.0). This was due to the extra vulnerability of the older-than-average occupants of the large cars. After adjusting for driver age, the fatality risk in the large cars was well below the risk in their collision partners (see Table 5-4).

[3] Dr. Lund's discussion is on pp. 5-6 of his letter, which may be found in the NHTSA docket for this report. Dr. Lund was also the first to recommend that 2-door SUVs be excluded from the analyses; that recommendation has been followed throughout this chapter.

Specifically, 72 percent of the 4x4 SUVs were registered in the primarily Northern States with low fatality rates (HIFAT_ST = 0), whereas 74 percent of the 4x2 SUVs were registered in the nearly-all-Southern States with high fatality rates (HIFAT_ST = 1). Since the overall fatal-crash involvement rate per million registered vehicles in the high-fatality-rate States was 77 percent higher than in the low-fatality-rate States, even for cars and vans where 4x4 is not an issue, that largely explains why 4x2 SUVs had so much higher unadjusted fatality rates. Thus, throughout Chapter 5, "4-door SUVs" will include both the 4x2 and 4x4 types; however, some detailed analyses will be presented in Sections 5.4 and 5.6 to demonstrate that, after control for HIFAT_ST and other variables such as driver age and gender, 4x2 and 4x4 SUVs had fairly similar fatality rates and incidence rates of high-risk driving behaviors.

5.3 Regressions of fatality risk by vehicle type/size group, by crash mode

Logistic regressions are used to calibrate fatality rates per vehicle or occupant mile as a function of vehicle type/size group for MY 1996-99 cars and LTVs in CY 1996-2000 crashes, in six crash modes: principal rollovers, fixed-object, pedestrian-bicyclist-motorcyclist, light vehicle-heavy truck, 2 light vehicles (fatalities in the case vehicle), and 2 light vehicles (fatalities in the other vehicle). Once again, **fixed-object collisions**, the most "typical" analysis, will be discussed first.

Fatal-crash and exposure data records are set up almost exactly as in Section 4.3, except that both cars and LTVs are now included, but limited to the 1996-99 models with air bags, etc., as described in Section 5.1. Curb weight is not a variable in the regressions. Instead, the key independent variables are the vehicle type/size group, expressed by nine dichotomous independent variables, MINICAR, SMALLCAR, BIGCAR, SMALLPKP, PKP100, SMALLSUV, MEDSUV, BIGSUV and MINIVAN. For a small car, SMALLCAR = 1 and the others are set to zero. For a mid-size car, all nine variables are set to zero.[4]

Another change from preceding chapters is that fatality rates in some crash modes, including fixed-object, are calibrated per occupant mile rather than per vehicle mile. Here are the average numbers of occupants per vehicle (including the driver) in National Automotive Sampling System (NASS) cases for MY 1991-99 vehicles in CY 1993-2001[5]:

[4] Mid-size cars were selected as the "default" vehicle group because they are the most numerous group.
[5] A wider range of MY and CY were included in the NASS analysis to increase available N.

	Average N of Occupants	N of NASS Cases
4-door cars (all sizes)	1.588[6]	7,859
Compact pickup trucks	1.349	1,256
Large (100-series) pickups	1.462	689
Small 4-door SUVs	1.446	213
Mid-size 4-door SUVs	1.629	947
Large 4-door SUVs	1.994	179
Minivans	2.071	802

Specifically, minivans and large 4-door SUVs (e.g., Suburbans) were likely to have more passengers than cars, while pickup trucks were more likely to have just the driver. The occupant fatality rate per occupant mile is the best measure of intrinsic risk per unit of exposure. It adjusts for the fact that minivans, for example, had more fatalities because more people are riding in them. The vehicle mileage, already on the exposure data file, is multiplied by the above occupancy rates to obtain occupant mileage.[7]

The list of control variables is essentially the same as in Section 4.2, but should preferably be limited to variables that have similar meaning and effect for cars and LTVs: driver demographics, roadway/environmental characteristics, and vehicle safety devices that have a similar function and effect in cars and LTVs ("comparably equipped"). Because the regression presupposes that the effects of control variables are uniform across cars and LTVs, no interaction terms with vehicle type are necessary:

Driver age	Male driver?	At night?
Rural?	Speed limit 55+?	Wet road?
Snowy/icy road?	Calendar year	Vehicle age
High-fatality State		

Air bags are not a control variable since all of the vehicles in this analysis have air bags. Rear-wheel ABS and all-wheel/4-wheel drive are excluded as control variables because these features are unavailable, or rarely available in MY 1996-99 passenger cars. Four-wheel ABS is excluded as a control variable because it cannot be assumed to have the same effect in cars and LTVs (thus, a car with ABS and an LTV with ABS are not really "comparably equipped").

Driver age and gender will again be represented by the nine independent variables DRVMALE, M14_30, M30_50, etc. defined in Section 3.3. Calendar year will be represented by four dichotomous variables, CY1996, CY1997, CY1998 and CY2000 and vehicle age, by two

[6] No significant differences between smaller and larger cars.
[7] Annual vehicle mileage, for LTVs relative to 4-door cars, is shown in Table 2-3. Two-door as well as 4-door SUVs are included in the computation; however, the NASS data do not show a significant difference between the mileage of 2-door and 4-door SUVs.

variables, VEHAGE and BRANDNEW, as in Section 4.2 (except CY1995 is no longer needed since the data are limited to CY 1996-2000).

The model compares, for example, the fatality risk of a large SUV and a minivan for, say, a 35-year-old female driver on an urban road. It assumes that the association of key parameters such as age, gender, urban/rural with fatality rates are fairly uniform across vehicle types. For a quick check on the validity of that assumption, the regression coefficients for the preceding chapters' baseline fixed-object regressions can be compared for passenger cars (from Section 3.4) and light trucks (from Section 4.3):

Regression Coefficients	Cars	LTVs
DRVMALE	.4824	.5106
M14_30	.1006	.0776
M30_50	.0279	.0100
M50_70	.0291	.0350
M70+	.0973	.0895
F14_30	.0806	.0597
F30_50	.0055	.0152
F50_70	.0561	.0727
F70+	.0928	.0664
NITE	1.5981	1.9043
RURAL	1.2659	1.2702
SPDLIM55	1.5985	1.7014

Both regressions showed higher risk for male drivers, similar U-shaped patterns of higher risk for young and old drivers of both genders, and substantially increased risk at night, on rural roads, and on speed limit 55+ roads. The coefficients are similar enough to encourage pooling the car and LTV data into a single regression.

There are 5,210 records of MY 1996-99 cars and LTVs in the ten size groups involved in fatal fixed-object collisions during CY 1996-2000, with non-missing values on each of the control variables. There are 522,404 induced-exposure cases for these vehicles, with non-missing values for the variables. Together, they will furnish 527,714 data points to the logistic regression, using the SAS procedure, LOGIST. FATAL = 1 for the fatal-crash data points, and FATAL = 2 for the induced-exposure data points. WEIGHTFA equals the number of fatalities, in the fatal-crash data points (failures). WEIGHTFA for induced-exposure cases is the number of occupant miles they represent (successes). Although LOGIST actually is performed on the 527,714 crash data points, each of these data points is weighted, and thereby "transformed" by WEIGHTFA. The 5,210 fatal-crash involvements represent 5,710 "failures" (crash fatalities) while the 522,404 induced-exposure involvements represent 3.78 trillion "successes" (occupant miles of travel in the United

States). WEIGHTFA in effect makes LOGIST calibrate the log-odds of a fatality per occupant mile of travel, generating the following coefficients:[8]

FIXED-OBJECT COLLISIONS (N = 5,210 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
MINICAR	0.421	0.132	10.2	0.0014
SMALLCAR	0.108	0.044	6.07	0.014
BIGCAR	-0.246	0.048	25.8	0.0001
SMALLPKP	0.163	0.047	12.0	0.0005
PKP100	-0.087	0.044	3.836	0.050
SMALLSUV	-0.197	0.106	5.63	0.018
MEDSUV	-0.027	0.051	0.01	0.94
BIGSUV	-0.472	0.074	30.6	0.0001
MINIVAN	-0.864	0.066	173.3	0.0001
DRVMALE	0.358	0.081	19.5	0.0001
M14_30	0.1082	0.0044	592.5	0.0001
M30_50	0.0171	0.0033	27.2	0.0001
M50_70	0.0294	0.0042	49.4	0.0001
M70+	0.0894	0.0073	150.1	0.0001
F14_30	0.0784	0.0077	104.2	0.0001
F30_50	-0.0019	0.0052	0.13	0.72
F50_70	0.0488	0.0064	58.5	0.0001
F70+	0.0741	0.0139	28.6	0.0001
NITE	1.788	0.027	4297.	0.0001
RURAL	1.196	0.030	1572.	0.0001
SPDLIM55	1.723	0.030	3388.	0.0001
HIFAT_ST	0.402	0.028	210.3	0.0001
WET	-0.180	0.037	23.6	0.0001
SNOW_ICE	0.051	0.073	0.50	0.48
VEHAGE	0.156	0.017	83.0	0.0001
BRANDNEW	0.139	0.046	9.17	0.0025
CY1996	-0.117	0.068	2.93	0.087
CY1997	-0.005	0.047	0.01	0.92
CY1998	0.033	0.039	0.74	0.39
CY2000	-0.041	0.036	1.26	0.26
INTERCPT	-23.089	0.085	74130.	0.0001

The regression calibrates the adjusted fatality rate in nine vehicle groups relative to the rate in mid-size 4-door cars. The coefficient of .421 for very small 4-door cars suggests they had

$$\exp(.421) - 1 = 52 \text{ percent}$$

[8] The text describes the most appropriate way to set up the data for the LOGIST procedure. However, the version of LOGIST used in this study interprets the WEIGHT statement not as a case-weighting but a count of independently-observed cases. It literally treated each mile of travel as an independent data point. That makes the standard errors of the coefficients about 2-5 percent smaller than they should be, and their chi-squares about 2-5 percent larger, as explained in Section 3.4.

higher fatality risk per occupant mile than mid-size cars, given the same age/gender driver, ambient conditions, vehicle age and calendar year. The increase is statistically significant, as evidenced by chi-square value 10.2. (For statistical significance at the .05 level, chi-square has to exceed 3.84, and for the .01 level, 6.64.) As in Sections 3.4 and 4.3, "statistically significant" here takes into account only the basic sampling error in the regression model and does not yet consider other sources of uncertainty, such as: State-to-State variation of the induced-exposure data or the influence of self-selection (i.e., safer drivers picking "safer" vehicle types) in this cross-sectional analysis of fatality rates.

Small MY 1996-99 4-door cars and compact pickup trucks also had significantly higher fatality risk per occupant mile in fixed-object crashes than mid-size cars. Large cars, large 4-door SUVs and, above all, minivans had significantly lower risk than mid-size cars. Full-sized (100-series) pickup trucks, small 4-door SUVs and mid-size 4-door SUVs had more or less the same risk as mid-size cars.

The coefficients for the control variables have a familiar pattern. Fatality risk is higher for male, young and old drivers. Nighttime, rural roads, high-speed roads and high-fatality States are associated with greatly increased risk. VEHAGE and BRANDNEW have positive coefficients, indicating that fatality rates per mile increase after cars are more than a year old. The CY terms indicate minor (nonsignificant) year-to-year variations in overall fatality risk. WET has a negative coefficient because adverse conditions force people to slow down, reducing the lethality of crashes while increasing the frequency of lower-speed collisions of the "induced-exposure" type.

The regression coefficients may be used directly to estimate an overall, adjusted fatality rate for each vehicle type. Given any specific occupant mile with known driver age/gender, etc., let

```
Z = -23.089 + .358*DRVMALE
    + .1082*M14_30 + .0171*M30_50 + .0294*M50_70 + .0894*(M70+)
    + .0784*F14_30 - .0019*F30_50 + .0488*F50_70 + .0741*(F70+)
    + 1.788*NITE  + 1.197*RURAL + 1.723*SPDLIM55
    + .402*HIFAT_ST - .180*WET + .051*SNOW_ICE
    + .156*VEHAGE + .139*BRANDNEW
    - .117*CY1996 - .005*CY1997 + .033*CY1998 - .041*CY2000
```

(Z is the sum of each control variable multiplied by its regression coefficient.[9]) The logistic regression model says that the fatality risk in a mid-size car on this particular occupant mile was

$$EFAT_{\text{mid-size}} = EXP(Z)/(1 + EXP(Z))$$

Since the coefficient for MINICAR is .421, the fatality risk in a very small car was

$$EFAT_{\text{very small}} = EXP(Z + .421)/(1 + EXP(Z + .421))$$

[9] All of the control variables are used in the computation, even those with nonsignificant coefficients in this regression, because these variables have significant effects in other regressions. Thereby, the computation of Z is based on the same general formula, with the same variables, for each of the regressions.

The average value of EFAT $_{mid\text{-}size}$ over all of the occupant miles on the induced-exposure file would have been the fatality rate, per occupant mile, in fixed-object collisions, under the assumptions that: (1) Every personal-transportation vehicle of MY 1996-99 on the road in CY 1996-2000 was a mid-sized car. (2) The distribution of drivers by age/gender, mileage by urban/rural, etc. for MY 1996-99 in CY 1996-2000 is unchanged from what is on the induced-exposure file. Similarly, the average value of EFAT $_{very\ small}$ over all of the occupant miles on the induced-exposure file would have been the fatality rate if every vehicle were a very small car, but with the same distribution of drivers and mileage. These are the "adjusted fatality rates" and they compare the fatality rates in various types of vehicles that would have occurred if the same drivers had driven them on the same roads in CY 1996-2000. They also measure the relative changes in fatality risk that would have occurred if any specific group of drivers had purchased one type of vehicle rather than another (since the model assumes the same effect for MINICAR, SMALLCAR, etc., for any value of the other control variables):

FIXED-OBJECT CRASHES (N = 5,210 fatal crash involvements)
Adjusted Fatality Rate per Billion Occupant Miles

Very small 4-door cars	2.53
Small 4-door cars	1.85
Mid-size 4-door cars	1.66
Large 4-door cars	1.30
Compact pickup trucks	1.96
Large (100-series) pickups	1.53
Small 4-door SUVs	1.37
Mid-size 4-door SUVs	1.62
Large 4-door SUVs	1.04
Minivans	.70

Note that the log ratio of the adjusted fatality rate of any vehicle type to the rate for mid-size cars almost exactly equals the regression coefficient – e.g., for minivans, log(0.70/1.66) = -0.86 – because the model assumes the same relative difference in risk for any value of the other control variables. (A reminder: throughout this study, "log" or "logarithm" means the natural logarithm.)

Larger passenger cars had sharply lower fatality rates than smaller ones, consistent with the results of Chapter 3. Similarly, there was a rate reduction for large vs. compact pickups, large vs. mid-size SUVs. Only the fairly low rate for small 4-door SUVs went against the trend. The low rate for these SUVs may involve a combination of crashworthiness; prudent drivers who don't run off the road frequently; and, given an off-road excursion, a tendency to roll over before they contact fixed objects (more discussion later).

A more interesting finding is that the fixed-object fatality rates, after adjustment, were quite similar for cars, pickups and SUVs. The rates for large pickups and mid-size SUVs were quite close to the rate for mid-size cars. Minivans had much lower risk than any other vehicle type, possibly reflecting, even more strongly, the factors that reduced the risk for the small 4-door SUVs. The high occupancy rate also helped minivans (when fatality rates are computed per occupant mile): more occupants were back-seat passengers than in other vehicle types, and they were at lower risk than front-seat occupants.[10]

The logistic regression of **principal-rollover fatalities** per occupant mile is based on 2,731 fatal crash involvements, resulting in 3,061 occupant fatalities and the same 522,404 induced-exposure cases as in the fixed-object regression. The independent variables are also the same.

PRINCIPAL ROLLOVERS (N = 2,713 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
MINICAR	0.303	0.248	1.49	0.22
SMALLCAR	0.029	0.081	0.13	0.72
BIGCAR	-0.460	0.098	22.1	0.0001
SMALLPKP	0.883	0.070	159.3	0.0001
PKP100	0.317	0.071	20.2	0.0001
SMALLSUV	0.755	0.125	31.4	0.0001
MEDSUV	1.697	0.060	825.7	0.0001
BIGSUV	0.760	0.085	93.9	0.0001
MINIVAN	0.060	0.085	0.49	0.48
DRVMALE	-0.185	0.102	3 30	0.069
M14_30	0.1116	0.0063	316.2	0.0001
M30_50	0.0206	0.0045	19.7	0.0001
M50_70	0.0235	0.0065	13.1	0.0003
M70+	0.0631	0.0145	18.8	0.0001
F14_30	0.1029	0.0086	142.7	0.0001
F30_50	-0.0039	0.0060	0.42	0.52
F50_70	0.0405	0.0088	21.1	0.0001
F70+	0.0241	0.0280	0.73	0.39
NITE	1.489	0.037	1642.	0.0001
RURAL	1.757	0.050	1213.	0.0001
SPDLIM55	2.777	0.049	3182.	0.0001
HIFAT_ST	0.940	0.040	556.5	0.0001
WET	-1.047	0.071	215.4	0.0001
SNOW_ICE	0.204	0.090	5.14	0.023
VEHAGE	0.150	0.024	38.0	0.0001
BRANDNEW	0.299	0.062	23.5	0.0001
CY1996	-0.018	0.087	0.04	0.84
CY1997	-0.020	0.063	0.10	0.76
CY1998	0.055	0.052	1.14	0.29
CY2000	-0.105	0.051	4.29	0.038
INTERCPT	-25.213	0.119	44986.	0.0001

[10] Evans, L., *Traffic Safety and the Driver*, Van Nostrand Reinhold, New York, 1991, pp. 47-50.

The regression shows greatly elevated rollover risk for some MY 1996-99 vehicles: 4-door SUVs of all sizes and compact pickup trucks. Large cars had very low rollover risk. The SUV, pickup and large-car coefficients are statistically significant. The effects of the control variables are quite similar to those in the regression for LTVs (Section 4.3). That's understandable: most of the rollovers were in LTVs, not cars (see Table 2-1). In general, the coefficients for control variables parallel the corresponding regressions for cars and light trucks, and will not be shown for the other crash modes. The adjusted fatality rates per billion occupant miles were:

PRINCIPAL ROLLOVERS (N = 2,713 fatal crash involvements)
Adjusted Fatality Rate per Billion Occupant Miles

Very small 4-door cars	.67
Small 4-door cars	.51
Mid-size 4-door cars	.50
Large 4-door cars	.31
Compact pickup trucks	1.20
Large (100-series) pickups	.68
Small 4-door SUVs	1.06
Mid-size 4-door SUVs	2.71
Large 4-door SUVs	1.06
Minivans	.53

The fatality rate in mid-size MY 1996-99 SUVs was five times higher than in large or mid-size cars. Compact pickup trucks, small SUVs and large SUVs had over double the fatalities per mile of mid-size cars. The direction of the results is no surprise, since at that time many of these SUVs, especially mid-size SUVs had lower static stability factors[11] than pickups, minivans or cars; what's remarkable is the geometric escalation of the fatality rate for each successive decrement of the stability factor.

In 1996-99 several new models of small 4-door SUVs with improved stability were introduced. For example, one of these small SUVs was measured by NHTSA to have a 1.19 stability factor, an excellent rating compared to most SUVs of the mid-1990's, especially mid-size SUVs (yet inferior to passenger cars of that era).[12] That explains why their fatality rate is lower than the mid-size SUVs, although still higher than any other vehicle type.[13] These small 4-door SUVs of 1996-99 may have been the beginning of a new generation of SUVs that have crash statistics more like cars. Indeed, rollover-resistance ratings published by NHTSA in 2001 show new

[11] Static stability factor = half the track width, divided by the center-of-gravity height. The higher this factor, the lower the rollover risk.
[12] "Consumer Information Regulation; Federal Motor Vehicle Safety Standards; Rollover Resistance," *Federal Register* 66 (12 January 2001): 3388.
[13] Donald Reinfurt, in his review of this report, recommended expanding the discussion of fatality rates for small vs. mid-size SUVs (his comment no. 14). Dr. Reinfurt's review is available in the NHTSA docket for this report.

models of SUVs in all three size groups with greater stability factors than the models they superseded: several small SUVs have stability factors of 1.19 or better, ranging up to 1.26; there is a mid-size SUV rated 1.21; and a large SUV rated 1.20.[14] The make-models with greater stability factors include entirely new designs such as car-based "crossover" SUVs and less sweeping redesigns of existing SUVs.

In the unadjusted data (Section 4.2), fatality rates for pickup trucks were not that much lower than SUVs. After adjustment for their overrepresentation of rural mileage and male drivers, pickup trucks clearly had lower fatality risk than SUVs of comparable size, but higher than cars. Minivans' fatality rates were much lower than SUVs and pickup trucks, but still nearly double the rate for large cars. In general, rollover fatality rates showed much greater variation among vehicle types than fixed-object collisions.

The total rate for "run-off-road" crashes, the sum of the rates for fixed-object and rollover, was 2.16 for mid-size cars, 2.43 for small SUVs, and 4.33 for mid-size SUVs. In other words, the small SUVs had a moderate rate of off-road excursions resulting in fatalities, only somewhat higher than cars of comparable weight. However, since a relatively larger proportion of these excursions ended up as rollovers, the fatality rate in fixed-object collisions for small SUVs was lower than for mid-size cars.

Pedestrian/bicyclist/motorcyclist fatality rates should be computed per car/LTV vehicle mile, not occupant mile. The fatalities were not occupants of the car or LTV, and their risk per car/LTV vehicle mile was the same whether the car/LTV had few or many occupants.[15] The regression uses the same 522,404 induced-exposure cases as the two preceding ones, but weighted by vehicle rather than occupant miles. They supply 2.33 trillion "successes" (vehicle miles of travel). WEIGHTFA is also defined differently in the 4,171 fatal-crash cases. In the two preceding regressions, each fatal crash involved exactly one car/LTV, and WEIGHTFA always equaled FATALS. Table 2-1 shows that 17 percent of the ped/bike/motorcycle crashes involved two or more cars or LTVs (crash types 25 and 28). In those cases, WEIGHTFA is set to FATALS divided by the number of cars/LTVs in the crash. In the 83 percent of crashes involving only one car or LTV, WEIGHTFA = FATALS, as usual. The adjusted fatality rates per billion vehicle miles were:

[14] *Model Year 2001 Front, Side and Rollover Resistance Ratings*, www.nhtsa.dot.gov/hot/rollover/fullWebd.html .
[15] Except for rare occasions when those occupants alerted the driver to the presence of pedestrians, or distracted the driver from seeing the pedestrians.

PEDESTRIANS-BICYCLISTS-MOTORCYCLISTS (N = 4,171 fatal crash involvements)
Adjusted Fatality Rate per Billion Car/LTV Vehicle Miles

Very small 4-door cars	2.53
Small 4-door cars	1.74
Mid-size 4-door cars	1.48
Large 4-door cars	1.28
Compact pickup trucks	2.07
Large (100-series) pickups	1.98
Small 4-door SUVs	2.11
Mid-size 4-door SUVs	1.72
Large 4-door SUVs	1.64
Minivans	1.56

Unlike rollovers, this crash mode shows only moderate differences between vehicle types. However, large and mid-size cars did the least harm, per mile, to pedestrians, bicyclists and motorcyclists. Pickup trucks of all sizes, small cars and small SUVs had the highest fatality rates. Large SUVs and minivans had about the same rate as mid-size cars, but higher than large cars. Section 3.6 discussed the possibilities that the geometry of small cars presented a greater hazard to pedestrians, and that small cars hit more pedestrians because they were driven less prudently. Section 5.6 will continue that discussion, comparing LTVs to cars.

In crashes between cars/LTVs and **heavy trucks** (GVWR > 10,000 pounds), the fatality rate of the car/LTV occupants should be computed per car/LTV occupant mile. There were 1,998 cars/LTVs with occupant fatalities in collisions with heavy trucks, and there were 2,372 occupant fatalities (WEIGHTFA = DEATHS, the number of occupant fatalities in the case vehicle). The usual 522,404 induced-exposure cases are weighted by occupant miles. The adjusted fatality rates per billion car/LTV occupant miles were:

COLLISIONS WITH HEAVY TRUCKS (N = 1,998 fatal crash involvements)
Adjusted Car/LTV Occupant Fatality Rate per Billion Car/LTV Occupant Miles

Very small 4-door cars	1.69
Small 4-door cars	1.08
Mid-size 4-door cars	.72
Large 4-door cars	.48
Compact pickup trucks	.90
Large (100-series) pickups	.49
Small 4-door SUVs	.79
Mid-size 4-door SUVs	.52
Large 4-door SUVs	.37
Minivans	.41

The association of low risk with large cars/LTVs was strong. Within cars, pickup trucks and SUVs, the larger vehicles had much lower fatality rates. The differences between vehicle types were not as large as the differences between size groups within vehicle types. For example, large cars and mid-size SUVs had fairly similar weights and fatality rates. Large SUVs, the heaviest vehicle group (averaging 5,141 pounds) had the lowest risk. The strong association of risk with vehicle weight is surprising because conservation of momentum would not appear to be an important factor except in cases where the "heavy" truck barely exceeds 10,000 pounds. Neither a 3,000 pound car nor a 5,000 pound SUV is going to transfer much momentum to a 50,000 pound trailer. There must have been something besides pure mass that made the larger cars/LTVs safer, presumably structural rigidity and geometric compatibility with heavy trucks (more sill engagement, less underride). Another possibility is that the heavier cars/LTVs were driven more prudently.

In Chapters 2-4, the last two crash modes were "collisions with cars" and "collisions with light trucks." In this chapter, where the case vehicle can be either a car or a light truck, the two crash modes will be combined: "collisions with another car/LTV." To simplify the analysis, it will be limited to collisions of exactly two car/LTVs, excluding crashes involving three or more vehicles. The case vehicle has to be a car or LTV in one of the ten groups, MY 1996-99. The other vehicle can be any car or LTV, of any model year, including 2-door cars, etc. The regression analyses, as in other chapters, consider only the vehicle type, driver age/gender, etc. of the case vehicle.

Two regressions are performed. The **vulnerability** of cars and LTVs – the risk for their own occupants – is compared by analyzing the rate of case-vehicle occupant fatalities per billion case-vehicle occupant miles. The **aggressiveness** – the risk for occupants of the other vehicle – is the rate of other-vehicle occupant fatalities per billion case vehicle miles. Here, as in the ped/bike/motorcycle analysis, the fatalities are not occupants of the case vehicle, and their risk per case vehicle mile is the same whether the case vehicle has few or many occupants.

The vulnerability analysis is based on 4,850 case vehicles with at least one occupant fatality, comprising 5,507 fatally injured occupants, and the usual 522,404 induced-exposure cases, accounting for 3.78 trillion occupant miles:

VULNERABILITY IN COLLISIONS WITH ANOTHER CAR OR LTV
Adjusted Rate of Case-Vehicle Occupant Fatalities per Billion Case-Vehicle Occupant Miles
(N = 4,850 fatal crash involvements)

Very small 4-door cars	4.46
Small 4-door cars	3.10
Mid-size 4-door cars	1.76
Large 4-door cars	1.08
Compact pickup trucks	1.59
Large (100-series) pickups	.86
Small 4-door SUVs	1.73
Mid-size 4-door SUVs	1.33
Large 4-door SUVs	.63
Minivans	.85

The association of low risk with heavy cars/LTVs was strong. The fatality rate was seven times higher in very small cars (average weight 2,105) than in large SUVs (average weight 5,141). Within cars, pickup trucks and SUVs, the larger vehicles had much lower fatality rates. The differences between vehicle types were unimportant. For example, large pickups, large SUVs and minivans were heavier than large cars, and they had lower fatality rates. Unlike the heavy-truck analysis, the inverse relationship of vehicle mass with risk for its own occupants is less of a surprise. Conservation of momentum can be an important factor in collisions of two vehicles of comparable weight, especially head-on collisions, although less so in side impacts. Other factors, such as better crashworthiness, a structure more suitable for resisting the impact of the striking vehicle, and better drivers may have helped the heavier vehicles.

The analysis of aggressiveness is based on 6,847 case vehicles that collided with another car or LTV, with at least one occupant fatality in that other car or LTV. There were a total of 7,738 fatalities in the "other" vehicles. The induced-exposure cases are the usual 522,404, accounting for 2.33 trillion vehicle miles:

AGGRESSIVENESS IN COLLISIONS WITH ANOTHER CAR OR LTV
Adjusted Rate of Other-Vehicle Occupant Fatalities per Billion Case Vehicle Miles
(N = 6,847 fatal crash involvements)

Very small 4-door cars	2.70
Small 4-door cars	2.19
Mid-size 4-door cars	2.55
Large 4-door cars	2.22
Compact pickup trucks	4.43
Large (100-series) pickups	4.86
Small 4-door SUVs	3.44
Mid-size 4-door SUVs	4.46
Large 4-door SUVs	4.30
Minivans	3.03

The results contrast greatly with the vulnerability analysis. Here, vehicle type was important and vehicle weight was relatively unimportant. Cars of all sizes were less aggressive than LTVs, even large cars. Pickup trucks and mid-size/large SUVs were about twice as aggressive as large cars, even the small pickup trucks. Minivans were more aggressive than cars but less than SUVs and pickups. The results suggest that, especially in side impacts, a vehicle's aggressiveness depends more on its geometry and rigidity than on its mass. Pickup trucks and SUVs of MY 1996-99 had a structure and geometry that was a greater threat to other vehicles, even when they were relatively light. Large cars, on the other hand, were deformable and built close to the ground like small cars. These findings are consistent with the car-to-LTV regressions in Sections 3.4 and 4.3 (where most of the fatalities were in the car): reducing the weight of the car was associated with a large increase in risk, but reducing the weight of the truck helped only a little. Imprudent or crash-prone driving in lighter vehicles (e.g., the very small cars) may also have been a factor: more crashes per mile = more fatalities in the other vehicle, per mile.

5.4 Regressions of overall fatality risk by vehicle type/size group

One additional regression provides a single comparison of the overall fatality risk in different types of vehicles. Combining the six crash modes, it estimates overall prorated crash fatalities per billion vehicle miles, adjusted for driver age/gender, urban/rural, etc.

"Crash fatalities" include occupants of the case vehicle and the other vehicle, plus non-occupants. However, in cases involving two or more cars/LTVs, there could be double-counting since the same crash might appear twice, once with Vehicle 1 as the case vehicle, once with Vehicle 2 as the case vehicle. "**Prorated crash fatalities**" for the case vehicle are defined to equal crash fatalities divided by the number of cars/LTVs involved in the crash. The total number of fatalities in the crash is equally apportioned among the light vehicles involved. For example, in a three-car crash that results in two fatalities, each vehicle, when and if it is a case vehicle in the regression, is apportioned a WEIGHTFA = 2/3 prorated crash fatalities (regardless of what vehicle(s) the fatally injured people were occupying). This eliminates double-counting and prevents giving too much weight to the multivehicle crashes.[16] Of course, in crashes that involved only car/LTV – viz., single-vehicle crashes, collisions of one car/LTV with a heavy truck or motorcycle, WEIGHTFA = FATALS as in most of the preceding regressions.

The regression includes every case vehicle involved in a crash classified in crash modes 1-6 in Table 2-1. Crash types 92-97 from Table 2-1 are excluded (primarily 3-4 vehicle crashes involving vehicles of at least three different types, and all crashes involving five or more vehicles). As in Section 5.3, data are limited to MY 1996-99 vehicles of the ten size groups, with air bags, in CY 1996-2000. On the other hand, collisions involving 3 or 4 cars/LTVs (crash types 49, 54, 57, 59, 69, 74, 77, 79) are included here in order to address all crashes in modes 1-6, even though they were excluded in the "vulnerability" and "aggressiveness" analyses of Section 5.3 (that focused more narrowly on 2-vehicle crashes, where there is no guesswork about which pairs of vehicles collided). There were 28,861 case vehicles involved in fatal crashes, comprising 23,029 prorated crash fatalities. The usual 522,404 induced-exposure cases accounted for 2.33 trillion vehicle miles:

[16] Prorating the crash fatalities was considered unnecessary in Chapters 3 and 4 (except in Section 4.8) because each regression was limited to a single crash mode.

OVERALL CRASH FATALITY RISK (N = 28,861 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
MINICAR	0.508	0.069	53.6	0.0001
SMALLCAR	0.183	0.023	64.2	0.0001
BIGCAR	-0.285	0.025	129.8	0.0001
SMALLPKP	0.216	0.025	77.3	0.0001
PKP100	0.010	0.023	0.19	0.66
SMALLSUV	0.101	0.048	4.50	0.034
MEDSUV	0.369	0.024	238.9	0.0001
BIGSUV	0.058	0.034	2.90	0.088
MINIVAN	-0.172	0.029	36.3	0.0001
DRVMALE	0.132	0.036	13.6	0.0002
M14_30	0.0815	0.0025	1071.	0.0001
M30_50	0.0090	0.0016	30.5	0.0001
M50_70	0.0270	0.0020	181.0	0.0001
M70+	0.0901	0.0035	658.0	0.0001
F14_30	0.0594	0.0036	276.2	0.0001
F30_50	-0.0041	0.0022	3.39	0.066
F50_70	0.0409	0.0028	211.0	0.0001
F70+	0.0738	0.0062	142.1	0.0001
NITE	1.263	0.014	8599.	0.0001
RURAL	0.918	0.015	3911.	0.0001
SPDLIM55	1.795	0.015	14708.	0.0001
HIFAT_ST	0.556	0.014	1614.	0.0001
WET	-0.362	0.020	338.7	0.0001
SNOW_ICE	0.042	0.037	1.26	0.26
VEHAGE	0.161	0.0087	344.7	0.0001
BRANDNEW	0.152	0.023	44.6	0.0001
CY1996	-0.034	0.034	1.01	0.31
CY1997	0.105	0.023	21.3	0.0001
CY1998	0.045	0.019	5.57	0.018
CY2000	-0.062	0.018	11.4	0.0008
INTERCPT	-20.748	0.039	290900.	0.0001

The regression coefficients for the control variables are essentially the averages of the coefficients in the individual crash modes (e.g., fixed-object crashes – see Section 5.3): risk per mile increases for male, young and old drivers, at night, on rural and high-speed roads, in high-fatality States, and in older vehicles. The adjusted overall fatality rates per billion vehicle miles were:

OVERALL CRASH FATALITY RISK (N = 28,861 fatal crash involvements)
Adjusted Prorated Crash Fatalities per Billion Case Vehicle Miles

	Fatality Rate	Average Curb Weight
Very small 4-door cars	15.73	2,105
Small 4-door cars	11.37	2,469
Mid-size 4-door cars	9.46	3,061
Large 4-door cars	7.12	3,596
Compact pickup trucks	11.74	3,339
Large (100-series) pickups	9.56	4,458
Small 4-door SUVs	10.47	3,147
Mid-size 4-door SUVs	13.68	4,022
Large 4-door SUVs	10.03	5,141
Minivans	7.97	3,942

Four-door SUVs of MY 1996-99 had greater crash fatality rates than mid-size/large 4-door passenger cars or minivans, even after controlling for driver age/gender, roadway type, etc.[17] Pickup trucks also had higher crash fatality risk than cars of comparable weight. Among 4-door cars, there was a consistent reduction in the crash fatality rate as mass and size increase, ranging from 15.73 in "very small" cars averaging 2,105 pounds to 7.12 in "large" cars averaging 3,596 pounds, respectively the highest and lowest rates in the ten vehicle groups. In contrast, the small SUVs had a lower rate than the mid-size SUVs.

Two additional regressions apportion these prorated crash fatalities between occupants of the case vehicles and occupants of other vehicles/pedestrians/bicyclists. In the first regression's fatal-crash cases, WEIGHTFA1 = DEATHS / (N of cars + LTVs), and in the second, WEIGHTFA2 = (FATALS – DEATHS) / (N of cars + LTVs). In other words, WEIGHTFA1 corresponds to the deaths in the case vehicle, prorated; WEIGHTFA2 corresponds to all other fatalities in the crash, prorated; and WEIGHTFA1 + WEIGHTFA2 = WEIGHTFA in the basic regression of prorated crash fatalities.[18] The fatality rates were:

[17] The discussion here is based on the point estimates. The statistical significance of these differences will be considered in Section 5.6.

[18] Regression coefficients are used to obtain adjusted fatality rates per billion miles, as in the preceding analyses. Furthermore, for each vehicle type, both rates are multiplied by a small computational correction, usually between .99 and 1.01, so that the rates will add up exactly to the overall rate in the preceding analysis. The correction addresses rounding errors and computational inaccuracy of the regression algorithm.

OVERALL CRASH FATALITY RISK
Adjusted Prorated Crash Fatalities per Billion Case Vehicle Miles
My Vehicle Vs. Other Vehicles/Pedestrians/Bicylists

	Prorated Fatal Crash Involvements		
Vehicle Type and Size	In My Vehicle	Other Veh + Peds	Total
Very small 4-door cars	11.24	4.49	15.73
Small 4-door cars	7.94	3.43	11.37
Mid-size 4-door cars	6.14	3.32	9.46
Large 4-door cars	4.26	2.86	7.12
Compact pickup trucks	6.74	5.00	11.74
Large (100-series) pickup trucks	4.65	4.91	9.56
Small 4-door SUVs	6.09	4.38	10.47
Mid-size 4-door SUVs	9.16	4.52	13.68
Large 4-door SUVs	5.69	4.34	10.03
Minivans	4.34	3.63	7.97

In other words, many of the 1996-99 pickup trucks and SUVs had higher fatality risk than large cars or minivans, both for their own occupants and for other road users. Rollover-proneness added risk for their own occupants, while aggressiveness in multi-vehicle collisions contributed to risk for other road users. Here are three adjusted fatality rates per billion case vehicle miles: (1) in principal rollovers, (2) occupants of the other vehicle, in collisions of two cars/LTVs, (3) case-vehicle occupant fatalities, excluding principal rollovers, but including all other crash types (single- and multivehicle). The first rate is obtained by multiplying the rollover fatalities per billion occupant miles (from Section 5.3) by the average N of occupants per vehicle (at the beginning of Section 5.3). The second rate is copied directly from Section 5.3. The third rate is derived from a regression of overall occupant fatalities per billion occupant miles, subtracting the rollover rate, and converting to vehicle miles:

ROLLOVERS, AGGRESSIVENESS, AND NON-ROLLOVER OCCUPANT FATALITIES
Adjusted Fatality Rates per Billion Case Vehicle Miles

	Rollover Occupant Fatalities	Occ Fat in Other Vehicle (2 Veh Crash)	Non-Rollover Occupant Fatalities
Very small 4-door cars	1.07	2.70	14.71
Small 4-door cars	.81	2.19	10.51
Mid-size 4-door cars	.79	2.55	7.35
Large 4-door cars	.50	2.22	4.97
Compact pickup trucks	1.62	4.43	6.72
Large (100-series) pickups	1.00	4.86	4.61
Small 4-door SUVs	1.53	3.44	6.33
Mid-size 4-door SUVs	4.42	4.46	6.44
Large 4-door SUVs	2.12	4.30	4.54
Minivans	1.09	3.03	4.55

As stated before, light trucks, especially some of the SUVs and pickup trucks had much higher rollover fatality rates than cars. Many of these vehicles were also substantially more aggressive than cars. But for almost everything else – i.e., occupant fatality rates in a wide variety of non-rollover crashes (fixed-object, big-truck, multi-car/LTV) – cars and LTVs provided quite similar protection. The fatality rates in compact pickup trucks (6.72), small 4-door SUVs (6.33) and mid-size 4-door SUVs (6.44) were slightly lower than in mid-size 4-door cars (7.35). The rates in large pickups (4.61), large SUVs (4.54) and minivans (4.55) were slightly lower than in large cars (4.97).

Tables 5-2, 5-3 and 5-4 present a more extensive set of fatal-crash rates and fatality rates per billion case vehicle miles. Table 5-5 surveys occupant fatality rates per billion occupant miles. The various occupant fatality rates per billion vehicle miles were obtained by multiplying the rates per occupant mile by the average vehicle occupancy; the non-rollover fatality rate is the occupant fatality rate minus the rollover fatality rate; and "occupant fatalities in both vehicles" is the sum of the occupant fatality rates for the case vehicle and the other vehicle. All other rates are based on their own regression analyses.

In Table 5-2, the statistics for overall fatal crash involvements (with each involved case vehicle simply given WEIGHTFA = 1, although adjusting as usual for driver age/gender, etc.) closely parallel the results for prorated crash involvements.

TABLE 5-2: ADJUSTED FATAL-CRASH INVOLVEMENT RATES
PER BILLION CASE VEHICLE MILES, BY VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, etc.)

Vehicle Type and Size	Average Curb Weight	**Prorated Fatal Crash Involvements**[19]	Fatal Crash Involvements[20]
Very small 4-door cars	2,105	**15.73**	20.62
Small 4-door cars	2,469	**11.37**	15.29
Mid-size 4-door cars	3,061	**9.46**	12.36
Large 4-door cars	3,596	**7.12**	9.32
Compact pickup trucks	3,339	**11.74**	16.04
Large (100-series) pickup trucks	4,458	**9.56**	12.95
Small 4-door SUVs	3,147	**10.47**	14.05
Mid-size 4-door SUVs	4,022	**13.68**	16.75
Large 4-door SUVs	5,141	**10.03**	12.95
Minivans	3,942	**7.97**	10.57

	Prorated Fatal Crash Involvements		
Vehicle Type and Size	In My Vehicle	Other Veh + Peds	Total
Very small 4-door cars	11.24	4.49	15.73
Small 4-door cars	7.94	3.43	11.37
Mid-size 4-door cars	6.14	3.32	9.46
Large 4-door cars	4.26	2.86	7.12
Compact pickup trucks	6.74	5.00	11.74
Large (100-series) pickup trucks	4.65	4.91	9.56
Small 4-door SUVs	6.09	4.38	10.47
Mid-size 4-door SUVs	9.16	4.52	13.68
Large 4-door SUVs	5.69	4.34	10.03
Minivans	4.34	3.63	7.96

[19] Each fatal crash involvement by a case vehicle is weighted by: the number of crash fatalities divided by the number of cars/LTVs involved in the crash.
[20] Each fatal crash involvement by a case vehicle is given a weight of 1.

In Table 5-3, various occupant and non-occupant fatality rates are calculated per billion vehicle miles. The occupant fatality rate per billion vehicle miles was high in small cars and mid-size SUVs, low in large cars, large pickups and minivans. Fatality rates per occupant mile were even lower in minivans and large SUVs, as will be seen in Table 5-5, because they had higher occupancy rates.

The column of driver fatality rates in Table 5-3 is especially interesting as "consumer information." It tells average drivers their own probability of a fatality in a billion miles of driving. The rates have been adjusted for age/gender, etc. and may be compared to one another. In MY 1996-99, minivans and large cars were the safest vehicles for their drivers. Large SUVs and large pickup trucks were next safest. According to these estimates, drivers of large 4-door cars or minivans had less than half the fatality rate of drivers of mid-sized 4-door SUVs. These estimates do not take into account the harm to other occupants or non-occupants, only the fatality risk to the drivers themselves. The driver fatality rate in small 4-door SUVs was slightly higher than in mid-size 4-door cars.

Table 5-4 appraises the performance of cars and LTVs in crashes with another car/LTV. Fatalities in the case vehicle and the other vehicle add up to net crash fatalities per billion vehicle miles. It is not a zero-sum game. Large cars combined excellent protection for their own occupants with very low aggressiveness to the other vehicle, and they had the lowest crash fatality rate (3.93). Minivans were highly protective but somewhat more aggressive, while mid-size cars were less aggressive but not as protective: they had the next-best crash fatality rates. Small cars had the highest crash fatality rates, because of high fatality rates for their own occupants. The two groups of pickups and three groups of SUVs, on the other hand, all had intermediate crash fatality rates fairly close to 6.

Table 5-5 summarizes occupant fatality rates per billion occupant miles. Overall, minivans had the lowest fatality rate for their own occupants, with large cars, large pickups and large SUVs nearly tied for second place. High rates in rollovers contributed to the overall rates of SUVs. Excluding rollovers, the fatality rates for small to mid-size SUVs and small pickups were comparable to mid-size cars. As stated earlier, minivans had especially low fatality rates in collisions with fixed objects, while large SUVs and other relatively heavy passenger vehicles had the lowest occupant fatality rates in heavy-truck and multivehicle collisions.

TABLE 5-3: ADJUSTED FATALITY RATES PER BILLION CASE VEHICLE MILES BY VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, etc.)

Vehicle Type and Size	**Occupant** Fatalities	**Driver** Fatalities	**Non-Rollover** Occ Fat
Very small 4-door cars	15.78	11.56	14.71
Small 4-door cars	11.32	7.85	10.51
Mid-size 4-door cars	8.14	5.26	7.35
Large 4-door cars	5.47	3.30	4.97
Compact pickup trucks	8.34	6.82	6.72
Large (100-series) pickup trucks	5.61	4.07	4.61
Small 4-door SUVs	7.86	5.68	6.33
Mid-size 4-door SUVs	10.86	6.73	6.44
Large 4-door SUVs	6.66	3.79	4.54
Minivans	5.64	2.76	4.55

Vehicle Type and Size	**Rollover** Occ Fat	**Fixed-Object** Occ Fat	**Ped-Bike-MC** Fatalities	**Heavy Truck** Fat in Car/LTV
Very small 4-door cars	1.07	4.02	2.53	2.68
Small 4-door cars	.81	2.94	1.74	1.72
Mid-size 4-door cars	.79	2.64	1.48	1.14
Large 4-door cars	.50	2.07	1.28	.76
Compact pickup trucks	1.62	2.64	2.07	1.21
Large (100-series) pickup trucks	1.00	2.23	1.98	.72
Small 4-door SUVs	1.53	1.98	2.11	1.14
Mid-size 4-door SUVs	4.42	2.64	1.72	.84
Large 4-door SUVs	2.12	2.07	1.64	.73
Minivans	1.09	1.45	1.56	.84

TABLE 5-4

ADJUSTED FATALITY RATES PER BILLION CASE VEHICLE MILES
IN COLLISIONS BETWEEN TWO CARS/LTVs, BY CASE VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, etc.)

Vehicle Type and Size	Occ Fat in **Case** Vehicle (2 Veh Crash)	Occ Fat in **Other** Vehicle (2 Veh Crash)	Occ Fat in **Both** Vehicles (2 Veh Crash)
Very small 4-door cars	7.08	2.70	9.78
Small 4-door cars	4.92	2.19	7.11
Mid-size 4-door cars	2.79	2.55	5.34
Large 4-door cars	1.71	2.22	3.93
Compact pickup trucks	2.14	4.43	6.57
Large (100-series) pickup trucks	1.26	4.86	6.12
Small 4-door SUVs	2.49	3.44	5.93
Mid-size 4-door SUVs	2.17	4.46	6.63
Large 4-door SUVs	1.26	4.30	5.56
Minivans	1.77	3.03	4.80

TABLE 5-5: ADJUSTED OCCUPANT FATALITY RATES
PER BILLION OCCUPANT MILES, BY VEHICLE TYPE

(Case vehicles are MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000, adjusted for age/gender, rural/urban, day/night, speed limit, etc.)

Vehicle Type and Size	**Occupant** Fatalities	**Rollover** Fatalities	**Non-Rollover** Fatalities
Very small 4-door cars	9.93	.67	9.26
Small 4-door cars	7.13	.51	6.62
Mid-size 4-door cars	5.13	.50	4.63
Large 4-door cars	3.44	.31	3.13
Compact pickup trucks	6.18	1.20	4.98
Large (100-series) pickup trucks	3.83	.68	3.15
Small 4-door SUVs	5.44	1.06	4.38
Mid-size 4-door SUVs	6.66	2.71	3.95
Large 4-door SUVs	3.34	1.06	2.28
Minivans	2.72	.53	2.19

Vehicle Type and Size	**Fixed-Object** Fatalities	**Heavy-Truck** Fat in Car/LTV	**Occ Fat in Case Veh (2 car/LTV crash)**
Very small 4-door cars	2.53	1.69	4.46
Small 4-door cars	1.85	1.08	3.10
Mid-size 4-door cars	1.66	.72	1.76
Large 4-door cars	1.30	.48	1.08
Compact pickup trucks	1.96	.90	1.59
Large (100-series) pickup trucks	1.53	.49	.86
Small 4-door SUVs	1.37	.79	1.73
Mid-size 4-door SUVs	1.62	.52	1.33
Large 4-door SUVs	1.04	.37	.63
Minivans	.70	.41	.85

The analysis of adjusted, prorated crash fatality rates per billion vehicle miles also provides an opportunity to compare the MY 1996-99 fatality risk of 4x2 and 4x4 4-door SUVs on a more "level playing field." If the regression at the beginning of this section is repeated, but with 4-door SUVs further subdivided by 4x2 vs. 4x4 as well as size group, the regression coefficients, representing the adjusted fatality rate relative to mid-size cars, are:

		Coefficient	Std. Error
SMALLSUV	4x2	0.379	0.114
SMALLSUV	4x4	0.074	0.078
MEDSUV	4x2	0.447	0.035
MEDSUV	4x4	0.324	0.028
BIGSUV	4x2	– 0.131	0.064
BIGSUV	4x4	+ 0.126	0.038

In the small 4-door SUVs, even after controlling for HIFAT_ST and other factors, the prorated fatal-crash risk was still substantially lower in the 4x4 vehicles than in the 4x4's. In the mid-size SUVs, adjustment for HIFAT_ST, etc. produced similar coefficients for 4x2 and 4x4, with the 4x4 vehicles about 12 percent safer [1 – exp(.324 - .447)]. But in the large SUVs, the 4x2 vehicles had a substantially lower fatal crash rate than the 4x4's. When all three size groups are taken into account, the average difference between 4x2 and 4x4 was rather small after adjusting for HIFAT_ST and the other variables.

5.5 Fatality rate differences between vehicle types: point estimates

The prorated fatal-crash involvement rates in Table 5-2 can be used to obtain point estimates of the percentage differences in these rates between vehicle types, after controlling for driver age/gender, urban/rural, annual mileage, etc. For example, in MY 1996-99, small 4-door SUVs had a fatal-crash rate of 10.47 while the rate for mid-size 4-door cars was 9.46, a 10 percent reduction. In the regression models, the effect of vehicle type/size group is independent and constant across the various control variables. In other words, people who drove mid-size MY 1996-99 4-door cars in CY 1996-2000 had a 10 percent lower fatal-crash rate than people of the same age and gender who drove small MY 1996-99 4-door SUVs on the same types of roads, the same number of miles per year, etc.

Table 5-6 compares the crash rates and vehicle weights of cars or minivans to various types of MY 1996-99 SUVs and pickup trucks. In every scenario of Table 5-6, the car/minivan experienced lower crash fatality risk and weighed less than the SUV/pickup trucks. For example, relative to mid-size MY 1996-99 4-door SUVs, the fatal-crash rates in mid-size 4-door cars, large 4-door cars, or minivans were 31, 48 or 42 percent lower, respectively, while the curb weights averaged 961, 426 or 80 pounds less.

TABLE 5-6: FATAL-CRASH RATES AND CURB WEIGHTS
OF SUVs AND PICKUPS VERSUS CARS AND MINIVANS

(MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000)

Vehicle Type and Size	Average Curb Weight	Prorated Fatal Crash Rate[21]	Fatal-Crash Reduction (%)
Small 4-door SUVs	3,147	10.47	
Mid-size 4-door cars	3,061	9.46	
	- 86		10%
Mid-size 4-door SUVs	4,022	13.68	
Mid-size 4-door cars	3,061	9.46	
	- 961		31%
Mid-size 4-door SUVs	4,022	13.68	
Large 4-door cars	3,596	7.12	
	- 426		48%
Mid-size 4-door SUVs	4,022	13.68	
Minivans	3,942	7.97	
	- 80		42%
Large 4-door SUVs	5,141	10.03	
Large 4-door cars	3,596	7.12	
	- 1,545		29%
Large 4-door SUVs	5,141	10.03	
Minivans	3,942	7.97	
	- 1,199		21%

[21] Each fatal crash involvement by a case vehicle is weighted by: the number of crash fatalities divided by the number of cars/LTVs involved in the crash. Rates are adjusted for age/gender, rural/urban, day/night, speed limit, etc

TABLE 5-6 (Continued): FATAL-CRASH RATES AND CURB WEIGHTS OF SUVs AND PICKUPS VERSUS CARS AND MINIVANS

(MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000)

Vehicle Type and Size	Average Curb Weight	Prorated Fatal Crash Rate[22]	Fatal-Crash Reduction (%)
Compact pickups	3,339	11.74	
Mid-size 4-door cars	3,061	9.46	
	- 278		19%
Large (100-series) pickups	4,458	9.56	
Large 4-door cars	3,596	7.12	
	- 862		26%
Large (100-series) pickups	4,458	9.56	
Minivans	3,942	7.97	
	- 516		17%

…………………………………………………………………………………………

Vehicle Type and Size	Average Curb Weight	Prorated Fatal Crash Rate	Fatal-Crash Reduction (%)
Very small 4-door cars	2,105	15.73	
Small 4-door cars	2,469	11.37	
	+ 364		28%

[22] Each fatal crash involvement by a case vehicle is weighted by: the number of crash fatalities divided by the number of cars/LTVs involved in the crash. Rates are adjusted for age/gender, rural/urban, day/night, speed limit, etc

To put these differences in perspective, Table 5-6 also compares the crash rates and vehicle weights of very small 4-door cars to small 4-door cars. In that scenario, the heavier vehicle group had 28 percent lower crash fatality rates.

The fatal-crash rates in Table 5-6 included fatalities to occupants of other vehicles and to pedestrians. Table 5-6a, on the other hand, compares **driver fatality rates** per billion miles of driving. The rates have been adjusted for age/gender, etc. Table 5-6a provides "consumer information" by comparing the drivers' own fatality rates in one type of vehicle versus another. **Each** of the scenarios in Table 5-6 that showed a reduction in the "societal" fatal-crash rates also shows in Table 5-6a a reduction in the driver's own fatality rates, ranging from 7 to 59 percent.

These estimates apply to 1996-99 models. A new generation of SUVs and pickups that is less rollover-prone and less aggressive could have lower fatal-crash rates than the vehicles analyzed in Table 5-6.

5.6 Sources of uncertainty, interval estimates

The adjusted and prorated crash fatality rates per billion miles (Table 5-2) showed some substantial differences between vehicles types in MY 1996-99:

OVERALL CRASH FATALITY RISK
Adjusted Prorated Crash Fatalities per Billion Case Vehicle Miles

Very small 4-door cars	15.73
Small 4-door cars	11.37
Mid-size 4-door cars	9.46
Large 4-door cars	7.12
Compact pickup trucks	11.74
Large (100-series) pickups	9.56
Small 4-door SUVs	10.47
Mid-size 4-door SUVs	13.68
Large 4-door SUVs	10.03
Minivans	7.97

The analyses by crash mode suggested that two tangible vehicle-design factors – rollover-instability and aggressiveness – explained most of the additional fatality risk of MY 1996-99 pickup trucks and SUVs. Nevertheless, there is room for suspicion that, in addition, people who selected LTVs drove more adventurously than people who bought cars. In particular, the analysis of collisions with pedestrians/bikes/motorcycles (Table 5-3) also showed somewhat higher involvement rates per mile for LTVs than cars:

TABLE 5-6a: DRIVER'S FATALITY RATES
IN SUVs AND PICKUPS VERSUS CARS AND MINIVANS

(MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000)

	Driver's Fatality Rate*		Driver's Fatality Rate*	Driver's Fatality Risk Reduction
Small 4-door SUVs	5.68	Mid-size 4-door cars	5.26	7%
Mid-size 4-door SUVs	6.73	Mid-size 4-door cars	5.26	22%
		Large 4-door cars	3.30	51%
		Minivans	2.76	59%
Large 4-door SUVs	3.79	Large 4-door cars	3.30	13%
		Minivans	2.76	27%
Compact pickups	6.82	Mid-size 4-door cars	5.26	23%
Large (100-ser) pickups	4.07	Large 4-door cars	3.30	19%
		Minivans	2.76	32%
…………				
Very small 4-door cars	11.56	Small 4-door cars	7.85	32%

* Driver fatalities per billion vehicle miles. Rates are adjusted for age/gender, rural/urban, day/night, speed limit, etc

PEDESTRIANS-BICYCLISTS-MOTORCYCLISTS
Adjusted Fatality Rate per Billion Car/LTV Vehicle Miles

Very small 4-door cars	2.53
Small 4-door cars	1.74
Mid-size 4-door cars	1.48
Large 4-door cars	1.28
Compact pickup trucks	2.07
Large (100-series) pickups	1.98
Small 4-door SUVs	2.11
Mid-size 4-door SUVs	1.72
Large 4-door SUVs	1.64
Minivans	1.56

A possible explanation for the high pedestrian fatality rates is that the LTVs were driven less prudently than the cars. In Section 3.6 the hypothesis of "driver quality" was examined for light vs. heavy cars; here, similar techniques are used to compare cars and LTVs. The first analysis in Section 3.6 was to compare the incidence of specific high-risk driving behaviors, such as drinking, speeding, etc. in light vs. heavy cars, after controlling for driver age, gender and other factors.

The same analysis can be used to compare high-risk driving behaviors across vehicle types. It is based on crash involvements of MY 1991-99 cars and LTVs on the 1995-2000 FARS files. A driver is assigned one point for each of the following nine indications of imprudent driving in this crash, or on previous occasions[23] (see Section 3.6 for details):

- Alcohol involvement on this crash
- Drug involvement on this crash
- Driving without a valid license at the time of this crash
- 2 or more crashes during the past 3 years
- 1 or more DWI convictions during the past 3 years
- 2 or more speeding convictions during the past 3 years
- 2 or more license suspensions or revocations during the past 3 years
- 2 or more other harmful moving violations during the past 3 years

[23] FARS driver history information is generally complete for most of the States. For example, on the 1999 FARS, 50 States appeared to have fairly complete information on previous speeding convictions and other violations; 48 States had fairly complete information on previous suspensions; 37-46 States on previous DWI; and 41-43 States on previous crashes.

- This crash involves driving on a suspended/revoked license, reckless/erratic/negligent driving, being pursued by police, racing, hit & run, or vehicular homicide

In other words, the dependent variable, BAD_DRIV = 0 for drivers who did not have any of the behaviors listed above, and could theoretically be as high as 9 if they had all of them. The average value of BAD_DRIV is 0.51 in these 131,115 cases. The GLM procedure in SAS[24] performs a regression of BAD_DRIV by vehicle type, driver age and gender (DRVMALE, M14_30, M30_50, etc.), NITE, RURAL, SPDLIM55, high-fatality State, and vehicle age. Eighteen dichotomous variables are used to indicate 19 vehicle types: the ten vehicle types studied in this chapter, plus nine other types of cars/LTVs (for comparison): police cars, heavy-duty pickup trucks, full-sized vans and various types of 2-door cars/SUVs. For mid-size 4-door cars, all 18 variables are set to zero, as in the rest of this chapter. In other words, BAD_DRIV is calibrated for the other vehicle types relative to mid-size 4-door cars, where it is approximately 0.51.

As in Section 3.6, the regression calibrated highly significant coefficients in the expected direction for DRVMALE (t = 12.1), M30_50 (t = 40.3), F30_50 (t = 17.3), NITE (t = 66.5), RURAL (t = 6.54), SPDLIM55 (t = -7.16) and vehicle age (t = 7.85). In other words, imprudent driving is more prevalent in males than females, drops very steeply from age 30 to 50 in both genders, but especially males, is much more common at night and in older vehicles, and somewhat more common in rural areas and low-speed roads. After controlling for those factors, the values of BAD_DRIV by vehicle type are as follows (vehicle types whose BAD_DRIV is significantly different from mid-size 4-door cars are listed in **bold** type):

[24] *SAS/STAT® User's Guide, Version 6, Fourth Edition*, Volume 2, SAS Institute, Cary, NC, 1989, pp. 893-996.

IMPRUDENT DRIVING BEHAVIORS PER FATAL-CRASH INVOLVED DRIVER
Adjusted for Driver Age/Gender, Day/Night, Vehicle Age, etc. (N = 131,115 FARS cases)

	Adjusted Average BAD_DRIV	Difference from Mid-Size 4-Door Cars	t-test for this Difference
Very small 4-door cars	.556	+ .046	1.90
Small 4-door cars	.523	+ .013	1.51
Mid-size 4-door cars	.510	-	-
Large 4-door cars	.515	+ .005	.51
Compact pickup trucks	**.530**	**+ .020**	**2.18**
Large (100-series) pickups	.522	+ .012	1.24
Small 4-door SUVs	.500	- .010	- .24
Mid-size 4-door SUVs	**.485**	**- .025**	**- 2.36**
Large 4-door SUVs	**.471**	**- .039**	**- 2.18**
Minivans	**.397**	**- .113**	**- 10.12**
Sporty 2-door cars	**.636**	**+ .126**	**8.81**
High-performance 2-door cars	**.727**	**+ .217**	**16.27**
Economy 2-door cars	**.592**	**+ .082**	**7.69**
Other 2-door cars	**.591**	**+ .081**	**6.77**
Small 2-door SUVs	**.609**	**+ .099**	**4.37**
Med/Lge 2-door SUVs	**.554**	**+ .054**	**2.63**
Police cars	**.058**	**- .452**	**- 14.96**
Heavy-duty (200/300) pickups	**.459**	**- .051**	**- 3.80**
Full-size vans	**.431**	**- .079**	**- 4.24**

Among the ten types of vehicles featured in the other analyses of this chapter, only minivans had a rate substantially different from mid-size 4-door cars, and it was lower: .397 vs. .510. All three types of 4-door SUVs had observed BAD_DRIV rates lower than mid-size cars (significantly lower for mid-size and large SUVs). Compact and 100-series pickup trucks had slightly higher rates (significant for compact pickups). However, in practical terms, the rates for 4-door SUVs and pickup trucks, ranging from .471 to .530 were little different from mid-size cars' .510. These data suggest that 4-door SUVs were driven just as prudently, and perhaps very slightly more so than 4-door cars.

The substantially lower incidence of unsafe driving behavior in minivans, even after controlling for driver age and gender, raises the possibility that the very low adjusted fatality rates of minivans, seen throughout this chapter, may at least in part be due to their exceptionally prudent drivers. However, importantly, the preceding analysis shows little difference between 4-door cars, 4-door SUVs and non-heavy-duty trucks in terms of their drivers' behavior, and if anything, suggests that 4-door SUVs had slightly more prudent drivers than 4-door cars.

By contrast, all types of 2-door cars and 2-door SUVs had substantially higher BAD_DRIV than any 4-door car or 4-door SUV – especially high-performance cars, but even "economy" and other 2-door cars as well as small 2-door SUVs. Police cars had an extremely low rate, because the risks their drivers must take as part of the job don't get counted in BAD_DRIV. Two groups of LTVs widely used for work, heavy-duty (200 or 300 series) pickup trucks and full-size vans also had substantially lower incidence of BAD_DRIV than the personal-transportation cars/LTVs. These differences are intuitively reasonable and they underscore the lack of differences between 4-door cars, 4-door SUVs and non-heavy-duty pickup trucks.

In the preceding regressions, BAD_DRIV can have values from 0 to 9 and it is treated as a linear dependent variable. A statistically more powerful (but perhaps less descriptive) approach is to define a categorical variable BAD_DRIV' – one or more bad-driving behaviors vs. none – and to run a logistic regression. Here, too, BAD_DRIV' was slightly lower in mid-size and large 4-door SUVs than in 4-door cars, about the same in small 4-door SUVs and 4-door cars, slightly higher in pickup trucks, and substantially lower in minivans (but considerably higher in 2-door cars and SUVs than in 4-door cars, pickup trucks or SUVs).

If this last analysis is repeated, but with 4-door SUVs further subdivided by 4x2 vs. 4x4 as well as by size group, it suggests small 4x2 SUVs had 20 percent higher BAD_DRIV' than small 4x4 SUVs; mid-size 4x2 9 percent higher than mid-size 4x4; and large 4x2 23 percent lower than large 4x4. This is directionally consistent with the regression of fatal-crash rates (Section 5.4), which showed higher rates for 4x2 than 4x4 in the small and mid-size SUVs, and lower rates for 4x2 than 4x4 in the large SUVs. However, the average of the three 4x2 coefficients in the BAD_DRIV' regression nearly equals the average of the three 4x4 coefficients; both averages are slightly lower than zero – i.e., slightly better than mid-size cars.

Conversely, the presence of child passengers age 0-12 in the vehicle can indicate a relatively safe driver, at least to the extent that drivers transporting children are unlikely to be drunk, drugged, or driving recklessly. It is a marker of limited utility, since only about 10 percent of vehicles in fatal crashes have child passengers. Nevertheless, it is possible to perform a logistic regression with presence/absence of a child passenger as the dependent variable. After controlling for driver age and gender, minivans and large SUVs (e.g., Suburbans) had substantially more child passengers than 4-door cars; mid-size SUVs, a bit more; pickup trucks and small SUVs, fewer. Two-door cars of all sizes had far fewer child passengers than 4-door cars.

These analyses do not show any important differences in "driver quality" in our ten groups of vehicles, except that minivans were driven more prudently than they other types (no surprise!). Specifically, they show little evidence that pickup trucks or SUVs were driven in a riskier manner than cars, after controlling for the age/gender, etc. of the drivers. However, they focus on the more obvious forms of poor driving that tend to get reported – drinking, speeding, bad driver history – or on other simple characteristics, such as the presence/absence of a child passenger. It is still possible that these vehicles are driven imprudently in more subtle ways that would not necessarily be identified in crash reports or driver records.

The literature suggests strongly that the geometric characteristics of LTVs (including minivans) ought to make them intrinsically more harmful than cars in pedestrian impacts.[25] The low bumpers and hoods of cars cause them to initially strike the legs of pedestrians (usually not life-threatening), scoop the pedestrians up, gradually accelerate them, resulting in a head impact at relatively low speed. On mid-size or large cars, the head impact is likely to be on the top of the hood, one of the softest areas on the car's exterior. By contrast, the high bumper and hood of LTVs can result in an immediate impact to the pedestrian's thorax at the full impact speed. If the LTV scoops up the pedestrian, head impact is sooner and may be more severe. Even worse, the LTV is likely to knock the pedestrian to the ground in front of the vehicle. The net result is that LTVs cause more severe injuries to pedestrians at lower impact speeds than cars.

Thus, there is little direct evidence that any one of our ten vehicle types, except minivans, was driven more prudently than others, whereas there is strong evidence that the geometry of LTVs makes them more harmful to pedestrians. As in Sections 3.6, 3.7 and 4.5, the regression results for pedestrian crashes will be used to appraise a likely range for the adjustments to the comparisons of SUVs/pickups with cars/minivans. The conclusion is that the observed size-safety effect in pedestrian crashes has to be real to quite some extent if not completely, and that it can't all be self-selection. We need to place a lower and an upper bound on the proportion of the pedestrian effect that will be ascribed to self-selection. The lower bound, clearly, is that **none** of the pedestrian effect is self-selection and all of it is real: the preceding analyses of driving behaviors, etc. did not show any evidence supporting the self-selection hypothesis (if anything, 4-door SUVs had slightly more prudent drivers than 4-door cars), whereas the literature suggested that LTVs are really more dangerous to pedestrians. The upper bound is more difficult to quantify. Even as an upper bound, we cannot assume the entire pedestrian effect is self-selection, because the literature clearly indicates the geometry of LTVs increases risk for pedestrians. Thus, the upper bound is some proportion, greater than zero but less than 100 percent, of the pedestrian effect. In the absence of evidence supporting any specific proportion, let us split the difference between 0 and 100 percent and use **half** the observed effect in pedestrian crashes is due to self-selection

The details of the calculation will be presented shortly, but they work approximately like this: if fatality risk in some type of SUVs or pickup trucks exceeds the risk in cars by 5 percent overall and by 2 percent in pedestrian crashes, deduct ½ of the effect in pedestrian crashes from the overall effect to obtain 4 percent.

The point estimates for the percentage differences in the fatal-crash rates of SUVs/pickups vs. cars/minivans were shown in Table 5-6. They were based on a single regression of the prorated crash fatality rate, per billion vehicle miles, by vehicle type and control variables. Three sources of **sampling error** will be considered (the first two are the same as in Sections 3.7 and 4.5):

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[25] Stammen, J., Ko, B., Guenther, D., and Heydinger, G., *A Demographic Analysis and Reconstruction of Selected Cases from the Pedestrian Crash Data Study*, Paper No. 2002-01-0560, Society of Automotive Engineers, Warrendale, PA, 2002.

- The basic sampling error specified on the SAS regression printouts.
- The additional error due to using induced-exposure data from just 8 of the States to subdivide the national exposure data by age/gender, etc.
- The error in the estimate, based on NASS data, for annual mileage of various types of LTVs relative to 4-door cars.

The full regression printout was shown in Section 5.4; the vehicle-type coefficients and their basic sampling errors were:

Variable	Parameter Estimate	Standard Error
MINICAR	0.508	0.069
SMALLCAR	0.183	0.023
BIGCAR	-0.285	0.025
SMALLPKP	0.216	0.025
PKP100	0.010	0.023
SMALLSUV	0.101	0.048
MEDSUV	0.369	0.024
BIGSUV	0.058	0.034
MINIVAN	-0.172	0.029

The "regression coefficient" for mid-size cars (the default vehicle type, therefore not a separate independent variable) is implicitly zero. However, the fatality risk in mid-size cars is not known with certainty, but must have some sampling error. Since the database for this regression included 3,181 prorated crash fatalities of small cars and 5,143 mid-size cars, the basic sampling error for mid-size cars can be estimated as

$$.023 \times (3{,}181 / 5{,}143)^{.5} = .018$$

The additional error due to using data from just 8 of the States can be computed for the analysis of prorated crash fatalities by the same procedure as in Section 3.5.[26] The procedure generates a State-to-State error term for each of the nine vehicle-type variables, and an implicit error term for mid-size cars is computed, as above.

The annual mileage of various types of LTVs, relative to 4-door cars, was estimated in Section 2.4 (Table 2-3) by a regression on 17,627 NASS vehicle cases, 8,323 of which were 4-door cars. The dependent variable was the logarithm of the annual mileage. The regression assigns a coefficient to each LTV type, equal to log(LTV mileage/4-door car mileage). The standard

[26] The basic regression model for prorated crash fatalities is run for a new database using all of the fatal crash cases, but only the induced-exposure cases from one State, weighted to give national mileage counts. This is repeated for seven States (all except Utah), and the standard error of the seven results is computed. HIFAT_ST has to be excluded from the list of control variables, since it is not meaningful when induced-exposure data from just one State are used. SNOW_ICE is also excluded, since it is almost always zero in Florida, and of little importance in the model elsewhere.

errors of the coefficients in the mileage regression may be added directly, on a root-sum-of-squares basis, to other sources of sampling error in the coefficients in the fatality regression.[27]

The regression coefficients for the fatal-crash rate, their basic errors, their State-to-State errors, the standard errors for the estimates of relative annual mileage, and the adjusted ped/bike/motorcycle fatality rates for each vehicle type, are:

	Regression Coefficient	Basic Error	State-to-State Error	NASS Mileage Error[28]	Ped/ Bike/ MC Rate
Very small 4-door cars	.508	.069	.074	0	2.53
Small 4-door cars	.183	.023	.020	0	1.74
Mid-size 4-door cars	[.000]	[.018]	[.015]	0	1.48
Large 4-door cars	- .285	.025	.021	0	1.28
Compact pickup trucks	.216	.025	.066	.018	2.07
Large (100-series) pickups	.010	.023	.092	.023	1.97
Small 4-door SUVs	.101	.048	.037	.029	2.11
Mid-size 4-door SUVs	.369	.024	.022	.018	1.72
Large 4-door SUVs	.058	.034	.037	.038	1.64
Minivans	- .172	.029	.029	.022	1.56

For cars, SUVs and minivans, the State-to-State errors are about the same magnitude as the basic errors. For pickup trucks, the State-to-State errors are much larger because the distribution and use of pickup trucks (e.g., urban vs. rural) varies a lot from State to State. The point estimates in Table 5-6 were actually derived by taking the ratio of the adjusted, prorated crash fatality rates worked out for the entire population. For example, the percentage difference in the fatal-crash rates of mid-size 4-door SUVs and mid-size 4-door cars was:

$$1 – (9.46 / 13.68) = 31 \text{ percent}$$

[27] Any error in this coefficient would have propagated to become an error of equal magnitude and opposite sign in the coefficient for relative fatality risk in the regression of prorated crash fatality rates (Section 5.4). For example, the fatality regression produced a coefficient of .369 for mid-size SUVs – i.e., the log(SUV fatality rate per mile/mid-size car fatality rate per mile) = .369. However, the fatality regression assumes that log(SUV mileage/car mileage) = .036, based on the mileage regression. If, if fact, the latter had been .026 rather than .036, the former would have been .379 instead of .369. Thus, the standard errors of the coefficients in the mileage regression may be added directly, on a root-sum-of-squares basis, to other sources of sampling error in the coefficients in the fatality regression. This source of error was not considered in Chapter 4 because the overall weight-safety coefficients (for all vehicle types) did not have such a direct relationship to the error in mileage, by vehicle type. If the fatality regression in Section 5.4 had addressed fatalities per occupant mile, the uncertainty in the NASS occupancy rates would have become a source of additional sampling error.

[28] For each LTV type, relative to 4-door cars.

However, a very similar estimate (identical to three significant digits) can be obtained by simply taking the antilog of the difference in the regression coefficients:

$$1 - \exp(.000 - .369) = 31 \text{ percent}$$

The difference of the regression coefficients has sampling error equal to the root-sum-of-squares of the basic, State-to-State and mileage errors of each coefficient:

$$(.018^2 + .015^2 + .024^2 + .022^2 + .018^2)^{.5} = .044$$

A 1.96 sigma upper bound of the percentage difference in the fatal-crash rates of mid-size 4-door SUVs and mid-size 4-door cars is:

$$1 - \exp(.000 - .369 - 1.96 \times .044) = 37 \text{ percent}$$

The adjusted pedestrian fatality rate was 1.48 in mid-size cars and 1.72 in mid-size SUVs. In other words, the risk was 1 – (1.48/1.72) = 14 percent lower in the cars. In logarithmic terms, the pedestrian effect was log (1.48/1.72) = -.15. The lower bound of the interval estimate is obtained by adding 1.96 sampling errors to the point estimate and also deducting half of the pedestrian effect:

$$1 - \exp(.000 - .369 + 1.96 \times .044 - .5 \times \log[1.48/1.72]) = 19 \text{ percent}$$

Table 5-7 provides the interval as well as point estimates of the percentage differences in the fatal-crash rates of SUVs/pickup trucks vs. cars/minivans. As stated earlier, each of the scenarios had a point estimate indicating fatality reduction. However, only the five interval estimates involving mid-size and full-size SUVs are strictly positive.

For mid-size 4-door SUVs of MY 1996-99 vs. mid-size 4-door cars, large 4-door cars or minivans, the lower bounds show substantial fatality reductions (19, 34 and 31 percent) even after deducting sampling error and the adjustment for self-selection. The difference between large 4-door SUVs and either large 4-door cars or minivans also had interval estimates entirely in the positive range, although not nearly as strong as for the mid-size SUVs.

The point estimate of the difference between small 4-door SUVs and mid-size 4-door cars was 10 percent, not statistically significant as evidenced by the interval estimate from –24 to +21. Similarly, none of the differences between pickup trucks and cars/minivans were statistically significant. The uncertainty of the results for pickup trucks was greater than for SUVs. The State-to-State variation was much higher. Pedestrian fatality rates were also especially high for pickups, resulting in a larger adjustment for self-selection.

A similar procedure can be used to obtain interval estimates for reductions in **driver fatality rates** per billion miles. Table 5-7a expands on the "consumer information" in Table 5-6a by showing interval as well as point estimates. Whereas all the point estimates of differences between SUVs/pickup trucks and cars/minivans were positive, ranging from 7 to 59 percent,

TABLE 5-7

CRASH FATALITY RATE DIFFERENCES OF SUVs AND PICKUPS VERSUS CARS AND MINIVANS: POINT AND INTERVAL ESTIMATES

(MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000)

		Crash Fatality[29] Reduction for Cars/Minivans (%)	
	Versus	Point Estimate[30]	Interval Estimate[31]
Small 4-door SUVs	Mid-size 4-door cars	10	– 24 to 21
Mid-size 4-door SUVs	Mid-size 4-door cars	31	19 to 37
	Large 4-door cars	48	34 to 53
	Minivans	42	31 to 48
Large 4-door SUVs	Large 4-door cars	29	8 to 38
	Minivans	21	5 to 32
Compact pickups	Mid-size 4-door cars	19	– 11 to 31
Large (100-series) pickups	Large 4-door cars	26	– 13 to 39
	Minivans	17	– 16 to 33
Very small 4-door cars	Small 4-door cars	28	– 7 to 41

[29] Crash fatalities include a vehicle's own occupants as well as occupants of other vehicles in the crash and pedestrians.
[30] From Table 5-6
[31] For lower bound, deduct 1.96 times sampling error and half the pedestrian effect; for upper bound add 1.96 times sampling error.

TABLE 5-7a

DRIVER'S FATALITY RATE DIFFERENCES OF SUVs AND PICKUPS VERSUS CARS AND MINIVANS: POINT AND INTERVAL ESTIMATES

(MY 1996-99 light trucks and 4-door cars with air bags in CY 1996-2000)

		Driver's Fatality Reduction For Cars/Minivans (%)	
	Versus	Point Estimate[32]	Interval Estimate[33]
Small 4-door SUVs	Mid-size 4-door cars	7	– 33 to 23
Mid-size 4-door SUVs	Mid-size 4-door cars	22	6 to 30
	Large 4-door cars	51	36 to 57
	Minivans	59	50 to 65
Large 4-door SUVs	Large 4-door cars	13	– 18 to 27
	Minivans	27	9 to 40
Compact pickups	Mid-size 4-door cars	23	– 9 to 35
Large (100-series) pickups	Large 4-door cars	19	– 25 to 35
	Minivans	32	3 to 46
....			
Very small 4-door cars	Small 4-door cars	32	– 7 to 48

[32] From Table 5-6a
[33] For lower bound, deduct 1.96 times sampling error and half the pedestrian effect; for upper bound add 1.96 times sampling error.

only the differences between mid-size SUVs and cars/minivans, and between other SUVs/pickups and minivans had entirely positive interval estimates. Drivers' fatality reductions for small SUVs, large SUVs or pickup trucks relative to cars were not statistically significant.

Tables 5-7 and 5-7a also analyze the percentage differences in the fatality rates of very small 4-door cars and small 4-door cars. The differences are not statistically significant; the sample of very small 4-door cars in our MY 1996-99 data was much smaller than ano of the other vehicle groups.

5.7 Effect of a different mix of vehicle types on the number of fatalities

The percentage changes in the adjusted, prorated crash fatality rate, as estimated in Table 5-7, are applied to the absolute numbers of "baseline" fatalities to estimate changes in the absolute numbers of fatalities per year if one percent of the vehicles on the road had been MY 1996-99 passenger cars or minivans rather than MY 1996-99 pickup trucks or SUVs. The analysis is based on the crash fatality rates developed in this chapter, and the definitions of the "baseline" fleet and annual fatalities, originally developed in Section 3.8 and used subsequently throughout this study. Since crash fatality rates include occupants of other vehicles and pedestrians as well as the occupants of the case vehicle, this analysis measures the net societal effect of a different mix of vehicle types. The baseline combines national fatality totals for CY 1999 with the vehicle-type distributions of both fatalities and registrations for MY 1996-99 vehicles in CY 1996-2000. The baseline represents the market shares and fatality counts that would likely have been seen in CY 1996-2000 if the vehicle mix of MY 1996-99 had constituted the entire on-road fleet.

Table 5-8 works out baseline totals and rates for 18 vehicle groups that comprise all cars/LTVs (including 2-door cars, etc.). The starting point for the analyses is the actual count of prorated crash fatalities for each vehicle group, for MY 1996-99 in CY 1996-2000. For example, mid-size 4-door SUVs had 2,801.6 prorated crash fatalities. As explained in Section 5.4, each fatal-crash involvement in crash modes 1-6 of Table 2-1 is weighted by the number of crash fatalities divided by the number of cars/LTVs in the crash; the sum of the weights is the number of prorated fatalities. The first column of Table 5-8 estimates how many fatalities in 1996-2000 FARS each of the 18 vehicle groups was "responsible" for. It adds up to 30,948.6 prorated fatalities actually on FARS.

The second column of Table 5-8 inflates the actual prorated fatalities to a full calendar year's worth of crash experience by the entire on-road fleet: specifically the baseline CY 1999 experience for the baseline MY 1996-99 vehicle mix. As stated in Section 3.8, the CY 1999 FARS has records of 41,717 fatalities. Among them, 37,654 fatalities are in crashes involving at least one car/LTV and classifiable in the six basic crash modes of Table 2-1. Each number in the first column is multiplied by 37,654/30,948.6. The fatality counts in the second column add up to 37,654. Each fatality of CY 1999 appears once, without double-counting. This column estimates how many fatalities per year each vehicle type would have been "responsible for" if the MY 1996-99 vehicle mix had constituted the entire on-road fleet in CY 1999. For example,

TABLE 5-8

BASELINE MARKET SHARES AND PRORATED CRASH FATALITIES
BY VEHICLE TYPE

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

Vehicle Type and Size	Prorated Fatal Crash Involvements[34] Actual[35]	Prorated Fatal Crash Involvements[34] Full-Year Projection[36]	Percent of Registration Years[37]	Fatals Per Pct of Reg Yrs[38]
Very small 4-door cars	219.7	267	.48	561
Small 4-door cars	3,180.5	3,870	10.67	363
Mid-size 4-door cars	5,143.0	6,257	21.14	296
Large 4-door cars	2,524.0	3,071	12.44	247
Compact pickup trucks	2,708.7	3,296	6.19	532
Large (100-series) pickups	3,461.9	4,212	8.51	495
Small 4-door SUVs	495.3	603	2.02	299
Mid-size 4-door SUVs	2,801.6	3,409	8.18	417
Large 4-door SUVs	1,071.3	1,303	3.74	349
Minivans	1,644.6	2,001	8.06	248
Sporty 2-door cars	468.5	570	1.37	417
Hi-performance 2-dr cars	1,184.2	1,441	2.38	605
Economy 2-door cars	1,732.2	2,108	4.44	475
Other 2-door cars	1,222.0	1,487	4.03	369
2-door SUVs	741.5	902	1.56	577
Police cars	230.0	280	.54	522
Heavy-duty (200/300) pkps	1,441.5	1,754	2.87	611
Full-size vans	678.1	825	1.39	592
	30,948.6	37,654	100.00	

[34] Each fatal crash involvement by a case vehicle is weighted by: the number of crash fatalities divided by the number of cars/LTVs involved in the crash.
[35] For MY 1996-99 vehicles in CY 1996-2000.
[36] Adds up to 37,654, baseline fatalities for CY 1999, in crashes with known crash mode and involving at least one car or LTV. For example, 267 = (37,654/30,948.6) x 219.7
[37] For MY 1996-99 cars and LTVs in CY 1996-2000.
[38] For example, 561 = 267/.48 (with rounding errors corrected).

mid-size 4-door SUVs would have been responsible for 3,409 fatalities per year: all their single-vehicle crash fatalities, half the crash fatalities in collisions with one other car/LTV, etc.

The third column of Table 5-8 is each vehicle group's share of the number of registration years for MY 1996-99 cars/LTVs on the 1996-2000 Polk files. Mid-size 4-door SUVs account for 8.18 percent of the MY 1996-99 registration years.

The last column of Table 5-8 measures the **actual** prorated fatality risk of each vehicle class per percentage point of the on-road fleet, per year. For example, if the MY 1996-99 vehicle mix had constituted the entire on-road fleet, mid-size 4-door SUVs would have accounted for 8.18 percent of all registered vehicles and been responsible for 3,409 fatalities per year. Each percentage point of registrations accounted for 3,409/8.18 = 417 fatalities per year. These are actual fatality rates for the people who drove the vehicles, and have not been adjusted for driver age/gender, urban/ rural, or annual mileage. For example, pickup trucks had high actual rates in part because they were extensively driven in rural areas; full-size vans – because they were driven many miles per year; high-performance 2-door cars – because they had exceptionally high-risk drivers.

Table 5-9 estimates the absolute change in fatalities in a year by applying the percentage fatality reductions based on adjusted rates, from Table 5-7, to the actual fatality rates in Table 5-8. For example, Table 5-8 shows that mid-size 4-door SUVs constituted 8.18 percent of the baseline fleet whereas mid-size 4-door cars constituted 21.14 percent. Table 5-9 estimates the annual effect of a "one percentage point change" in the vehicle mix towards more cars and fewer of the MY 1996-99 SUVs – i.e., if MY 1996-99 vehicles had constituted the entire on-road fleet and if their vehicle mix had consisted of 7.18 percent rather than 8.18 percent mid-size SUVs and 22.14 percent rather than 21.14 percent mid-size cars.

Table 5-8 shows the actual fatality rate of mid-size 4-door SUVs was 417 prorated crash fatalities, per year, per percentage point of the on-road fleet (because they accounted for 8.18 percent of the fleet and 3,409 fatalities). Tables 5-6 and 5-7 estimated that the adjusted crash fatality rate was 31 percent lower in mid-size 4-door cars than in mid-size 4-door SUVs (9.46 vs. 13.68 prorated fatalities per billion miles). In other words, people who drove mid-size MY 1996-99 cars in CY 1996-2000 had a 31 percent lower fatal-crash rate than people of the same age and gender who drove mid-size MY 1996-99 SUVs on the same types of roads, the same number of miles per year, etc. The reduction takes into account the occupants of the case vehicles, the occupants of the other vehicles they collide with, and pedestrians, on a prorated basis, as explained in Section 5.4.

Specifically, if the fatal-crash rate of a group of mid-size 4-door SUVs comprising 1 percentage point of the on-road fleet had been reduced, by 31 percent, to the rate for mid-size 4-door cars, crash fatalities would have decreased by

$$.31 \times 417 = 129 \text{ per year}$$

TABLE 5-9: CHANGE IN FATALITIES PER YEAR GIVEN A ONE-PERCENTAGE POINT CHANGE IN THE ON-ROAD FLEET FROM MY 1996-99 SUVs AND PICKUPS TO CARS OR MINIVANS: POINT AND INTERVAL ESTIMATES

(Baseline = CY 1999 total fatalities, MY 1996-99/CY 1996-2000 fatality distribution)

			Crash Fatality Reduction for Cars/Minivans (%)			**Absolute Reduction of Fatalities Per Year**	
	Versus	Weight Red Per Veh	Point Estimate (Tbl 5-7)	Interval Estimate (Tbl 5-7)	Fatals Per Year Per Pct of Fleet (Tbl 5-8)	**Point Estimate**	**Interval Estimate**
Small 4-door SUVs	Mid-size 4-dr cars	86	10	– 24 to 21	299	**29**	**– 72 to 64**
Mid-size 4-dr SUVs	Mid-size 4-dr cars	961	31	19 to 37	417	**129**	**79 to 152**
	Large 4-door cars	426	48	34 to 53	417	**200**	**140 to 220**
	Minivans	80	42	31 to 48	417	**174**	**130 to 201**
Large 4-door SUVs	Large 4-door cars	1,545	29	8 to 38	349	**101**	**27 to 133**
	Minivans	1,199	21	5 to 32	349	**72**	**17 to 111**
Compact pickups	Mid-size 4-dr cars	278	19	– 11 to 31	532	**103**	**– 57 to 163**
Large (100-ser) pkps	Large 4-dr cars	862	26	– 13 to 39	495	**127**	**– 65 to 194**
	Minivans	516	17	– 16 to 33	495	**82**	**– 80 to 161**
Very small 4-dr cars	Small 4-dr cars	– 364	28	– 7 to 41	561	**156**	**– 40 to 231**

Since the interval estimate for the reduction of the fatality rate extended from 19 to 37 percent (taking into account sampling error and the adjustment for self-selection), the interval estimate of the absolute reduction would have ranged from .19 x 417 = 79 to .37 x 417 = 152 fatalities per year.[1]

Table 5-9 considers nine hypothetical scenarios in which the MY 1996-99 vehicle mix changed to a higher share of some type of car or minivan and a lower share of some type of pickup truck or SUV. All of the scenarios considered in Table 5-9 combine a likely reduction in fatalities (point estimates) with a reduction in vehicle weight (first column of Table 5-9). That contrasts with the overall results in Tables 3-4 and 4-4, where reductions of vehicle weight within the same vehicle type were always associated with increases in crash fatality risk. The point estimates of the fatality reductions in Table 5-9 ranged from 29 to 200 per year, per percentage point change in the vehicle mix. However, the fatality reductions in the scenarios involving small SUVs or pickup trucks of any size were not statistically significant, as evidenced by interval estimates ranging from negative to positive numbers.[2] The largest fatality reductions are estimated for the three scenarios involving mid-size SUVs, which in MY 1996-99 included some rollover-prone and aggressive make-models. Table 5-9 estimates fatality reductions of 129-200 per year, with entirely positive interval estimates.

For comparison purposes, Table 5-9 also considers one other hypothetical scenario: a percentage point change from very small 4-door cars to small 4-door cars.[3] The point estimate is a reduction of 156 fatalities per year, well within the 29-to-200 range of the point estimates of the preceding nine scenarios, but somewhat larger than the average of those nine (113).

The estimates in Table 5-9 are additive: the effect of a 2 percentage point change in the fleet mix would have been double the effect of a 1 percentage point change, both in the point and the interval estimate. The point estimate of the effect of two separate change scenarios would have been the sum of the point estimates. The interval estimates would also be nearly additive.[4]

The estimates in Table 5-9 are based on cross-sectional analyses of the actual fatality rates of MY 1996-99 vehicles. Some of the pickup trucks and SUVs in those years were rollover-prone, aggressive vehicles. A new generation of more stable, less aggressive SUVs and pickup trucks, including entirely new designs such as car-based "crossover" SUVs as well as less sweeping redesigns of existing LTVs, could have significantly lower fatality rates.

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[1] The 37 percent fatality reduction in Tables 5-6, 5-7 and 5-9 is a rounded number. When the actual, observed fatality reduction, 36.54 percent, is multiplied by 417 fatalities, the product is 152 lives saved.
[2] As explained in Section 5.6, the results for pickup trucks are subject to greater uncertainty. The State-to-State component of the sampling error is much larger because the distribution and use of pickup trucks (e.g., urban vs. rural) varies a lot from State to State.
[3] In a way, this scenario is even more "hypothetical" than the others, since very small 4-door cars constituted less than 1 percent of the MY 1996-99 vehicle fleet (see Table 5-8).
[4] Only the basic sampling error would accrue on a root-sum-square basis, and even that error would be more nearly additive if the two changes were from, or to the same vehicle type

CHAPTER 6

CAR-LIGHT TRUCK COMPATIBILITY: ANALYSES OF CRASH DATA

6.0 Summary

Fatality rates in two-vehicle collisions per billion vehicle miles traveled (VMT) for each vehicle were compared for car-to-car, SUV-to-car, pickup-to-car and minivan-to-car crashes of model years 1991-99 vehicles in calendar years 1995-2000, controlling for each vehicle's weight, each driver's age and gender, urban/rural, etc., in order to compare the relative risk of these crashes for the occupants of the struck car.

The analysis shows that light trucks and vans (LTVs) of MY 1991-99 were quite aggressive when they impacted the side of a car. The driver of a 4-door car, struck on the left side (the "near side") by another vehicle, had 1.77 times higher fatality risk if the striking vehicle was a pickup truck than if the striking vehicle was a 4-door car of the same mass as that pickup truck. The driver of the struck car had 2.35 times higher fatality risk if the striking vehicle was an SUV, and 1.30 times higher risk if it was a minivan, than when the striking vehicle was a car of the same mass as that SUV or van. LTVs were also more aggressive than cars in farside impacts and head-on collisions, although not as aggressive as in nearside impacts. These statistics are for MY 1991-99 vehicles. Risk ratios can change, depending on vehicle design. For example, since 1999, new technologies such as "blocker bars" have been introduced on some LTVs to make them less aggressive in collisions with other vehicles.

Two physical parameters that have been measured on vehicles during frontal impact tests with barriers – the average rigidity of a vehicle's front structure, and the average height of the vehicle's contact with the barrier – had statistically significant correlation with vehicle aggressiveness in crashes. In other words, the stiffer the front of the LTV, and the higher above the ground, the greater was the fatality risk to occupants of cars hit by that LTV. These are statistical findings; by themselves, they don't necessarily prove that height and rigidity in general, or the two specific test parameters in particular, were "the" explanation for LTV aggressiveness. But they are consistent with the already substantial evidence from other NHTSA research that a reduction in the rigidity and height of frontal structures of LTVs could make them less aggressive and could lower the fatality rates in the struck vehicle.

6.1 MY 1991-99 LTV aggressiveness in head-on collisions

The analyses so far in this report were based on fatality rates of various vehicles per billion miles, set on a "level playing field" by controlling for driver age/gender, urban/rural, etc., in order to find what types of vehicles were intrinsically safer than others. However, a simpler approach is possible for analyzing fatal head-on collisions. Each individual head-on collision is a sort of controlled experiment. Which of the drivers (if any) survives depends almost entirely on the relative mass, crashworthiness and aggressiveness of the two vehicles, and the relative ability of the two drivers to survive physical insult. What the two drivers were doing before the crash, how many miles they drove, or how prudently, is largely irrelevant.

Specifically, if the two vehicles are the same mass and the two drivers the same age/gender, both drivers experience essentially the same collision. Odds are the fatality will be in the less crashworthy and/or less aggressive vehicle. Given hundreds of crashes of make-model A with make-model B, both models the same weight and both drivers the same age/gender, the fatality ratio (driver fatalities in model A divided by driver fatalities in model B) quantifies the relative crashworthiness/aggressiveness of the two models. If the two models are equally crashworthy and equally aggressive, the fatality ratio will converge on 1 as sample size grows.

More generally, even if models A and B are not the same mass, and (as would usually occur in reality), the two drivers in the various crashes are not the same age, the expected fatality odds in each crash can be calibrated as a function of the relative mass of the two vehicles, and the relative age/gender of the two drivers. Given hundreds of crashes, if there are consistently fewer fatalities than expected in model A, and consistently more than expected in model B, then model A has to be more crashworthy and/or more aggressive than model B in head-on collisions.

The analysis approach was the basis for NHTSA's evaluation of the relationship between New Car Assessment Program (NCAP) scores and fatality risk in actual head-on collisions.[1] That analysis was limited to collisions between two passenger cars with belted drivers on the Fatality Analysis Reporting System (FARS). After controlling for relative vehicle mass, driver age and gender, the make-models with the superior NCAP scores consistently had fewer driver fatalities in actual head-on collisions than would have been expected, given the relative weights of the two cars, and the age/gender of the two drivers. Since the report assumed that passenger cars of the same mass were more or less equally (un)aggressive, it concluded that the cars with superior NCAP scores were more crashworthy.

Here, the analysis is extended to include head-on collisions of cars with LTVs as well as cars with cars, specifically collisions where the "case" vehicle was a car and the "other" vehicle was a car, pickup, SUV or van. After controlling for vehicle mass, driver age/gender, etc., were the odds of a driver fatality in the case car higher when the other vehicle was an LTV than when the other vehicle was a car? If they were, it means LTVs were either more aggressive or more crashworthy than cars (or possibly both) – they either increased risk in the vehicle they hit, or they were better at protecting their own occupants. Since there is little evidence that LTVs of model years 1991-99 were more crashworthy than cars in the same weight range (if anything, NCAP tests suggest the contrary), that must mean they were more aggressive than cars in frontal crashes.

The 1995-2000 FARS includes 3,453 records of head-on collisions of model year 1991-99 cars and/or LTVs with decodable VINs, in which at least one or possibly both drivers were fatally injured. A head-on collision is a two-vehicle crash, each vehicle being a car or LTV, and having

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[1] Kahane, C.J., *Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions*, NHTSA Technical Report No. DOT HS 808 061, Washington, 1994. See also Evans, L., *Traffic Safety and the Driver*, Van Nostrand Reinhold, New York, 1991, pp. 64-71.

principal impact 11, 12 or 1 o'clock. The 3,453 collisions involved 6,906 vehicles and resulted in 3,851 driver fatalities. Each collision may appear twice in the analyses, once with vehicle 1 as the "case" vehicle and vehicle 2 as the "other" vehicle, and once vice-versa.

The analyses will focus on the 3,959 cases where the case vehicle was a passenger car. They include 2,276 cases where the other vehicle was also a passenger car (actually, 1,138 collisions, but each collision appears twice in the analysis), and 1,683 cases where the other vehicle was an LTV. The analyses will calibrate the driver's fatality risk in the case vehicle. "Passenger cars" in these analyses of head-on collisions include 2-door cars and police cars. Those vehicles have been excluded in the various calibrations of fatality rates per billion miles because their drivers have high crash rates per mile. This analysis, however, measures the probability of a fatality in the case vehicle, given that a crash severe enough to kill somebody has already occurred. The behavior of the driver prior to the crash is largely irrelevant, and in this case, 2-door and 4-door cars are largely interchangeable, since their performance in frontal crashes is similar.[2]

"Curb weight" throughout Sections 6.1-6.5 has been adjusted by the procedure discussed in Section 2.1, and it is directly comparable for cars and LTVs. The "nominal" weights listed in Appendices A and B have been inflated by the percentages (averaged by manufacturer and vehicle type) whereby actual curb weights measured before NHTSA crash and compliance tests exceeded the nominal weights.

Curb weight, however, is measured for empty vehicles. In actual crashes, vehicles carry the additional weight of a driver and, possibly, passengers and/or cargo. That extra weight provides a momentum-conserving advantage in a head-on collision with another vehicle. If, for example, pickup trucks typically carried a lot of cargo, that extra weight, rather than intrinsically aggressive vehicle design, might explain why the fatality is less often than expected in the truck. The National Automotive Sampling System (NASS) reports the number of occupants and weight of cargo in each crash-involved vehicle. If the average weight of an occupant is estimated to be 150 pounds, NASS data for MY 1991-99 vehicles in CY 1993-2001 show that the actual, loaded weight of vehicles was very close to 108 percent of the curb weight for all types of vehicles except full-sized vans. If the 69 collisions of cars with full-sized vans are excluded from the analyses, the ratio of loaded weight to curb weight was essentially the same across vehicle types:

	Curb Wt	Occupant Wt	Cargo Wt	Loaded Wt	Loaded Wt / Curb Wt
2-door cars	2,664	229	6	2,899	1.09
4-door cars	2,863	238	7	3,108	1.09
Police cars	3,860	191	155	4,206	1.09
Pickup trucks	3,603	206	99	3,908	1.08
SUVs	3,814	242	22	4,078	1.07
Minivans	3,687	307	29	4,023	1.09
Full-sized vans	4,559	299	281	5,139	1.13

[2] Kahane (1994 NCAP), pp. 35-51.

The calibration of a model is initially based on the 2,276 cases of cars hit head-on by other cars. Each case vehicle furnishes one data point to the logistic regression. The dependent variable, FATAL equals 1 if the driver of the case vehicle was a fatality, equals 2 if the driver survived. Six independent variables are measured for the case vehicle relative to the other vehicle:

D_CURBWT = log(case car's curb weight) – log(other car's curb weight) (Throughout this study, "log" or "logarithm" means the natural logarithm.)

D_AGE = case car driver's age – other car driver's age

D_SEX = 0 if both drivers were the same gender, 1 if the case driver was female and the other driver was male, -1 if the case driver was male and the other driver was female

D_BELT = C_BELT – O_BELT; where C_BELT = 1 if the case driver was belted, C_BELT = 0 if the case driver was unbelted, and C_BELT = .65 if the case driver's belt use is unknown, 65 percent being the average belt use in 1995-2000; O_BELT is similarly defined for the other driver

D_BAG = C_BAG – O_BAG; where C_BAG =1 if the case vehicle was equipped with a driver air bag, C_BAG = 0 if not equipped; O_BAG is similarly defined for the other vehicle

D_1100 = 0 if both vehicles, or neither vehicle had 11:00 principal impact; 1 if the case vehicle had 11:00 impact and the other vehicle did not; -1 if the other vehicle had 11:00 impact and the case vehicle did not (Since an 11:00 impact is concentrated on the driver's side, it increases fatality risk for the driver).

Using the LOGIST procedure in SAS, a disaggregate logistic regression analysis, calibrating the log-odds of a case-vehicle driver fatality as a linear function of the independent variables, generates the following coefficients:

ALL CAR-TO-CAR HEAD-ON COLLISIONS (N = 2,276)

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.510	79.0	.0001
D_CURBWT	- 5.139	316.5	.0001
D_AGE	.0489	360.7	.0001
D_SEX	.161	3.80	.051
D_BELT	- 1.399	165.6	.0001
D_BAG	- .706	54.7	.0001
D_1100	.695	23.9	.0001

In other words, the heavier the case car, or the lighter the other car, the lower the fatality risk for the driver of the case car. A 1 percent increase in the case car's weight relative to the other car reduces the case driver's fatality risk by 5.14 percent (since D_CURBWT is the logarithm of the weight ratio, the coefficient measures the "elasticity" of fatality risk to the weight ratio). The older the driver of the case car, the higher the fatality risk. At the same time, the younger the driver of the other car, the higher the fatality risk for the driver of the case car: because this analysis is limited to crashes where at least one of the drivers died, anything that helps the driver of the other car survive (e.g., being younger), by default implies that the driver of the case car must have died. A 1-year increase in the case driver's age, relative to the other driver's age, increases the case driver's fatality risk by about 4.89 percent. Male drivers are about 16 percent less likely to die than female drivers, given the same physical insult (not a statistically significant difference, $p = .051$). Safety belts and air bags both greatly reduce fatality risk in head-on collisions (and the calibrated effectiveness of safety belts is somewhat exaggerated because belt use of survivors is not always accurately reported in FARS[3]). As above, belt use or air bags in the other car imply higher fatality risk in the case car, since the data are limited to crashes where at least one driver died. An 11:00 impact significantly increases fatality risk.

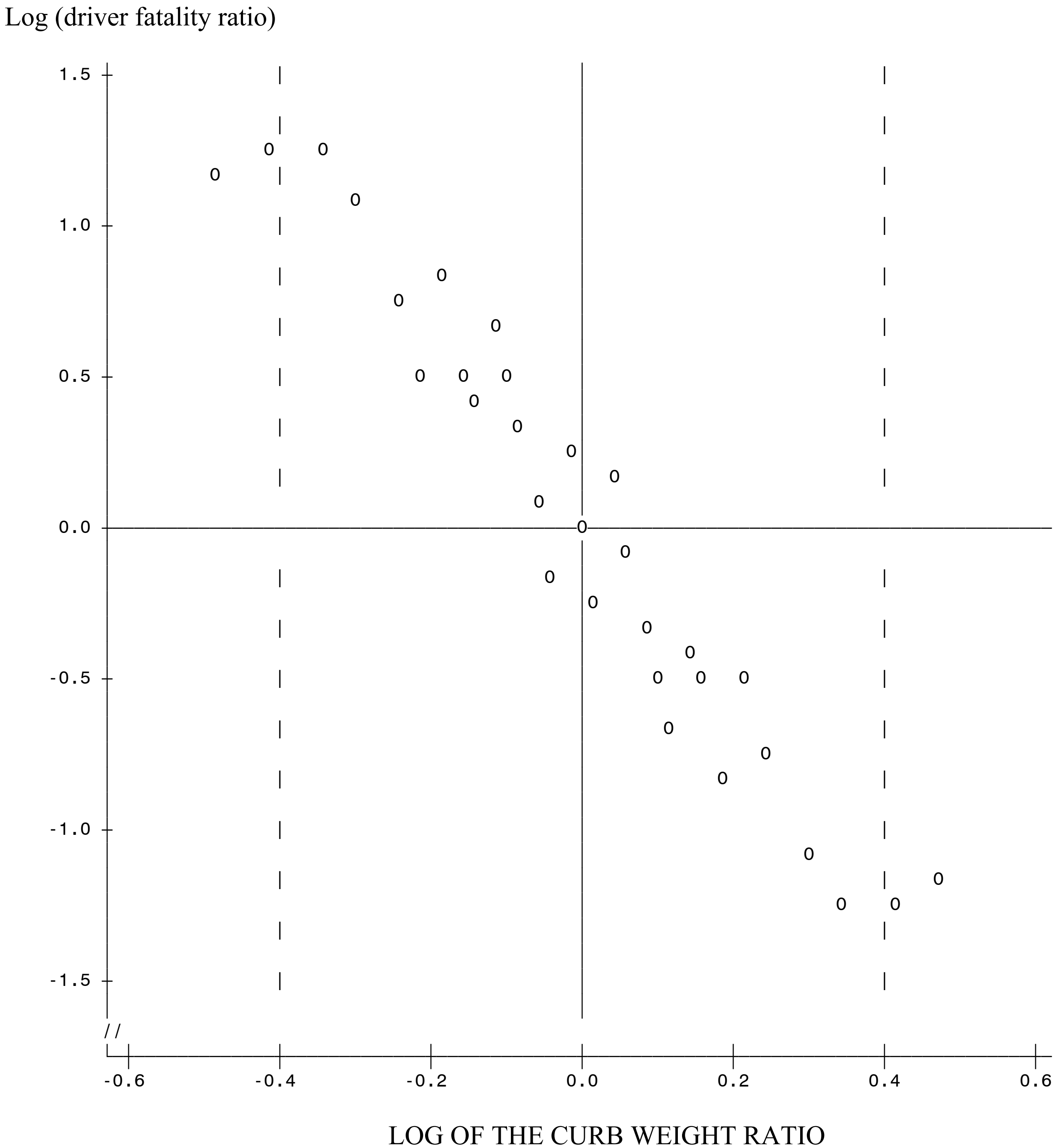
Figure 6-1 graphs the actual log ratio of fatalities in the case vehicle to the other vehicle for various class intervals of D_CURBWT, the log of the curb weight ratio. Since each crash contributes two cases, one with V1 as the case vehicle and the other V2, the graph is forced to pass through the origin and its upper-left and lower-right sectors are mirror images. However, the graph shows an extremely good linear fit between the two parameters when $-.4 <$ D_CURBWT $< +.4$, i.e., when the heavier car weighs at most 50 percent more than the lighter car. In other words, there is a predictable relationship between the number of fatalities that may be expected in the lighter vs. the heavier cars. When the weight mismatch is more than 50 percent (which doesn't happen often when both vehicles are cars), the linear relationship breaks down, because the fatality is almost always in the lighter car, except for unusual events (e.g., post-crash rollover with ejection) that kill somebody in the heavier car. Another regression with a quadratic term D_CURBWT^2 does not obtain a statistically significant coefficient for that term, and confirms the linearity of the relationship. Similarly, a regression with a quadratic term D_AGE^2 does not obtain a statistically significant coefficient for that term, and confirms the linearity of the relationship between relative driver age and relative log-odds of fatality risk.

The preliminary regression suggests the analysis should be limited to crashes where the two vehicles were not severely mismatched in weight: $-.4 <$ D_CURBWT $< +.4$. The regression for the 2,034 case vehicles (a subset of the 2,276 cases in the preceding regression) with $-.4 <$ D_CURBWT $< +.4$, resulting in 1,167 fatalities to the drivers of the case vehicles (and, by symmetry, 1,167 fatalities to the drivers of the other vehicles) produces coefficients:

[3] Kahane, C.J., *Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 809 199, Washington, 2000, pp. 10-22.

FIGURE 6-1

LOG OF THE DRIVER FATALITY RATIO BY LOG OF THE CURB WEIGHT RATIO*
IN HEAD-ON COLLISIONS OF TWO MY 1991-99 PASSENGER CARS, CY 1995-2000



* Throughout this study, “log” means the natural logarithm.

CAR-TO-CAR HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4 (N = 2,034)
FATALITY RISK FOR THE CASE DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.515	71.9	.0001
D_CURBWT	- 5.585	256.2	.0001
D_AGE	.0486	334.9	.0001
D_SEX	.174	4.05	.044
D_BELT	- 1.377	149.7	.0001
D_BAG	- .677	47.2	.0001
D_1100	.693	22.3	.0001

Removing the cases with extreme weight mismatch strengthens the D_CURBWT term (to –5.59 from –5.14) and also brings the term for male vs. female up to statistical significance (p = .044). Symmetrically, the fatality risk for the "other" driver is:

CAR-TO-CAR HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4 (N = 2,034)
FATALITY RISK FOR THE OTHER DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	+ .515	71.9	.0001
D_CURBWT	+ 5.585	256.2	.0001
D_AGE	- .0486	334.9	.0001
D_SEX	- .174	4.05	.044
D_BELT	+ 1.377	149.7	.0001
D_BAG	+ .677	47.2	.0001
D_1100	- .693	22.3	.0001

In other words, when two cars hit head-on and at least one, or possibly both drivers died, if the two cars were the same weight/air bag equipment, and both drivers had the same age/gender/belt use, and both/neither vehicles had an 11:00 impact, then both drivers can be expected to have equal fatality risk, and that risk is exp(.5153)/[1+exp(.5153)] = 63 percent. Out of 100 FARS cases, we can expect 37 would be fatal to the case driver only, 37 to the other driver only, and 26 to both drivers, for a total of 126 fatalities. However, if the two vehicles had different weight, or the drivers were of different ages, etc., let

Z = 5.585 D_CURBWT - .0486 D_AGE -.174 D_SEX + 1.377 D_BELT + .677 D_BAG - .693 D_1100

The expected fatality risk for the case vehicle's driver is

C_EFAT = exp (.515 + Z) / [1 + exp(.515 + Z)]

The expected fatality risk for the other vehicle's driver is

O_EFAT = exp (.515 – Z) / [1 + exp(.515 – Z)]

C_EFAT and O_EFAT are probabilities between 0 and 1 – i.e., the regression model does not predict "this driver is dead and that one is alive" as in the actual cases, but rather gives a probability of each driver's death. Over the 2,034 cases used in the regression, these probabilities C_EFAT and O_EFAT both add up to 1,167, the actual numbers of fatalities in the case and other vehicles. In other words, on the calibration data set, the regression model correctly predicts the total number of driver fatalities in the case vehicles and in the other vehicles.

Now consider another data set consisting of 773 head-on collisions where the case vehicle was a car and the other vehicle was a pickup truck or SUV, and -.4 < D_CURBWT < +.4 – i.e., excluding cases with extreme weight mismatches, where the strong log-linear relationship of relative curb weight and relative fatality risk breaks down. This is not a symmetric data set: each collision appears only once, always with the car as the case vehicle and the LTV as the other vehicle. Although the cases with extreme weight mismatch have been removed, the LTVs in this data set were still, on the average, considerably heavier than the cars. Furthermore, the LTV drivers were, on the average, better able to survive physical insults, because they were slightly younger and more of them were males. The only advantages for the car drivers were slightly higher belt use and a slightly higher proportion of MY 1991-99 vehicles equipped with air bags. Even if pickup trucks and SUVs were as unaggressive as cars, nobody would expect the same number of fatalities in the LTVs as in the cars.

The above regression formulas predict the numbers of fatalities expected in the cars and in the LTVs under the assumption that LTVs were as unaggressive as cars: that getting hit by an LTV is no different from getting hit by a car of the same mass as that LTV. For these 773 cases, C_EFAT adds up to 567.87 and O_EFAT adds up to 370.74. In other words, the expected fatality ratio is 567.87/370.74 = 1.53.

However, the actual number of driver fatalities in the cars was 608, even greater than the expected 567.87. The actual number of fatalities in the pickups and SUVs was 252, less than the expected 310.74. The actual fatality ratio was 608/252 = 2.41. The actual proportion of driver fatalities that is in the cars, p = 608/(608+252) = .7070 was significantly higher than the expected proportion P = 567.67/(567.67+310.74) = .6436: with N = 860, the sample standard deviation for P is .0163, and Z = (.7070-.6436)/.0163 = 3.89. It was significantly worse to be frontally impacted by a MY 1991-99 pickup truck or SUV than by a MY 1991-99 passenger car of the same mass as that pickup or SUV.

Unlike NHTSA's evaluation of NCAP[4], this analysis will not provide a single point estimate of how much worse it was to be hit by an LTV, only a range of possible values. The upper bound for the range is obtained by the method in the NCAP evaluation. The fatalities in the other vehicle (the pickup or SUV) are treated as a perfect control group, and the actual vs. expected fatalities in the cars are measured relative to the LTVs:

$$[(608/252) / (567.87/310.74)] – 1 = 32 \text{ percent}$$

In logarithmic terms, the increase was log(1.32) = .278. This method is appropriate for NCAP, because improving the NCAP scores in the case vehicle should not, in absolute terms, have any effect whatsoever on fatality risk in the other vehicle. In that evaluation, fatalities in the other vehicle were a perfect control group, and the actual vs. expected fatalities in the case vehicle were appropriately measured relative to the actual vs. expected in the other vehicle. But in this study it exaggerates the effect: increasing the aggressiveness of the other vehicle not only increases fatalities in the case vehicle but may also have a protective effect for occupants of the other vehicle (more damage to the car = less damage to the truck). The above formula may be partially double-counting, but it is unknown to what extent.

The lower bound for the range is obtained by comparing the actual to the expected fatalities in the case vehicle alone:

$$(608 / 567.87) – 1 = 7 \text{ percent}$$

In logarithmic terms, the increase was log(1.07) = .068.

Figures 6-2 and 6-3 show how consistently the risk of getting hit by a pickup truck or SUV was worse than getting hit by a car. Figure 6-2 graphs the actual log ratio of driver fatalities in the case vehicle to the other vehicle for various class intervals of D_CURBWT. The points labeled "C" on the graph are for the car-to-car collisions and they repeat some of the information in Figure 6-1. The points labeled "T" are for collisions where the case vehicle was a car and the other vehicle was a pickup truck or SUV. The T's were higher than the C's for 8 out of 9 class intervals of D_CURBWT (and T was just below the C on the 9th). Although there is some fluctuation due to limited N's, the C's basically fit a diagonal line through the origin. The T's fit a diagonal line more or less parallel to the C's, but higher. In other words, at all weight ratios ranging from equality to fairly sizable mismatches, it was worse to get hit by a truck than by a car.

Figure 6-3 graphs the difference between the actual fatality ratio and log(C_EFAT/O_EFAT), the expected fatality ratio calibrated from the car-to-car collisions. The points labeled C average close to zero; 4 are positive, 5 negative, and 1 exactly zero (by design), with no obvious trend. By contrast, all 10 T's were positive, indicating higher-than-expected fatality risk for the driver of the car when the other vehicle was a truck, at every level of weight mismatch up to D_CURBWT = .4.

[4] Kahane (1994 NCAP), pp. 64-66.

FIGURE 6-2

LOG OF THE DRIVER FATALITY RATIO BY LOG OF THE CURB WEIGHT RATIO IN HEAD-ON COLLISIONS OF TWO MY 1991-99 VEHICLES, CY 1995-2000

"T" = OTHER VEHICLE WAS PICKUP TRUCK OR SUV, CASE VEHICLE WAS CAR
"C" = BOTH VEHICLES WERE CARS

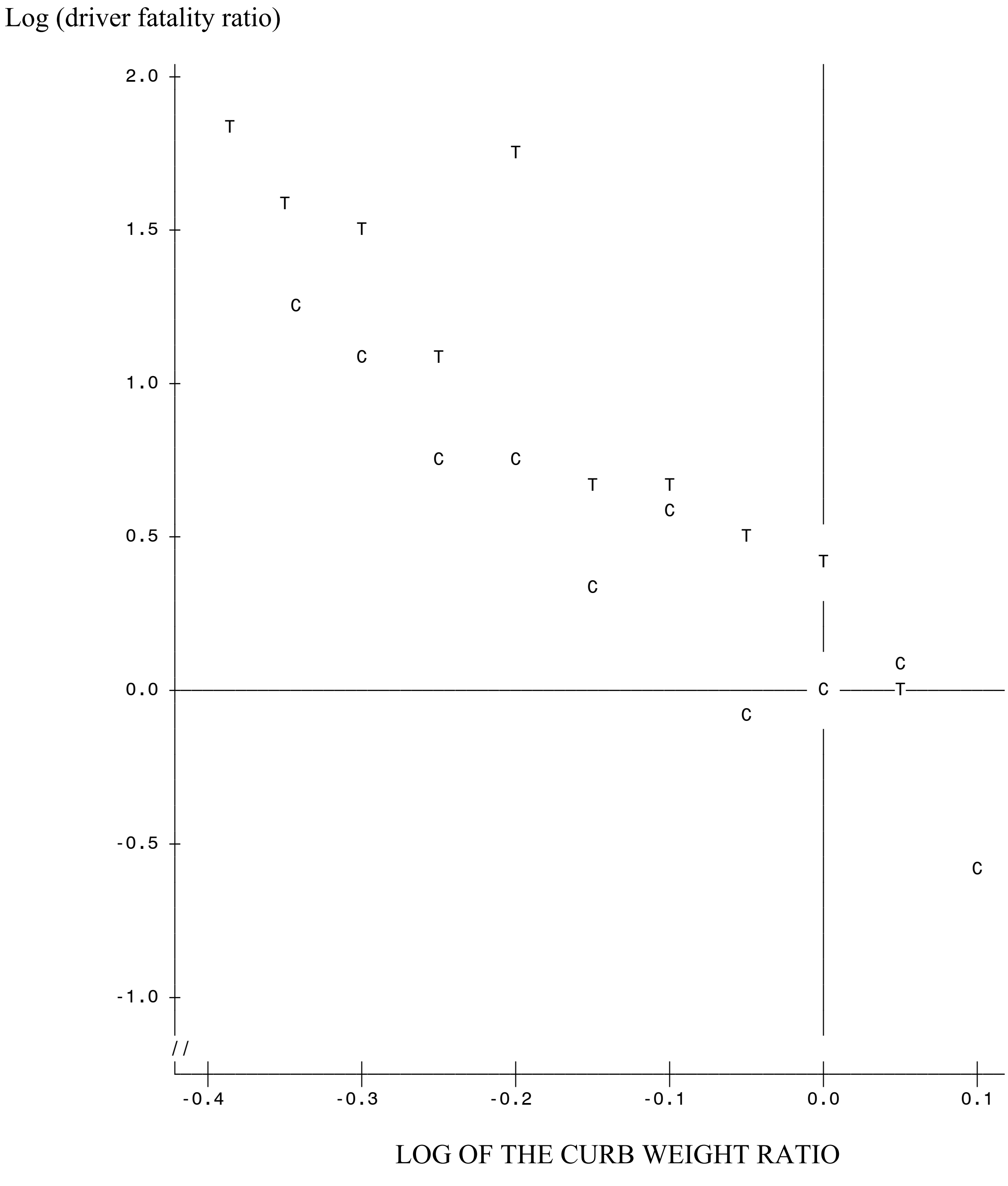
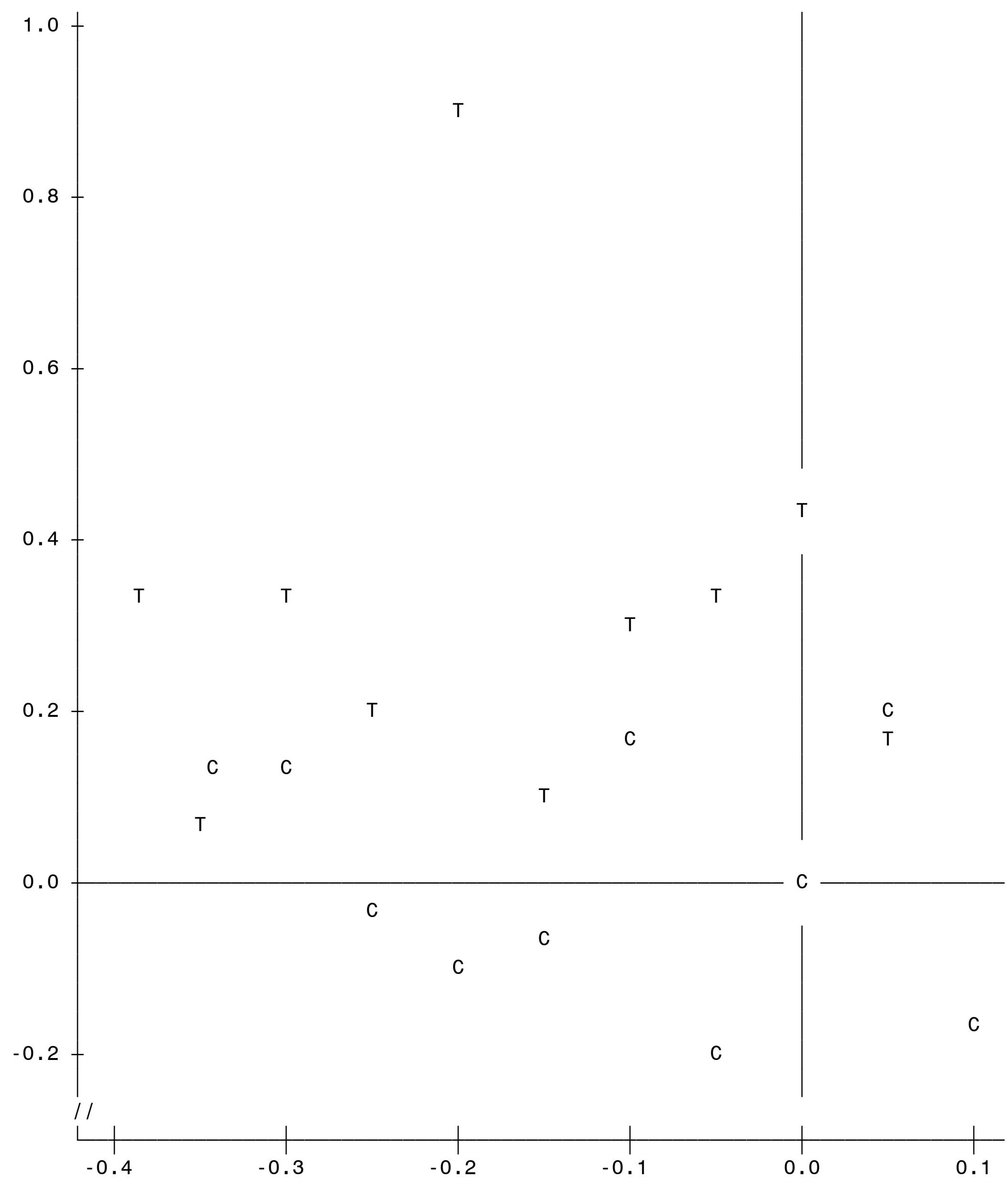


FIGURE 6-3

ACTUAL MINUS EXPECTED LOG DRIVER FATALITY RATIO
IN HEAD-ON COLLISIONS OF TWO MY 1991-99 VEHICLES, CY 1995-2000

"T" = OTHER VEHICLE WAS PICKUP TRUCK OR SUV, CASE VEHICLE WAS CAR
"C" = BOTH VEHICLES WERE CARS

Actual minus expected log (driver fatality ratio)



LOG OF THE CURB WEIGHT RATIO

The preceding analysis combined pickup trucks and SUVs and found them more aggressive than cars. Computations may be performed separately for pickup trucks and SUVs, and also for minivans, although data are limited. Here are the results for the individual truck types, as well as for pickups and SUVs, combined:

Collisions of Cars with:	N of Crashes	Risk Increase (%) Rel. to Car-Car	Statistical Significance?
Pickups & SUVs	773	7 to 32	Yes (Z = 3.89)
Pickup trucks	526	10 to 37	Yes (Z = 3.58)
SUVs	247	2 to 21	No (Z = 1.36)
Minivans	176	– 16 to – 6	No (Z = 1.16)

The results for pickup trucks and SUVs are fairly consistent, given the small N of SUVs. The fatality risk for the driver of the car was actually lower than expected when the other vehicle is a minivan, but not significantly lower; there is no evidence here that minivans were more aggressive than cars in head-on collisions.

As an alternative to the preceding analyses, it might be desirable to calibrate fatality risk in car-to-car collisions without the D_BELT parameter, since belt use may be inaccurately reported for survivors in FARS, and because belt use is almost uncorrelated with car weight (see Table 3-2).[5] When the expected fatality probabilities in car-LTV collisions are computed with these regression coefficients, the estimated extra aggressiveness of LTVs becomes:

[5] The regression without D_BELT produces coefficients:

CAR-TO-CAR HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4 (without D_BELT)

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.463	65.6	.0001
D_CURBWT	- 5.355	266.0	.0001
D_AGE	.0437	324.6	.0001
D_SEX	- .013	0.03	.87
D_BAG	- .681	53.3	.0001
D_1100	.686	23.3	.0001

The D_AGE and D_SEX coefficients are weaker than in the calibration with D_BELT because belt use was somewhat higher for older drivers and females, partly compensating for their higher vulnerability to injury.

Collisions of Cars with:	N of Crashes	Risk Increase (%) Rel. to Car-Car	Statistical Significance?
Pickups & SUVs	773	6 to 28	Yes (Z = 3.25)
Pickup trucks	526	7 to 29	Yes (Z = 2.84)
SUVs	247	3 to 26	Yes[6] (Z = 1.65)
Minivans	176	– 21 to – 8	No (Z = 1.58)

The results are almost the same as in the preceding analyses, but the extra aggressiveness of pickup trucks was a bit lower: pickup trucks had somewhat lower belt use than cars during the 1990's.[7] This new model, by not controlling for D_BELT, implicitly assumes pickup trucks had the same high belt use as cars, underestimates the expected fatalities in the pickup trucks, consequently overestimates the expected fatalities in the cars, and finally understates the ratio of actual to expected fatalities. In SUVs and minivans, where belt use was even slightly higher than in cars, the change was in the opposite direction. But in either case, the change is small compared to the uncertainty in the results.

6.2 Frontal rigidity and height-of-force in head-on collisions

NHTSA's research program on the compatibility of cars and LTVs focuses on three physical factors that to date have made LTVs more aggressive than passenger cars: greater mass, a more rigid frontal structure, and a front end that's higher off the ground.[8]

The preceding analyses show that the relative mass of two vehicles of course has extremely strong correlation with the relative fatality risk of their drivers in head-on collisions. Even after controlling for any difference in mass, however, MY 1991-99 LTVs were more aggressive than cars, resulting in a higher fatality risk for the car driver in a car-LTV collision than would have been expected based on relative mass, driver age, etc. alone. The next steps are to look for correlations between the car driver's fatality risk and the LTV's rigidity or height, and to find out to what extent, statistically, those factors explained the extra aggressiveness of the LTVs.

First, the concepts of "frontal rigidity" and "frontal height" must be translated into specific parameters that can be reliably measured on vehicles. NHTSA's compatibility research group has measured two parameters (among others) on frontal NCAP tests of cars and LTVs since 1982:

SLOPE, the average slope of the force-deflection profile measured in frontal NCAP barrier testing. Load cells in the barrier measure the force and accelerometers mounted in the occupant compartment measure the deflection. The force-deflection profile must fit a

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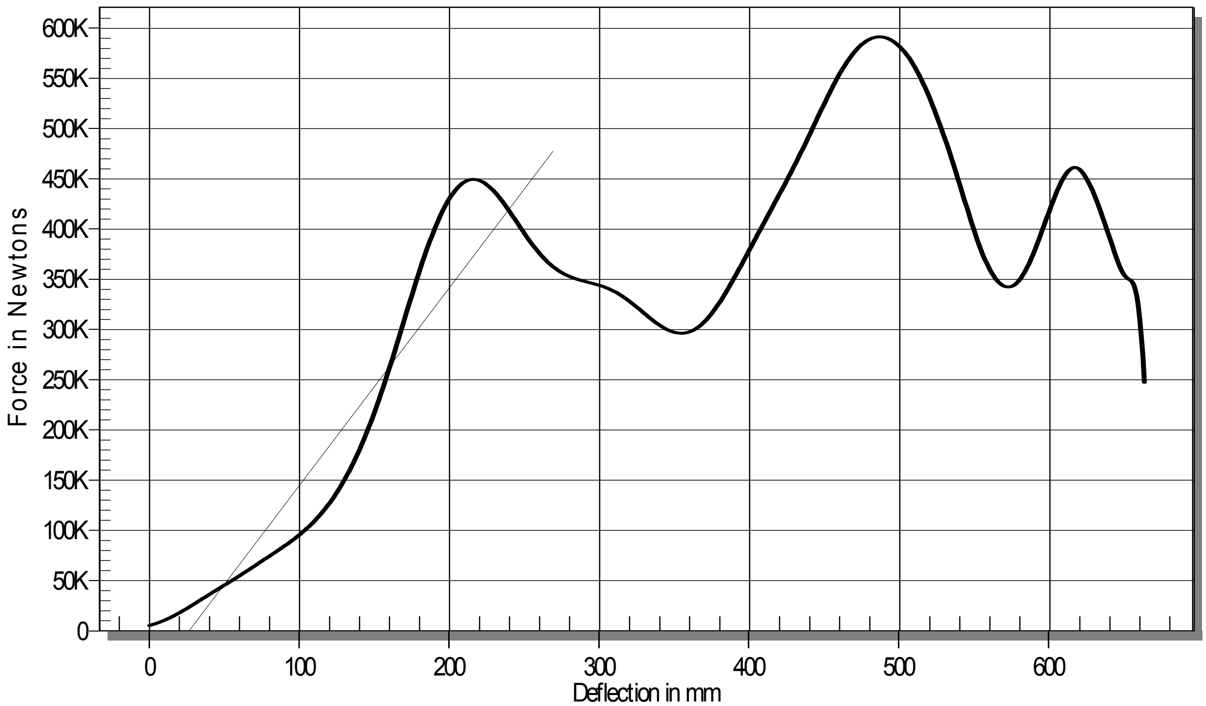
[6] At the one-sided .05 level.
[7] Kahane (2000), p. 54.
[8] Summers, S., Prasad, A., and Hollowell, W.T., *NHTSA's Compatibility Research Program Update*, Paper No. 01B-257, Society of Automotive Engineers, Warrendale, PA, 2000.

straight line with an r-squared greater than 0.95, extending for a minimum of 150 millimeters, and beginning within the first 200 mm of deflection. The slope for the longest region of crush meeting these criteria was selected for the SLOPE variable.[9] SLOPE ranged from 450 to 3,364 Newtons per millimeter in model year 1991-99 cars and LTVs. SLOPE averaged about 1,100 in cars, 1,800 in minivans, and 2,350 in pickup trucks and SUVs. Here is a sample SLOPE calculation:



The solid curve shows force, in thousands of Newtons, as a function of deflection, in millimeters, as the front of this vehicle is crushed in an NCAP barrier impact. The dotted line extending from approximately 30 to 270 millimeters fits the curve, in that region, with R-squared = .95, and it is the longest line that can be drawn, starting in the first 200 millimeters, with R-squared .95 or greater. The SLOPE of this dotted line is 1968.8 Newtons per millimeter, typical for LTVs

AHOF, the average height-of-force is also measured by load cells set at various height levels in the NCAP barrier. It is the weighted average of the effective height of the applied force on the barrier face over the duration of the impact. AHOF ranged from 363 to 633 millimeters, averaging about 460 in MY 1991-99 cars, 500 in minivans and 550 in pickup trucks and SUVs.

[9] The crush region used to measure SLOPE ranged from 150 to 777 millimeters in the NCAP tests, averaging 398 millimeters, with a standard deviation of 154.

SLOPE and AHOF are measured only on the specific make-model-MY-body style combinations tested by NCAP. Nevertheless, the test results indicate that SLOPE and, especially, AHOF are highly repeatable measurements that tend to be almost the same for all the vehicles of the same general design, including “corporate cousins” in the same car or LTV group as defined in Section 2.1 (e.g., Ford Crown Victoria and Mercury Grand Marquis); vehicles of previous and subsequent model years, as long as no major redesign has intervened; vehicles of the same make-model but different body styles (2-door, 4-door); even vehicles built on the same body platform that are not exactly “corporate cousins” (e.g., 1990’s Buick LeSabre and Buick Park Avenue); and even vehicles built on different chassis, if one is basically a "stretch" version of the other (e.g., Ford Ranger conventional-cab and extended-cab). However, the AHOF measurement for a 4x4 test vehicle cannot be assumed to hold for its 4x2 counterpart, or vice versa, because the frontal heights are often different (e.g., due to oversized tires or a raised suspension in the 4x4 vehicle).

With these extensions, an NCAP match could be found for nearly 81 percent of the 6,906 MY 1991-99 vehicles involved in 3,453 head-on collisions with one another. In 2,253 of these collisions, both vehicles had an NCAP match – i.e., SLOPE and AHOF information. A file was created, comprising 4,506 case vehicles involved in head-on collisions fatal to one or both drivers, with known SLOPE and AHOF for both vehicles.

The first analysis question is whether relative SLOPE or AHOF had any correlation with relative fatality risk in head-on collisions. This is tested by performing regression analyses with the previously defined variables D_CURBWT, D_AGE, etc., plus two new variables. Let

DL_SLOPE = log(case vehicle’s SLOPE) – log(other vehicle’s SLOPE)

D_AHOF = case vehicle’s AHOF – other vehicle’s AHOF

In other words, the stiffer and higher the case vehicle, the more positive DL_SLOPE and D_AHOF. They are defined in the same way as D_CURBWT and, if their effects are in the expected direction (stiffer and higher = less fatality risk), they should have negative coefficients, as does D_CURBWT. The logarithmic transformation of SLOPE, similar to the transformation of mass in D_CURBWT, makes the variable less skewed to the right and more uniformly distributed. The transformation is not needed for AHOF, since it is already uniformly distributed over a fairly narrow range.

The first regression focuses on 620 collisions in which the case vehicle was a car, the other vehicle was any LTV (pickup, SUV or van), $-.4 < D\_CURBWT < +.4$, and both vehicles had known SLOPE and AHOF.

CAR-TO-LTV HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4 (N = 620)
FATALITY RISK FOR THE CAR DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.329	1.83	.18
D_CURBWT	- 6.146	53.3	.0001
DL_SLOPE	- .459	3.36	.067
D_AHOF	- .00046	.05	.82
D_AGE	.0497	78.7	.0001
D_SEX	- .011	.00	.95
D_BELT	- 1.280	40.2	.0001
D_BAG	- .360	3.28	.070
D_1100	.116	.17	.68

The effect for DL_SLOPE is in the expected direction and statistically significant at the one-sided .05 level (because Chi-square exceeds $2.71 = 1.645^2$): the softer the car and/or the stiffer the truck, the higher the fatality risk for the car driver relative to the truck driver. Statistical significance at the one-sided .05 level is "good enough" for these analyses of head-on collisions, since potential biases from non-crashworthiness factors have generally been eliminated.[10]

The results are especially strong because the case vehicle was always a car and the other vehicle was always an LTV. The analysis accepts as a given that MY 1991-99 LTVs were more aggressive than cars; the coefficient for DL_SLOPE says in particular that the more rigid LTVs were even more aggressive than the less rigid LTVs. If the analysis had included both cars and LTVs among the "other" vehicles, the coefficient would, to some extent, just say that LTVs were more aggressive than cars; any physical parameter that distinguishes between LTVs and cars, even an intuitively unrelated parameter, might have been significant in that weaker analysis.

A very rigid frontal structure in the LTV may increase risk to the car driver because: (1) In an extremely severe head-on collision, there would be more compartment intrusion in the car, and less in the LTV; (2) In a head-on collision with substantial offset, where damage spills over to the side of the car, the more rigid the LTV, the greater the damage to the side of the car. However, in a more typical head-on collision without substantial compartment intrusion or side damage, the relative rigidity of the two vehicles is probably not so important, and that explains why the aggressiveness of LTVs was substantially less in head-on collisions than in front-to-side impacts (see Section 6.4).

The effect for D_AHOF was not statistically significant. Apparently, height mismatch was unimportant in head-on collisions between cars and LTVs (unlike, say, cars and heavy trailers without rear impact guards), because the mismatch was never extreme, and eventually the two front structures engaged.

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[10] Chi-square values are generally lower than in the regressions of Section 6.1 because the N of cases is about one-fourth as large.

Variations in the setup of the regression model produced the following results:

- A regression without D_AHOF calibrated virtually the same coefficient for DL_SLOPE (-.457) as in the above, baseline regression (-.459).

- A regression without DL_SLOPE still showed little or no effect for D_AHOF (-.00028).

- A regression with neither DL_SLOPE nor D_AHOF calibrated about the same coefficients for the other variables as the baseline regression. In other words, the effect of DL_SLOPE was nearly orthogonal to the other effects, and D_AHOF had little effect at all.

- If DL_SLOPE is split into two variables, CAR_L_SLOPE (log of the car's SLOPE) and TRK_L_SLOPE, both got nearly the same coefficient, in the expected direction, as DL_SLOPE (-.470 for CAR_L_SLOPE, +.445 for TRK_L_SLOPE), but the separate coefficients were not statistically significant.

- Without the logarithmic transformation, D_SLOPE used in place of DL_SLOPE was not statistically significant (Chi-square = 1.25).

- When the "other" vehicles were limited to just pickup trucks and SUVs, excluding vans, the coefficient for DL_SLOPE strengthened to -.5450. Due to the decreased N, Chi-square dropped to 3.08, but was still significant at the one-sided .05 level.

The additional analyses confirm that DL_SLOPE was associated with the fatality risk of the car driver, but suggest it was a somewhat delicate parameter. It needed to be rescaled by the logarithmic transformation before it achieved statistical significance.

The purpose of DL_SLOPE and D_AHOF is to study LTV aggressiveness in LTV-to-car collisions, not to study car-to-car head-on collisions, where aggressiveness is intuitively not much of an issue. Nevertheless, an explanation is needed because DL_SLOPE has a sign in the unexpected direction (significant at the one-sided .05 level) in a regression of car-to-car collisions, based on 1,812 cases (906 crashes) where -.4 < D_CURBWT < +.4, and both cars have known SLOPE and AHOF:

CAR-TO-CAR HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4 (N = 1,812)
FATALITY RISK FOR THE CASE CAR DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.512	63.9	.0001
D_CURBWT	- 5.357	187.9	.0001
DL_SLOPE	+ .245	2.82	.093
D_AHOF	- .00029	.05	.82
D_AGE	.0495	310.7	.0001
D_SEX	.230	6.32	.012
D_BELT	- 1.336	129.1	.0001
D_BAG	- .659	39.7	.0001
D_1100	.683	19.6	.0001

This says the more rigid car had higher fatality risk, statistically significant at the one-sided .05 level. It is not a regression that went awry from excessive correlation of the independent variables: another regression without DL_SLOPE produced nearly identical coefficients for the other variables. Rather, it demonstrates that SLOPE is a more complicated parameter whose intuitive meaning varies with context. In car-to-LTV collisions, where LTV aggressiveness can often be a risk-increasing factor, SLOPE conveys information about the truck's aggressiveness and the car's vulnerability, and had significant negative correlation with relative risk. But aggressiveness or extreme intrusion is probably not an important factor in most car-to-car head-on collisions where the cars have fairly comparable weights (-.4 < D_CURBWT < +.4). Instead, SLOPE primarily conveys information about the car's force-deflection characteristics: a lower SLOPE may indicate more gradual deceleration, better cushioning of the occupant, and greater crashworthiness. The correlation of SLOPE with relative fatality risk can be positive.

Thus, the answer to the first analysis question is that relative log(SLOPE) was correlated with relative fatality risk in head-on collisions, but relative AHOF was not. The second analysis goal is to find out to what extent, statistically, log(SLOPE) explained the extra aggressiveness of pickup trucks and SUVs. This is tested by performing two regression analyses on a set of 2,282 head-on collision cases (1,376 separate crashes) where the case vehicle was always a car, the other vehicle was either a car, pickup truck or SUV, and -.4 < D_CURBWT < +.4. Vans are excluded because the preceding analyses did not show them to be more aggressive than cars.

The first, baseline regression does not include any parameters based on SLOPE or AHOF, only the usual variables D_CURBWT, D_AGE, etc., plus a new variable, O_PKPSUV = 1 if the other vehicle was a pickup truck or SUV, = 0 if it was a car:

BASELINE REGRESSION (N = 2,282)

HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4
CASE VEHICLE WAS CAR, OTHER VEHICLE WAS CAR, PICKUP OR SUV
FATALITY RISK FOR THE CASE CAR DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.509	64.2	.0001
D_CURBWT	- 5.449	267.4	.0001
D_AGE	.0489	367.8	.0001
D_SEX	.194	5.32	.021
D_BELT	- 1.356	165.4	.0001
D_BAG	- .604	40.8	.0001
D_1100	.550	15.7	.0001
O_PKPSUV	.453	7.7	.0054

The baseline regression assigned a coefficient of .453 to O_PKPSUV, statistically significant at the .01 level. Controlling for vehicle mass, driver age/gender, etc., but not controlling for SLOPE, fatality risk in the case car was significantly higher when the other vehicle was a pickup truck or SUV than when it was a car. The coefficients for the other variables are quite similar to the baseline car-to-car regression in Section 6.1.

It was shown above that SLOPE had different relationships with fatality risk in car-to-LTV and car-to-car collisions. Since this is the first data set to include both cars and LTVs as "other" vehicles, it is appropriate to define two new variables:

CT_DL_SLOPE = DL_SLOPE if the other vehicle was a truck, = 0 if the other vehicle was a car

CC_DL_SLOPE = DL_SLOPE if the other vehicle was a car, = 0 if the other vehicle was a truck

A regression on the same data set including all the preceding variables plus CT_DL_SLOPE, but not CC_DL_SLOPE, reduced the O_PKPSUV coefficient to a nonsignificant level:

REGRESSION WITH CT_DL_SLOPE (N = 2,282)

HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4
CASE VEHICLE WAS CAR, OTHER VEHICLE WAS CAR, PICKUP OR SUV
FATALITY RISK FOR THE CASE CAR DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.510	64.4	.0001
D_CURBWT	- 5.491	268.7	.0001
CT_DL_SLOPE	- .510	2.97	.085
D_AGE	.0490	368.5	.0001
D_SEX	.194	5.33	.021
D_BELT	- 1.355	165.2	.0001
D_BAG	- .614	41.9	.0001
D_1100	.548	15.6	.0001
O_PKPSUV	.079	.09	.77

The reduction of the O_PKPSUV coefficient from a significant .453 to a nonsignificant .079 suggests that CT_DL_SLOPE "explained" almost all the extra aggressiveness of pickup trucks and SUVs. Taken literally, it says that if MY 1991-99 pickup trucks and SUVs had had frontal structures as soft as cars', they would not have significantly increased, in head-on collisions, the relative fatality risk of the car driver above the risk from a collision with a car of the same mass as that pickup or SUV. The coefficient for CT_DL_SLOPE (-.510), and its Chi-square (2.97) are about the same as the coefficient for DL_SLOPE (-.545, with Chi-square 3.08) in the regression limited to crashes where the case vehicle was a car and the other vehicle was a pickup or SUV. The coefficients for all the other variables (except O_PKPSUV) are almost the same as in the baseline regression.

Adding CC_DL_SLOPE to the regression barely changes the other coefficients. The .255 coefficient for CC_DL_SLOPE is very close to the coefficient for DL_SLOPE in the regression of car-to-car collisions (.245)[11]:

[11] The use of separate variables CT_DL_SLOPE and CC_DL_SLOPE in these analyses suggests a possibility that these variables are really just surrogates "LTV" and "car" – i.e., for other factors that make LTVs different from cars. However, DL_SLOPE had a statistically significant effect in head-on collisions, and approximately the same regression coefficient (close to -.5) even in those analyses where every striking vehicles was an LTV, and where only a single variable was used to characterize SLOPE (earlier in Section 6.2).

REGRESSION WITH CT_DL_SLOPE AND CC_DL_SLOPE (N = 2,282)

HEAD-ON COLLISIONS WITH -.4 < D_CURBWT < +.4
CASE VEHICLE WAS CAR, OTHER VEHICLE WAS CAR, PICKUP OR SUV
FATALITY RISK FOR THE CASE CAR DRIVER

	Coefficient	Wald Chi-Square	P <
INTERCEPT	.511	64.5	.0001
D_CURBWT	- 5.503	269.2	.0001
CT_DL_SLOPE	- .513	3.00	.083
CC_DL_SLOPE	+ .255	3.47	.062
D_AGE	.0492	369.3	.0001
D_SEX	.192	5.18	.023
D_BELT	- 1.357	165.2	.0001
D_BAG	- .623	42.9	.0001
D_1100	.552	15.8	.0001
O_PKPSUV	.081	.09	.76

Either way, appropriately formulated variables derived from SLOPE statistically explained most of the extra aggressiveness of MY 1991-99 pickup trucks and SUVs in head-on collisions. Adding D_AHOF to either of these regressions did not produce statistically significant coefficients for D_AHOF, nor did it substantially change O_PKPSUV or any other coefficients. In other words, D_AHOF did not explain any significant portion of the extra aggressiveness of these pickup trucks and SUVs in head-on crashes.

6.3 Exposure database to study fatality rates in 2-vehicle crashes

The preceding exploration of head-on collisions is a prologue, and eventually a consistency check for the principal analyses of this chapter: a study of MY 1991-99 LTV aggressiveness based on fatality rates per billion miles in LTV-to-car vs. car-to-car crashes, controlling for vehicle mass, driver age and gender, urban/rural, etc. If these LTVs had had the same mass as MY 1991-99 cars, drivers the same age and gender, the same annual mileage, etc., would there still have been a higher fatality rate per billion miles in LTV-to-car impacts than in car-to-car impacts? Chapter 2 described the creation of databases from FARS, NASS, Polk, and State crash data that classified fatalities and mileage of MY 1991-99 vehicles in CY 1995-2000 by age, gender, urban/rural, etc. The data made it possible to compute fatality rates per billion miles for any specific type of vehicle/driver/environment. Now, these databases need to be modified to address two-vehicle crashes, and to compute the fatality risk relative to the mileage of either vehicle – e.g., the risk of a fatality in a head-on collision of a 3000-pound car with a 30-year-old female driver and a 4000-pound pickup truck with a 40-year-old male driver.

The fatal-crash data are a subset of the file created in Section 2.2. That file contained 137,800 records of crash-involved MY 1991-99 cars and LTVs with decodable VINs on the 1995-2000

FARS files. Of them, 65,607 were involved in collisions with car(s) or LTV(s), crash modes 5 and 6 in Table 2-1, and 51,310 of those were in collisions involving exactly two vehicles. The new database contains 23,922 vehicle records; it is a subset of those 51,310 2-vehicle collision involvements where the "other" vehicle is likewise an MY 1991-99 car or LTV with decodable VIN. Actually, 11,961 separate crashes generated those 23,922 vehicle records, because each crash appears twice on the original file, once with Vehicle 1 as the "case" vehicle, and once with Vehicle 2 as the case vehicle. The 11,961 crashes resulted in 14,401 occupant fatalities, distributed as follows:

	Crashes	Fatalities
Two cars	3,890	4,743
One car, one LTV	6,397	6,039 in the cars, 1,587 in the LTVs
Two LTVs	1,674	2,032

In these fairly recent model years and calendar years, the 6,039 car occupant fatalities in car-to-LTV crashes outnumber the 4,743 fatalities in car-to-car crashes, and the ratio of car-occupant (6,039) to LTV-occupant (1,587) fatalities in car-to-LTV crashes is close to 4:1.

The database is vehicle-oriented, with one record for each of the 23,922 case vehicles. It contains crash-level information shared by both vehicles: the State, calendar year and time-of-day when the crash occurred, urban/rural, speed limit of the principal road (FARS only records one speed limit per crash), road surface condition. The information is conveyed by the variables HIFAT_ST, CY, NITE, RURAL, SPDLIM55, WET, and SNOW_ICE, carried over from the original database. The new database also contains all the original information about the case vehicle and its driver. The original variables are prefixed with "C_" to indicate "case" vehicle – e.g., C_CURBWT, C_M14_30, C_ABS, C_VEHAGE, etc. It also contains exactly the same variables for the "other" vehicle, prefixed with "O_": O_CURBWT, O_M14_30, etc. Those O_ fields are obtained from the record in the original database where what is now the O_ vehicle was the case vehicle. As stated above, curb weight for both vehicles has been adjusted by the procedure discussed in Section 2.1, and it is directly comparable for cars and LTVs. These adjustments tend to be small, ranging from ½ to 4 percent in cars and LTVs of the 1990's. The new database also describes the crash configuration from the case vehicle's point of view (as in Table 2-1) and it counts and locates the occupant fatalities (FATALS, C_DEATHS, O_DEATHS, etc.).

The statistical analyses, however, will be limited to crashes in which both vehicles are 4-door cars, pickup trucks (excluding heavy-duty 200/300-series trucks), SUVs, or minivans. Crashes in which either, or both vehicles are 2-door cars, police cars, 200/300-series pickup trucks or full-size vans are excluded. The set of vehicles is similar to the one used in Chapter 5 (see Section 5.1), except that 2-door SUVs have been included. As in Section 4.4, the inclusion or exclusion of 2-door SUVs has little impact on the analysis results in this chapter; thus, they have been included to increase the sample size.

The corresponding exposure database needs to be a list of paired vehicles, containing the same variables as the fatality database – crash-level, "case"-vehicle and "other"-vehicle – plus a measure-of-size/weight factor/probability of occurrence. It should be, so to speak, a sample of pairs of vehicles/drivers that might conceivably have collided at a given time and location, selected at random from the VMT streaming through that location at that time.

The setup of the new database is clarified by reviewing the makeup of the existing exposure database generated in Section 2.6. The nation's VMT in CY 1995-2000 were partitioned into mutually exclusive cells by the time- and location variables, State, CY, NITE, RURAL, SPDLIM55, WET, and SNOW_ICE. The theory of induced exposure is that the non-culpable involvements in two-vehicle crashes in any cell are a more-or-less random sample of the VMT (vehicle/driver combinations) streaming through that cell: if 1 percent of the VMT is 30-year-old females driving Hondas, close to 1 percent of the induced-exposure crash involvements ought to be the same. Polk's national and State registration data were used to weight the induced-exposure cases to make sure the registration years for each make-model added up to their actual national totals. Thus, the existing database is a properly weighted random sample of individual vehicle/driver combinations passing through various locations at various times.

The new database must do the same for pairs of vehicle/driver combinations. The 1,658,124 records of induced-exposure involvements of 4-door cars and LTVs are partitioned into mutually exclusive cells by State, CY, NITE, RURAL, SPDLIM55, WET, and SNOW_ICE. No pairs are selected across cells: if V1 is in Florida and V2 in Utah, V1 could not have collided with V2. However, within each of the cells, any two induced-exposure vehicle records are eligible to be selected as a pair, and the probability of selection of that specific pair is proportional to the mileages apportioned to the two vehicle records. For example, if V1 and V2 each have a weight of 1,000,000 miles on the original file, and V3 and V4 each have a weight of 2,000,000 miles, the probability of selecting the (V3,V4) pair should be 4 times as high as the probability of selecting the (V1,V2) pair.

The procedure that will now be described allows the creation of a database consisting of pairs of induced-exposure vehicles – and this database can be any size the researcher desires. However, a database of approximately 500,000 pairs is desirable, because that is about the largest database that logistic regressions can handle efficiently with so many independent variables. With 1,635,124 induced-exposure vehicle cases, randomly assigned as pairs (with replacement, both vehicles in a pair coming from the same cell) we could conceivably make a file incomparably larger than 500,000 pairs, but that file would be impractical for regression analyses: 500,000 pairs is enough. One [of many] ways to obtain approximately 500,000 pairs is to select NPAIRS = N/4 pairs from cells containing N = 5,000 or more induced-exposure cases, NPAIRS = N/2 pairs from cells containing N = 1,000 or fewer cases, and proportionate numbers for cells of intermediate size.[12]

[12] NPAIRS is truncated down to an integer. If 1001 LE N LE 5000, NPAIRS = INT(.1875*N + 312.5). Cells with N < 20 are discarded, because the process would generate too many pairs where both vehicles are the same. These cells account for less than 1 percent of total VMT; total VMT for the remaining cells is adjusted upward by make-model-MY to account for the VMT lost in the deleted cells.

The following procedure is carried out separately for each cell: list all the induced-exposure vehicle cases in the cell, together with the VMT apportioned to each vehicle case (see Section 2.6), and the cumulative VMT from the beginning of the list up to that case. Add the total VMT for that cell, TOT_VMT. Compute how many pairs should be selected in that cell (NPAIRS). Every pair selected from this cell will have the same measure-of-size/weight factor/probability of occurrence

NEWWTFA = TOT_VMT / NPAIRS

and the NEWWTFA's for the various pairs will add up exactly to the total VMT in that cell.

The N induced-exposure cases in the cell have been listed, showing next to the j^{th} case the VMT apportioned to that case, VMT(j) and the cumulative VMT from the beginning of the list up to and including that case, CUMUL_VMT(j). CUMUL_VMT(N) = TOT_VMT. To select the first pair, pick a random number r uniformly distributed between 0 and 1. Check down the list and find the induced exposure case where CUMUL_VMT(j-1) < r x TOT_VMT < CUMUL_VMT(j). Pick the j^{th} induced-exposure vehicle as the "case" vehicle in the first pair. Pick a second random number r'; the k^{th} induced-exposure vehicle, where CUMUL_VMT(k-1) < r' x TOT_VMT < CUMUL_VMT(k), will be the "other" vehicle in the first pair. The process is repeated NPAIRS times to pick all the pairs for that cell.

For a hypothetical example, consider a cell with six induced-exposure cases, and assume that four pairs need to be picked:

	VMT Weight Factor	CUMUL_VMT
1. Ford F-150, 40-year-old male	5,000,000	5,000,000
2. Honda Accord, 40-year-old female	4,000,000	9,000,000
3. Dodge Caravan, 35-year-old female	3,000,000	12,000,000
4. Chevrolet Cavalier, 30-year-old male	4,000,000	16,000,000
5. Toyota 4-Runner, 25-year-old male	2,000,000	18,000,000
6. Nissan Altima, 45-year-old female	2,000,000	20,000,000

For four pairs, eight random numbers are needed, say .1956, .5414, .3001, .7587, .5379, .4041, .9215 and .8566. Since .1956 x 20,000,000 = 3,912,000, the first vehicle in the first pair is the Ford F-150. Since .5414 x 20,000,000 = 10,818,000, the second vehicle in the first pair is the Dodge Caravan. The four pairs are:

1. Ford F-150 with Dodge Caravan
2. Honda Accord with Chevrolet Cavalier
3. Dodge Caravan with Honda Accord
4. Nissan Altima with Toyota 4-Runner

Each pair has NEWWTFA = 5,000,000. The NEWWTFAs for the four pairs add up to exactly 20,000,000, the total VMT in the cell. Whereas the specific pairs selected, by chance, include two Caravans and two Accords, if this procedure had been repeated, say, 10,000 times, it would have ended up with Ford F-150 as about 25 percent of all the vehicles, Honda Accord as 20 percent, etc.

Since this is random sampling with replacement, a single induced-exposure case may be picked more than once and participate in several pairs, or even as both vehicles in the same pair, while some cases might not be picked at all. (Since most of the actual cells have hundreds or thousands of vehicle cases in them, rather than the six in this hypothetical example, the probability of picking the same vehicle twice for the same pair is low, but it can happen.) The probability of selection of a specific vehicle within any given cell is directly proportional to the VMT allotted to that vehicle case in Section 2.6. For example, if pickup trucks constitute 20 percent of the VMT in a specific cell, very close to 20 percent of the vehicles selected for pairs will be pickup trucks; in 4 percent of the selected pairs the "case" and "other" vehicles will both be pickup trucks, in 16 percent of the pairs, only the "case" vehicle will be a pickup truck, and in 16 percent, only the "other" vehicle. If make-model A has twice the VMT of B, and C has twice the VMT of D, there will be four times as many pairs of A with C as of B with D.

Each record in the two-vehicle exposure database has a weight factor variable NEWWTFA, plus variables also found in the two-vehicle fatal-crash database: the crash-level variables HIFAT_ST, CY, NITE, RURAL, SPDLIM55, WET, and SNOW_ICE, "case"-vehicle variables C_CURBWT, C_M14_30, C_ABS, C_VEHAGE, etc., and "other"-vehicle variables O_CURBWT, O_M14_30, etc.

6.4 MY 1991-99 LTV aggressiveness in 2-vehicle collisions

The data are now almost ready to calibrate the aggressiveness of MY 1991-99 LTVs in crashes with MY 1991-99 cars. Regressions are performed on the fatal-crash database combined with the exposure database, both limited as follows: the "case" (struck) vehicle was a 4-door passenger car, excluding police cars, and the "other" (striking) vehicle was a 4-door car or LTV, excluding police cars, full-sized vans and 200/300-series pickup trucks. An occupant fatality rate in the case (struck) vehicle is calibrated per billion miles of the case and other (striking) vehicles by striking-vehicle-type, curb weight of each vehicle, age of each driver, etc. How much higher was the risk in the case vehicle when the other vehicle was an LTV, than when the other vehicle was a car, all other factors equal?

The first regression calibrates the crash configuration where, intuitively, LTV aggressiveness would have been the largest: the driver's fatality risk in the struck car that has been frontally impacted in the left side (the "near" side relative to the driver) by the other vehicle. The FARS cases have 8-10:00 principal impact (IMPACT2) for the case vehicle and 11, 12 or 1:00 IMPACT2 for the other vehicle. These nearside impacts include, but are not limited to crashes where the impact was directly into the driver's door area (FARS does not specify the exact damage location, only the general impact area).

There are 1,352 records of struck-driver fatalities in left-side impacts to MY 1991-99 4-door cars by frontally impacting MY 1991-99 4-door cars and LTVs during CY 1995-2000, excluding police cars, etc., with non-missing values on the control variables. There are 266,123 pairs of induced-exposure vehicles on the exposure data base where the case vehicle is a 4-door car and the other vehicle is a 4-door car or LTV, both MY 1991-99, excluding police cars, etc., with non-missing values for the control variables. Together, they will furnish 267,475 data points – vehicle pairs (V1,V2) – to the logistic regression.

FATAL is a flag that indicates whether a data point is a fatal-crash record or an exposure record. FATAL=1 for fatal-crash records – i.e., cases where the driver of V1 is fatally injured, V1 struck on the left by the front of V2. All exposure pairs have FATAL = 2.[13]

NEWWTFA is the weight factor for each data point. It **counts** the number of fatalities implied by each fatal-crash record or the number of miles implied by each exposure record. NEWWTFA = 1 for each fatal-crash record in this regression: 1 driver fatality. NEWWTFA for the exposure pairs was defined above; it represents a mileage accumulated by each of a pair of vehicles.

The LOGIST procedure in SAS is a disaggregate logistic regression analysis. It is performed on 267,475 data points that are pairs of crash-involved vehicles: the 1,352 fatal crash involvements, each of which is a pair of vehicles that actually collided, left to front, resulting in a fatality to the driver of V1, plus the 266,123 exposure data points. Each exposure data point, as explained in Section 6.3, is a pair of randomly selected vehicles (with probability proportional to VMT) that had been involved in induced-exposure crashes. Although the two vehicles did not actually collide with one another, the fact that their induced-exposure crashes happened in the same State, calendar year, road type, and time of day meant they "could have" collided with one another.

However, each of these 267,475 data points are weighted, and thereby "transformed" by NEWWTFA. The 1,352 fatal-crash involvements represent 1,352 "failures" (case driver fatalities) while the 266,123 exposure data points represent 3.22 trillion "successes" (pairs of vehicles, each of which traveled a mile in the same State, calendar year, road type, and time of day, without getting into a fatal crash). While LOGIST procedure operates on the crash data points, the weighting by NEWWTFA in effect makes it calibrate the log-odds of a fatality in a crash between V1 and V2 per one mile of travel by each vehicle.[14]

The independent variables include vehicle type and curb weight. O_PKP = 1 if the other vehicle was a pickup truck, zero otherwise. O_SUV = 1 if the other vehicle was an SUV, 0 otherwise. O_MINVAN = 1 if it was a minivan. When the other vehicle was a car, all three of these variables equal zero. They are the key independent variables in the regression. Their coefficients will indicate, in logarithmic terms, how much worse it was to get hit by an LTV than by a car.

[13] *SAS/STAT® User's Guide, Version 6, Fourth Edition*, Volume 2, SAS Institute, Cary, NC, 1989, pp. 1071-1126. For computing fatality rates, the LOGIST procedure in SAS prefers values of 2, not 0 for the non-fatal events.

[14] The text describes the most appropriate way to set up the data for the LOGIST procedure. However, the version of LOGIST used in this study interprets the WEIGHT statement not as a case-weighting but a count of independently-observed cases. It literally treated each mile of travel by a pair of vehicles as an independent data point. That makes the standard errors of the coefficients about 2-5 percent smaller than they should be, and their chi-squares about 2-5 percent larger, as explained in Section 3.4.

Curb weight is entered as a 2-piece linear variable for the case vehicle, which was always a car. If the curb weight was less than 3,000 pounds, set

C_L_WT00 = .01 (curb weight – 3,000), C_M_WT00 = -5

If the curb weight was 3,000 or more, set

C_L_WT00 = 0, C_M_WT00 = .01 (curb weight – 3,500)

Curb weight is entered as a 3-piece linear variable for the other vehicle, which could have been a car or an LTV. If the curb weight was less than 3,000, set

O_L_WT00 = .01 (curb weight – 3,000), O_M_WT00 = -5, O_H_WT00 = 0

If the curb weight was between 3,000 and 4,000, set

O_L_WT00 = 0, O_M_WT00 = .01 (curb weight – 3,500), O_H_WT00 = 0

If the curb weight exceeded 4,000, set

O_L_WT00 = 0, O_M_WT00 = 5, O_H_WT00 = .01 (curb weight – 4,000)

Weights are divided by 100 so that the regression coefficient will indicate the effect of a 100-pound weight increase. Other than making the printout easier to read it has no effect on the regressions. The curb weights in this section are always the "adjusted" weights described in Section 2.1, slightly higher than the published "nominal" weights. Therefore, the hinge points in Chapters 3 and 4 (2,950 and 3,870 pounds) have been rounded up to the nearest thousand.

Air bags are not included as independent variables for either vehicle in this regression: air bags in the case vehicle have little effect in nearside impacts[15]; all-wheel drive and rear-wheel antilock are included for the other vehicle (O_AWD and O_RWAL), which might have been an LTV, but not for the case vehicle, which was always a car. As elsewhere in this report, O_AWD = 1 if the vehicle was equipped with all-wheel drive, 4-wheel drive, or 4x4. The calendar year variables are not included because they are excessively confounded with the more important vehicle age variables.

The coefficients for this regression are shown in Table 6-1. It was significantly more risky to get hit in the left side by any kind of MY 1991-99 LTV than by a MY 1991-99 car of the same mass as that LTV. When the "other" vehicle was a pickup truck, the coefficient is .497; per mile, the fatality risk was

exp(.497) – 1 = 64 percent higher

[15] Kahane, C.J., *Fatality Reduction by Air Bags: Analyses of Accident Data through Early 1996*, NHTSA Technical Report No. DOT HS 808 470, Washington, 1996, pp. 23-25.

TABLE 6-1: CAR DRIVER FATALITY RISK IN A LEFT-SIDE IMPACT BY THE FRONT OF A CAR OR LTV (N = 1,252 fatal crash involvements)

(per billion miles of each vehicle; excluding 2-door cars, police cars, 200/300-series pickup trucks and full-sized vans)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	**0.497**	**0.107**	**21.5**	**0.0001**
O_SUV	**0.681**	**0.103**	**43.6**	**0.0001**
O_MINVAN	**0.288**	**0.121**	**5.69**	**0.017**
O_AWD	**0.318**	**0.080**	**15.9**	**0.0001**
C_L_WT00	-0.1072	0.013	68.9	0.0001
O_L_WT00	0.0594	0.022	7.44	0.0064
C_M_WT00	-0.0912	0.011	63.8	0.0001
O_M_WT00	0.0035	0.010	0.11	0.74
O_H_WT00	-0.0109	0.011	0.94	0.33
C_MALE	0.167	0.164	1.04	0.31
O_MALE	-0.087	0.148	0.35	0.56
C_M14_30	0.0511	0.0196	6.77	0.0093
C_M30_50	-0.0334	0.0108	9.51	0.0020
C_M50_70	0.0733	0.0081	82.8	0.0001
C_M70+	0.1276	0.0076	280.7	0.0001
C_F14_30	0.0540	0.0167	10.5	0.0012
C_F30_50	-0.0247	0.0096	6.68	0.0097
C_F50_70	0.0939	0.0078	143.3	0.0001
C_F70+	0.1049	0.0094	124.8	0.0001
O_M14_30	0.0587	0.0098	36.0	0.0001
O_M30_50	0.0215	0.0066	10.5	0.0012
O_M50_70	0.0050	0.0098	0.25	0.61
O_M70+	0.0267	0.0266	1.00	0.32
O_F14_30	0.0551	0.0135	16.8	0.0001
O_F30_50	0.0069	0.0087	0.62	0.43
O_F50_70	0.0022	0.0141	0.02	0.88
O_F70+	-0.0405	0.053	0.58	0.45
C_ABS	0.0705	0.085	0.69	0.41
O_ABS	-0.0369	0.107	0.12	0.73
NITE	0.372	0.071	27.1	0.0001
RURAL	0.763	0.060	161.4	0.0001
SPDLIM55	1.511	0.062	589.2	0.0001
HIFAT_ST	0.676	0.058	134.5	0.0001
O_RWAL	0.301	0.113	7.13	0.0076
C_VEHAGE	0.136	0.0135	100.2	0.0001
O_VEHAGE	0.088	0.0141	39.2	0.0001
C_BRANDNEW	0.040	0.118	0.12	0.73
O_BRANDNEW	-0.109	0.108	1.02	0.31
WET	-0.112	0.075	2.22	0.14
SNOW_ICE	-0.044	0.177	0.06	0.80
INTERCPT	-25.332	0.219	13353.	0.0001

than when the other vehicle was a car of the same mass as that pickup, same driver age, urban/rural, etc. The increase is statistically significant: Chi-square is 21.5 (exceeding the 3.84 required for significance at the two-sided .05 level; "statistical significance" in this discussion refers only to the Chi-square in the regression printout and does not consider other sources of uncertainty). When the "other" vehicle was a MY 1991-99 SUV, the fatality risk was exp(.681) – 1 = 98 percent higher than when the other vehicle was a car. Even when the other vehicle was a minivan, the increase was exp(.288) – 1 = 33 percent, relative to a car.

These increases are calibrated for LTVs with 2-wheel drive. When the striking LTV had 4-wheel or all-wheel drive, the risk for the driver of the struck car was substantially higher. The coefficient for O_AWD was a statistically significant .318. When the other vehicle was an SUV with all-wheel/4-wheel drive, fatality risk was exp(.681 + .318) – 1 = 172 percent higher than when the other vehicle was a car.[16]

It is important to note that, unlike the analyses of head-on crashes in Sections 6.1 and 6.2, these estimates of extra risk incorporate not only the extra aggressiveness of LTVs given that a crash occurred, but also any pre-crash factors (except those adjusted by the control variables) that made LTVs have more crashes than cars, per mile – e.g., if the LTV drivers were more crash-prone than car drivers, after controlling for driver age/gender, urban/rural, etc. Specifically, it is unclear to what extent the strong coefficient for all-wheel-drive represents extra aggressiveness because those LTVs were often extra-high off the ground, with oversized tires, etc, and to what extent it merely represents more risky driving by people who selected vehicles with AWD/4x4.

However, the generally moderate difference between SUVs and 4-door cars in pedestrian crashes (Section 5.3), the similar rates of imprudent driving behavior in 4-door cars, pickup trucks and SUVs (Section 5.6), and the far smaller effects of AWD in other crash modes (Section 4.3) all suggest that the very large effects in Table 6-1 primarily represent the extra aggressiveness of MY 1991-99 LTVs given that a crash has occurred. In fact, Section 5.6 suggested that minivans had more prudent drivers than any other vehicle type, yet the risk for the struck driver is significantly higher when the striking vehicle was a minivan than when it was a car [exp(.288)–1 = 33 percent]

The coefficients for case car weight are strong: -.1072 for cars up to 3,000 pounds and -.0912 for cars heavier than 3,000 pounds. The vulnerability of the case car driver was substantially lower in the heavier cars, not necessarily because of conservation of momentum in these side impacts, but because the heavier cars had a structure better able to withstand the impacts. However, the coefficients for the other vehicle's weight were only strong in the opposite direction when that weight was under 3,000 pounds. The small vehicles (mostly cars) were not aggressive. Above 3,000 pounds, the weight of the other vehicle (O_M_WT00 and O_H_WT00) became nonsignificant. The coefficients suggest that the aggressiveness of the larger striking vehicles had a stronger relationship with their body type (pickup, SUV, minivan or car) than with how much they weighed.

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[16] When the regression in Table 6-1 is performed on a database excluding 2-door SUVs, it produces coefficients of .476 for O_PKP, .756 for O_SUV, .316 for O_MINVAN and .346 for O_AWD. Statistical significance is the same as in Table 6-1.

The driver age coefficients for the case vehicle are strongest for the older drivers, because they are highly vulnerable to injury and also prone to be involved in angle collisions. The coefficients for the other vehicle are strongest for the young drivers, because they have higher risk of crash involvement, per mile (but their low vulnerability to injury is irrelevant, because the dependent variable is the case vehicle's driver fatality). The coefficients for NITE, RURAL, SPDLIM55, HIFAT_ST and vehicle age are similar to those in multivehicle crash regressions of Chapters 3 and 4. The slightly negative coefficient for O_ABS and significantly positive (unfavorable) coefficient for O_RWAL suggests that 4-wheel ABS is effective in reducing involvements of LTVs in front-to-side collisions with cars.

The preceding regression, and others of the same type, can also be run without the variable O_AWD (all-wheel or 4-wheel drive). Frankly, the regressions with O_AWD, such as Table 6-1, probably model the data more accurately, but a parallel set of regressions without O_AWD is also presented for comparison with the results in Section 6.5 – regressions including SLOPE and AHOF. The regressions in Section 6.5 have to exclude O_AWD because NCAP tests have been conducted almost exclusively on 4x2 pickup trucks and 4x4 SUVs (thereby confounding AWD and truck type).

When O_AWD is omitted from the list of control variables, its effect is absorbed by the remaining control variables, including the vehicle-type coefficients, O_PKP, O_SUV and O_MINVAN:

REGRESSION NO. 1a
NEAR (LEFT) SIDE IMPACTS (without O_AWD; N = 1,252 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.571	0.105	29.4	0.0001
O_SUV	0.855	0.093	85.0	0.0001
O_MINVAN	0.262	0.120	4.76	0.029

Since 76 percent of MY 1991-99 SUVs registered in CY 1995-2000 were equipped with 4-wheel or all-wheel drive, the O_SUV coefficient absorbed much of the O_AWD effect and rises to .855, a considerable increase on the .681 in Table 6-1. Since only 30 percent of pickup trucks (excluding 200/300 series trucks), and 5 percent of minivans were equipped with 4-wheel or all-wheel drive, their coefficients remained close to those in Table 6-1. Getting hit in the left side by a pickup truck (average of 4x2 and 4x4) increased the car driver's risk by exp(.571) – 1 = 77 percent; by an SUV, 135 percent, and by a minivan, 30 percent.

Intuitively, the extra aggressiveness of LTVs ought to be much lower in **head-on collisions** than in front-to-nearside impacts with cars. In a moderately severe head-on collision, the deceleration experienced by occupants of the struck car should be fairly similar for a striking LTV of mass M or a striking car of mass M. Perhaps, in very severe or strongly offset collisions, the extra rigidity of the LTV could increase the intrusion in the car, and the risk to its occupants. By contrast, even in fairly low-speed side impacts, intrusion in the struck car is greater when the striking vehicle is a tall, rigid LTV.

Table 6-2 calibrates these relationships for 1,444 head-on collisions that were fatal to the driver of the case cars (i.e., both vehicles have IMPACT2 = 11, 12 or 1:00). The regression setup is the same as in Table 6-1, except that C_BAG is added, since air bags are highly effective in head-on collisions. The number of exposure pairs, 265,943, is just slightly smaller than before, since pairs cannot be included if the air bag status of either vehicle is unknown.

As long as they were equipped with 2-wheel drive, neither pickups, SUVs nor vans were significantly more aggressive than cars in head-on collisions. The coefficients were .040, .090 and .063, respectively, and the Chi-squares were all less than 1. That's a huge contrast with the nearside impacts. The coefficient for all-wheel-drive, however, was a surprisingly high, statistically significant .329.[17] It is difficult to judge to what extent the coefficient for O_AWD is due to: (1) Suspensions being "jacked up" in enough AWD/4x4 vehicles to make a real difference in risk for the occupants of the struck car; (2) High-risk crash-prone driving by people who selected AWD/4x4 vehicles, rather than extra aggressiveness of the vehicle structure in crashes; (3) The regression confused the effects of O_SUV and O_AWD, since most vehicles with AWD/4x4 were SUVs and vice-versa.

The coefficient for C_BAG is a statistically significant -.306, indicating high effectiveness for air bags. The coefficients for the other control variables are not too different from Table 6-1.

The regression of head-on collisions without the O_AWD control variable generated the following coefficients for O_PKP, O_SUV and O_MINVAN:

REGRESSION NO. 2a
HEAD-ON IMPACTS (without O_AWD; N = 1,444 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.127	0.103	1.51	0.22
O_SUV	0.275	0.093	8.83	0.0030
O_MINVAN	0.041	0.110	0.14	0.71

The coefficient for O_PKP increased to .127, but it is still not statistically significant. The coefficient for O_SUV, on the other hand, increased to a statistically significant .275, corresponding to a 32 percent increase in fatality risk for the car driver. The O_MINVAN coefficient was a negligible .041.

[17] When the regression in Table 6-2 is performed on a database excluding 2-door SUVs, it produces coefficients of .005 for O_PKP, .074 for O_SUV, .059 for O_MINVAN and .355 for O_AWD. Statistical significance is the same as in Table 6-2.

TABLE 6-2: CAR DRIVER FATALITY RISK IN HEAD-ON IMPACTS BY ANOTHER CAR OR AN LTV (N = 1,444 fatal crash involvements)

(per billion miles of each vehicle; excluding 2-door cars, police cars, 200/300-series pickup trucks and full-sized vans)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	**0.040**	**0.106**	**0.14**	**0.71**
O_SUV	**0.090**	**0.105**	**0.74**	**0.39**
O_MINVAN	**0.063**	**0.111**	**0.32**	**0.57**
O_AWD	**0.329**	**0.084**	**15.5**	**0.0001**
C_L_WT00	-0.0924	0.012	60.7	0.0001
O_L_WT00	0.0790	0.020	15.4	0.0001
C_M_WT00	-0.1148	0.013	78.6	0.0001
O_M_WT00	-0.0092	0.010	0.79	0.37
O_H_WT00	0.0083	0.011	0.55	0.46
C_MALE	0.337	0.140	5.81	0.016
O_MALE	0.252	0.138	3.32	0.069
C_M14_30	0.0258	0.0136	3.59	0.058
C_M30_50	-0.0115	0.0080	2.07	0.15
C_M50_70	0.0328	0.0077	18.3	0.0001
C_M70+	0.1173	0.0098	142.1	0.0001
C_F14_30	0.0219	0.0141	2.41	0.12
C_F30_50	-0.0115	0.0081	2.03	0.15
C_F50_70	0.0644	0.0079	67.2	0.0001
C_F70+	0.1032	0.0113	83.4	0.0001
O_M14_30	0.0425	0.0103	17.2	0.0001
O_M30_50	0.0071	0.0063	1.28	0.26
O_M50_70	0.0024	0.0085	0.08	0.78
O_M70+	0.0548	0.0190	8.31	0.0039
O_F14_30	0.0163	0.0141	1.34	0.25
O_F30_50	0.0162	0.0084	3.75	0.053
O_F50_70	0.0319	0.0112	8.16	0.0043
O_F70+	0.0110	0.0309	0.13	0.72
C_BAG	-0.306	0.070	19.0	0.0001
C_ABS	-0.006	0.083	0.01	0.94
O_ABS	0.032	0.098	0.11	0.75
NITE	0.681	0.062	122.1	0.0001
RURAL	1.140	0.061	355.3	0.0001
SPDLIM55	2.007	0.061	1081.	0.0001
HIFAT_ST	0.569	0.056	104.3	0.0001
O_RWAL	0.168	0.113	2.21	0.14
C_VEHAGE	0.1584	0.0142	124.8	0.0001
O_VEHAGE	0.0958	0.0138	48.5	0.0001
C_BRANDNEW	-0.108	0.126	0.74	0.39
O_BRANDNEW	-0.150	0.106	2.01	0.16
WET	-0.082	0.072	1.31	0.25
SNOW_ICE	0.140	0.140	1.00	0.32
INTERCPT	-25.276	0.219	13345.	0.0001

Estimates of LTV aggressiveness in head-on collisions based on the Regression No. 2a can be directly compared to the results from Section 6-1, based on relative fatality risk in head-on collisions, without control for belt use. The estimate for "Pickups & SUVs" based on the current analysis uses a weighted average of the O_PKP (.127) and O_SUV (.275) coefficients[18]:

FATALITY RISK INCREASE IN HEAD-ON COLLISIONS

	Section 6.1		Current Analysis	
Collisions of Cars with:	Risk Increase (%) Rel. to Car-Car	Stat. Sig.?	Risk Increase (%) Rel. to Car-Car	Stat. Sig.?
Pickups & SUVs	6 to 28	Yes	19	Yes
Pickup trucks	7 to 29	Yes	14	No
SUVs	3 to 26	Yes	32	Yes
Minivans	– 21 to – 8	No	4	No

The combined estimate for pickup trucks and SUVs, based on the current analysis (without O_AWD) was a 19 percent increase, close to the middle of the 6-to-28 percent range obtained in Section 6.1. That is reassuring. The method of Section 6.1, based on the fatality ratio of the two vehicles given that a fatal head-on collision had occurred, isolated the effects of relative aggressiveness and crashworthiness and eliminated all driver and pre-crash effects. The current method yielded nearly the same result. That suggests the control variables – age/gender, urban/rural, etc. – adjusted for the driver and pre-crash effects, and isolated the difference due to the aggressiveness of the vehicle structure. Neither method showed a statistically significant effect for minivans.

On the other hand, when pickup trucks and SUVs are looked at separately, the current analysis may have slightly overstated the extra aggressiveness of SUVs, and slightly understated for pickups. It is hard to say for sure, since the differences are in the "noise" range. (The ranges for the estimates from Section 6.1 are not interval estimates, since they do not include sampling error, but only include the variation in methods for obtaining a point estimate. Thus, even though the current estimate for SUVs is above the Section 6.1 "range," it is not significantly higher than the Section 6.1 results.) One possibility is that SUV drivers may have been somewhat more risk-prone than the average driver of the same age and gender, and pickup-truck drivers somewhat less. Another possibility is that pickup trucks were often driven in areas where there were relatively few passenger cars, and had fewer collisions with cars than might have been expected based on total VMT, whereas SUVs were driven extensively in urban areas where there were lots of cars. In either case, the discrepancies between the Section 6.1 and the current results for head-on collisions are small compared to the huge difference between LTV aggressiveness in

[18] The analysis in Section 6.1 includes 526 pickups and 247 SUV, using these as weights, the average of the coefficients for O_PKP and O_SUV is .178; exp(.178) – 1 = 19 percent; the standard error of the weighted average is .076; .178/.076 = 2.34, statistically significant.

side impacts and head-on collisions. The contrast between Table 6-1 (side impacts) and Table 6-2 (head-on collisions) suggests the aggressiveness of the MY 1991-99 LTVs observed in the side impacts was "real" and not due to pre-crash or driver factors.

Intuitively, the aggressiveness of LTVs when they hit cars on the far side from the driver, or in rear impacts ought to be somewhere between the results for head-on collisions and nearside impacts: more severe than in head-on collisions, because the side and back of a car have less protective structure than its front, but not as severe as in nearside collisions, because the intrusion is less likely to result directly in occupant injury. Regressions on 588 **farside and rear impacts** that were fatal to the driver of the case cars (i.e., the car had IMPACT2 = 2-7:00, the other vehicle had IMPACT2 = 11, 12 or 1:00), plus the same exposure pairs as in the nearside impacts, produced coefficients consistent with intuition. The regression that includes O_AWD produced:

FARSIDE AND REAR IMPACTS (N = 588 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.305	0.164	3.47	0.063
O_SUV	0.422	0.159	7.02	0.0081
O_MINVAN	0.227	0.170	1.78	0.18
O_AWD	0.110	0.127	0.75	0.39

And the regression without O_AWD generated:

FARSIDE AND REAR IMPACTS (without O_AWD; N = 588 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.333	0.160	4.31	0.038
O_SUV	0.482	0.143	11.3	0.0008
O_MINVAN	0.219	0.169	1.68	0.19

The effects for O_PKP, O_SUV and O_MINVAN were about one-half to two-thirds as large as in nearside impacts. They were statistically significant for O_SUV in both regressions, and for O_PKP in the second regression. The effect for O_AWD was not significant, and considerably smaller than in head-on and nearside impacts. It is not clear why the effect of all-wheel-drive is low here, but it suggests that O_AWD is not merely a surrogate for "risk-taking driver" (because in that case, it should have had large effects here, too).

An **overall** estimate of LTV aggressiveness for the **driver of the struck car** can be obtained by performing regressions on all 3,406 impacts that were fatal to the driver of the case cars, where the striking vehicle had frontal IMPACT2 = 11, 12 or 1:00. They comprise the 3,384 nearside, head-on, farside and rear impacts in the preceding regressions, plus 22 impacts, fatal to the driver of the case car, with unknown damage area on the case car (due to missing data in FARS). The exposure pairs are the same as in the preceding regressions:

ALL IMPACTS, DRIVER FATALITIES IN THE STRUCK CAR; FRONTAL IMPACTS BY THE STRIKING LTV (N = 3,406 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.256	0.068	14.1	0.0002
O_SUV	0.382	0.066	33.5	0.0001
O_MINVAN	0.169	0.073	5.34	0.021
O_AWD	0.285	0.052	29.5	0.0001

The regression without O_AWD generated:

ALL IMPACTS (without O_AWD; N = 3,406 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.326	0.067	24.0	0.0001
O_SUV	0.539	0.059	83.6	0.0001
O_MINVAN	0.148	0.073	4.15	0.042

With this larger set of fatal crashes, every effect was statistically significant. The effects for O_PKP, O_SUV and O_MINVAN were, understandably, weaker than in nearside impacts but stronger than in head-on collisions.

Finally, a global estimate of the **overall aggressiveness of LTVs** can be obtained by performing regressions that include all occupant fatalities in the car, not just the drivers, and in all crash modes (but not including fatalities in the striking LTV). The fatal-crash data points include all collisions where the case vehicle was a 4-door car, with at least one occupant fatality, and the other vehicle was a 4-door car or LTV. All impacts are included, even those where IMPACT2 for the other vehicle was not necessarily frontal. As usual, police cars, 200/300-series pickup trucks and full-size vans are excluded. In the fatal-crash cases, NEWWTFA equals the number of occupant fatalities in the case cars. The exposure pairs are the same as in the analysis of head-on collisions (since C_BAG is included in the regression). Here, there are 5,299 fatal crash cases, contributing 5,994 “failures” (case car occupant fatalities), a much larger number than in the preceding regressions. In the regression that included O_AWD, the effects for O_PKP, O_SUV and O_MINVAN were .276, .435 and .119, respectively. They were all statistically significant, and nearly in the middle between the corresponding results for nearside and head-on impacts. The effect for O_AWD was a significant, but relatively moderate .124:

ALL IMPACTS, ALL OCCUPANT FATALITIES IN THE STRUCK CAR; ALL IMPACTS BY THE STRIKING LTV (N = 5,299 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.276	0.051	29.5	0.0001
O_SUV	0.435	0.050	77.0	0.0001
O_MINVAN	0.119	0.055	4.65	0.031
O_AWD	0.124	0.040	9.53	0.0020

The regression without O_AWD generated:

REGRESSION NO. 3a
ALL IMPACTS (without O_AWD; N = 5,299 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.306	0.050	37.6	0.0001
O_SUV	0.503	0.044	128.2	0.0001
O_MINVAN	0.110	0.055	4.02	0.045

The coefficients for pickup trucks, SUVs and minivans, including both 4x2 and 4x4 drive, were .306, .503 and .110, respectively, all statistically significant. The extra aggressiveness of the MY 1991-99 pickup trucks was exp(.306) – 1 = 36 percent; of SUVs, 65 percent; of minivans, 12 percent.

Stated another way, the occupant fatality risk in cars when the striking vehicles were other cars can be assigned an index value 100. If those striking vehicles had been pickup trucks instead of cars, but everything else remained the same – the mass of the striking vehicles, the crash configuration, etc. – the fatality risk for the occupants of the struck cars would have risen to 136; if they had been SUVs, 165; if minivans, 112.

Table 6-3 summarizes the results of the four regressions without O_AWD, quantifying the aggressiveness of MY 1991-99 LTVs by crash mode, comparing the fatality risk in the struck car when the striking vehicle was an LTV, relative to the index value of 100 when the striking vehicle was a car of the same mass as that LTV. SUVs were significantly more aggressive than cars in every crash mode. Pickup trucks were significantly more aggressive than cars in every crash mode except head-on collisions.

Table 6-4 summarizes the results of the four regressions with O_AWD. Pickup trucks and SUVs with 4-wheel drive were significantly more aggressive than cars in every crash mode. Without 4-wheel drive, they were not significantly more aggressive than cars in head-on collisions.

TABLE 6-3

AGGRESSIVENESS OF MY 1991-99 LTVs IN IMPACTS WITH MY 1991-99 CARS

FATALITY RISK IN THE CASE CAR
BY OTHER VEHICLE TYPE AND CRASH MODE

ADJUSTED FOR THE STRIKING VEHICLE'S WEIGHT*

Striking Vehicle's Front Impacted the Struck Car on the	**Driver** Fatality Risk Index in the Struck Car by Striking Vehicle Type			
	Car	Pickup	SUV	Minivan
Left side	100**	**177*** **	**235*** **	**130*** **
Front (head-on collision)	100**	114	**132*** **	104
Right side or rear	100**	**139*** **	**162*** **	125
Anywhere	100**	**139*** **	**171*** **	**116*** **

	All Occupants' Fatality Risk Index in the Struck Car by Striking Vehicle Type			
	Car	Pickup	SUV	Minivan
All 2-vehicle crashes****	100**	**136*** **	**165*** **	**112*** **

*For example, if the risk for the driver of the struck car was 100 when the striking vehicle was a 3,500 pound car, the risk increased to 177 when the striking vehicle was a 3,500 pound pickup.
**Arbitrarily assigned index value.
*****Significantly greater than 100.**
****Including even crashes where the striking vehicle had nonfrontal damage.

TABLE 6-4

AGGRESSIVENESS OF MY 1991-99 4x2 AND 4x4 PICKUP TRUCKS AND SUVs
IN IMPACTS WITH MY 1991-99 CARS

FATALITY RISK IN THE CASE CAR
BY OTHER VEHICLE TYPE, DRIVE TRAIN AND CRASH MODE

ADJUSTED FOR THE STRIKING VEHICLE'S WEIGHT*

Striking Vehicle's Front Impacted the Struck Car on the	**Driver** Fatality Risk Index in the Struck Car by Striking Vehicle Type				
	Car	4x2 Pickup	4x4 Pickup	4x2 SUV	4x4 SUV
Left side	100**	**164*** **	**226*** **	**198*** **	**272*** **
Front (head-on collision)	100**	104	**145*** **	109	**152*** **
Right side or rear	100**	136	**151*** **	**152*** **	**170*** **
Anywhere	100**	**129*** **	**172*** **	**147*** **	**195*** **

	All Occupants' Fatality Risk Index in the Struck Car by Striking Vehicle Type				
	Car	4x2 Pickup	4x4 Pickup	4x2 SUV	4x4 SUV
All 2-vehicle crashes****	100**	**132*** **	**149*** **	**155*** **	**175*** **

*For example, if the risk for the driver of the struck car was 100 when the striking vehicle was a 3,500 pound car, the risk increased to 164 when the striking vehicle was a 3,500 pound 4x2 pickup.
**Arbitrarily assigned index value.
*****Significantly greater than 100.**
****Including even crashes where the striking vehicle had nonfrontal damage.

6.5 Frontal rigidity and height-of-force in 2-vehicle collisions

The preceding analyses showed that MY 1991-99 LTVs were more aggressive than MY 1991-99 cars of the same mass, resulting in a higher fatality risk for occupants of the struck vehicle in all types of 2-vehicle collisions, including side impacts and head-on collisions. As in Section 6.2, the next steps are to determine what factors explain the extra aggressiveness of those LTVs. We will look for correlations between the fatality risk of occupants in the struck vehicle and the rigidity or height of the striking LTV, and find out to what extent, statistically, those factors explain the extra aggressiveness.

As in Section 6.2, a vehicle's frontal rigidity and height are characterized by two parameters measured on frontal NCAP tests:

SLOPE, the average slope of the force-deflection profile maintained for at least 150 millimeters during the vehicle's initial crush.

AHOF, the average height-of-force of the vehicle on the NCAP barrier.

In over 76 percent of the records on the 2-vehicle crash and exposure files created in Section 6.3, SLOPE and AHOF are known for both vehicles – i.e., they have been measured for those specific make-model-MY-body style combinations, or for closely related make-models, as defined in Section 6.2. These variables are added to the file of 2-vehicle fatal collisions and the file of exposure pairs, with the names C_SLOPE, O_SLOPE, C_AHOF and O_AHOF.

The first analysis question is whether SLOPE or AHOF had any correlation with the car occupants' fatality risk in collisions between LTVs and cars, in various crash configurations. This is tested by performing regression analyses similar to those in Section 6.4, but limited to crashes where the "case" vehicle was a 4-door car **and the "other" vehicle was an LTV**, and with two additional variables:

OL_SLOPE = log(O_SLOPE) = log(SLOPE of the LTV)

D_AHOF = C_AHOF – O_AHOF = car AHOF – LTV AHOF

In other words, the stiffer the LTV, the more positive OL_SLOPE, but the higher the LTV relative to the car, the more negative D_AHOF. Thus, if their effects are in the expected direction (stiffer and higher LTV = more fatality risk in the car), OL_SLOPE should have a positive coefficient and D_AHOF should have a negative coefficient. The logarithmic transformation of SLOPE, as in Section 6.2, makes it less skewed to the right and more uniformly distributed.

The first regression calibrates car driver's fatality rate in the crash configuration where LTV aggressiveness was the largest: where the front of the LTV (IMPACT2 = 11, 12, 1:00) impacted the **left side** of the car (IMPACT2 = 8-10:00).

Intuitively, for these front-to-side collisions, the best measure of relative height might not be D_AHOF, but rather the difference between AHOF for the frontally impacting LTV and the side sill height of the struck car. Unfortunately, NHTSA did not routinely measure the side sill height of cars until it phased in dynamic testing for Federal Motor Vehicle Safety Standard 214 during 1994-97, too late for much of the MY 1991-99 database.[19] OL_SLOPE is used rather than DL_SLOPE (difference of the log SLOPEs) because, unlike head-on collisions, the car's frontal stiffness is irrelevant when the car is hit in the side. D_AHOF is used only because the car's frontal ground clearance ought to be similar to its side ground clearance; but there is no obvious relationship between frontal and side rigidity.

There are 598 records of driver fatalities ("failures") in MY 1991-99 4-door cars, excluding police cars, impacted on the left side by the front of an MY 1991-99 LTV, excluding 200/300-series pickups and full-sized vans during CY 1995-2000, with non-missing values on D_AHOF, OL_SLOPE, and the other control variables. There are 208,624 corresponding pairs of induced-exposure vehicles on the exposure data base where the case vehicle is a 4-door car and the other vehicle is an LTV, excluding police cars, etc., with known D_AHOF, OL_SLOPE, etc., contributing 1.16 trillion "successes" (vehicle miles of travel by each vehicle in a pair).[20] Together, they furnish 209,222 data points – vehicle pairs (V1,V2). The logistic regression is set up as in Section 6.4, but some modifications are needed.

- O_AWD cannot be included in the control variables because as of MY 1999, NCAP only tested SUVs with AWD or 4x4 and (with one exception) pickup trucks and minivans without it. Thus, in the cases with known AHOF and SLOPE, AWD is essentially a surrogate for SUV and has no independent meaning.

- Since the "other" vehicle was always an LTV and never a car, O_PKP is not needed: the other vehicle has to be a pickup truck if O_SUV = O_MINVAN = 0.

- Since the "other" vehicle was always an LTV, its curb weight is simplified from a 3-piece to a 2-piece linear variable, with the "hinge" at 4,000 pounds (O_L_WT00, O_H_WT00). The curb weight of the case car remains 2-piece linear, with the hinge at 3,000, as in Section 6.4 (but it is now called C_L_WT00, C_H_WT00).

The regression coefficients are presented in Table 6-5. The effect for OL_SLOPE was in the expected positive direction, but it fell short of statistical significance (Chi-square = 1.76). However, the effect for D_AHOF was statistically significant in the expected negative direction (Chi-square = 4.37, exceeding the 3.84 needed for significance at the two-sided .05 level). The higher the LTV and/or the lower the car, the higher the car driver's fatality rate per billion miles, because the greater the risk that the LTV overrode the car's side sill and applied forces on a weaker part of the car's structure, close to the driver's torso. "Height" in this context, of course,

[19] *Code of Federal Regulations*, Title 49, Government Printing Office, Washington, 2001, Part 571.214.
[20] For a more accurate regression, the number of exposure pairs on the original file was doubled as follows: (1) Inclusion of all applicable pairs on the original file; (2) Inclusion of all pairs where originally the "case" vehicle is an LTV and the "other" vehicle is a car, but switching the "case" and the "other" vehicle – i.e., switching C_CURBWT and O_CURBWT, etc.; (3) multiply NEWWTFA by .5 for each exposure pair.

TABLE 6-5: ASSOCIATION OF OL_SLOPE AND D_AHOF WITH CAR DRIVER FATALITY RISK IN A LEFT-SIDE IMPACT BY THE FRONT OF AN LTV (N = 598 fatal crash involvements)

(per billion miles of each vehicle; excluding 2-door cars, police cars, 200/300-series pickup trucks and full-sized vans)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
OL_SLOPE	**0.173**	**0.131**	**1.76**	**0.19**
D_AHOF	**-0.00167**	**0.00080**	**4.37**	**0.037**
C_L_WT00	-0.0668	0.0200	11.2	0.0008
O_L_WT00	-0.0111	0.0130	0.73	0.39
C_H_WT00	-0.0863	0.0185	21.8	0.0001
O_H_WT00	-0.0179	0.0148	1.46	0.23
O_SUV	0.397	0.123	10.5	0.0012
O_MINVAN	-0.037	0.145	0.06	0.80
C_MALE	-0.003	0.240	0.0002	0.99
O_MALE	-0.192	0.221	0.75	0.39
C_M14_30	0.0280	0.0314	0.79	0.37
C_M30_50	-0.0319	0.0162	3.8530	0.050
C_M50_70	0.0718	0.0121	35.3	0.0001
C_M70+	0.1214	0.0118	106.7	0.0001
C_F14_30	0.0563	0.0253	4.94	0.026
C_F30_50	-0.0367	0.0142	6.70	0.0097
C_F50_70	0.0805	0.0114	50.0	0.0001
C_F70+	0.1048	0.0140	55.9	0.0001
O_M14_30	0.0424	0.0141	9.07	0.0026
O_M30_50	0.0186	0.0093	3.99	0.046
O_M50_70	-0.0039	0.0154	0.06	0.80
O_M70+	0.0198	0.0516	0.15	0.70
O_F14_30	0.0366	0.0243	2.28	0.13
O_F30_50	-0.0064	0.0139	0.21	0.65
O_F50_70	-0.0018	0.0269	0.004	0.95
O_F70+	0.0860	0.0902	0.91	0.34
C_ABS	0.049	0.128	0.15	0.70
O_ABS	0.774	0.221	12.2	0.0005
NITE	0.389	0.108	13.0	0.0003
RURAL	0.750	0.091	68.4	0.0001
SPDLIM55	1.333	0.093	204.0	0.0001
HIFAT_ST	0.555	0.088	40.0	0.0001
O_RWAL	0.990	0.212	21.9	0.0001
C_VEHAGE	0.142	0.021	46.0	0.0001
O_VEHAGE	0.099	0.022	19.4	0.0001
C_BRANDNEW	0.119	0.173	0.47	0.49
O_BRANDNEW	0.084	0.166	0.26	0.61
WET	-0.235	0.119	3.90	0.048
SNOW_ICE	-0.172	0.277	0.39	0.53
INTERCPT	-26.115	1.01	668.7	0.0001

refers not to the roof height, but to the height of the strongest elements in the frontal structure (which, in the car, was presumably correlated with side sill height).

As in Section 6.2, the results are especially strong because the case vehicle was always a car and the other vehicle was always an LTV. The analysis accepts as a given that MY 1991-99 LTVs were more aggressive than cars; the coefficient for D_AHOF says in particular that the LTVs with high AHOF were even more aggressive than LTVs with AHOF that was low by LTV standards. It is also noteworthy that D_AHOF was significant while O_L_WT00 and O_H_WT00 were not: fatality rates in the cars didn't rise much as LTVs got heavier, but they did rise as LTV's got higher off the ground.[21]

In these side impacts, the truck's AHOF may have more had effect than its rigidity because most LTVs were high enough off the ground to concentrate force above the car's side sill. The door area of the car was much softer than the front of almost any truck. LTVs with relatively soft fronts could crush the door almost as easily as the most rigid LTVs.

Limiting the regression to make-model-MY-body style combinations that more closely matched NCAP test vehicles (as discussed in Section 6.2) yielded similar results: a significant effect for D_AHOF, but not for OL_SLOPE.

Although the primary goal of this section is to study OL_SLOPE and D_AHOF in LTV-to-car collisions, it is nevertheless quite interesting to calibrate their effects when the striking vehicle was a car, not an LTV:

OTHER CAR'S FRONT HIT CASE CAR'S LEFT SIDE (N = 385 fatal crash involvements)
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
OL_SLOPE	0.407	0.173	5.54	0.019
D_AHOF	- 0.00231	0.00106	4.71	0.030

Both coefficients were significant and in the expected direction, even though this regression is based on fewer fatality cases (385 vs. 598 in Table 6-5). The effect of OL_SLOPE is over twice as strong as when the other vehicle was an LTV, and the effect of D_AHOF has also become stronger. The higher and stiffer the other car, the greater the fatality risk in the case car. Unlike the severe height mismatch in LTV-to-car collisions, most car-to-car collisions are well-enough matched in height that there was significant engagement with the struck car's sill – and when there is sill engagement, the frontal rigidity of the striking car is important, and it can make a

[21] When the regression in Table 6-5 is performed on a database excluding 2-door SUVs, it produces coefficients of .164 for OL_SLOPE and –.00164 for D_AHOF – very similar to the coefficients in Table 6-5, but the D_AHOF coefficient now falls short of statistical significance at the two-sided .05 level (chi-square = 3.83, p = .0504), in part because this regression is based on fewer crash cases (566 fatal crash involvements, vs. 598 in Table 6-5).

difference in the amount of intrusion in the struck car. Of course, if there is height mismatch, that continues to be important.

The analysis of **head-on collisions between LTVs and cars** is based on 537 crashes where the case vehicle was a 4-door car and the driver was a fatality, while the other vehicle was an LTV, plus the same exposure pairs as in Table 6-5. C_BAG is added to the control variables:

HEAD-ON COLLISIONS
CASE VEHICLE WAS 4-DOOR CAR OTHER VEHICLE WAS LTV
EFFECT ON FATALITY RATE OF THE CAR DRIVER (N = 537 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
OL_SLOPE	0.327	0.133	6.07	0.014
D_AHOF	+ 0.00064	0.00087	.54	0.46

OL_SLOPE had a strong effect, statistically significant and in the "right" direction: the stiffer the LTV, the higher the fatality risk in the car. D_AHOF was not significant; the observed effect is in the "wrong" direction, but negligible.[22] The result is nearly the same as in the analysis of Section 6.2, based on fatality ratios rather than fatalities per billion miles. The two analyses corroborate one another. As explained in Section 6.2, the rigidity of the LTV could be an important factor in exceptionally severe or strongly offset collisions, but height mismatch is unlikely to play much of a role in head-on collisions.

An analysis of **head-on collisions between two cars** is based on 563 crashes where the case vehicle was a 4-door car and the driver was a fatality, while the other vehicle was also a 4-door passenger car. Neither OL_SLOPE nor D_AHOF had a statistically significant coefficient:

HEAD-ON COLLISIONS BETWEEN TWO 4-DOOR CARS
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER
(N = 563 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
OL_SLOPE	- 0.0120	0.1421	.0072	0.9324
D_AHOF	- 0.00084	0.000873	.9245	0.3363

That contrasts somewhat with the corresponding car-to-car analysis in Section 6.2, where OL_SLOPE had a significant negative effect, but D_AHOF was not significant.

[22] When this regression is performed on a database excluding 2-door SUVs, it produces coefficients of .359 for OL_SLOPE and .00041 for D_AHOF. Statistical significance is the same as in the regression including the 2-door SUVs.

The answer to the first analysis question is that driver fatality risk in the case vehicle was correlated with log(SLOPE) in the other vehicle and/or with relative AHOF, depending on the crash mode and the types of vehicles involved:

• Front of LTV hit L side of car	D_AHOF was significant
• Front of car 2 hit L side of car 1	Car 2's log(SLOPE) and D_AHOF significant
• Front of LTV hit front of car	LTV's log(SLOPE) significant
• Front of car 2 hit front of car 1	Neither was significant

Adrian Lund, in his review of this report, expressed surprise at the regression results for head-on collisions of cars with LTVs. The regressions found the LTV's log(SLOPE) significant and D_AHOF nonsignificant. Dr. Lund cited staged crash tests and investigations of actual car-LTV head-on crashes in which height mismatch (override/underride), not rigidity mismatch was the primary factor that increased injury risk for the car occupants. He believes AHOF is not the appropriate measure to study height mismatch in head-on collisions: relative bumper heights or frame-rail heights, for example, are more relevant. In response to Dr. Lund's comments, it should be noted that this report is NHTSA's first attempt at directly calibrating the effect of geometric and force parameters such as AHOF and SLOPE on fatality risk in head-on collisions. These results should be considered preliminary, and could be followed up with additional analyses, possibly considering other parameters. In addition, Dr. Lund questioned this report's use of D_AHOF as a measure of the height mismatch in front-to-side impact collisions: the struck car's AHOF is not necessarily a good surrogate for its side sill height. Here, too, additional analyses could be appropriate in the future, when side sill height has been measured on a large number of cars. The analyses would use the difference between the striking LTV's AHOF and the struck car's side sill height instead of D_AHOF as the measurement of height mismatch.[23]

The **second analysis goal** is to find out to what extent, statistically, OL_SLOPE and D_AHOF explained, in various crash configurations, the extra aggressiveness of MY 1991-99 LTVs. This is tested by performing, in each crash mode, two regression analyses on the fatal-crash cases plus corresponding exposure pairs, where the case vehicle always was a car, and the other vehicle was either a car, pickup truck, SUV, or minivan.

The first crash configuration is the driver fatality risk in the case car, where the case car is impacted in the **left side** by the front of the other vehicle. The first, baseline regression is set up exactly as in Regression No. 1a in Section 6.4 (nearside impacts, without O_AWD), to calibrate the overall aggressiveness of pickup trucks, SUVs and minivans, relative to cars, without including any parameters based on SLOPE or AHOF. However, it is limited to the 983 fatal crash cases where SLOPE and AHOF are known for both vehicles (as opposed to 1,352 cases in

[23] Dr. Lund's discussion is on pp. 7-8 of his letter, which may be found in the NHTSA docket for this report.

Regression No. 1a). As stated above, O_AWD is not included in the regression because all SUVs with known SLOPE and AHOF had AWD or 4x4, but very few pickup trucks and no minivans:

OTHER VEHICLE'S FRONT HIT CASE CAR'S LEFT SIDE
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER

BASELINE REGRESSION (N = 983 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.318	0.123	6.642	0.010
O_SUV	0.899	0.118	58.4	0.0001
O_MINVAN	0.211	0.132	2.57	0.11

The baseline aggressiveness of pickups, SUVs and minivans, relative to cars, was similar to the findings in Regression No. 1a (.57, .85 and .26, respectively). However, the coefficients O_PKP and O_MINVAN were somewhat lower in this data set, presumably because almost all AWD vehicles were excluded (and, as a result, the O_MINVAN coefficient was no longer significant). The O_SUV coefficient was slightly higher because all non-AWD SUVs were excluded.

The next regression finds out how much these baseline coefficients decreased – i.e., how much of the aggressiveness was "explained" – when SLOPE and AHOF variables were added to the analysis. Because it was shown above that OL_SLOPE had different relationships with fatality risk in LTV-to-car and car-to-car collisions, it needs to be expressed as two separate variables:

TRKSLOPE = log(O_SLOPE / 1,052) if the other vehicle was an LTV,
= 0 if the other vehicle was a car

CARSLOPE = log(O_SLOPE / 1,052) if the other vehicle was a car,
= 0 if the other vehicle was an LTV

where 1,052 is the average value of SLOPE for all vehicles on the file.[24] A second regression on the same data, with TRKSLOPE, CARSLOPE and D_AHOF added to the variables in the baseline regression, substantially reduced the O_PKP, O_SUV and O_MINVAN coefficients:

[24] O_SLOPE has to be divided by its average value to assure that the next regression has the same intercept as the baseline regression, and that O_PKP, O_SUV and O_MINVAN have the same meaning as in the baseline regression. To the extent that TRKSLOPE = CARSLOPE = 0 for a vehicle of average rigidity TRKSLOPE is not merely a surrogate for "truck" and CARSLOPE for "car." On the other hand, since most trucks have SLOPE > 1,052 and most cars have SLOPE < 1,052, there could be a tendency in that direction.

OTHER VEHICLE'S FRONT HIT CASE CAR'S LEFT SIDE
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER

REGRESSION WITH TRKSLOPE, CARSLOPE AND D_AHOF
(N = 983 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.157	0.137	1.31	0.25
O_SUV	0.619	0.154	16.1	0.0001
O_MINVAN	0.135	0.144	.88	0.35
TRKSLOPE	0.189	0.126	2.24	0.13
CARSLOPE	0.409	0.164	6.23	0.013
D_AHOF	- 0.00203	0.00065	9.94	0.0016

As above, D_AHOF was always significant, and OL_SLOPE was significant if the striking vehicle was a car. The coefficient for O_PKP is reduced from a statistically significant .318 in the baseline regression to a nonsignificant .157. In logarithmic terms, about half of the extra aggressiveness of pickup trucks, relative to cars, is statistically explained by the specific rigidity and height variables TRKSLOPE and D_AHOF.

The coefficient for O_SUV was reduced from .899 to .619; in logarithmic terms, TRKSLOPE and D_AHOF explained nearly one-third of SUV aggressiveness. Nevertheless, the O_SUV coefficient remained statistically significant, and quite high. It is not clear from these data whether the residual aggressiveness of SUVs was mostly driver/environmental factors, or vehicle-structure factors not conveyed in the variables OL_SLOPE and D_AHOF. At least, OL_SLOPE and D_AHOF did explain a substantial portion of the baseline aggressiveness. The coefficient for O_MINVAN was reduced from .211 to .135.

The second crash configuration is the driver fatality risk in the case car, in **head-on collisions**. The baseline regression is set up exactly as Regression No. 2a in Section 6.4 (head-on collisions, without O_AWD), limited to the 1,100 fatal crash cases where SLOPE and AHOF are known for both vehicles (as opposed to 1,444 cases in Regression No. 2a):

HEAD-ON COLLISIONS, CASE VEHICLE WAS CAR
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER

BASELINE REGRESSION (N = 1,100 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	- 0.002	0.122	.0003	0.99
O_SUV	0.358	0.120	8.82	0.0030
O_MINVAN	0.014	0.123	.01	0.91

The baseline aggressiveness in this limited data set was again lower for pickups and minivans, but higher for SUVs than the findings in Regression No. 2a (.13, .28 and .04, respectively). Only the O_SUV coefficient was significant here. The second regression, with TRKSLOPE, CARSLOPE and D_AHOF added to the variables, made the O_PKP, O_SUV and O_MINVAN coefficients all nonsignificant:

HEAD-ON COLLISIONS, CASE VEHICLE WAS CAR
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF THE CASE CAR DRIVER

REGRESSION WITH TRKSLOPE, CARSLOPE AND D_AHOF
(N = 1,100 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	- 0.164	0.138	1.42	0.23
O_SUV	0.135	0.159	.72	0.40
O_MINVAN	- 0.130	0.137	.90	0.34
TRKSLOPE	0.339	0.133	6.54	0.011
CARSLOPE	- 0.069	0.137	.26	0.61
D_AHOF	+ 0.000014	0.00062	.0005	0.98

OL_SLOPE was significant if the other vehicle was an LTV. The coefficient for O_SUV was reduced from a significant .358 to a nonsignificant .135; in logarithmic terms, TRKSLOPE explained nearly two-thirds of SUV aggressiveness. The coefficients for O_PKP and O_MINVAN were pushed down to negative, but not statistically significant levels. On the whole, TRKSLOPE statistically explained pretty much all the extra aggressiveness of LTVs in head-on collisions, corroborating the findings of Section 6.2.[25]

Finally, the overall aggressiveness of MY 1991-99 LTVs can be analyzed by performing regressions that include all occupant fatalities in the car, not just the drivers, and in all crash modes. The baseline regression is set up exactly as Regression No. 3a in Section 6.4, limited to the 4,042 fatal crash cases, resulting in 4,581 case-car occupant fatalities, where SLOPE and AHOF are known for both vehicles (as opposed to 5,299 cases and 5,994 fatalities in Regression No. 3a):

ALL 2-VEHICLE COLLISIONS, CASE VEHICLE WAS CAR
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF ALL CASE CAR OCCUPANTS

BASELINE REGRESSION (N = 4,042 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.205	0.058	12.6	0.0004
O_SUV	0.526	0.057	86.1	0.0001
O_MINVAN	0.012	0.061	.04	0.84

The baseline aggressiveness in this limited data set was lower for pickups and minivans, but about the same as for SUVs as in Regression No. 3a (.31 for pickups, .50 for SUVs and .11 for minivans). The O_PKP and O_SUV coefficients were significant here. The second regression, with TRKSLOPE, CARSLOPE and D_AHOF added to the variables, substantially reduced the O_PKP and O_SUV coefficients:

[25] The use of separate variables TRKSLOPE and CARSLOPE in these analyses suggests a possibility that these variables are really just surrogates "LTV" and "car" – i.e., for other factors that make LTVs different from cars. However, OL_SLOPE has a statistically significant effect in head-on collisions, and approximately the same regression coefficient (close to .33) even in those analyses where every striking vehicles is an LTV, and where only a single variable is used to characterize SLOPE (earlier in Section 6.5).

ALL 2-VEHICLE COLLISIONS, CASE VEHICLE WAS CAR
OTHER VEHICLE WAS CAR, PICKUP, SUV OR MINIVAN
EFFECT ON FATALITY RATE OF ALL CASE CAR OCCUPANTS

REGRESSION WITH TRKSLOPE, CARSLOPE AND D_AHOF
(N = 4,042 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
O_PKP	0.086	0.066	1.73	0.19
O_SUV	0.340	0.075	20.7	0.0001
O_MINVAN	- 0.064	0.067	.90	0.34
TRKSLOPE	0.178	0.063	7.98	0.0047
CARSLOPE	0.083	0.070	1.73	0.19
D_AHOF	- 0.00087	0.00030	8.55	0.0035

With all crash modes combined, OL_SLOPE was significant at the .01 level if the other vehicle was an LTV; D_AHOF was significant at the .01 level. The coefficient for O_PKP was reduced from a significant .205 to a nonsignificant .086; in logarithmic terms, TRKSLOPE and D_AHOF explained nearly two-thirds of the aggressiveness. O_SUV was reduced from .526 to .340: in logarithmic terms, by about one-third (although the residual aggressiveness was still significant). If pickup trucks and SUVs had been combined, TRKSLOPE and D_AHOF would have statistically explained, on the average, about half of their extra aggressiveness relative to cars.

6.6 Vehicle weight and crash fatality risk in 2-vehicle crashes

The basic analyses of vehicle weight and fatality risk in Sections 3.4 (cars) and 4.3 (LTVs) calibrated the number of crash fatalities per million years or billion miles as a function of the curb weight, and other characteristics of the case vehicle only. The regression model was conceptually straightforward for single-vehicle crashes, such as rollovers, or fixed-object crashes. The "case" vehicle is, in fact, the only vehicle in the crash, and the regression simply describes by how much fatality rates decrease as the weight of the case vehicle is reduced by 100 pounds. (In this section, as in Chapters 3 and 4, "reducing the case vehicle by 100 pounds" does not mean literally removing 100 pounds from a specific vehicle, but comparing the average percentage difference in the fatality rates of 1991-99 models weighing W pounds and the fatality rates of other 1991-99 models weighing W-100 pounds, given drivers of the same age/gender, etc.)

The regressions for the last two crash modes, however, "collisions with cars" and "collisions with LTVs" were harder to interpret. The regression variables, curb weight, driver age, etc. were known only for the case vehicle. Nothing was known about the "other" vehicle in these crashes, except whether it was a car or an LTV. The regressions treat the other vehicles as invariant, unspecified "black boxes," somewhat like the trees in the analyses of fixed-object impacts. The regression coefficients for case-vehicle weight measure the effect of reducing case vehicles by 100 pounds, while all the other vehicles in the crashes stay the same. The discussion in Section

3.7 explains why the effect of reducing every vehicle on the road by 100 pounds would be double the calibrated regression coefficient in collisions of two vehicles of the same type (e.g. two cars weighing over 2,950 pounds), whereas in a collision of two different vehicle types, it would be the sum of the coefficients for the two types. The explanation is not intuitively obvious, and the analysis might still conceivably raise questions such as:

- When both vehicles are the same type, would reducing the weight of both have double the effect of reducing one (as Section 3.7 explains), or would the effects cancel?
- The assumptions in the model are clearly acceptable when only the case vehicle is reduced in weight, but if many other vehicles on the road are also reduced, could that violate the model's assumption that those other vehicles are "invariant" black boxes?

The databases generated in this chapter allow calibration of various fatality rates in 2-vehicle crashes, based on the weights, driver ages, etc. of each vehicle, provided that both are MY 1991-99. In Sections 6.3-6.5, they were used for analyzing occupant fatality risk in the case vehicle only. However, by calibrating crash fatality risk (fatalities in the "case" plus "other" vehicles) as a function of each vehicle's weight, each driver's age/gender, etc., the databases can be used to corroborate the results of Chapters 3 and 4, and to confirm that the effect of reducing the weights of both vehicles is the sum of reducing each one separately. To the extent these databases allow, the regressions will be set up as close as possible to the corresponding analyses in Sections 3.4 and 4.3.

The first regression calibrates the crash fatality risk in collisions of **two passenger cars**, both MY 1991-99, per million vehicle years of each car. The regression is based on 1,897 separate 2-car crashes – collisions of two MY 1991-99 4-door cars, excluding police cars – resulting in 2,295 occupant fatalities. Each crash will appear twice in the analysis, once with V1 as the "case" vehicle and V2 as the "other" vehicle, and once vice-versa, a total of 3,794 data points (case vehicles). A corresponding file of 323,817 exposure pairs is generated by the same method as in Section 6.3, except that both vehicles have to be MY 1991-99 4-door cars, excluding police cars, and cases are weighted by registration years, not miles (for consistency with the analyses in Section 3.4).

The logistic regression is based on 327,611 data points, each a pair of crash-involved vehicles: 3,794 fatal-crash cases involving two cars that actually collided, and 323,817 exposure pairs of randomly selected vehicles that had been involved in induced-exposure crashes. However, the weight factor NEWWTFA in effect makes it a regression of fatality risk per vehicle year, for each vehicle in the crash. The 3,794 fatal-crash cases represent 2,295 "failures" (in each crash, NEWWTFA = half[26] the sum of the occupant fatalities in both vehicles), while the 323,817 exposure pairs represent 243,244,195 "successes" (registration years without a fatality for each vehicle in a pair). The regression calibrates the log-odds of a "failure." To the extent possible, the same independent variables are used as in Section 3.4. Curb weight is entered as a 2-piece linear variable, based on the unadjusted, "nominal" weights in Appendix A, with the "hinge" at

[26] Since each crash appears twice in the database, NEWWTFA for the fatal-crash records will add up to the actual number of crash fatalities.

2,950 pounds. Of course, this regression has curb weights for both the case and other cars. If the curb weight of the case car is less than 2,950 pounds, set

$$C\_U\_WT00 = .01\,(C\_CURBWT - 2{,}950),\; C\_O\_WT00 = 0$$

If the curb weight is 2,950 or more, set

$$C\_U\_WT00 = 0,\; C\_O\_WT00 = .01\,(C\_CURBWT - 2{,}950)$$

O_U_WT00 and O_O_WT00 are similarly defined for the other car.[27] (By contrast, the regression in Section 3.4 only included UNDRWT00 and OVERWT00 for the case car.) The other variables defined for both vehicles are the nine age/gender parameters, air bags and ABS. The crash-level variables are NITE, RURAL and SPDLIM55. Table 6-6 shows the coefficients.

The calibrated effect of a 100-pound reduction, in cars weighing less than 2,950 pounds, is a 2.14 percent fatality increase in the "case" vehicles and 2.54 percent in the other vehicles, averaging out to a 2.34 percent fatality increase. In cars weighing 2,950 pounds or more, the calibrated effects of a 100-pound reduction are 1.91 and 1.69 percent, averaging out to a 1.80 percent fatality increase.[28] These average effects, 2.34 and 1.80 percent, are nearly the same as the corresponding estimates in the analysis of Section 3.4: 2.48 and 1.59 percent. That's remarkably close considering the Section 3.4 analysis was based on a much larger set of 13,513 fatal crash records, including collisions where the other car could be a 2-door car, not MY 1991-99, or with unknown VIN, and also including involvements in 3- and 4-car crashes. The full results from that analysis were as follows:

[27] In the regression data set, the correlation between the curb weight of the case and other vehicle is only R = .01.
[28] The "case" and "other" effects are close, but not exactly equal because the fatal-crash data are symmetric (each crash used twice, once with V1 and once with V2 as the "case" vehicle, whereas the exposure pairs are not symmetric. To check that using the fatal-crash data twice is not somehow biasing the analysis, this regression was also run using each crash just once, picking the case vehicle at random from V1 or V2. It produced the same average effects for vehicle weight.

TABLE 6-6: CRASH FATALITY RISK IN COLLISIONS OF TWO MY 1991-99 PASSENGER CARS, CY 1995-2000
(N = 3,794 fatal crash involvements)

(per million registration years of each car; excluding 2-door cars and police cars)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
C_U_WT00	**-0.0214**	**0.0105**	**4.16**	**0.041**
C_O_WT00	**-0.0191**	**0.0083**	**5.27**	**0.022**
O_U_WT00	**-0.0254**	**0.0105**	**5.88**	**0.015**
O_O_WT00	**-0.0169**	**0.0084**	**4.07**	**0.044**
C_MALE	0.111	0.114	0.94	0.33
O_MALE	0.088	0.114	0.60	0.44
C_M14_30	0.0627	0.0093	45.5	0.0001
C_M30_50	0.0110	0.0063	3.10	0.078
C_M50_70	0.0340	0.0063	29.3	0.0001
C_M70+	0.0992	0.0085	136.4	0.0001
C_F14_30	0.0578	0.0103	31.3	0.0001
C_F30_50	-0.0061	0.0065	0.90	0.34
C_F50_70	0.0464	0.0067	48.3	0.0001
C_F70+	0.0902	0.0110	67.2	0.0001
O_M14_30	0.0635	0.0093	46.3	0.0001
O_M30_50	0.0108	0.0063	2.94	0.087
O_M50_70	0.0320	0.0063	25.7	0.0001
O_M70+	0.1029	0.0087	141.1	0.0001
O_F14_30	0.0602	0.0103	34.0	0.0001
O_F30_50	-0.0075	0.0064	1.35	0.24
O_F50_70	0.0448	0.0067	44.7	0.0001
O_F70+	0.1010	0.0113	80.4	0.0001
C_BAG	-0.137	0.054	6.40	0.011
O_BAG	-0.102	0.054	3.50	0.061
C_ABS	-0.088	0.066	1.79	0.18
O_ABS	-0.102	0.066	2.38	0.12
NITE	0.624	0.050	157.3	0.0001
RURAL	0.980	0.045	466.7	0.0001
SPDLIM55	1.782	0.047	1416.	0.0001
INTERCPT	-13.357	0.137	9464.	0.0001

RESULTS FROM SECTION 3.4:

CRASH FATALITY RISK IN COLLISIONS OF A MY 1991-99 CASE CAR WITH ANOTHER PASSENGER CAR(S) (N = 13,513 fatal crash involvements)

	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0248**	**33.5**	**.0001**
OVERWT00	**- .0159**	**20.9**	**.0001**
DRVMALE	.202	19.5	.0001
M14_30	.0526	182.0	.0001
M30_50	.0059	5.53	.019
M50_70	.0274	113.8	.0001
M70+	.1006	759.2	.0001
F14_30	.0378	78.2	.0001
F30_50	- .0013	.27	.61
F50_70	.0430	237.1	.0001
F70+	.0913	376.5	.0001
DRVBAG	- .180	66.6	.0001
ABS	- .156	32.4	.0001
NITE	.707	1313.	.0001
RURAL	.856	2172.	.0001
SPDLIM55	1.540	6344.	.0001
INTERCEPT	- 11.004	71819.	.0001

The two models agree quite well not only on the curb-weight coefficients, but also on the crucial driver-age parameters, and on NITE, RURAL, and SPDLIM55. DRVMALE, DRVBAG and ABS are somewhat stronger in the Section 3.4 analysis, perhaps because a male driver in the case car may “increase” the probability of a male driver in the other car (e.g., for crashes in locations where most drivers are males)[29], while air bags/ABS in the case car may “increase” the likelihood of air bags/ABS in the other car (e.g., in more recent calendar years, both cars are more likely to have air bags/ABS). The intercept is less negative in Section 3.4 (-11 vs. -13.4) since the rate per year includes collisions with pre-1991 cars, 2-door cars, 3-vehicle crashes, etc., whereas Table 6-6 is limited to fatalities in collisions where both cars are MY 1991-99, with 4 doors.

Best of all, the model in Table 6-6 is intuitively straightforward in describing the effect of reducing both cars’ weights: (1) If the case and other car are both under 2,950 pounds, reducing each by 100 pounds will increase the fatality rate by 2.14 + 2.54 = 4.68 percent, double the effect

[29] For example, in 1999 North Carolina 2-vehicle crashes, 47,042 involved two male drivers, 28,017 involved two females, and 67,919, one male and one female. Based on the binomial law, we would have expected only 45,890 male-male, 26,865 female-female crashes, but 70,223 male-female crashes. Thus, there is a modest but quite significant excess of crashes in which both drivers are the same gender. This is presumably because the gender distribution of drivers is not uniform, but varies by location and time of day.

of reducing just the case car; (2) If both cars are over 2,950 pounds, reducing each by 100 pounds will increase risk by 1.91 + 1.69 = 3.60 percent, again double the coefficient for one vehicle; (3) If one car weighs less than 2,950 pounds and the other more than 2,950 pounds, the effect of reducing both is the sum of the coefficients for each one. This confirms the conclusions in Section 3.7 that the effects of the Section 3.4 models are additive, for collisions between cars of different weight classes (< 2,950, 2,950+), if both cars are reduced by 100 pounds; and the effect should be doubled to estimate the fatality increase in collisions between two cars of the weight class.

Even though the model in Table 6-6 is intuitively simpler, this study will continue to rely on the point and interval estimates from Section 3.4, because they are based on more than three times the number of fatal-crash cases, and are statistically far more precise.

It is widely believed that a collision between two cars of similar mass should result in fewer crash fatalities than a collision of two badly mismatched cars. Even intuitively, that's not obvious. On the one hand, a moderately severe collision of two 3,000-pound cars might be survived by both drivers, whereas the same collision between a 4,000- and a 2,000-pound car might be fatal for the driver of the light car. But by the same token, a very severe collision of two 3,000-pound cars might kill both drivers, while the same collision between the 4,000- and 2,000-pound cars might be survived by the driver of the heavy car. The 2-car collision and exposure databases permit statistical testing of this hypothesis. In the regression of Table 6-6, the four variables describing the curb weights of the case car and the other car are replaced by:

LBS100 = .005 x (C_CURBWT + O_CURBWT)

D_LBS100 = .005 x | C_CURBWT – O_CURBWT |

LBS100 is simply the average of the two weights, in hundreds of pounds. D_LBS100 is half the absolute value of the difference of the two weights. In a collision between two 3,000-pound cars, LBS100 = 30 and D_LBS100 = 0. In a collision between a 4,000- and a 2,000-pound car, LBS100 = 30 and D_LBS100 = +10, regardless of whether the 4,000-pound car is the "case" car or the "other" car. The regression produces coefficients:

CRASH FATALITY RISK IN 2-CAR COLLISIONS
BY AVERAGE OF THE TWO CURB WEIGHTS AND
DIFFERENTIAL OF THE TWO CURB WEIGHTS (N = 3,794 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
LBS100	- 0.0397	0.0080	24.6	0.0001
D_LBS100	- 0.0066	0.0102	.41	0.52

The LBS100 coefficient says that when both cars in the crash are reduced by 100 pounds, or undergo any other combination of weight reductions that makes the average weight of the two cars 100 pounds less, the crash fatality rate increases by 3.97 percent. The D_LBS100 coefficient is not statistically significant, and it suggests that the weight differential between the two cars has little effect on crash fatality rate. This analysis, at least, does not support the widely-held hypothesis that weight mismatch increases risk, at least not when both vehicles are passenger cars, over the range of weight mismatch that typically occurs between cars.

For collisions between cars and LTVs, Section 3.4 estimated the effect of reducing car weight on the crash fatality rate, and Section 4.3, the effect of reducing the weight of the LTV. Close to 80 percent of the fatalities in these crashes were occupants of the cars. Thus, it was hardly surprising that Section 3.4 showed that a reduction of car weight was associated with a substantial increase of crash fatality risk, but it was noteworthy that Section 4.3 did not show a commensurate fatality reduction for LTVs:

RESULTS FROM SECTION 3.4:
CRASH FATALITY RISK IN COLLISIONS OF A MY 1991-99 CASE CAR WITH AN LTV
(N = 12,119 fatal crash involvements)

Curb Weight of the Car	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0563**	**195.1**	**.0001**
OVERWT00	**- .0262**	**59.1**	**.0001**

RESULTS FROM SECTION 4.3:
CRASH FATALITY RISK IN COLLISIONS OF A MY 1991-99 CASE LTV WITH A CAR
(N = 19,227 fatal crash involvements)

Curb Weight of the LTV	Coefficient	Wald Chi-Square	P <
UNDRWT00	**- .0113**	**22.6**	**.0001**
OVERWT00	**+ .0068**	**14.2**	**.0002**

The databases generated in Section 6.3 can be used to confirm the general trend that the effect of reducing curb weight is much stronger in the cars than in the LTVs. The regression is based on car-to-LTV fatal-crash cases and exposure pairs where the case vehicles are MY 1991-99 4-door cars, excluding police cars, and the other vehicles are MY 1991-99 LTVs, excluding 200/300-series pickup trucks and full-sized vans. The fatal-crash cases include all collisions that were fatal to an occupant of the car and/or the LTV. The regression calibrates the crash fatality rate per billion VMT of each vehicle. The regression is based on 3,962 separate crashes, resulting in 4,672 occupant fatalities ("failures"). (Since the case vehicle is a car and the other vehicle an LTV, each crash appears only once in the analysis). The 241,715 exposure pairs represent 1.43 trillion "successes" (miles of travel by each vehicle in the pair).

The regression uses the unadjusted, "nominal" curb weights in Appendices A and B. Curb weight for the case car is entered as a 2-piece linear variable with the hinge at 2,950 pounds, as in Section 3.4. Curb weight for the other LTV is entered as a 2-piece linear variable with the hinge at 3,870 pounds, as in Section 4.3. The control variables are based on the same list as in Section 4.3. They include the nine age/gender parameters, air bags, ABS, VEHAGE and BRANDNEW for both vehicles; O_SUV, O_MINVAN, O_AWD and O_RWAL for the LTV, only; and the crash-level variables NITE, RURAL, SPDLIM55, HIFAT_ST, WET and SNOW_ICE.

The regression coefficients for vehicle weight were:

CRASH FATALITY CAR-TO-LTV COLLISIONS
CASE VEHICLE WAS CAR, OTHER VEHICLE WAS LTV
(N = 3,962 fatal crash involvements)

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square
		FOR THE CAR		
C_U_WT00	- 0.0655	0.0072	83.7	0.0001
C_O_WT00	- 0.0602	0.0062	94.5	0.0001
		FOR THE LTV		
O_U_WT00	- 0.0118	0.0050	5.53	0.019
O_O_WT00	- 0.0086	0.0052	2.76	0.096

This regression confirms the strong effect of curb weight in cars, and the weak effect in LTVs, and it demonstrates that the effects obtained in Chapters 3 and 4 for different vehicle types should be additive when both vehicles are reduced in weight.

In cars weighing less than 2,950 pounds, the 6.55 percent increase per 100-pound reduction, which has standard error 0.72 percentage points, is essentially the same as the 5.63 effect in Section 3.4. In LTVs weighing less than 3,870 pounds, the 1.18 percent increase is almost exactly the same as the 1.13 percent in Section 4.3. For cars weighing more than 2,950 pounds, this regression calibrates a stronger effect than Section 3.4, 6.02 percent vs. 2.62 percent, but in the same direction. For LTVs weighing more than 3,870 pounds, this regression calibrates a nonsignificant fatality increase of .86 percent, per 100-pound reduction, while the Section 4.3 analysis calibrated a weak, but significant .68 percent fatality reduction.

This regression should not be expected to yield exactly the same results as the analyses in Sections 3.4 and 4.3. This regression is based on 3,962 fatal-crash cases, limited to 2-vehicle collisions between MY 1991-99 4-door cars and MY 1991-99 LTVs excluding 200/300-series pickups and full-sized vans. The regression in Section 3.4 was based on 12,119 fatal-crash cases, including collisions with any type of LTV of any model year, and even collisions involving 3 or 4 cars and LTVs. The regression in Section 4.3 was based on 19,227 fatal crash cases; case vehicles included 200/300-series pickups and full-sized vans; the other vehicle(s) could be any car of any model year, including 2-door cars, or even multiple cars and LTVs. The important finding is that all the analyses calibrated a strong effect of curb weight in cars, and weak in LTVs.

The analyses of Section 6.5 explain why the effect of curb weight was weak in MY 1991-99 LTVs. When the front of an LTV hit the side of a car, the fatality risk of the car occupants was more strongly correlated with the height mismatch than with LTV weight.

6.7 Update of the Mengert-Borener model of car-to-car crash fatality risk

At the U.S. Department of Transportation in 1989, Mengert and Borener developed a model for estimating the effect of car weight reductions on fatalities in car-to-car collisions.[30] They applied it to MY 1978-87 cars in CY 1978-87 FARS and Polk data. Cars are subdivided into groups by class intervals of weight (Mengert and Borener used six intervals). The relative fatality risk in crashes between cars of group j and group k is estimated by $Risk_{jk} = F_{jk} / R_j R_k$, where F_{jk} is the number of fatalities in crashes between vehicles of group j and group k, and R_j is the proportion of car registration years in group j. For example, if collisions between cars of the groups j and k account for F_{jk} = 2 percent of car-to-car fatalities, R_j = 10 percent and R_k = 10 percent of car registrations, then the relative risk is 2.0. With these measures of relative risk, Mengert and Borener could estimate the net effect on total fatalities for **any** hypothetical redistribution of car registrations among the weight groups – e.g., if the lightest groups had accounted for a larger proportion of registrations, and the heavy groups, a smaller proportion. The baseline number of fatalities was

$$\text{Summation over j and k } (Risk_{jk} R_j R_k)$$

and if the distribution of car registrations had been R'_j the number of fatalities would have changed to

$$\text{Summation over j and k } (Risk_{jk} R'_j R'_k)$$

The model does not adjust for driver age/gender, urban/rural or any other factors, but it is transparent and practical, allowing many types of changes in the distribution of weights (e.g., across the board, only on the heaviest cars, etc.).

Mengert and Borener applied the model to CY 1978-87 data. It predicts that if cars had been 100 pounds lighter, fatalities in car-to-car collisions would have been **reduced** by 0.8 percent. However, when the data were limited to CY 1983-87, that prediction changed to an intuitively more reasonable fatality increase. Partly because of those uncertainties, the model was never used for an "official" NHTSA estimate, but the study may have reinforced perceptions that the

[30] Mengert, P., *Estimating Relative Safety of Hypothetical Weight Distribution for the National Passenger Car Population*, 1989 SAE Government/Industry Meeting, Washington, May 3, 1989.

effect of weight reduction on car-to-car crash fatalities is small. Thus, for example, a similar finding during the analyses for NHTSA's 1997 report did not immediately trigger an intensive search for flaws in those analyses.

Since the current study's regression analysis found a significant increase in car-to-car crash fatality rates as car weight decreased, it would be reassuring to learn that the Mengert-Borener method, if applied to the current study's MY 1991-99/CY 1995-2000 FARS and Polk data, also showed increases. Four-door car make-models were subdivided into intervals of curb weight, based on the weights in Appendix A, each accounting for as close as possible (but not always exactly equal) to 10 percent of MY 1991-99 car registration years in CY 1995-2000 (deciles). The numbers of crash fatalities were tabulated for each of the cells and risk factors computed. The analysis is based purely on FARS and Polk data and does not use the induced-exposure data at all. It is exactly what Mengert and Borener did, except with more recent data, limited to 4-door cars, and using 10 weight intervals instead of six.

After 100 pounds was subtracted from the Appendix A weight of every make-model, the new proportion of registrations was computed in each of the ten groups, and the new number of total fatalities was estimated. Fatalities increased by 2.74 percent over the original number. This is the effect, so to speak, of reducing the weight of both cars in every collision and it is equivalent to a 1.37 percent increase if just one of the cars were reduced by 100 pounds (by comparison, the regressions in Section 3.4 suggest a somewhat higher 2.48 percent increase in cars weighing less than 2,950 pounds and a very similar 1.59 percent increase in cars weighing 2,950 pounds or more). Of course, the Mengert-Borener model does not control for driver age/gender, urban/rural, etc., and its results are therefore not directly comparable to the regression analyses. However, readers may rest assured that the Mengert-Borener model, applied to MY 1991-99 4-door cars, no longer finds a decrease in car-to-car crash fatalities as cars get lighter; instead, fatalities would have increased.

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APPENDIX A: CURB WEIGHTS OF 1991-99 PASSENGER CARS, BY MODEL YEAR

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
618	CV	616 CHRY-LeBARON	3025	3024	3035	3122	3122	.	.	.	.
	2CP	616 CHRY-LeBARON	2884	2870	2860	.	.	.	.	.	.
620	CV	717 DODGE SHADOW	2889	2924	2888	.	.	.	.	.	.
	3HB	715 DODGE DAYTONA	2840	2848	2810	.	.	.	.	.	.
	3HB	717 DODGE SHADOW	2629	2652	2642	2626	.	.	.	.	.
	3HB	917 PLYM-SUNDANCE	2623	2663	2642	2677	.	.	.	.	.
	5HB	717 DODGE SHADOW	2641	2675	2641	2694	.	.	.	.	.
	5HB	917 PLYM-SUNDANCE	2665	2674	2640	2698	.	.	.	.	.
621	4SD	618 CHRY-NEW YORKER C	3286	3273	3231	.	.	.	.	.	.
	4SD	718 DODGE DYNASTY	3121	3090	3028	.	.	.	.	.	.
622	4SD	616 CHRY-LeBARON	3038	2961	2954	2979	.	.	.	.	.
	4SD	719 DODGE SPIRIT	2878	2808	2787	2793	2822	.	.	.	.
	4SD	919 PLYM-ACCLAIM	2846	2815	2784	2793	2756	.	.	.	.
623	4SD	620 CHRY-5TH AVE/IMPERIAL	3426	3390	3342	.	.	.	.	.	.
624	CV	713 DODGE VIPER	.	3476	3476	3476	3487	3445	3383	3383	3319
	2CP	713 DODGE VIPER	.	.	.	.	.	3445	3383	3383	3383
625	4SD	641 CHRY-CONCORDE	.	.	3382	3415	.	3492	3552	3451	3446
	4SD	642 CHRY-LHS/NYer	.	.	.	3595	.	3595	3619	.	3579
	4SD	650 CHRY-UNK LH	.	.	.	.	3495	.	.	.	.
	4SD	651 CHRY-300M	.	.	.	.	.	.	.	.	3567
	4SD	741 DODGE INTREPID	.	.	3306	3295	3310	3360	3411	3422	3422
	4SD	1041 EAGLE VISION	.	.	3356	3344	3408	3427	3446	.	.
626	4SD	644 CHRY-CIRRUS	.	.	.	.	3145	3148	3076	3172	3146
	4SD	743 DODGE STRATUS	.	.	.	.	2937	2890	2922	2919	2921
	4SD	938 PLYM-BREEZE	.	.	.	.	.	2931	2920	2929	2925
627	2CP	720 DODGE NEON	.	.	.	.	2318	2385	2385	2470	2470
	2CP	920 PLYM-NEON	.	.	.	.	2318	2385	2385	2470	2470
	4SD	720 DODGE NEON	.	.	.	.	2384	2406	2428	2507	2507
	4SD	920 PLYM-NEON	.	.	.	.	2384	2406	2428	2507	2507
629	CV	939 PLYM-PROWLER	.	.	.	.	.	.	.	.	2838
1227	CV	1203 FORD MUSTANG	3278	3272	3172	.	.	.	.	.	.
	2CP	1203 FORD MUSTANG	2896	3088	2864	.	.	.	.	.	.
	3HB	1203 FORD MUSTANG	3090	3147	3003	.	.	.	.	.	.
1228	4SD	1216 FORD CROWN VICTORIA	3831	3765	3797	3786	3762	3780	3780	3917	3917
	4SD	1416 MERC-GRAND MARQUIS	3807	3777	3802	3801	3761	3796	3797	3917	3917
	SW	1216 FORD CROWN VICTORIA	4060	.	.	.	.	.	.	.	.
	SW	1416 MERC-GRAND MARQUIS	4016	.	.	.	.	.	.	.	.
1230	4SD	1301 LINC-TOWN CAR/LINCOLN	4043	4025	4046	4049	4031	4040	4040	4020	4020
1232	2CP	1302 LINC-MARK	3802	3779	.	.	.	.	.	.	.
1234	2CP	1215 FORD TEMPO	2539	2538	2511	2511	.	.	.	.	.
	2CP	1415 MERC-TOPAZ	2546	2546	2539	2534	.	.	.	.	.
	4SD	1215 FORD TEMPO	2640	2618	2572	2569	.	.	.	.	.
	4SD	1415 MERC-TOPAZ	2608	2620	2607	2588	.	.	.	.	.
1235	4SD	1217 FORD TAURUS	3125	3131	3126	3120	3125	.	.	.	.
	4SD	1417 MERC-SABLE	3191	3160	3152	3141	3144	.	.	.	.
	SW	1217 FORD TAURUS	3290	3283	3282	3259	3285	.	.	.	.
	SW	1417 MERC-SABLE	3340	3311	3308	3289	3292	.	.	.	.
1236	4SD	1305 LINC-CONTINENTAL	3634	3627	3606	3592	3972	3911	3884	3868	3868
1237	2CP	1204 FORD THUNDERBIRD	3608	3581	3566	3576	3539	3536	3561	.	.
	2CP	1302 LINC-MARK	.	.	3741	3741	3768	3767	3767	3765	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
1237	2CP	1404 MERC-COUGAR TO 1997	3617	3606	3527	3576	3533	3559	3536	.	.
1238	CV	1203 FORD MUSTANG	.	.	.	3319	3200	3200	3200	3200	3200
	2CP	1203 FORD MUSTANG	.	.	.	3146	3077	3065	3084	3065	3069
1239	3HB	1438 MERC-COUGAR 1998-	.	.	.	.	.	.	.	.	2891
	4SD	1235 FORD CONTOUR	.	.	.	.	2769	2769	2769	2774	2777
	4SD	1437 MERC-MYSTIQUE	.	.	.	.	2822	2831	2831	2808	2805
1240	4SD	1217 FORD TAURUS	.	.	.	.	.	3326	3326	3329	3329
	4SD	1417 MERC-SABLE	.	.	.	.	.	3388	3388	3388	3302
	SW	1217 FORD TAURUS	.	.	.	.	.	3480	3480	3480	3480
	SW	1417 MERC-SABLE	.	.	.	.	.	3536	3536	3536	3470
1839	4SD	1804 BUIC-ROADMASTER B	.	4095	4105	4229	4211	4211	.	.	.
	4SD	2002 CHEV-CAPRICE/IMPALA	3944	3972	3972	4061	4061	4061	.	.	.
1840	SW	1802 BUIC-LeSABRE	4415	.	.	.	.	.	.	.	.
	SW	1804 BUIC-ROADMASTER B	.	4468	4508	4572	4563	4563	.	.	.
	SW	2002 CHEV-CAPRICE/IMPALA	4354	4403	4403	4473	4473	4473	.	.	.
	SW	2102 OLDS-DELTA 88	4435	4394	.	.	.	.	.	.	.
1842	4SD	1903 CADI-DeVILLE	4275	4277	4418	4513	4477	4447	.	.	.
1848	CV	2016 CHEV-CAVALIER J	2700	2735	2769	2867	.	.	.	.	.
	CV	2216 PONT-SUNBIRD/FIRE J	2684	2736	2723	2677	.	.	.	.	.
	2CP	2016 CHEV-CAVALIER J	2497	2534	2538	2553	.	.	.	.	.
	2CP	2216 PONT-SUNBIRD/FIRE J	2508	2551	2548	2497	.	.	.	.	.
	4SD	2016 CHEV-CAVALIER J	2491	2530	2529	2604	.	.	.	.	.
	4SD	2216 PONT-SUNBIRD/FIRE J	2505	2543	2544	2503	.	.	.	.	.
	SW	2016 CHEV-CAVALIER J	2601	2600	2643	2666	.	.	.	.	.
1849	CV	2009 CHEV-CAMARO F	3360	3323	.	3465	3400	3440	3455	3468	3500
	CV	2209 PONT-FIREBIRD F	3374	3393	.	3455	3400	3400	3400	3400	3400
	2CP	2009 CHEV-CAMARO F	3217	3204	3301	3308	3251	3306	3307	3331	3306
	2CP	2209 PONT-FIREBIRD F	3214	3204	.	.	.	.	.	.	.
	3HB	2209 PONT-FIREBIRD F	.	.	3331	3330	3230	3311	3311	3340	3323
1850	2CP	1817 BUIC-CENTURY A	2913	2952	2896	.	.	.	.	.	.
	2CP	2117 OLDS-CIERA A	2920	.	.	.	.	.	.	.	.
	4SD	1817 BUIC-CENTURY A	2946	2952	2945	2975	2986	2950	.	.	.
	4SD	2117 OLDS-CIERA A	2949	2990	2919	2927	2941	2924	.	.	.
	4SD	2217 PONT-6000 A	2837	.	.	.	.	.	.	.	.
	SW	1817 BUIC-CENTURY A	3152	3135	3092	3150	3130	3118	.	.	.
	SW	2117 OLDS-CIERA A	3094	3115	3117	3180	3239	3229	.	.	.
	SW	2217 PONT-6000 A	3164	.	.	.	.	.	.	.	.
1851	CV	2004 CHEV-CORVETTE Y	3333	3375	3377	3360	3360	3360	.	.	.
	2CP	2004 CHEV-CORVETTE Y	3317	3333	3337	3314	3314	3298	.	.	.
1852	2CP	1802 BUIC-LeSABRE	3267	.	.	.	.	.	.	.	.
	2CP	1903 CADI-DeVILLE	3523	3521	3519	.	.	.	.	.	.
	2CP	2102 OLDS-DELTA 88	3267	.	.	.	.	.	.	.	.
	4SD	1802 BUIC-LeSABRE	3286	3431	3429	3449	3421	3430	3441	3443	3444
	4SD	1803 BUIC-ELECTRA/PA C	3596	3558	3564	3553	3532	3536	.	.	.
	4SD	2102 OLDS-DELTA 88	3296	3424	3417	3440	3400	3455	3477	3503	3455
	4SD	2103 OLDS-98 C	3586	3598	3531	3520	3514	3515	.	.	.
	4SD	2202 PONT-BONNEVILLE	3353	3473	3467	3436	3418	3446	3470	3461	3458
1854	2CP	1818 BUIC-SKYLARK N	2633	2850	2804	2803	2917	2917	2945	.	.
	2CP	2118 OLDS-CALAIS N	2551	.	.	.	.	.	.	.	.
	2CP	2121 OLDS-ACHIEVA/ALERO N	.	2719	2717	2768	2826	2851	2886	.	.
	2CP	2218 PONT-GRAND AM N	2573	2752	2762	2756	2819	2881	2835	2835	.
	4SD	1818 BUIC-SKYLARK N	2687	2895	2848	2859	2948	2948	2985	2985	.
	4SD	2118 OLDS-CALAIS N	2639	.	.	.	.	.	.	.	.
	4SD	2121 OLDS-ACHIEVA/ALERO N	.	2806	2779	2828	2888	2913	2917	2917	.
	4SD	2218 PONT-GRAND AM N	2654	2794	2805	2803	2855	2854	2876	2877	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
1855	2CP	1805 BUIC-RIVIERA E	3496	3498	3504	.	.	.	.	.	.
	2CP	1905 CADI-ELDORADO E	3458	3569	3604	3786	3790	3779	3838	3855	3857
	2CP	2105 OLDS-TORONADO E	3503	3516	.	.	.	.	.	.	.
	4SD	1914 CADI-SEVILLE K	3514	.	.	.	.	.	.	.	.
1856	2CP	2019 CHEV-BERETTA/CORSICA L	2736	2796	2774	2774	2756	2756	.	.	.
	4SD	2019 CHEV-BERETTA/CORSICA L	2699	2752	2743	2743	2745	2745	.	.	.
	5HB	2019 CHEV-BERETTA/CORSICA L	2773	.	.	.	.	.	.	.	.
1857	CV	1909 CADI-ALLANTE V	3480	3494	3752	.	.	.	.	.	.
1858	CV	1821 BUIC-REATTA EC	3596	.	.	.	.	.	.	.	.
	2CP	1821 BUIC-REATTA EC	3391	.	.	.	.	.	.	.	.
1859	CV	2120 OLDS-SUPREME W	3602	3589	3714	3636	3629	.	.	.	.
	2CP	1820 BUIC-REGAL W	3296	3267	3295	3279	3258	3232	.	.	.
	2CP	2020 CHEV-LUMINA W	3242	3288	3355	3331	.	.	.	.	.
	2CP	2036 CHEV-MONTE CARLO W	.	.	.	.	3343	3306	3243	3239	3332
	2CP	2120 OLDS-SUPREME W	3236	3248	3252	3302	3290	3283	3283	.	.
	2CP	2220 PONT-GRAND PRIX W	3256	3203	3232	3248	3243	3243	.	.	.
	4SD	1820 BUIC-REGAL W	3366	3336	3361	3353	3335	3331	.	.	.
	4SD	2020 CHEV-LUMINA W	3274	3310	3280	3332	3320	3330	3330	3330	3330
	4SD	2120 OLDS-SUPREME W	3367	3382	3358	3384	3380	3388	3388	.	.
	4SD	2220 PONT-GRAND PRIX W	3292	3308	3320	3319	3318	3318	.	.	.
1860	4SD	1903 CADI-DeVILLE	3597	3594	3607	.	.	.	.	.	.
1861	2CP	2402 SATURN SC Z	2375	2372	2369	2334	2328	2331	.	.	.
1862	2CP	2402 SATURN SC Z	.	.	.	.	.	.	2360	2420	2413
	4SD	2401 SATURN SL Z	2319	2335	2376	2394	2362	2390	2360	2368	2363
	SW	2403 SATURN SW Z	.	.	2432	2424	2429	2491	2441	2392	2440
1863	4SD	1914 CADI-SEVILLE K	.	3661	3685	3853	3892	3848	3900	.	.
1864	4SD	1903 CADI-DeVILLE	.	.	.	3813	3791	3961	4013	4022	4021
1865	2CP	1805 BUIC-RIVIERA E	.	.	.	.	3682	3690	3720	3699	3713
	4SD	1803 BUIC-ELECTRA/PA C	.	.	.	.	.	.	3788	3740	3740
	4SD	2122 OLDS-AURORA	.	.	.	.	3953	3967	3967	3967	3967
1866	CV	2016 CHEV-CAVALIER J	.	.	.	.	2838	2838	2838	2899	2838
	CV	2216 PONT-SUNBIRD/FIRE J	.	.	.	.	2835	2835	2870	2870	2898
	2CP	2016 CHEV-CAVALIER J	.	.	.	.	2617	2617	2617	2584	2617
	2CP	2216 PONT-SUNBIRD/FIRE J	.	.	.	.	2679	2679	2627	2637	2630
	4SD	2016 CHEV-CAVALIER J	.	.	.	.	2676	2676	2676	2676	2676
	4SD	2216 PONT-SUNBIRD/FIRE J	.	.	.	.	2723	2723	2670	2674	2670
1867	4SD	1914 CADI-SEVILLE K	.	.	.	.	.	.	.	3988	3970
1868	2CP	2121 OLDS-ACHIEVA/ALERO N	.	.	.	.	.	.	.	.	3026
	2CP	2218 PONT-GRAND AM N	.	.	.	.	.	.	.	.	3065
	4SD	2037 CHEV-MALIBU FWD	.	.	.	.	.	.	2976	2976	3054
	4SD	2120 OLDS-SUPREME W	.	.	.	.	.	.	2982	2982	3102
	4SD	2121 OLDS-ACHIEVA/ALERO N	.	.	.	.	.	.	.	.	3026
	4SD	2218 PONT-GRAND AM N	.	.	.	.	.	.	.	.	3112
1869	2CP	2220 PONT-GRAND PRIX W	.	.	.	.	.	.	3395	3396	3396
	4SD	2220 PONT-GRAND PRIX W	.	.	.	.	.	.	3394	3414	3414
1870	2CP	2404 GM EV1 (ELECTRIC)	.	.	.	.	.	.	2970	.	2970
1871	4SD	1817 BUIC-CENTURY A	.	.	.	.	.	.	3348	3335	3368
	4SD	1820 BUIC-REGAL W	.	.	.	.	.	.	3455	3447	3439
	4SD	2123 OLDS INTRIGUE	.	.	.	.	.	.	.	3455	3467
1872	CV	2004 CHEV-CORVETTE Y	.	.	.	.	.	.	.	3245	3246

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
1872	2CP	2004 CHEV-CORVETTE Y	.	.	.	.	.	.	3298	3245	3246
3004	CV	3042 VW GOLF/CABRIOLET	2307	2307	2350	.	.	.	.	.	.
3006	CV	3043 VW CABRIO	.	.	.	.	2778	2778	2701	2771	2771
	2CP	3040 VW JETTA	2298	.	.	.	.	.	.	.	.
	2CP	3045 VW CORRADO	2558	2797	2810	2808	.	.	.	.	.
	3HB	3042 VW GOLF/CABRIOLET	2350	2338	2506	2511	2652	2634	2669	2696	.
	4SD	3040 VW JETTA	2424	2340	2647	2653	2666	2658	2684	2659	.
	5HB	3042 VW GOLF/CABRIOLET	2375	2375	2577	2577	2615	2615	2615	2544	.
3007	2CP	3044 VW FOX	2172	2172	2172	.	.	.	.	.	.
	4SD	3044 VW FOX	2238	2238	2238	.	.	.	.	.	.
3008	4SD	3046 VW PASSAT	2985	2985	3136	3152	3140	3140	3076	.	.
	SW	3046 VW PASSAT	3029	3029	3197	3197	3201	3201	3170	.	.
3009	4SD	3046 VW PASSAT	.	.	.	.	.	.	.	3120	3120
	SW	3046 VW PASSAT	.	.	.	.	.	.	.	3194	3201
3010	3HB	3047 VW NEW BEETLE	.	.	.	.	.	.	.	2712	2769
3098	3HB	3042 VW GOLF/CABRIOLET	.	.	.	.	.	.	.	.	2700
	4SD	3040 VW JETTA	.	.	.	.	.	.	.	.	2750
	5HB	3042 VW GOLF/CABRIOLET	.	.	.	.	.	.	.	.	2700
3205	4SD	3237 AUDI 100/200	3273	3438	3492	3411	.	.	.	.	.
	4SD	3240 AUDI S4/S6	.	.	.	.	3825	.	.	.	.
	4SD	3242 AUDI A6	.	.	.	.	3581	3611	3686	.	.
	SW	3237 AUDI 100/200	3726	3892	3892	3620	.	.	.	.	.
	SW	3240 AUDI S4/S6	.	.	.	.	3825	.	.	.	.
	SW	3242 AUDI A6	.	.	.	.	3809	3819	3843	3704	.
3206	2CP	3236 AUDI 80/90	3308	.	.	.	.	.	.	.	.
	4SD	3236 AUDI 80/90	2957	2936	.	.	.	.	.	.	.
3207	4SD	3236 AUDI 80/90	.	.	3285	3245	3233	.	.	.	.
	4SD	3243 AUDI A4	.	.	.	.	.	3119	3118	3110	3109
3208	CV	3241 AUDI CABRIOLET	.	.	.	3494	3494	3364	3364	3364	.
3209	4SD	3244 AUDI A8	.	.	.	.	.	.	3886	3900	3813
3210	4SD	3242 AUDI A6	.	.	.	.	.	.	.	3679	3560
	SW	3242 AUDI A6	.	.	.	.	.	.	.	.	3857
3407	CV	3434 BMW 300	2920	2953	2988	.	.	.	.	.	.
	2CP	3434 BMW 300	2684	2974	.	.	.	.	.	.	.
	4SD	3434 BMW 300	2702	.	.	.	.	.	.	.	.
3410	4SD	3437 BMW 700	3793	3795	4001	4001	.	.	.	.	.
3411	4SD	3437 BMW 700	4058	4013	4094	4058	.	.	.	.	.
3412	4SD	3435 BMW 500	3525	3495	3491	3601	3541	.	.	.	.
	SW	3435 BMW 500	.	3759	3760	3830	3767	.	.	.	.
3413	2CP	3438 BMW 850	4123	4123	4123	4132	4175	4227	4190	.	.
3414	CV	3434 BMW 300	.	.	.	3301	3282	3120	3322	3368	3377
	2CP	3434 BMW 300	.	.	3006	3000	3092	3053	3118	3116	3156
	3HB	3434 BMW 300	.	.	.	.	2734	2734	2745	2778	2778
	4SD	3434 BMW 300	.	3003	3037	3008	3026	3060	3088	2997	.
3415	4SD	3437 BMW 700	.	.	.	.	4145	.	4255	4255	4255
3416	4SD	3437 BMW 700	.	.	.	.	4219	4252	4296	4311	4308

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
3417	CV	3439 BMW Z3	.	.	.	.	.	2690	2690	2826	2935
	3HB	3439 BMW Z3	.	.	.	.	.	.	.	.	3057
3418	4SD	3435 BMW 500	.	.	.	.	.	.	3519	3507	3552
	SW	3435 BMW 500	.	.	.	.	.	.	.	.	3791
3419	4SD	3434 BMW 300	.	.	.	.	.	.	.	.	3170
3522	4SD	3542 NISSAN STANZA	2788	2788	.	.	.	.	.	.	.
	4SD	5833 INFINITI G20	2747	2789	2745	2877	2877	2877	.	.	.
3524	2CP	3543 NISSAN SENTRA	2286	2280	2335	2387	.	.	.	.	.
	2CP	3546 NISSAN NX	2445	2401	2404	.	.	.	.	.	.
	4SD	3543 NISSAN SENTRA	2266	2288	2368	2407	.	.	.	.	.
3525	4SD	3539 NISSAN MAXIMA	3129	3135	3145	3165	.	.	.	.	.
3526	CV	3532 NISSAN 200/240SX	.	3093	3093	2870	.	.	.	.	.
	2CP	3532 NISSAN 200/240SX	2684	2699	2699	.	.	.	.	.	.
	3HB	3532 NISSAN 200/240SX	2748	2748	2730	.	.	.	.	.	.
3527	CV	3534 NISSAN 300ZX	.	.	.	3446	3446	3401	.	.	.
	3HB	3534 NISSAN 300ZX	3272	3272	3272	3351	3363	3358	.	.	.
3528	3HB	3534 NISSAN 300ZX	3313	3313	3313	3413	3414	3401	.	.	.
3529	CV	5831 INFINITI M30	3576	3576	.	.	.	.	.	.	.
	2CP	5831 INFINITI M30	3333	3333	.	.	.	.	.	.	.
3530	4SD	5832 INFINITI Q45	3950	3957	3957	4039	4039	4039	.	.	.
3531	SW	3548 NISSAN AXXESS	2937	.	.	.	.	.	.	.	.
3532	4SD	3547 NISSAN ALTIMA	.	.	2829	2829	2853	2853	2853	2859	2859
3533	4SD	5834 INFINITI J30	.	.	3527	3527	3527	3527	3527	.	.
3534	4SD	3539 NISSAN MAXIMA	.	.	.	.	3002	3001	3001	3069	3012
	4SD	5835 INFINITI I30	.	.	.	.	.	3090	3090	3150	3150
3535	2CP	3532 NISSAN 200/240SX	.	.	.	.	2752	2753	2800	2800	.
3536	2CP	3532 NISSAN 200/240SX	.	.	.	.	.	2330	2330	2363	.
	2CP	3543 NISSAN SENTRA	.	.	.	.	2320	.	.	.	.
	4SD	3543 NISSAN SENTRA	.	.	.	.	2300	2315	2315	2315	2392
3537	4SD	5832 INFINITI Q45	.	.	.	.	.	.	3879	3879	4007
3538	4SD	5833 INFINITI G20	.	.	.	.	.	.	.	.	2913
3710	4SD	5431 ACURA INTEGRA	2680	2666	2664	.	.	.	.	.	.
3711	4SD	6131 STERLING	3181	.	.	.	.	.	.	.	.
	5HB	6131 STERLING	3285	.	.	.	.	.	.	.	.
3714	3HB	3735 HONDA CRX/DEL SOL	2098	.	.	.	.	.	.	.	.
3715	3HB	3731 HONDA CIVIC	2164	.	.	.	.	.	.	.	.
	4SD	3731 HONDA CIVIC	2290	.	.	.	.	.	.	.	.
	SW	3731 HONDA CIVIC	2414	.	.	.	.	.	.	.	.
3716	2CP	3733 HONDA PRELUDE	2679	.	.	.	.	.	.	.	.
3717	2CP	3733 HONDA PRELUDE	.	2841	2868	2765	2809	2809	.	.	.
	3HB	5431 ACURA INTEGRA	2617	2616	2616	.	.	.	.	.	.
3718	2CP	3732 HONDA ACCORD	2841	2874	2907	.	.	.	.	.	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
3718	4SD	3732 HONDA ACCORD	2869	2901	2928	.	.	.	.	.	.
	SW	3732 HONDA ACCORD	3126	3126	3162	.	.	.	.	.	.
3719	2CP	5433 ACURA NSX	3010	3009	3020	3020	3047	3047	3047	3066	3066
3720	2CP	5432 ACURA LEGEND	3408	3437	3438	3583	3516	.	.	.	.
3721	4SD	5432 ACURA LEGEND	3455	3464	3532	3583	3516	.	.	.	.
3722	3HB	3731 HONDA CIVIC	.	2158	2178	2108	2108	.	.	.	.
	3HB	5431 ACURA INTEGRA	.	.	.	2529	2529	2529	2529	2527	2643
3723	2CP	3731 HONDA CIVIC	.	.	2298	2231	2221	2271	2271	2271	2359
	3HB	3731 HONDA CIVIC	.	.	.	.	.	2238	2238	2238	2359
	4SD	3731 HONDA CIVIC	.	2318	2327	2313	2313	2319	2319	2319	2339
	4SD	5431 ACURA INTEGRA	.	.	.	2628	2628	2628	2703	2703	2703
3724	4SD	5434 ACURA VIGOR	.	3200	3199	3142	.	.	.	.	.
3725	2CP	3735 HONDA CRX/DEL SOL	.	.	2349	2301	2295	2295	2302	.	.
3726	2CP	3732 HONDA ACCORD	.	.	.	2756	2822	2855	2855	.	.
	2CP	5437 ACURA CL	.	.	.	.	.	.	3009	3062	3120
	4SD	3732 HONDA ACCORD	.	.	.	2800	2800	2855	2855	2888	2888
	SW	3732 HONDA ACCORD	.	.	.	3076	3076	3053	3053	.	.
3727	4SD	5435 ACURA TL	.	.	.	.	3461	3327	3377	3420	.
3728	4SD	5436 ACURA RL	.	.	.	.	.	3660	3660	3660	3840
3729	2CP	3733 HONDA PRELUDE	.	.	.	.	.	.	2954	2954	2954
3730	2CP	3732 HONDA ACCORD	.	.	.	.	.	.	.	2943	2943
3731	3HB	3736 HONDA EV PLUS	.	.	.	.	.	.	3594	3594	3594
3732	4SD	5435 ACURA TL	.	.	.	.	.	.	.	.	3461
3804	2CP	3832 ISUZU IMPULSE	2437	2437	.	.	.	.	.	.	.
	3HB	2035 GEO STORM R	2315	2303	2314	.	.	.	.	.	.
	3HB	3832 ISUZU IMPULSE	2367	2367	.	.	.	.	.	.	.
	4SD	3833 ISUZU STYLUS	2304	2289	2253	.	.	.	.	.	.
3903	4SD	3932 JAGUAR XJ* VANDEN P	3965	3990	4026	4076	4100	4088	4084	4009	3959
3904	CV	3931 JAGUAR XJ-S/XK* COUPE	4250	4250	3941	3969	3805	3855	.	.	.
	2CP	3931 JAGUAR XJ-S/XK* COUPE	4050	4050	3725	3742	3805	.	.	.	.
3905	4SD	3932 JAGUAR XJ* VANDEN P	.	.	.	.	.	4160	4110	4056	3967
3906	CV	3931 JAGUAR XJ-S/XK* COUPE	.	.	.	.	.	.	3673	3673	3709
	2CP	3931 JAGUAR XJ-S/XK* COUPE	.	.	.	.	.	.	3673	3673	3709
4112	CV	4134 MAZDA RX-7	3071	.	.	.	.	.	.	.	.
	2CP	4134 MAZDA RX-7	2795	.	.	.	.	.	.	.	.
4113	4SD	4137 MAZDA 626	2690	2610	.	.	.	.	.	.	.
	5HB	4137 MAZDA 626	2732	.	.	.	.	.	.	.	.
4114	4SD	4143 MAZDA 929	3555	.	.	.	.	.	.	.	.
4115	2CP	4144 MAZDA MX-6	2746	2745	.	.	.	.	.	.	.
	3HB	1218 FORD PROBE	2892	2812	.	.	.	.	.	.	.
4116	3HB	4135 MAZDA 323/GLC/PROTEGE	2238	2238	2238	2238	.	.	.	.	.
4117	2CP	1213 FORD ESCORT	.	.	.	.	.	.	.	2478	2478

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
4117	3HB	1213 FORD ESCORT	2350	2350	2331	2335	2316	2323	.	.	.
	4SD	1213 FORD ESCORT	.	2379	2361	2371	2385	2378	2468	2468	2468
	4SD	1436 MERC-TRACER	2376	2368	2357	2396	2418	2409	2457	2469	2469
	4SD	4135 MAZDA 323/GLC/PROTEGE	2406	2423	2419	2388	.	.	.	.	.
	5HB	1213 FORD ESCORT	2355	2355	2354	2419	2404	2398	.	.	.
	SW	1213 FORD ESCORT	2411	2411	2403	2419	2451	2444	2525	2531	2531
	SW	1436 MERC-TRACER	2468	2468	2462	2476	2498	2485	2523	2532	2532
4118	CV	4145 MAZDA MIATA	2182	2216	2216	2293	2293	2293	2293	.	2299
4119	2CP	4146 MAZDA MX-3	.	2411	2399	2456	2443	.	.	.	.
4120	4SD	4143 MAZDA 929	.	3596	3596	3627	3627	.	.	.	.
4121	2CP	4144 MAZDA MX-6	.	.	2657	2625	2625	2625	2625	.	.
	3HB	1218 FORD PROBE	.	.	2754	2769	2750	2755	2690	.	.
	4SD	4137 MAZDA 626	.	.	2670	2670	2743	2749	2749	.	.
4122	2CP	4134 MAZDA RX-7	.	.	2789	2826	2830	.	.	.	.
4123	4SD	4135 MAZDA 323/GLC/PROTEGE	.	.	.	.	2448	2448	2448	2448	.
4124	4SD	4147 MAZDA MILLENIA	.	.	.	.	3216	3216	3216	3244	3241
4125	4SD	4137 MAZDA 626	.	.	.	.	.	.	.	2840	2840
4126	4SD	4135 MAZDA 323/GLC/PROTEGE	.	.	.	.	.	.	.	.	2449
4210	4SD	4237 MERCEDES S THRU 1991	3761	.	.	.	.	.	.	.	.
4211	4SD	4236 MERCEDES SEL/SEC	3950	.	.	.	.	.	.	.	.
4212	2CP	4236 MERCEDES SEL/SEC	3915	.	.	.	.	.	.	.	.
4213	4SD	4239 MERCEDES 190	2958	2968	2984	.	.	.	.	.	.
4214	4SD	4231 MERCEDES E THRU 1995	3377	3474	3536	3580	3530	.	.	.	.
	SW	4231 MERCEDES E THRU 1995	3718	3694	3783	3750	3750	.	.	.	.
4216	CV	4231 MERCEDES E THRU 1995	.	.	4025	4025	4025	.	.	.	.
	2CP	4231 MERCEDES E THRU 1995	3505	3505	3525	3525	3525	.	.	.	.
4217	CV	4244 MERCEDES SL CV	4091	4266	4196	4199	4140	4126	4148	4189	4135
4218	2CP	4236 MERCEDES SEL/SEC	.	.	4917	.	.	.	.	.	.
	4SD	4243 MERCEDES S430/S500	.	4609	4687	4627	4610	4500	4500	4500	4506
4219	4SD	4236 MERCEDES SEL/SEC	.	4985	5095	.	.	.	.	.	.
	4SD	4243 MERCEDES S430/S500	.	4740	4830	4801	4700	4617	4628	4607	4650
4220	CV	4247 MERCEDES CLK 2CP	.	.	.	.	.	.	.	.	3669
	2CP	4247 MERCEDES CLK 2CP	.	.	.	.	.	.	.	3240	3365
	4SD	4242 MERCEDES C SEDAN	.	.	.	3278	3259	3245	3266	3268	3279
4221	2CP	4246 MERCEDES CL COUPE	.	.	.	4856	4835	4763	4763	4780	4798
4222	4SD	4248 MERCEDES E SEDAN	.	.	.	.	.	3588	3652	3652	3572
	SW	4248 MERCEDES E SEDAN	.	.	.	.	.	.	.	3757	3757
4223	CV	4245 MERCEDES SLK	.	.	.	.	.	.	.	3036	2992
4407	SW	4434 PEUGEOT 505	3338	3397	.	.	.	.	.	.	.
4408	4SD	4436 PEUGEOT 405	2602	2607	.	.	.	.	.	.	.
	SW	4436 PEUGEOT 405	2692	2625	.	.	.	.	.	.	.
4501	CV	4531 PORSCHE 911	3031	.	.	.	3064	3076	3078	3171	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
4501	2CP	4531 PORSCHE 911	3097	.	.	.	3031	3226	3223	3197	.
4503	CV	4537 PORSCHE 944	3109	.	.	.	.	.	.	.	.
	CV	4539 PORSCHE 968	.	.	.	.	3240	.	.	.	.
	2CP	4537 PORSCHE 944	2998	.	.	.	.	.	.	.	.
	2CP	4539 PORSCHE 968	.	.	.	.	3086	.	.	.	.
4504	2CP	4535 PORSCHE 928	3505	.	.	.	3593	.	.	.	.
4505	CV	4550 PORSCHE UNK MDL	.	3109	3230	3142	.	.	.	.	.
	2CP	4550 PORSCHE UNK MDL	.	3051	3103	3133	.	.	.	.	.
4506	CV	4540 PORSCHE BOXSTER	.	.	.	.	.	.	2822	2822	2822
4507	CV	4531 PORSCHE 911	.	.	.	.	.	.	.	.	3197
	2CP	4531 PORSCHE 911	.	.	.	.	.	.	.	.	3031
4609	4SD	740 DODGE MONACO	3013	3004	.	.	.	.	.	.	.
	4SD	1040 EAGLE PREMIER	3079	3059	.	.	.	.	.	.	.
4704	CV	4731 SAAB 900	3002	3001	3012	3009	.	.	.	.	.
	3HB	4731 SAAB 900	2835	2768	2797	.	.	.	.	.	.
	4SD	4731 SAAB 900	2818	2776	2810	.	.	.	.	.	.
4705	4SD	4734 SAAB 9000	3150	3245	3160	3210	3250	.	.	.	.
	5HB	4734 SAAB 9000	3082	3109	3135	3129	3250	3154	3147	3250	.
4706	CV	4731 SAAB 900	.	.	.	.	3086	3080	3090	3090	.
	CV	4735 SAAB 9-3	.	.	.	.	.	.	.	.	3145
	3HB	4731 SAAB 900	.	.	.	2990	2940	2940	2940	2980	.
	3HB	4735 SAAB 9-3	.	.	.	.	.	.	.	.	2991
	5HB	4731 SAAB 900	.	.	.	2950	2980	2990	2990	2990	.
	5HB	4735 SAAB 9-3	.	.	.	.	.	.	.	.	2993
4707	4SD	4736 SAAB 9-5	.	.	.	.	.	.	.	.	3445
	SW	4736 SAAB 9-5	.	.	.	.	.	.	.	.	3640
4806	2CP	4835 SUBARU XT	2763	.	.	.	.	.	.	.	.
	4SD	4831 SUBARU GL/DL/LOYALE	2389	2375	2365	.	.	.	.	.	.
	SW	4831 SUBARU GL/DL/LOYALE	2602	2595	2588	2635	.	.	.	.	.
4808	3HB	4836 SUBARU JUSTY	1897	1850	1847	1845	.	.	.	.	.
	5HB	4836 SUBARU JUSTY	2045	2045	2045	2045	.	.	.	.	.
4809	4SD	4834 SUBARU LEGACY	2851	2934	2849	2831	.	.	.	.	.
	SW	4834 SUBARU LEGACY	2972	2922	3054	2977	.	.	.	.	.
4810	2CP	4837 SUBARU SVX	.	3575	3580	3460	3525	3525	3525	.	.
4811	2CP	4838 SUBARU IMPREZA	.	.	.	.	2504	2715	2720	2720	2730
	4SD	4838 SUBARU IMPREZA	.	.	2397	2369	2523	2683	2690	2690	2735
	SW	4838 SUBARU IMPREZA	.	.	2573	2488	2750	2795	2795	2846	2835
4812	4SD	4834 SUBARU LEGACY	.	.	.	.	2766	2825	2885	2885	2885
	SW	4834 SUBARU LEGACY	.	.	.	.	2912	2915	2975	2905	2898
4919	2CP	4932 TOYOTA COROLLA	2296	.	.	.	.	.	.	.	.
	4SD	2032 CHEV-NOVA/PRIZM S	2436	2436	.	.	.	.	.	.	.
	4SD	4932 TOYOTA COROLLA	2257	2267	.	.	.	.	.	.	.
	5HB	2032 CHEV-NOVA/PRIZM S	2486	.	.	.	.	.	.	.	.
	SW	4932 TOYOTA COROLLA	2355	2374	.	.	.	.	.	.	.
4920	4SD	4940 TOYOTA CAMRY	2786	.	.	.	.	.	.	.	.
	4SD	5931 LEXUS ES-250/300	3219	.	.	.	.	.	.	.	.
	SW	4940 TOYOTA CAMRY	2988	.	.	.	.	.	.	.	.
4923	3HB	4934 TOYOTA SUPRA	3512	3509	.	.	.	.	.	.	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
4924	CV	4933 TOYOTA CELICA	2844	2844	3020	.	.	.	.	.	.
	2CP	4933 TOYOTA CELICA	2555	2526	2733	.	.	.	.	.	.
	3HB	4933 TOYOTA CELICA	2747	2689	2902	.	.	.	.	.	.
4925	CV	4942 TOYOTA PASEO	.	.	.	.	.	.	2163	.	.
	2CP	4938 TOYOTA TERCEL	1950	1957	1955	1955	1950	1950	2010	2090	.
	2CP	4942 TOYOTA PASEO	.	2070	2070	2070	2070	2025	2025	.	.
	4SD	4938 TOYOTA TERCEL	2005	2005	2005	2005	2005	1974	2035	.	.
4926	4SD	5932 LEXUS LS-400	3759	3759	3858	3859	.	.	.	.	.
4927	2CP	4941 TOYOTA MR2	2599	2638	2663	2657	2657	.	.	.	.
4928	2CP	4940 TOYOTA CAMRY	.	.	.	2991	2910	2910	.	.	.
	4SD	4940 TOYOTA CAMRY	.	2965	2965	2957	2949	2945	.	.	.
	4SD	5931 LEXUS ES-250/300	.	3406	3362	3374	3374	3373	.	.	.
	SW	4940 TOYOTA CAMRY	.	3116	3218	3216	3263	3263	.	.	.
4929	2CP	5933 LEXUS SC-300/400	.	3556	3547	3578	3597	3585	3552	3600	3590
4930	4SD	2032 CHEV-NOVA/PRIZM S	.	.	2350	2359	2359	2359	2359	2403	2403
	4SD	4932 TOYOTA COROLLA	.	.	2315	2315	2315	2315	2337	2414	2414
	SW	4932 TOYOTA COROLLA	.	.	2392	2480	2403	2403	.	.	.
4931	3HB	4934 TOYOTA SUPRA	.	.	3320	3320	3320	3320	3320	3320	.
4932	4SD	5934 LEXUS GS-300	.	.	3625	3660	3669	3660	3660	.	.
4933	CV	4933 TOYOTA CELICA	.	.	.	.	2755	2755	2755	2755	2755
	2CP	4933 TOYOTA CELICA	.	.	.	2490	2490	2490	2490	2560	.
	3HB	4933 TOYOTA CELICA	.	.	.	2510	2510	2510	2510	2580	2580
4934	4SD	5932 LEXUS LS-400	.	.	.	.	3650	3649	3726	3890	3890
4935	4SD	4943 TOYOTA AVALON	.	.	.	.	3285	3285	3285	3340	3340
4936	2CP	4944 TOYOTA CAMRY SOLARA	.	.	.	.	.	.	.	.	3120
	4SD	4940 TOYOTA CAMRY	.	.	.	.	.	.	2976	2998	2998
	4SD	5931 LEXUS ES-250/300	.	.	.	.	.	.	3296	3378	3351
4937	4SD	4935 TOYOTA CRESSIDA	3439	3439	.	.	.	.	.	.	.
4938	4SD	5934 LEXUS GS-300	.	.	.	.	.	.	.	3657	3652
5104	4SD	5134 VOLVO 240	2919	2954	2919	.	.	.	.	.	.
	SW	5134 VOLVO 240	3051	3084	3054	.	.	.	.	.	.
5105	2CP	5138 VOLVO 760/780	3415	.	.	.	.	.	.	.	.
	4SD	5139 VOLVO 740	2977	2996	.	.	.	.	.	.	.
	4SD	5140 VOLVO 940	3120	3042	3067	3205	3208	.	.	.	.
	4SD	5141 VOLVO 960	.	3460	3460	3490	3461	3461	3461	.	.
	4SD	5144 VOLVO 90-SERIES	.	.	.	.	.	.	.	3461	.
	SW	5139 VOLVO 740	3077	3156	.	.	.	.	.	.	.
	SW	5140 VOLVO 940	3140	3194	3177	3280	3283	.	.	.	.
	SW	5141 VOLVO 960	.	3370	3370	3460	3547	3547	3547	.	.
	SW	5144 VOLVO 90-SERIES	.	.	.	.	.	.	.	3547	.
5106	CV	5143 VOLVO 70-SERIES	.	.	.	.	.	.	.	3601	3601
	2CP	5143 VOLVO 70-SERIES	.	.	.	.	.	.	.	3365	3365
	4SD	5142 VOLVO 850	.	.	3187	3180	3235	3232	3244	.	.
	4SD	5143 VOLVO 70-SERIES	.	.	.	.	.	.	.	3152	3221
	SW	5142 VOLVO 850	.	.	.	3300	3342	3342	3355	.	.
	SW	5143 VOLVO 70-SERIES	.	.	.	.	.	.	.	3500	3500
5107	4SD	5145 VOLVO S80	.	.	.	.	.	.	.	.	3602
5208	SW	744 DODGE VISTA	2800	.	.	.	.	.	.	.	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
5208	SW	944 PLYM-VISTA	2807	.	.	.	.	.	.	.	.
5209	4SD	5234 MITS-GALANT	2752	2729	2734	.	.	.	.	.	.
5210	3HB	1034 EAGLE SUMMIT	2262	.	.	.	.	.	.	.	.
	4SD	1034 EAGLE SUMMIT	2277	2278	.	.	.	.	.	.	.
	4SD	5235 MITS-MIRAGE	2271	2272	.	.	.	.	.	.	.
5211	3HB	734 DODGE COLT	2262	2232	.	.	.	.	.	.	.
	3HB	934 PLYM-COLT/CHAMP	2262	2266	.	.	.	.	.	.	.
	3HB	1034 EAGLE SUMMIT	.	2221	.	.	.	.	.	.	.
	3HB	5235 MITS-MIRAGE	2205	2205	.	.	.	.	.	.	.
5212	3HB	937 PLYM-LASER	2658	2604	2619	2533	.	.	.	.	.
	3HB	1037 EAGLE TALON	2873	2858	2741	2566	.	.	.	.	.
	3HB	5237 MITS-ECLIPSE	2651	2611	2603	2617	.	.	.	.	.
5213	CV	5239 MITS-3000GT	.	.	.	.	4083	4123	.	.	.
	3HB	739 DODGE STEALTH	3274	3404	3207	3124	3116	3180	.	.	.
	3HB	5239 MITS-3000GT	3499	3486	3387	3255	3270	3287	3230	3180	3221
5214	SW	944 PLYM-VISTA	.	2825	2791	2800	.	.	.	.	.
	SW	1044 EAGLE SUMMIT SW	.	2797	2804	2814	2840	2836	.	.	.
	SW	5244 MITS-EXPO LRV	.	2732	2740	2745	.	.	.	.	.
5215	4SD	5240 MITS-DIAMANTE	.	3480	3447	3483	3605	3483	3483	3417	3440
	SW	5240 MITS-DIAMANTE	.	.	3609	3610	3638	.	.	.	.
	SW	5245 MITS-EXPO SP	.	2981	3025	3034	3066	.	.	.	.
5216	2CP	734 DODGE COLT	.	.	2093	2130	.	.	.	.	.
	2CP	934 PLYM-COLT/CHAMP	.	.	2093	2121	.	.	.	.	.
	2CP	1034 EAGLE SUMMIT	.	.	2094	2164	2085	2085	.	.	.
	2CP	5235 MITS-MIRAGE	.	.	2103	2085	2085	2085	.	.	.
5217	4SD	734 DODGE COLT	.	.	2231	2188	.	.	.	.	.
	4SD	934 PLYM-COLT/CHAMP	.	.	2231	2171	.	.	.	.	.
	4SD	1034 EAGLE SUMMIT	.	.	2236	2195	2195	2250	.	.	.
	4SD	5235 MITS-MIRAGE	.	.	2217	2195	2085	2085	2227	2225	2249
5218	2CP	643 CHRY-SEBRING	.	.	.	.	2912	2908	2959	2959	2967
	2CP	742 DODGE AVENGER	.	.	.	.	2822	2879	2888	2888	2893
	4SD	5234 MITS-GALANT	.	.	.	2755	2755	2755	2800	2850	2900
5219	CV	5237 MITS-ECLIPSE	.	.	.	.	.	2767	2888	2888	2888
	3HB	1037 EAGLE TALON	.	.	.	.	2921	2838	2750	2760	.
	3HB	5237 MITS-ECLIPSE	.	.	.	.	2723	2777	2785	2780	2773
5220	CV	643 CHRY-SEBRING	.	.	.	.	.	3350	3350	3344	3331
5221	2CP	5235 MITS-MIRAGE	.	.	.	.	.	.	2127	2125	2150
5303	CV	2034 CHEVY/GEO METRO M	1753	1753	1753	.	.	.	.	.	.
	3HB	2034 CHEVY/GEO METRO M	1620	1646	1645	1621	.	.	.	.	.
	3HB	5334 SUZUKI SWIFT	1762	1766	1791	1802	.	.	.	.	.
5304	3HB	2034 CHEVY/GEO METRO M	.	.	.	.	1808	1808	1832	1895	1895
	3HB	5334 SUZUKI SWIFT	.	.	.	.	1856	1878	1878	1895	1895
	4SD	2034 CHEVY/GEO METRO M	.	.	.	.	1940	1940	1962	1984	1984
	4SD	5334 SUZUKI SWIFT	1848	1861	1900	1894	.	.	.	.	.
	5HB	2034 CHEVY/GEO METRO M	1693	1694	1694	1694	.	.	.	.	.
	5HB	5334 SUZUKI SWIFT	1720	.	.	.	.	.	.	.	.
5305	4SD	5332 SUZUKI ESTEEM	.	.	.	.	2183	2183	2183	2227	2227
	SW	5332 SUZUKI ESTEEM	.	.	.	.	.	.	.	2359	2359
5501	4SD	5533 HYUN-SONATA	2806	2798	2801	2863	.	.	.	.	.

CURB WEIGHTS OF 1991-99 PASSENGER CARS

CGP	BOD2	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
5502	2CP	5534 HYUN-SCOUPE	2192	2197	2208	2226	2226	.	.	.	.
	3HB	5236 MITS-PRECIS	2197	2197	2197	2197	.	.	.	.	.
	3HB	5532 HYUN-EXCEL	2197	2197	2197	2197	.	.	.	.	.
	4SD	5532 HYUN-EXCEL	2235	2235	2235	2235	.	.	.	.	.
5503	4SD	5535 HYUN-ELANTRA	.	2550	2550	2550	2550	.	.	.	.
5504	3HB	5536 HYUN-ACCENT	.	.	.	.	2150	2150	2150	2150	2150
	4SD	5536 HYUN-ACCENT	.	.	.	.	2150	2150	2150	2150	2150
5505	4SD	5533 HYUN-SONATA	.	.	.	.	2864	2864	2935	2935	3070
5506	4SD	5535 HYUN-ELANTRA	.	.	.	.	.	2560	2560	2560	2560
	SW	5535 HYUN-ELANTRA	.	.	.	.	.	2670	2670	2670	2670
5507	2CP	5537 HYUN-TIBURON	.	.	.	.	.	.	2566	2566	2566
5701	3HB	5731 YUGO	1870	.	.	.	.	.	.	.	.
6001	3HB	6031 DAIHATSU CHARADE	1853	1825	.	.	.	.	.	.	.
	4SD	6031 DAIHATSU CHARADE	2045	2061	.	.	.	.	.	.	.
6202	4SD	1917 CADI-CATERA	.	.	.	.	.	.	3770	3770	3770
6301	3HB	1234 FORD FESTIVA	1785	1797	1797	.	.	.	.	.	.
6302	4SD	6331 KIA SEPHIA	.	.	2474	2474	2454	2476	2476	.	.
6303	3HB	1236 FORD ASPIRE	.	.	.	2004	2004	2004	2004	.	.
6304	5HB	1236 FORD ASPIRE	.	.	.	2053	2053	2053	2053	.	.
6305	4SD	6331 KIA SEPHIA	.	.	.	.	.	.	.	2478	2478
6401	3HB	2231 PONT-LeMANS T	2178	2175	2155	.	.	.	.	.	.
	3HB	6431 DAEWOO LANOS	.	.	.	.	.	.	.	2447	2447
	4SD	2231 PONT-LeMANS T	2246	2241	2203	.	.	.	.	.	.
	4SD	6431 DAEWOO LANOS	.	.	.	.	.	.	.	2552	2552
6402	4SD	6432 DAEWOO NUBIRA	.	.	.	.	.	.	.	2566	2566
	5HB	6432 DAEWOO NUBIRA	.	.	.	.	.	.	.	2546	2546
	SW	6432 DAEWOO NUBIRA	.	.	.	.	.	.	.	2694	2694
6403	4SD	6433 DAEWOO LEGANZA	.	.	.	.	.	.	.	3086	3086
6501	CV	1431 MERC-CAPRI (IMP.)	2402	2422	2410	2423	.	.	.	.	.

APPENDIX B: CURB WEIGHTS OF 1991-99 LIGHT TRUCKS, BY MODEL YEAR

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7005	R	7006 JEEP CHEROKEE	2775	2775	2829	2902	2912	2930	2970	3175	3174
7005	44	7007 JEEP CHEROKEE 4X4	3125	3125	3179	3252	3262	3280	3320	3330	3337
7006	44	7008 JEEP WAGONEER 4X4	3316	3316	.	.	.	.	.	.	.
7007	44	7009 JEEP GRAND WAGONEER 4X4	4362	.	.	.	.	.	.	.	.
7010	44	7014 JEEP WRANGLER 4X4	2829	2829	2935	3000	3000	.	3229	3257	3216
7011	R	7015 JEEP COMANCHE	2657	2657	.	.	.	.	.	.	.
7011	44	7016 JEEP COMANCHE 4X4	2846	2846	.	.	.	.	.	.	.
7102	R	7103 DODGE D100 PK	3615	.	.	.	.	.	.	.	.
		7104 DODGE D150 PK	3800	3800	3800	.	.	.	.	.	.
7102	44	7105 DODGE W100 4WD PK	4150	.	.	.	.	.	.	.	.
		7106 DODGE W150 4WD PK	4200	4200	4200	.	.	.	.	.	.
7103	R	7107 DODGE D250 PK	4045	4045	4145	.	.	.	.	.	.
		7109 DODGE D350 PK	4250	4250	4365	.	.	.	.	.	.
7103	44	7108 DODGE W250 4WD PK	4505	4505	4580	.	.	.	.	.	.
		7110 DODGE W350 4WD PK	4805	4805	4880	.	.	.	.	.	.
7105	R	7113 DODGE RAMCHARGER	4270	4270	4235	.	.	.	.	.	.
7105	44	7114 DODGE RAMCHARGER 4X4	4640	4640	4580	.	.	.	.	.	.
7106	R	7115 DODGE B150 RAM VAN	3695	3695	3785	3785	3795	3880	3925	.	.
		7116 DODGE B150 RAM WAGON	4025	4025	4085	4085	4110	4245	4365	.	.
		7117 DODGE B250 RAM VAN	3950	3950	4000	4000	4000	4050	4100	.	.
7107	R	7118 DODGE B250 RAM WAGON	4325	4325	4375	4375	4400	4445	4705	.	.
		7119 DODGE B350 RAM VAN	4200	4200	4200	4200	4205	4290	4415	.	.
		7120 DODGE B350 RAM WAGON	4650	4650	4650	4650	4650	4645	5015	.	.
7108	R	7130 DODGE DAKOTA	3050	3050	3050	3050	3065	3055	.	.	.
7108	44	7131 DODGE DAKOTA 4X4	3660	3660	3655	3635	3630	3610	.	.	.
7110	R	7109 DODGE D350 PK	.	5337	5537	.	.	.	.	.	.
		7134 DODGE D150 CLUB CAB PK	4140	4140	4140	.	.	.	.	.	.
		7136 DODGE D250 CLUB CAB PK	4385	4385	4455	.	.	.	.	.	.
7110	44	7110 DODGE W350 4WD PK	.	6025	6025	.	.	.	.	.	.
		7135 DODGE W150 4X4 CLUB CAB PK	4660	4660	4660	.	.	.	.	.	.
		7137 DODGE W250 4X4 CLUB CAB	4730	4730	4810	.	.	.	.	.	.
7111	R	7138 DODGE DAKOTA CLUB CAB	3460	3460	3485	3510	3525	3505	.	.	.
7111	44	7139 DODGE DAKOTA CLUB CAB 4X4	3870	3870	3880	3880	3900	3820	.	.	.
7112	F	7140 DODGE CARAVAN	3385	3368	3329	3401	3401	.	.	.	.
		7142 DODGE CARAVAN CARGO	3170	3170	3155	3140	3140	.	.	.	.
		7203 PLYMOUTH VOYAGER	3385	3368	3330	3401	3401	.	.	.	.
7112	44	7141 DODGE CARAVAN 4X4	3911	3939	3939	.	.	.	.	.	.
		7143 DODGE CARAVAN CARGO 4X4	3615	3615	.	.	.	.	.	.	.
		7204 PLYMOUTH VOYAGER 4X4	3911	3939	3939	.	.	.	.	.	.
7113	F	7144 DODGE GRAND CARAVAN	3680	3698	3675	3642	3642	.	.	.	.
		7146 DODGE CARAVAN CARGO EXT	3475	3475	3448	3420	3420	.	.	.	.
		7205 PLYMOUTH GRAND VOYAGER	3732	3698	3675	3642	3642	.	.	.	.
		7302 CHRYSLER T & C	3934	3934	3929	3960	3960	.	.	.	.

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7113	44	7145 DODGE GRAND CARAVAN 4X4	3978	3978	3978	4019	4019	.	.	.	.
		7147 DODGE CARAVAN CARGO 4X4 EXT	3775	3775	.	.	.	.	.	.	.
		7206 PLYMOUTH GRAND VOYAGER 4X4	4023	4000	3978	4019	4019	.	.	.	.
		7303 CHRYSLER T & C 4X4	.	4234	4212	4276	4276	.	.	.	.
7114	R	7017 JEEP GRAND CHEROKEE	.	.	3530	3530	3569	3614	3700	3700	3700
7114	44	7018 JEEP GRAND CHEROKEE 4X4	.	.	3830	3830	3850	3875	3900	3900	3900
		7019 JEEP GRAND WAGONEER 4X4	.	.	3753	.	.	.	.	.	.
7115	R	7148 DODGE RAM 1500 PK	.	.	.	4150	4160	4170	4180	4290	4290
7115	44	7149 DODGE RAM 1500 4WD PK	.	.	.	4515	4540	4555	4565	4693	4693
7116	R	7150 DODGE RAM 2500 PK	.	.	.	4655	4600	4610	4825	4825	4860
		7152 DODGE RAM 3500 PK	.	.	.	5210	5160	5160	5390	5328	5265
7116	44	7151 DODGE RAM 2500 4WD PK	.	.	.	4950	4910	4910	5240	5234	5234
		7153 DODGE RAM 3500 4WD PK	.	.	.	5615	5560	5520	5710	5867	5867
7117	R	7154 DODGE RAM 1500 CLUB CAB PK	.	.	.	.	4490	4490	4550	4720	4721
		7156 DODGE RAM 2500 CLUB CAB PK	.	.	.	.	4800	4800	4985	5095	5095
		7158 DODGE RAM 3500 CLUB CAB PK	.	.	.	.	5480	5480	5495	.	.
		7163 DODGE RAM 1500 QUAD CAB PK	.	.	.	.	.	.	.	4760	4758
		7165 DODGE RAM 2500 QUAD CAB PK	.	.	.	.	.	.	.	5130	5130
		7167 DODGE RAM 3500 QUAD CAB PK	.	.	.	.	.	.	.	5904	5904
7117	44	7155 DODGE RAM 1500 4WD CLUB CAB PK	.	.	.	.	4875	4875	4875	5077	5077
		7157 DODGE RAM 2500 4WD CLUB CAB PK	.	.	.	.	5095	5095	5210	5395	5395
		7159 DODGE RAM 3500 4WD CLUB CAB PK	.	.	.	.	5840	5840	5940	.	.
		7164 DODGE RAM 1500 QUAD CAB 4X4 PK	.	.	.	.	.	.	.	5077	5077
		7166 DODGE RAM 2500 QUAD CAB 4X4 PK	.	.	.	.	.	.	.	5410	5410
		7168 DODGE RAM 3500 QUAD CAB 4X4 PK	.	.	.	.	.	.	.	6215	6215
7118	F	7140 DODGE CARAVAN	.	.	.	.	.	3607	3607	3607	3607
		7203 PLYMOUTH VOYAGER	.	.	.	.	.	3607	3607	3607	3607
		7304 CHRYSLER T & C SX	.	.	.	.	.	.	3971	3969	3969
7119	F	7144 DODGE GRAND CARAVAN	.	.	.	.	.	3863	3863	3863	3863
		7205 PLYMOUTH GRAND VOYAGER	.	.	.	.	.	3863	3863	3863	3863
		7302 CHRYSLER T & C	.	.	.	.	.	3993	4062	4075	4075
7119	44	7145 DODGE GRAND CARAVAN 4X4	.	.	.	.	.	.	4275	4262	4327
		7206 PLYMOUTH GRAND VOYAGER 4X4	.	.	.	.	.	.	4275	.	.
		7303 CHRYSLER T & C 4X4	.	.	.	.	.	.	4347	4358	4358
7121	R	7170 DODGE DURANGO	.	.	.	.	.	.	.	.	4260
7121	44	7169 DODGE DURANGO 4X4	.	.	.	.	.	.	.	4465	4513
7122	R	7115 DODGE B150 RAM VAN	.	.	.	.	.	.	.	4173	4108
		7116 DODGE B150 RAM WAGON	.	.	.	.	.	.	.	4559	4578
		7117 DODGE B250 RAM VAN	.	.	.	.	.	.	.	4689	4654
7123	R	7118 DODGE B250 RAM WAGON	.	.	.	.	.	.	.	5177	5156
		7119 DODGE B350 RAM VAN	.	.	.	.	.	.	.	4681	4681
		7120 DODGE B350 RAM WAGON	.	.	.	.	.	.	.	5575	5496
7124	R	7130 DODGE DAKOTA	.	.	.	.	.	.	3400	3450	3450
7124	44	7131 DODGE DAKOTA 4X4	.	.	.	.	.	.	3767	3826	3810
7125	R	7138 DODGE DAKOTA CLUB CAB	.	.	.	.	.	.	3762	3723	3749
7125	44	7139 DODGE DAKOTA CLUB CAB 4X4	.	.	.	.	.	.	4018	4027	4025
7198	F	7398 CHRYSLER T & C UNK WB	.	.	.	.	.	3993	.	.	.

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7401	R	7401 FORD RANGER -92	2900	2900	.	.	.	.	.	.	.
7401	44	7402 FORD RANGER 4X4 -92	3200	3200	.	.	.	.	.	.	.
7402	R	7403 FORD F150 PK	3900	3900	3900	3900	3957	3919	.	.	.
7402	44	7404 FORD F150 4X4 PK	4150	4150	4150	4150	4150	4150	.	.	.
7403	R	7405 FORD F250 PK	4109	4214	4219	4252	4320	4333	4333	.	.
		7407 FORD F350 PK	4777	4777	4892	4872	4893	4768	4642	.	.
		7461 FORD F250 4X2 CHASSIS CAB	.	.	.	.	4500	4500	4500	.	.
		7462 FORD F350 4X2 CHASSIS CAB	5190	5000	5000	4870	5000	5000	5000	.	.
7403	44	7406 FORD F250 4X4 PK	4824	4824	4829	4948	4969	5002	5002	.	.
		7408 FORD F350 4X4 PK	5005	5005	5010	5037	5058	5101	5101	.	.
		7463 FORD F350 4X4 CHASSIS CAB	5428	5533	5400	5521	5400	5294	5294	.	.
7404	R	7409 FORD F150 SUPERCAB PK	4218	4218	4164	4196	4196	4189	.	.	.
7404	44	7410 FORD F150 4X4 SUPERCAB PK	4428	4428	4374	4435	4435	4438	.	.	.
7405	R	7411 FORD F250 SUPERCAB PK	4702	4772	4718	4761	4775	4745	4745	.	.
		7431 FORD F350 SUPERCAB DUAL-REAR-WHEEL	5297	5297	5329	5399	5342	5343	5343	.	.
7405	44	7412 FORD F250 4X4 SUPERCAB PK	5134	5221	5167	5242	5236	5259	5259	.	.
7407	44	7417 FORD BRONCO 4X4	4566	4566	4574	4587	4587	4587	.	.	.
7409	R	7418 FORD E-150 CARGO VAN -91	4134	.	.	.	.	.	.	.	.
		7419 FORD E-150 SUPER VAN -91	4422	.	.	.	.	.	.	.	.
		7420 FORD E-150 CLUB WAGON -91	4459	.	.	.	.	.	.	.	.
		7421 FORD E-250 CARGO VAN -91	4558	.	.	.	.	.	.	.	.
		7422 FORD E-250 SUPER VAN -91	4748	.	.	.	.	.	.	.	.
		7423 FORD E-250 CLUB WAGON -91	5048	.	.	.	.	.	.	.	.
		7424 FORD E-350 CARGO VAN -91	4763	.	.	.	.	.	.	.	.
		7425 FORD E-350 SUPER VAN -91	4927	.	.	.	.	.	.	.	.
		7426 FORD E-350 SUPER CLUB WAGON -91	5377	.	.	.	.	.	.	.	.
		7464 FORD E350 RV CUTAWAY	4609	.	.	.	.	.	.	.	.
		7469 FORD E350 COMMERCIAL CUTAWAY	4445	.	.	.	.	.	.	.	.
7410	R	7427 FORD RANGER SUPERCAB -92	3128	3155	.	.	.	.	.	.	.
7410	44	7428 FORD RANGER SUPERCAB 4X4 -92	3479	3512	.	.	.	.	.	.	.
7411	R	7429 FORD AEROSTAR CARGO VAN	3296	3296	3296	3296	3402	3402	3414	.	.
		7430 FORD AEROSTAR WAGON	3600	3600	3600	3600	3646	3714	3717	.	.
		7432 FORD AEROSTAR EXT VAN	3390	3390	3390	3390	.	.	.	.	.
		7433 FORD AEROSTAR EXT WAGON	3700	3700	3700	3700	3833	3824	3827	.	.
7411	44	7436 FORD AEROSTAR 4X4 VAN (CARGO)	3584	3584	3584	3584	.	.	.	.	.
		7437 FORD AEROSTAR 4X4 WAGON	3900	3900	3900	3900	.	.	.	.	.
		7438 FORD AEROSTAR 4X4 EXT VAN	3668	3668	3668	3668	.	.	.	.	.
		7439 FORD AEROSTAR 4X4 EXT WAGON	4000	4000	4000	4000	4076	4076	4077	.	.
7412	R	7434 FORD F350 CREW CAB PK	5034	5094	5178	5212	5226	5214	5214	.	.
7412	44	7435 FORD F350 4X4 CREW CAB PK	5446	5530	5530	5621	5635	5658	5658	.	.
7413	R	7440 FORD EXPLORER 2DR	3681	3675	3679	3700	3745	.	.	.	.
		8311 MAZDA NAVAJO	.	3681	3785	3785	.	.	.	.	.
7413	44	7441 FORD EXPLORER 2DR 4X4	3841	3879	3890	3900	3981	.	.	.	.
		8310 MAZDA NAVAJO 4X4	3841	3841	3980	3980	.	.	.	.	.
7414	R	7442 FORD EXPLORER 4DR	3824	3854	3858	3900	4004	.	.	.	.
7414	44	7443 FORD EXPLORER 4DR 4X4	4100	4100	4100	4150	4239	.	.	.	.

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP		WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7415	R	7444	FORD E-150 CARGO VAN	4600	4600	4450	4677	4677	4677	4660	4650	4680
		7445	FORD E-150 CLUB WAGON	5050	5050	5022	5141	5121	5121	5136	5125	5125
		7446	FORD E-250 CARGO VAN	5000	5000	4966	5067	5073	5073	5032	5012	5135
		7447	FORD E-250 SUPER VAN	.	5134	5109	5225	5211	5211	5174	5145	5215
		7448	FORD E-350 CARGO VAN	5200	5200	5117	5204	5211	5211	5336	5356	5380
		7449	FORD E-350 SUPER VAN	5300	5300	5285	5372	5379	5379	5484	5495	5520
		7450	FORD E-350 CLUB WAGON	5500	5500	5484	5628	5615	5615	5767	5783	5783
		7451	FORD E-350 SUPER CLUB WAGON	5800	5800	5697	5863	5840	5840	6000	6030	6030
		7464	FORD E350 RV CUTAWAY	.	4749	4879	4886	4892	5232	4733	4803	4805
		7465	FORD E350 COMMERCIAL CUTAWAY	.	4675	4720	4727	4783	5572	4651	4676	4680
		7470	FORD E250 STRIPPED CHASSIS	.	3437	3437	3437	3437	3437	3437	3437	3440
		7471	FORD E350 STRIPPED CHASSIS	.	3696	3696	3696	3702	3702	3949	3949	3950
7416	R	7452	FORD RANGER	.	.	3000	3000	3000	3000	3000	.	.
		8312	MAZDA B PK	.	.	.	2918	2927	2927	2927	.	.
7416	44	7453	FORD RANGER 4X4	.	.	3325	3325	3325	3340	3410	.	.
		8313	MAZDA B PK 4X4	.	.	.	3325	3325	3548	3548	.	.
7417	R	7454	FORD RANGER SUPERCAB	.	.	3208	3209	3237	3237	3240	.	.
		8314	MAZDA B CAB-PLUS PK	.	.	.	3275	3197	3197	3242	.	.
7417	44	7455	FORD RANGER SUPERCAB 4X4	.	.	3516	3555	3642	3647	3650	.	.
		8315	MAZDA B CAB-PLUS PK 4X4	.	.	.	3550	3550	3829	3829	.	.
7418	F	7501	MERCURY VILLAGER CARGO VAN	.	.	3660	3660	3660	3660	3660	.	.
		7502	MERCURY VILLAGER WAGON	.	.	3876	3876	3876	3876	3876	3876	.
		8118	NISSAN QUEST PASS VAN	.	.	3851	3876	3876	3871	3969	3992	.
		8119	NISSAN QUEST CARGO VAN	.	.	3660	.	.	.	.	.	.
7419	F	7456	FORD WINDSTAR CARGO VAN	.	.	.	.	3487	3487	3519	3546	.
		7457	FORD WINDSTAR WAGON	.	.	.	.	3733	3733	3733	3710	.
7420	R	7442	FORD EXPLORER 4DR	.	.	.	.	.	3915	3931	3911	3911
		7503	MERCURY MOUNTAINEER 4DR	.	.	.	.	.	.	3930	3930	3930
7420	44	7443	FORD EXPLORER 4DR 4X4	.	.	.	.	.	4150	4166	4146	4146
		7504	MERCURY MOUNTAINEER 4DR 4X4	.	.	.	.	.	.	4374	4374	4374
7421	R	7440	FORD EXPLORER 2DR	.	.	.	.	.	3690	3707	3692	3692
7421	44	7441	FORD EXPLORER 2DR 4X4	.	.	.	.	.	3927	3939	3919	3919
7422	R	7458	FORD F250 CREW CAB PK	.	.	.	.	.	5286	5286	.	.
7422	44	7459	FORD F250 4X4 CREW CAB PK	.	.	.	.	.	5730	5730	.	.
7423	R	7466	FORD EXPEDITION 4DR	.	.	.	.	.	.	4900	4900	4900
		9501	LINCOLN NAVIGATOR	.	.	.	.	.	.	.	5150	5150
7423	44	7467	FORD EXPEDITION 4DR 4X4	.	.	.	.	.	.	5275	5275	5275
		9502	LINCOLN NAVIGATOR 4X4	.	.	.	.	.	.	.	5350	5350
7424	R	7403	FORD F150 PK	.	.	.	.	.	.	3850	3880	3923
7424	44	7404	FORD F150 4X4 PK	.	.	.	.	.	.	4235	4260	4299
7425	R	7409	FORD F150 SUPERCAB PK	.	.	.	.	.	.	4045	4067	4216
		7411	FORD F250 SUPERCAB PK	.	.	.	.	.	.	4379	4364	4517
7425	44	7410	FORD F150 4X4 SUPERCAB PK	.	.	.	.	.	.	4478	4480	4613
		7412	FORD F250 4X4 SUPERCAB PK	.	.	.	.	.	.	4768	4756	4894
7426	R	7405	FORD F250 PK	.	.	.	.	.	.	4310	4300	4352
7426	44	7406	FORD F250 4X4 PK	.	.	.	.	.	.	4720	4689	4725

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7427	R	7452 FORD RANGER	.	.	.	.	.	.	.	3100	3100
		8312 MAZDA B PK	.	.	.	.	.	.	.	3025	2998
7427	44	7453 FORD RANGER 4X4	.	.	.	.	.	.	.	3437	3437
		8313 MAZDA B PK 4X4	.	.	.	.	.	.	.	3433	3396
7428	R	7454 FORD RANGER SUPERCAB	.	.	.	.	.	.	.	3300	3300
		8314 MAZDA B CAB-PLUS PK	.	.	.	.	.	.	.	3237	3210
7428	44	7455 FORD RANGER SUPERCAB 4X4	.	.	.	.	.	.	.	3625	3625
		8315 MAZDA B CAB-PLUS PK 4X4	.	.	.	.	.	.	.	3625	3616
7429	R	7405 FORD F250 PK	.	.	.	.	.	.	.	.	4956
		7407 FORD F350 PK	.	.	.	.	.	.	.	.	4966
		7462 FORD F350 4X2 CHASSIS CAB	.	.	.	.	.	.	.	.	4759
7429	44	7406 FORD F250 4X4 PK	.	.	.	.	.	.	.	.	5439
		7408 FORD F350 4X4 PK	.	.	.	.	.	.	.	.	5449
		7463 FORD F350 4X4 CHASSIS CAB	.	.	.	.	.	.	.	.	5231
7430	R	7411 FORD F250 SUPERCAB PK	.	.	.	.	.	.	.	.	5189
		7413 FORD F350 SUPERCAB PK	.	.	.	.	.	.	.	.	5199
		7462 FORD F350 4X2 CHASSIS CAB	.	.	.	.	.	.	.	.	5081
7430	44	7412 FORD F250 4X4 SUPERCAB PK	.	.	.	.	.	.	.	.	5635
		7414 FORD F350 4X4 SUPERCAB PK	.	.	.	.	.	.	.	.	5645
		7463 FORD F350 4X4 CHASSIS CAB	.	.	.	.	.	.	.	.	5527
7431	R	7434 FORD F350 CREW CAB PK	.	.	.	.	.	.	.	.	5497
		7458 FORD F250 CREW CAB PK	.	.	.	.	.	.	.	.	5487
		7462 FORD F350 4X2 CHASSIS CAB	.	.	.	.	.	.	.	.	5586
7431	44	7435 FORD F350 4X4 CREW CAB PK	.	.	.	.	.	.	.	.	5942
		7459 FORD F250 4X4 CREW CAB PK	.	.	.	.	.	.	.	.	5932
		7463 FORD F350 4X4 CHASSIS CAB	.	.	.	.	.	.	.	.	5824
7433	F	7502 MERCURY VILLAGER WAGON	.	.	.	.	.	.	.	.	3759
		8118 NISSAN QUEST PASS VAN	.	.	.	.	.	.	.	.	3992
7434	F	7456 FORD WINDSTAR CARGO VAN	.	.	.	.	.	.	.	.	3800
		7457 FORD WINDSTAR WAGON	.	.	.	.	.	.	.	.	4000
7604	R	7609 CHEVY S10 BLAZER 2DR	3196	3186	3261	3261	3533	3507	3531	3518	3604
		7709 GMC S15 JIMMY 2DR	3196	3196	3261	3261	3533	3536	3533	3518	3604
7604	44	7610 CHEVY S10 4X4 BLAZER 2DR	3488	3482	3553	3553	3812	3875	3855	3848	3883
		7710 GMC S15 4X4 JIMMY 2DR	3488	3488	3553	3553	3812	3814	3855	3848	3883
7605	44	7611 CHEVY K10/V10 4X4 BLAZER	4521	.	.	.	.	.	.	.	.
		7711 GMC K15/V15 4X4 JIMMY	4521	.	.	.	.	.	.	.	.
7606	R	7612 CHEVY C10/R10 SUBURBAN	4581	.	.	.	.	.	.	.	.
		7712 GMC C15/R15 SUBURBAN	4581	.	.	.	.	.	.	.	.
7606	44	7613 CHEVY K10/V10 4X4 SUBURBAN	4943	.	.	.	.	.	.	.	.
		7713 GMC K15/V15 4X4 SUBURBAN	4943	.	.	.	.	.	.	.	.
7607	R	7614 CHEVY C20/R20 SUBURBAN	5013	.	.	.	.	.	.	.	.
		7714 GMC C25/R25 SUBURBAN	5013	.	.	.	.	.	.	.	.
7607	44	7615 CHEVY K20/V20 4X4 SUBURBAN	5303	.	.	.	.	.	.	.	.
		7715 GMC K25/V25 4X4 SUBURBAN	5303	.	.	.	.	.	.	.	.
7608	R	7616 CHEVY ASTRO CARGO VAN	3503	3554	3571	3653	.	.	.	.	.
		7617 CHEVY ASTRO PASS VAN	3826	3909	3904	3998	.	.	.	.	.
		7644 CHEVY ASTRO EXT CARGO VAN	3561	3618	3633	3741	3804	3932	3913	3887	3907
		7645 CHEVY ASTRO EXT PSGR VAN	3913	3993	3980	4064	4150	4250	4250	4250	4250

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7608	R	7716 GMC SAFARI CARGO VAN	3503	3554	3571	3653	.	.	.	.	.
		7717 GMC SAFARI PASS VAN	3826	3826	3904	3998	.	.	.	.	.
		7744 GMC SAFARI EXT CARGO VAN	3561	3618	3633	3741	3804	3885	3913	3909	3909
		7745 GMC SAFARI EXT PASS VAN	3913	3913	3980	4064	4150	4250	4250	4250	4250
7608	44	7646 CHEVY ASTRO 4X4 CARGO VAN	3850	3856	3884	3974	.	.	.	.	.
		7647 CHEVY ASTRO 4X4 PASS VAN	4156	4182	4210	4291	.	.	.	.	.
		7648 CHEVY ASTRO 4X4 EXT CARGO VAN	3913	3917	3938	4030	4115	4210	4179	4141	4141
		7649 CHEVY ASTRO 4X4 EXT PSGR VAN	4237	4259	4274	4344	4450	4550	4550	4550	4550
		7746 GMC SAFARI 4X4 CARGO VAN	3850	3850	3884	3974	.	.	.	.	.
		7747 GMC SAFARI 4X4 PASS VAN	4156	4156	4210	4291	.	.	.	.	.
		7748 GMC SAFARI 4X4 EXT CARGO VAN	3913	3913	3938	4030	4115	4173	4179	4141	4141
		7749 GMC SAFARI 4X4 EXT PSGR VAN	4237	4237	4274	4344	4450	4550	4550	4550	4550
7609	R	7618 CHEVY G10 CARGO VAN	3900	3900	3900	3900	4069	.	.	.	.
		7619 CHEVY G10 PASS VAN	4300	4300	4300	.	.	.	.	.	.
		7620 CHEVY G20 CARGO VAN	4000	4000	4000	4000	4052	.	.	.	.
		7718 GMC G10 CARGO VAN	3900	3900	3900	3900	4069	.	.	.	.
		7719 GMC G10 PASS VAN	4300	4300	4300	.	.	.	.	.	.
		7720 GMC G20 CARGO VAN	4000	4000	4000	4000	4052	.	.	.	.
7610	R	7621 CHEVY G20 PASS VAN	4600	4600	4650	4700	4770	.	.	.	.
		7622 CHEVY G30 CARGO VAN	4510	4572	4478	4478	4811	.	.	.	.
		7623 CHEVY G30 PASS VAN	5018	5097	5100	5266	5326	.	.	.	.
		7679 CHEVY CUTAWAY	4350	4076	4185	4032	4224	.	.	.	.
		7721 GMC G20 PASS VAN	4600	4600	4650	4700	4770	.	.	.	.
		7722 GMC G30 CARGO VAN	4510	4510	4478	4478	4811	.	.	.	.
		7723 GMC G30 PASS VAN	5018	5097	5100	5266	5326	.	.	.	.
		7775 GMC CUTAWAY	4350	4076	4185	3976	4224	.	.	.	.
7612	R	7627 CHEVY C30/R30 4 DR PK	5221	.	.	.	.	.	.	.	.
		7727 GMC C35/R35 4 DR PK	5221	.	.	.	.	.	.	.	.
7612	44	7628 CHEVY K30/V30 4 DR PK	5698	.	.	.	.	.	.	.	.
		7728 GMC K35/V35 4X4 4 DR PK	5698	.	.	.	.	.	.	.	.
7613	R	7601 CHEVY S10 PK	2900	2900	2900	3000	3000	3070	3029	3031	3015
		7701 GMC S15/SONOMA PK	2900	2900	2900	3000	3000	3000	3029	3031	3015
		8223 ISUZU HOMBRE PK	.	.	.	.	.	3125	3125	3075	3024
7613	44	7602 CHEVY T10 4X4 PK	3350	3350	3350	3429	3500	3589	3556	3564	3586
		7702 GMC T15/SONOMA 4X4 PK	3350	3350	3350	3429	3500	3518	3556	3564	3586
		8225 ISUZU HOMBRE 4X4 PK	.	.	.	.	.	.	.	3582	.
7614	R	7629 CHEVY S10 MAXICAB PK	3000	3000	3000	3157	3185	3246	3350	3350	3350
		7729 GMC S15/SONOMA MAXICAB PK	3000	3000	3000	3157	3185	3204	3350	3350	3350
		8224 ISUZU HOMBRE SPACECAB PK	.	.	.	.	.	.	3214	3301	3278
7614	44	7630 CHEVY T10 4X4 MAXICAB PK	3450	3450	3450	3645	3723	3755	3800	3800	3800
		7730 GMC T15/SONOMA 4X4 MAXICAB PK	3450	3450	3450	3645	3723	3741	3800	3800	3800
		8226 ISUZU HOMBRE SPACECAB 4X4	.	.	.	.	.	.	.	3751	3786
7615	R	7631 CHEVY C10 PK	3800	3800	3850	3850	3900	3900	3950	3950	.
		7731 GMC SIERRA C1500 PK	3800	3800	3850	3850	3900	3900	3950	3950	.
7615	44	7632 CHEVY K10 4X4 PK	4200	4200	4250	4250	4300	4300	4350	4350	.
		7732 GMC SIERRA K1500 4X4 PK	4200	4200	4250	4250	4300	4300	4350	4350	.
7616	R	7633 CHEVY C20 PK	4100	4100	4150	4150	4119	4285	4299	4292	4292
		7635 CHEVY C30 PK	4636	4636	4670	4649	4772	4837	4838	4870	4870
		7733 GMC SIERRA C2500 PK	4100	4100	4150	4150	4119	4269	4299	4292	4292
		7735 GMC SIERRA C3500 PK	4636	4636	4670	4649	4772	4802	4838	4870	4870
7616	44	7634 CHEVY K20 4X4 PK	4500	4500	4550	4550	4550	5067	5165	5178	5178
		7636 CHEVY K30 4X4 PK	5042	5042	5053	5024	5133	5214	5219	5256	5256
		7734 GMC SIERRA K2500 4X4 PK	4500	4500	4550	4550	4550	4640	5165	5178	5178
		7736 GMC SIERRA K3500 4X4 PK	5042	5042	5053	5024	5133	5181	5181	5256	5256

CGP	WHEELS	MMP		WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7617	R	7641	CHEVY C30 X-CAB PK	5243	5243	5243	5325	5300	5283	5427	5458	5269
		7741	GMC SIERRA C3500 X-CAB PK	5243	5243	5243	5325	5300	5283	5427	5458	5458
7617	44	7642	CHEVY K30 4X4 X-CAB PK	5653	5653	5653	5789	5743	5771	5824	5889	5889
		7742	GMC SIERRA K3500 4X4 X-CAB	5653	5653	5653	5789	5743	5806	5806	5890	5890
7618	R	7650	CHEVY G30 EXT CARGO VAN	4783	4852	4850	4881	5154	.	.	.	.
		7651	CHEVY G30 EXT PASS VAN	5527	5635	5655	5642	5661	.	.	.	.
		7750	GMC G30 EXT CARGO VAN	4783	4783	4850	4850	5154	.	.	.	.
		7751	GMC G30 EXT PASS VAN	5527	5527	5655	5642	5661	.	.	.	.
7619	F	7652	CHEVY LUMINA APV	3521	3563	3563	3563	3563	3532	.	.	.
		7667	CHEVY APV CARGO VAN	.	3100	3100	3100	3252	3275	.	.	.
		7801	OLDS SILHOUETTE	3653	3660	3675	3702	3638	3709	.	.	.
		7901	PONTIAC TRANS SPORT	3583	3583	3550	3581	3550	3598	.	.	.
7620	R	7653	CHEVY C10 X-CAB PK	4050	3998	4025	4110	4071	4140	4173	4200	4200
		7655	CHEVY C20 X-CAB PK	4300	4300	4350	4350	4350	4434	4437	4432	4432
		7753	GMC SIERRA C1500 X-CAB PK	4050	4050	4025	4133	4071	4121	4173	4200	4200
		7755	GMC SIERRA C2500 X-CAB PK	4300	4300	4350	4350	4350	4400	4437	4433	4432
7620	44	7654	CHEVY K10 4X4 X-CAB PK	4450	4426	4449	4528	4497	4513	4566	4600	4600
		7656	CHEVY K20 4X4 X-CAB PK	4700	4700	4750	4750	4750	5348	5470	5300	5300
		7754	GMC SIERRA K1500 4X4 X-CAB PK	4450	4450	4449	4528	4497	4489	4489	4600	4600
		7756	GMC SIERRA K2500 4X4 X-CAB	4700	4700	4750	4750	4750	5186	5217	5301	5301
7621	R	7657	CHEVY S10 BLAZER 4DR	3378	3378	3403	3446	3689	3692	3683	3671	3712
		7757	GMC S15 JIMMY 4DR	3378	3378	3403	3446	3689	3692	3683	3671	3712
7621	44	7658	CHEVY S10 4X4 BLAZER 4DR	3725	3725	3765	3811	4020	4023	4043	4049	4109
		7758	GMC S15 4X4 JIMMY 4DR	3725	3725	3765	3811	4020	4023	4043	4070	4109
		7802	OLDS BRAVADA 4X4	3789	3939	4041	4031	.	4023	4023	4023	4049
7622	R	7660	CHEVY C30 CREW CAB PK	.	5279	5295	5290	5397	5475	5509	5488	5488
		7760	GMC SIERRA C3500 CREW CAB PK	.	5279	5295	5290	5397	5475	5509	5489	5489
7622	44	7661	CHEVY K30 4X4 CREW CAB PK	.	5652	5674	5679	5780	5880	5881	5875	5875
		7761	GMC SIERRA K3500 4X4 CREW CAB	.	5652	5674	5679	5780	5827	5881	5876	5876
7623	R	7680	CHEVY TAHOE 2DR	.	.	.	.	.	4453	4514	4525	4525
		7777	GMC YUKON 2DR	.	.	.	.	.	4456	4514	.	.
7623	44	7662	CHEVY TAHOE 2DR 4X4	.	4700	4750	4757	4730	4807	4858	4876	4876
		7762	GMC YUKON 2DR 4X4	.	4700	4750	4757	4730	4858	4858	.	.
7624	R	7663	CHEVY C1500 SUBURBAN	.	4801	4808	4808	4808	4883	4925	4925	4950
		7763	GMC C1500 SUBURBAN	.	4801	4808	4808	4808	4883	4925	4925	4950
7624	44	7664	CHEVY K1500 4X4 SUBURBAN	.	5269	5269	5269	5269	5316	5393	5397	5411
		7764	GMC K1500 4X4 SUBURBAN	.	5269	5269	5269	5269	5316	5393	5397	5411
7625	R	7665	CHEVY C2500 SUBURBAN	.	5123	5165	5227	5176	5227	5249	5286	5299
		7765	GMC C2500 SUBURBAN	.	5123	5165	5227	5176	5226	5249	5286	5286
7625	44	7666	CHEVY K2500 4X4 SUBURBAN	.	5535	5584	5632	5587	5671	5693	5574	5763
		7766	GMC K2500 4X4 SUBURBAN	.	5535	5584	5632	5587	5603	5693	5574	5574
7626	R	7618	CHEVY G10 CARGO VAN	.	.	.	.	.	4642	4665	4660	4663
		7619	CHEVY G10 PASS VAN	.	.	.	.	.	5066	5034	5142	5142
		7620	CHEVY G20 CARGO VAN	.	.	.	.	.	4817	4816	4850	4849
		7621	CHEVY G20 PASS VAN	.	.	.	.	.	5793	5774	5823	5823
		7622	CHEVY G30 CARGO VAN	.	.	.	.	.	5378	5363	5387	5381
		7623	CHEVY G30 PASS VAN	.	.	.	.	.	5928	5998	5987	5987
		7679	CHEVY CUTAWAY	.	.	.	.	.	4583	4417	4474	4495
		7718	GMC G10 CARGO VAN	.	.	.	.	.	4642	4665	4660	4663
		7719	GMC G10 PASS VAN	.	.	.	.	.	5066	5034	5141	5266
		7720	GMC G20 CARGO VAN	.	.	.	.	.	4817	4816	4851	4849

CGP	WHEELS	MMP		WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
7626	R	7721	GMC G20 PASS VAN	.	.	.	.	.	5793	5775	5824	5857
		7722	GMC G30 CARGO VAN	.	.	.	.	.	5378	5363	5387	5381
		7723	GMC G30 PASS VAN	.	.	.	.	.	5928	5899	5987	5996
		7775	GMC CUTAWAY	.	.	.	.	.	4583	4417	4475	4494
7627	R	7650	CHEVY G30 EXT CARGO VAN	.	.	.	.	.	5596	5493	5589	5574
		7651	CHEVY G30 EXT PASS VAN	.	.	.	.	.	6132	6056	6208	6208
		7671	CHEVY G20 EXT CARGO VAN	.	.	.	.	.	4969	4997	5052	5038
		7672	CHEVY G20 EXT PASS VAN	.	.	.	.	.	.	.	6045	6045
		7750	GMC G30 EXT CARGO VAN	.	.	.	.	.	5596	5493	5590	5574
		7751	GMC G30 EXT PASS VAN	.	.	.	.	.	6132	6056	6208	6204
		7771	GMC G20 EXT CARGO VAN	.	.	.	.	.	4969	4997	5052	5039
		7772	GMC G20 EXT PASS VAN	.	.	.	.	.	.	.	6045	6045
7628	R	7673	CHEVY TAHOE 4DR	.	.	.	.	4769	4797	4865	4865	4865
		7773	GMC YUKON 4DR	.	.	.	.	4769	4725	4865	4865	4865
7628	44	7674	CHEVY TAHOE 4DR 4X4	.	.	.	.	5124	5206	5268	5251	5251
		7774	GMC YUKON 4DR 4X4	.	.	.	.	5124	5149	5268	5268	5268
		9701	CADILLAC ESCALADE	.	.	.	.	.	.	.	.	5573
7629	R	7678	CHEVY FORWARD CONTROL 4X2	3363	3363	3374	3355	3355	3493	3507	3507	3762
		7776	GMC FORWARD CONTROL 4X2	3363	3363	3374	3355	3355	3493	3508	3762	3762
7630	F	7681	CHEVY VENTURE VAN	.	.	.	.	.	.	3704	3704	3745
		7801	OLDS SILHOUETTE	.	.	.	.	.	.	3751	3751	3751
		7901	PONTIAC TRANS SPORT	.	.	.	.	.	.	3735	3735	.
		7902	PONTIAC MONTANA	.	.	.	.	.	.	.	.	3735
7631	R	7631	CHEVY C10 PK	.	.	.	.	.	.	.	.	4000
		7633	CHEVY C20 PK	.	.	.	.	.	.	.	.	4586
		7731	GMC SIERRA C1500 PK	.	.	.	.	.	.	.	.	4000
		7733	GMC SIERRA C2500 PK	.	.	.	.	.	.	.	.	4586
7631	44	7632	CHEVY K10 4X4 PK	.	.	.	.	.	.	.	.	4350
		7634	CHEVY K20 4X4 PK	.	.	.	.	.	.	.	.	5266
		7732	GMC SIERRA K1500 4X4 PK	.	.	.	.	.	.	.	.	4350
		7734	GMC SIERRA K2500 4X4 PK	.	.	.	.	.	.	.	.	5266
7632	R	7653	CHEVY C10 X-CAB PK	.	.	.	.	.	.	.	.	4235
		7655	CHEVY C20 X-CAB PK	.	.	.	.	.	.	.	.	4767
		7753	GMC SIERRA C1500 X-CAB PK	.	.	.	.	.	.	.	.	4235
		7755	GMC SIERRA C2500 X-CAB PK	.	.	.	.	.	.	.	.	4767
7632	44	7654	CHEVY K10 4X4 X-CAB PK	.	.	.	.	.	.	.	.	4621
		7656	CHEVY K20 4X4 X-CAB PK	.	.	.	.	.	.	.	.	5485
		7754	GMC SIERRA K1500 4X4 X-CAB PK	.	.	.	.	.	.	.	.	4621
		7756	GMC SIERRA K2500 4X4 X-CAB	.	.	.	.	.	.	.	.	5485
7636	R	7696	CHEVY C2500 CREW PK	.	.	.	.	.	.	.	.	5416
		7796	GMC C2500 CREW PK	.	.	.	.	.	.	.	.	5416
7636	44	7697	CHEVY K2500 CREW PK	.	.	.	.	.	.	.	.	5707
		7797	GMC K2500 CREW PK	.	.	.	.	.	.	.	.	5707
7637	F	7681	CHEVY VENTURE VAN	.	.	.	.	.	.	3843	3843	3900
		7801	OLDS SILHOUETTE	.	.	.	.	.	.	3879	3951	3951
		7901	PONTIAC TRANS SPORT	.	.	.	.	.	.	3885	3885	.
		7902	PONTIAC MONTANA	.	.	.	.	.	.	.	.	3885
8001	R	8001	VW VANAGON	3625	.	.	.	.	.	.	.	.
		8002	VW CAMPER	3622	.	.	.	.	.	.	.	.
8002	F	8004	VW EUROVAN	.	.	3755	3800	4745	.	4745	4745	4220
8103	R	8107	NISSAN STD-BED PK	2740	2753	2755	2790	2805	2814	2815	.	.

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
8103	44	8108 NISSAN STD-BED 4X4 PK	3300	3325	3360	3390	3390	3395	3405	.	.
8104	R	8109 NISSAN LBED PK	2810	2850	2850	3115	3001	.	.	.	.
		8110 NISSAN KING CAB PK	2835	2845	2900	2885	2900	2945	2945	.	.
8104	44	8112 NISSAN KING CAB 4X4 PK	3430	3455	3490	3525	3525	3550	3550	.	.
8105	R	8116 NISSAN PATHFINDER 4DR	3513	3550	3550	3815	3815	.	.	.	.
8105	44	8117 NISSAN PATHFINDER 4DR 4X4	3840	3840	3840	4090	4090	.	.	.	.
8107	R	8116 NISSAN PATHFINDER 4DR	.	.	.	.	.	3675	3675	3675	3886
8107	44	8117 NISSAN PATHFINDER 4DR 4X4	.	.	.	.	.	3920	3920	3920	4111
		9401 INFINITI QX4 4DR	.	.	.	.	.	.	4285	4285	4285
8108	R	8120 NISSAN FRONTIER	.	.	.	.	.	.	.	2911	2999
8108	44	8121 NISSAN FRONTIER 4X4	.	.	.	.	.	.	.	3554	3499
8109	R	8122 NISSAN FRONTIER KING CAB	.	.	.	.	.	.	.	3032	3149
8109	44	8123 NISSAN FRONTIER KING 4X4	.	.	.	.	.	.	.	3669	3633
8203	44	8205 ISUZU TROOPER II 4X4	3635	.	.	.	.	.	.	.	.
8204	R	8208 ISUZU P-UP STD BED	2680	2680	2700	2700	2855	.	.	.	.
8204	44	8209 ISUZU 4X4 P-UP STD BED	3055	3150	3215	3215	3355	.	.	.	.
8205	R	8210 ISUZU P-UP LBED	2740	2775	2810	2810	2965	.	.	.	.
		8212 ISUZU P-UP SPACE CAB	2810	2886	3000	3000	.	.	.	.	.
		8214 ISUZU 1-TON P-UP LBED	2740	2855	.	.	.	.	.	.	.
8205	44	8213 ISUZU 4X4 P-UP SPACE CAB	3195	3310	3400	3400	.	.	.	.	.
8206	R	8215 ISUZU AMIGO	3170	3170	3170	3170	.	.	.	.	.
8206	44	8216 ISUZU AMIGO 4X4	3410	3410	3530	3530	.	.	.	.	.
8208	R	8218 ISUZU RODEO	3450	3450	3535	3545	3545	3705	3715	.	.
8208	44	8219 ISUZU RODEO 4X4	3660	3660	3945	3995	3995	4115	4115	.	.
8209	44	8220 ISUZU TROOPER 4DR 4X4	.	4210	4210	4210	4210	4315	4315	4540	4455
		9101 ACURA SLX 4X4	.	.	.	.	.	4315	4315	4609	4609
8210	44	8221 ISUZU TROOPER 2DR 4X4	.	.	4060	4060	4060	.	.	.	.
8211	R	8901 HONDA PASSPORT	.	.	.	3681	3700	3805	3805	.	.
8211	44	8902 HONDA PASSPORT 4X4	.	.	.	3981	3950	4050	4050	.	.
8212	F	8222 ISUZU OASIS	.	.	.	.	.	3477	3480	3483	3483
		8903 HONDA ODYSSEY	.	.	.	.	3455	3455	3460	3466	.
8213	R	8218 ISUZU RODEO	.	.	.	.	.	.	.	3471	3471
		8901 HONDA PASSPORT	.	.	.	.	.	.	.	3499	3499
8213	44	8219 ISUZU RODEO 4X4	.	.	.	.	.	.	.	3861	3861
		8902 HONDA PASSPORT 4X4	.	.	.	.	.	.	.	3786	3786
8214	44	8227 ISUZU VEHICROSS	.	.	.	.	.	.	.	.	3815
8215	R	8215 ISUZU AMIGO	.	.	.	.	.	.	.	3329	3329
8215	44	8216 ISUZU AMIGO 4X4	.	.	.	.	.	.	.	3583	3583

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
8301	R	8301 MAZDA B2000... PK SBED	2750	2750	2750	.	.	.	.	.	.
8301	44	8304 MAZDA B2000... 4X4 PK SBED	3309	3305	3305	.	.	.	.	.	.
8302	R	8302 MAZDA B2000... PK LBED	2850	2850	2850	.	.	.	.	.	.
		8303 MAZDA B2000... PK CAB PLUS	2850	2850	2850	.	.	.	.	.	.
8302	44	8305 MAZDA B2000... 4X4 PK LBED	3340	3340	.	.	.	.	.	.	.
		8306 MAZDA B2000... 4X4 PK CAB PLUS	3430	3430	3430	.	.	.	.	.	.
8303	R	8307 MAZDA MPV CARGO VAN	3228	3295	.	.	.	.	.	.	.
		8308 MAZDA MPV WAGON	3704	3801	3759	3759	3787	3787	3825	3825	.
8303	44	8309 MAZDA MPV 4X4 WAGON	4010	4010	4010	4205	4205	4205	4205	4212	.
8402	44	8402 SUBARU FORESTER	.	.	.	.	.	.	.	3120	3180
8501	R	8501 TOYOTA PK SBED	2600	2600	2600	2600	2600	.	.	.	.
8501	44	8502 TOYOTA 4X4 PK SBED	3200	3200	3200	3200	3200	.	.	.	.
8502	R	8503 TOYOTA PK LBED	2700	2700	2700	.	.	.	.	.	.
8502	44	8504 TOYOTA 4X4 PK LBED	3300	3300	.	.	.	.	.	.	.
8503	R	8515 TOYOTA 4RUNNER	3744	3744	3740	3760	3760	.	.	.	.
8503	44	8507 TOYOTA 4RUNNER 4X4	4000	4000	4000	4000	4000	.	.	.	.
8506	R	8511 TOYOTA PK XTRACAB LBED	2800	2800	2800	2800	2800	.	.	.	.
8506	44	8514 TOYOTA 4X4 PK XCAB LBED	3400	3400	3400	3400	3400	.	.	.	.
8507	44	8516 TOYOTA LAND CRUISER 4X4	4603	4603	4768	4762	4751	4834	4751	5225	5115
		9201 LEXUS LX450 4X4	.	.	.	.	.	4978	4978	.	.
		9202 LEXUS LX470	.	.	.	.	.	.	.	5263	5263
8508	R	8517 TOYOTA PREVIA VAN	3700	3700	3700	3610	3615	3755	3755	.	.
8508	44	8518 TOYOTA PREVIA 4X4 VAN	3900	3900	3900	3830	3830	3975	3975	.	.
8509	R	8519 TOYOTA T100 PK	.	.	3350	3320	3320	3320	3320	3320	.
		8520 TOYOTA T100 1-TON PK	.	.	3430	3490	3520	.	.	.	.
		8522 TOYOTA T100 XTRACAB PK	.	.	.	.	3550	3550	3550	3550	.
8509	44	8521 TOYOTA T100 4X4 PK	.	.	3845	3875	3875	3875	.	.	.
		8523 TOYOTA T100 XTRACAB 4X4 PK	.	.	.	.	4005	4005	4005	4005	.
8510	R	8515 TOYOTA 4RUNNER	.	.	.	.	.	3520	3565	3565	3600
8510	44	8507 TOYOTA 4RUNNER 4X4	.	.	.	.	.	3900	3900	3900	3900
8511	F	8532 TOYOTA RAV4 2DR 4X2	.	.	.	.	.	2461	2472	2524	2547
8511	44	8524 TOYOTA RAV4 2DR 4X4	.	.	.	.	.	2700	2700	2701	2723
8512	F	8533 TOYOTA RAV4 4DR 4X2	.	.	.	.	.	2605	2616	2668	2668
8512	44	8525 TOYOTA RAV4 4DR 4X4	.	.	.	.	.	2900	2900	2900	2900
8513	R	8526 TOYOTA TACOMA PK	.	.	.	.	2560	2560	2560	2580	2580
8513	44	8527 TOYOTA TACOMA PK 4X4	.	.	.	.	3185	3185	3190	3215	3215
8514	R	8528 TOYOTA TACOMA PK XTRACAB	.	.	.	.	2740	2740	2745	2750	2760
8514	44	8529 TOYOTA TACOMA 4X4 PK XTRACAB	.	.	.	.	3400	3400	3400	3400	3400

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP	WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
8515	R	8530 TOYOTA INCOMPLETE CAB & CHASSIS	4000	4000	4000	.	.	.	.	.	.
8516	F	8534 TOYOTA SIENNA VAN	.	.	.	.	.	.	.	3800	3800
8518	F	9203 LEXUS RX300	.	.	.	.	.	.	.	.	3698
8518	44	9204 LEXUS RX300 4X4	.	.	.	.	.	.	.	.	3900
8603	R	7124 DODGE RAM-50 PK	2580	2580	2585	.	.	.	.	.	.
		8604 MITS MIGHTY MAX	2578	2580	2580	2580	2580	2600	.	.	.
8603	44	7125 DODGE RAM-50 4X4 PK	2985	2985	2995	.	.	.	.	.	.
		8605 MITS MIGHTY MAX 4X4	3190	3030	3030	3190	.	.	.	.	.
8604		7126 DODGE RAM-50 PK LBED	2690	.	.	.	.	.	.	.	.
		7127 DODGE RAM-50 4X4 PK LBED	3285	.	.	.	.	.	.	.	.
8604	R	7128 DODGE RAM-50 PK EXT CAB	2750	.	.	.	.	.	.	.	.
		8606 MITS MIGHTY MAX LBED	2788	2788	2788	.	.	.	.	.	.
		8608 MITS MIGHTY MAX EXT CAB	2815	2765	2765	2765	.	.	.	.	.
8604	44	7129 DODGE RAM-50 4X4 PK EXT CAB	3350	.	.	.	.	.	.	.	.
8606	44	8612 MITS MONTERO 4DR 4X4	3863	.	.	.	.	.	.	.	.
8607	R	8614 MITS MONTERO SPORT 4DR	.	.	.	.	.	.	3435	3500	3510
8607	44	8613 MITS MONTERO 4DR 4X4	.	4130	4175	4190	4265	4290	4431	4431	4431
		8615 MITS MONTERO SPORT 4DR 4X4	.	.	.	.	.	.	3945	4000	4005
8698	R	7124 DODGE RAM-50 PK	2600	2640	2600	.	.	.	.	.	.
8698	44	7125 DODGE RAM-50 4X4 PK	3130	3000	3010	.	.	.	.	.	.
8701	R	8706 SUZUKI SAMURAI	1997	1997	1945	.	.	.	.	.	.
8701	44	8701 SUZUKI SAMURAI 4X4	2110	2110	2088	2062	2062	.	.	.	.
8702	R	7659 CHEVY GEO TRACKER	2196	2196	2196	2196	2249	2342	2342	2277	.
		8702 SUZUKI SIDEKICK 2DR	2208	2208	2225	2256	2256	2342	2342	2340	.
		8707 SUZUKI X-90 2DR	.	.	.	.	.	2325	2349	2403	.
8702	44	7643 CHEVY GEO TRACKER 4X4	2371	2384	2373	2373	2468	2468	2468	2468	.
		8703 SUZUKI SIDEKICK 2DR 4X4	2371	2384	2404	2439	2479	2479	2479	2483	.
		8708 SUZUKI X-90 2DR 4X4	.	.	.	.	.	2497	2503	2542	.
8703	R	7675 CHEVY GEO TRACKER 4DR	.	.	.	.	.	2617	2603	2619	.
		8704 SUZUKI SIDEKICK 4DR	.	2620	2574	2574	2574	2636	2730	2727	.
8703	44	7676 CHEVY GEO TRACKER 4DR 4X4	.	.	.	.	.	2731	2731	2740	.
		8705 SUZUKI SIDEKICK 4DR 4X4	2746	2746	2728	2728	2728	2836	2855	2859	.
8704	R	7659 CHEVY GEO TRACKER	.	.	.	.	.	.	.	.	2602
		8709 SUZUKI VITARA 2DR	.	.	.	.	.	.	.	.	2601
8704	44	7643 CHEVY GEO TRACKER 4X4	.	.	.	.	.	.	.	.	2726
		8710 SUZUKI VITARA 2DR 4X4	.	.	.	.	.	.	.	.	2726
8705	R	7675 CHEVY GEO TRACKER 4DR	.	.	.	.	.	.	.	.	2870
		8711 SUZUKI VITARA 4DR	.	.	.	.	.	.	.	.	2870
		8713 SUZUKI GRAND VITARA	.	.	.	.	.	.	.	.	3068
8705	44	7676 CHEVY GEO TRACKER 4DR 4X4	.	.	.	.	.	.	.	.	2987
		8712 SUZUKI VITARA 4DR 4X4	.	.	.	.	.	.	.	.	2991
		8714 SUZUKI GRAND VITARA 4X4	.	.	.	.	.	.	.	.	3201
8801	44	8801 DAIHATSU ROCKY	2800	2800	.	.	.	.	.	.	.

CURB WEIGHTS OF 1991-99 LIGHT TRUCKS

CGP	WHEELS	MMP		WT91	WT92	WT93	WT94	WT95	WT96	WT97	WT98	WT99
8901	F	8905	HONDA CR-V	.	.	.	.	.	.	.	3036	3036
8901	44	8904	HONDA CR-V 4X4	.	.	.	.	.	.	3074	3146	3146
8902	F	8903	HONDA ODYSSEY	.	.	.	.	.	.	.	.	4233
9001	R	9001	KIA SPORTAGE 4DR	.	.	.	.	3100	3100	3100	3100	3100
		9003	KIA SPORTAGE 2DR	.	.	.	.	.	.	.	.	3000
9001	44	9002	KIA SPORTAGE 4DR 4X4	.	.	.	.	3325	3347	3358	3396	3396
		9004	KIA SPORTAGE 2DR 4X4	.	.	.	.	.	.	.	.	3230
9301	44	9301	LAND ROVER RANGE ROVER 4DR 4X4	.	.	4574	4574	4960	4960	4960	4960	4960
9302	44	9302	LAND ROVER DISCOVERY 4DR 4X4	.	.	.	4379	4379	4465	4465	4465	4465
9303	44	9303	LAND ROVER DEFENDER	.	.	4840	4840	4840	.	.	.	.
9304	44	9305	LAND ROVER COUNTY 4DR	4401	4401	4401	4401	4401	.	.	.	.
9305	44	9306	LAND ROVER DEFENDER 90	.	.	.	.	.	.	3913	.	.
9306	44	9307	LAND ROVER DISCOVERY II	.	.	.	.	.	.	.	.	4575
9601	44	9601	MERCEDES ML320	.	.	.	.	.	.	.	4387	4387
		9602	MERCEDES ML450	.	.	.	.	.	.	.	.	4387