CAFE – why it is so difficult to estimate its effect on traffic fatalities and fuel use

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Leonard Evans
President, Science Serving Society
973 Satterlee Road
Bloomfield Hills, MI 48304-3153
Tel: (248) 646 0031 or (248) 203 6417
LE@ScienceServingSociety.com
http://www.scienceservingsociety.com

Tel: (248) 203 6417
Email: LE@ScienceServingSociety.com
Internet: http://www.scienceservingsociety.com

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ABSTRACT

Despite the National Research Council's recent report on the Federal Government's Corporate Average Fuel Economy (CAFE) program, there is still no consensus on how CAFE affects safety or the nation's fuel use. There is general agreement that the program has led to reductions in the mass of the average new car and the mass of the average light truck sold. This paper explains why it is so difficult to quantitatively estimate fatality changes due to such changes in fleet composition. At the core of the problem is that any estimate must address single vehicle crashes and two-vehicle crashes in separate calculations. Quantification of single-vehicle effects is particularly difficult because of the absence of appropriate data on single-vehicle crashes in which all occupants survived. Even if one knows the risk of death, given a crash, this still does not answer how CAFE affects fatalities. If CAFE, by reducing the fuel cost per mile, induces additional travel, fatality increases are expected to increase approximately in proportion. These and other problems are discussed. Alternative approaches to reducing fatalities and fuel use are presented.

INTRODUCTION

The Federal Government's Corporate Average Fuel Economy (CAFE) program specifies that the average fuel economies of the vehicles sold by each manufacturer must be not less than 27.5 miles per gallon for cars and 20.7 miles per gallon for light trucks. There is general agreement that that these standards have indeed increased the average fuel economies of new cars and light trucks sold[1]. Superficially, this might seem to imply that the program must therefore reduce the total amount of fuel consumed in the nation. This is not necessarily so, as discussed later.

While the effect of CAFE on national fuel use is uncertain, there is more agreement that that CAFE has led to lighter vehicles. Making a vehicle lighter reduces its fuel use because the energy required to accelerate it from rest to a given speed is, according to Newton's laws, proportional to the vehicle's mass. When in motion, rolling resistance forces are proportional to vehicle weight. Thus the energy required to move a vehicle is linked to its mass through fundamental physical laws. While reducing a vehicle's mass reduces fuel use, equally inexorable physical laws dictate that this also increases injury-producing forces on occupants during crashes.

While lighter vehicles expose their occupants to increased fatality risks in nearly all types of crashes, the net effect of CAFE standards on safety has proved difficult to disentangle. One barrier precluding an immediately understandable simple analysis is that the role of mass in single-vehicle crashes is so conceptually distinct from its role in multiple vehicle crashes. For single-vehicle crashes, other vehicles and how they are driven does not affect outcome. For two-vehicle crashes, a specific driver's risk is not only dependent on his or her choice of vehicle, but (in principle) on the choices and behavior of all the other drivers. Any estimate of overall effects must be a synthesis of separately computed single-vehicle effects and multiple-vehicle effects.

Of the 36,262 people killed as occupants of motor vehicles in motion in US traffic in 2000, 48% died single-vehicle crashes and 43% in two-vehicle crashes. Because cars now constitute less than half of the vehicles on US roads, about one in five of all two-vehicle crashes involves two cars.

While the effect of mass on fatality risk in the single-vehicle crash case is conceptually simpler than the multiple-vehicle case, far less is known. This is because the detailed information in the Fatality Analysis Reporting System (FARS)[2] on occupants killed in single-vehicle crashes is not accompanied by any information on the single-vehicle crashes in which no one was killed. The most precise and reliable information on vehicle mass effects on fatality risk is derived from analysis of two-car crashes, which now account for 8% of US traffic deaths. The information on multiple-vehicle crashes that are not two-car crashes is more uncertain.

In this paper we do not offer a new estimate of changes in fatalities attributable to CAFE, but rather address why it has proved so difficult to progress much beyond the estimates that have already been published[1,4,5]. In discussing the problems, no criticism of prior work (including my own) is intended. The reason why there are not clearer answers is because the problems are exceedingly difficult.

Only results from an experiment somewhat like the following can be almost free from alternative interpretations. Randomly select 5,000 drivers, and require them to drive only one type of vehicle. Randomly select a second set of 5,000 drivers, and require them to drive another type of vehicle. Later, count the total number of casualties associated with each vehicle type. Technically, the problem has similarities to the problem of determining how smoking affects health. In the past, many statisticians testified that the finding that smokers died younger did not imply that smoking harmed health because the smoking and non-smoking populations were not assigned at random. In both smoking and vehicle weight cases, when large numbers of different, but imperfect, data-based examinations all point to similar conclusions, rejecting these conclusions becomes less plausible. In the vehicle weight case, there are reasons based on physical principles that complement the general agreement among a large numbers of data-based studies.

SINGLE-VEHICLE CRASHES

Many studies[5-15] have reported relationships between vehicle weight and such measures as the number of driver deaths per million vehicles. These relationships do not directly address what happens when a driver transfers to a different vehicle because they reflect effects due to the driving behavior, domicile, and vehicle use patterns of the drivers who previously chose those vehicles. Yet the aim of CAFE is that drivers will travel in different vehicles, not that they will become like former drivers of lighter vehicles. Assuming that a relationship between observed risk and a vehicle property reflects the influence of the vehicle property can lead to grossly erroneous conclusions.

Fig.1 shows that the number of driver deaths in single-car crashes per million registered cars in different weight categories[14] depends strongly on the number of doors, an effect even more pronounced for rollover crashes (Fig. 2). To help place the magnitudes of the effects in perspective, the reduction in fatality risk from airbags is indicated. There is no reason why adding doors to a car should materially affect occupant risk. This effect is due not to the addition of the doors, but because the life-style and risk-taking characteristics of drivers who choose two-door cars differ in so many ways from those choosing four door cars. The effects are far larger than explainable in terms of any broad known demographic characteristics such as age and gender.

While Figs 1 and 2 show a tendency of increasing risk with decreasing weight, the tendancy is far from systematic (though additional data for all vehicles[13] show more regular behavior). How are these figures to be interpreted? Nominally, Fig. 1 indicates that 2500-2999 pound cars have higher risks than cars that are either lighter or heavier. Yet there are clear theoretical reasons, backed up by much empirical evidence, that vehicle weight affects safety in a systematic continuous manner, so that departures from such regular behavior appear to be due to non-vehicle factors.

The *pedestrian fatality exposure approach*[15,16] attempts to determine the effect of vehicle characteristics independent of driver behavior. Ideally, we would like to know the number of driver deaths from, say, impacts with trees divided by the number of impacts with trees. The FARS data provide information on drivers killed hitting trees, but essentially no information on non-fatal tree impacts. However, if a vehicle strikes a pedestrian, this event is coded in FARS if the pedestrian is killed. So, the ratio of the number of driver deaths to the number of pedestrian deaths for a set of vehicles is a surrogate for the number of driver deaths per tree impact, and accordingly measures how driver risk depends on the physical properties of the vehicle. This ratio plotted versus vehicle mass will therefore estimate how driver fatality risk depends on vehicle mass subject to the additional assumption that the probability of pedestrian death is independent of vehicle mass. This is approximately so because even the lightest vehicle is so much heavier than the heaviest pedestrian.

Fig. 3, derived[15,17] from 1975-1983 FARS data, shows the number of driver deaths per pedestrian death versus car mass. This is interpreted to measure how driver fatality risk depends on mass. Note that Fig. 3 shows a relatively noise-free relationship, with the data fitting well

$$R = a \times \exp(b\,m) \tag{1}$$

where a is a scaling factor, essentially irrelevant as the units are arbitrary, and b indicates the fractional change in risk per linear change in mass.

Systematic relationships between risk and vehicle mass are expected on physical grounds. Nearly all crashes are into objects that will to some extent move, bend, uproot, break or distort, so that increased mass of the vehicle will systematically reduce the deceleration forces experienced within the vehicle. Inflicting more damage on the struck object lowers risk to the vehicle occupants. While mass should not have a direct influence on rollover risk, vehicle size, which is correlated strongly with mass[18], does. Wider vehicles offer more resistance to rollover, and longer vehicles have higher lateral stability.

Thus there are compelling physical and empirical (Fig. 3) reasons why single-vehicle fatality risk decreases systematically with increasing mass. The non-systematic behavior of measures such as driver fatalities per million vehicles most likely reflects large influences from factors, particularly driver behavior, not directly related to the vehicle.

It seems that the best way to estimate how single-vehicle (and rollover) fatality risk depends on mass is as follows. Assume that the effects are systematic, and that risk is a simple function of mass. A function with the form of eqn 1 is a good choice. While measures such as driver deaths per million registered vehicles have inadequacies, they are the best available data to determine the parameters for the simple functional form assumed to apply. The parameter b in Fig. 3 indicates a 4.4% decrease in single-vehicle fatality risk for each additional 100 pounds of vehicle mass. The least-squares fit (not very good) to the data in Fig. 1 indicates corresponding decreases of 3.7% for four-door cars and 3.1% for two-door cars. The estimate from Fig. 3 is expected to be high because it is based on assuming that pedestrian fatality risk does not increase with increasing mass of the striking vehicle, when in fact it does slightly. These values are higher than the a reported 1.1% increase in occupant fatalities per hundred pound increase per million cars[7,1] for cars crashing into fixed objects, though it should be noted increases are expected to be less for all occupants than for drivers because occupancy, and therefore those at risk, increases with increasing vehicle size.

EFFECT OF MASS IN TWO-CAR CRASHES

Two-car crashes, which account for 8% of all deaths, are studied intensively because they provide insight into crashes between any pair of vehicles and also into single-vehicle crashes. For two-vehicle crashes useful information is available for both struck and striking object in that we know information about injuries in each vehicle, which in turn provides information relating to impact severity. The curb masses of most cars are given in the FARS data; while such information is not conveniently available for most of the wide variety of other vehicles coded in FARS.

Definitions for two-vehicle crashes

From a formal perspective, each of the vehicles involved in a two-vehicle crash can be considered to have a symmetrical role -- they crash into each other. However, for expository clarity it is convenient to make an arbitrary distinction between them, using such terminology as:

vehicle$_1$ = "first", "struck", "bullet", "subject", "driven" or "your" vehicle

vehicle$_2$ = "second", "striking", "target" or "other" vehicle

The vehicle masses are designated by m_1 and m_2. It is convenient for the heavier of the two vehicles to be vehicle$_2$, so we can define a mass ratio, m, for every crash between two vehicles of known mass as

$$m = \frac{m_2}{m_1} = \left(\frac{\text{mass of heavier vehicle}}{\text{mass of lighter vehicle}} \right) \tag{2}$$

The choice of m_2 as the heavier vehicle insures that m is greater than one.

Consider a set of crashes with the same value of m, or with values of m confined to a narrow range. Assume that the total number of drivers killed in the lighter vehicles is N_1 and that N_2 drivers are killed in the heavier vehicles. A driver fatality ratio, R, can be defined as

$$R = \frac{F_1}{F_2} = \frac{\text{Number of driver fatalities in the lighter vehicles}}{\text{Number of driver fatalities in the heavier vehicles}} \quad . \tag{3}$$

The interpretation of R is remarkably assumption free – a simple count of driver fatalities in two sets of clearly defined vehicles. It is a measure of relative fatality risk in pairs of crashing vehicles, essentially regardless of driver behavior or vehicle use patterns. Higher risk driving by, say, drivers of heavier vehicles will increase the number of driver fatalities in heavier vehicles, but also in lighter vehicles into which they crash by a similar proportion. Higher risk driving affects the total number of fatalities, which affects the precision with which R can be determined, but not its expected value.

Factors that affect survivability in crashes do influence R. For example, systematically different rates of safety belt use or systematically different average ages in the heavier and lighter vehicles would influence the value of R.

Empirical findings

Many analyses of FARS data[19] have found that R and m are related according to

$$R = \mu^{l} \tag{4}$$

Fig. 4 shows results for cars with unbelted drivers crashing head-on into other cars with unbelted drivers. In this case, based on 15,356 unbelted drivers killed in 13,162 crashes, $l = 3.58 \pm 0.05$. Note again that thet risk outcome depends on the mass measure in a relatively systematic and regular way.

Crashes between cars of the same (or similar) mass

When cars of the same mass crash into each other, eqn (4) provides no useful information. However, five sets of data and a calculated relationship[20] support (Fig.5) that the relative driver risk, R_{MM}, when two cars of the same mass, M, crash into each other is given by

$$R_{MM} = k / M \tag{5}$$

where k is a constant[21]. Although the relationship is in terms of mass, it is the larger size of heavier vehicles that is the causative factor. In terms of Newtonian mechanics, mass is irrelevant when two cars of the same mass crash into each other.

Adding a passenger

Eqn (4) can be modified when the two vehicles differ in some additional factor[19] to give

$$R = a \mu^{l} \quad . \tag{6}$$

where a measures the influence of the other factor. Fig. 6 shows the risk to a driver accompanied by a passenger relative to the risk to a lone driver. This shows the influence of adding mass to a vehicle without any corresponding increase in size. When two cars, identical except that one has a passenger and the other does not, crash head-on into each other, the accompanied driver is (14.5 ± 2.3)% less likely to die than the lone driver solely due to the mass difference resulting from the passenger's presence. This result, together with eqn (5), leads[21] to

$$\begin{array}{ccccccc} r_1 & = & k & \times & \dfrac{1}{m_1 + m_2} & \times & \left(\dfrac{m_2}{m_1}\right)^t \\ \text{[neteffect]} & = & & & \text{[intinsic size]} & \times & \text{[intinsic mass]} \end{array} \tag{7}$$

where r_1 is the risk to the driver in car_1 when it crashes into car_2 when car_1 and car_2 have masses m_1 and m_2 and sizes equal to those of average cars of masses m_1 and m_2, respectively. Once k is chosen, eqn (7) estimates risks in the same arbitrary units for any pair of cars; the choice k = 2800 kg insures that r_1=1 for the case of a 1400 kg car crashing into another 1400 kg car. The other parameter has the value $t = l/2 = 1.79$.

If cars of unequal mass crash into each other, the ratio of the risks to the drivers, r_1/r_2 is computed from (7) as

$$\frac{r_1}{r_2} = \frac{m_2 + m_1}{m_1 + m_2} \times \left(\frac{m_2}{m_1}\right)^t \times \left(\frac{m_1}{m_2}\right)^{1/t} = m^{2t} = m^{l} , \tag{8}$$

the same relationship as in eqn (4).

If the cars are of the same mass M, eqn (7) computes the risk in each as k/M, the same the relationship as in eqn (5) plotted in Fig.5.

Eqn (8) thus contains the two relationships that are so well established that they have been referred to as the two fundamental laws of two-car crashes[21].

Consider two 1400 kg cars crashing into each other with identical initial driver risks $r_1 = r_2 = 1$. If the mass of the first car is increased to 1475 kg by adding 75 kg cargo, its driver risk is reduced to (1400/1475) = 0. 911 but the risk in the struck car with unaltered mass is increased to (1475/1400) = 1.098. The ratio of these gives a reduction in risk ratio of 17.0%, somewhat larger than the empirically observed 14.5% reduction associated with the addition of a passenger. The difference may be a reflection of the fact that the passenger was unbelted and accordingly not locked to the vehicle structure, thereby discounting the influence of mass. If the risks to the individual drivers are rescaled so that the risk ratio matches the empirically determined value, we conclude that the addition of a passenger reduces the risk to the accompanied driver by 7.5%, but increases the lone driver's risk by 8.1% . A small net increase in risk results.

A driver transferring from a 1400 kg car to a 1475 kg car which, will also be larger, will enjoy a personal risk reduction of 11.3%, but will increase the risk to the other driver by 6.9%. The net effect is a 2.2% risk reduction averaged over both drivers. A net reduction always results if the lighter car in a two-car crash is replaced by a heavier one.

Replacing the heavier car by one yet heavier may increase or decrease net risk – it is necessary to substitute specific values into eqn (8) in order to determine the net effect. If there is a large disparity in mass, the risk in the heavier car is already so low that there is little, in absolute terms, to be gained by lowering it further. On the other hand, the risk in the lighter car is high, and even a small percentage increase in it might overwhelm a far larger percentage reduction in the smaller risk to the larger-car driver. Eqn (8) enables one to compute the total risk in a population as a function of the distribution of cars by mass. All cars in the population becoming lighter by a constant amount, or a constant percent, will increase net fatality risk.

CRASHES INVOLVING VEHICLES OTHER THAN CARS

Table 1 shows relative risks when cars of different weights crash into other vehicles (all crash directions included)[18]. Quantitative estimates of weight are not coded in FARS for vehicles other than cars. When light cars and large trucks crash into each other, the driver in the light car is 44 times as likely to die as the truck driver. When heavy cars and large trucks crash into each other, the driver in the heavy car is 22 times as likely to die as the truck driver. When cars crash into large trucks, the driver of a light car is about twice as likely to die as a driver of a heavy car, a result in agreement with the finding using the pedestrian exposure approach[16]. As the mass of large trucks are unaffected by CAFE (cargo-carrying capacity is the main factor), occupants of vehicles with masses reduced by CAFE are intrinsically at higher risk in such multiple-vehicle crashes.

Interpreting risk ratios

The comparisons above are based on risk ratios – the risk to one driver divided by the risk to the other. While large risk ratios have been recognized for decades (note the 139 ratio when mopeds and light cars crash), it is only in recent years that the term "vehicle aggressivity" has appeared. This term has been most commonly applied to crashes between cars and light trucks, especially sport utility vehicles (SUVs)[22]. In frontal crashes between cars and SUVs, five car-drivers die for each SUV-driver killed[23]. The major portion of this difference arises because of a difference in average weight between the vehicles. When the weight factor is controlled[24], the car driver is about twice as likely to die as the SUV driver.

The following hypothetical example illustrates that increasing risk ratios does not necessarily imply lowering safety. Suppose we start with two identical "original" vehicles. If they crash head-on into each other, each driver has identical risk, say, equal to 1 in arbitrary units. Now suppose that one vehicle is replaced by a "new" vehicle that reduces risk to its occupants by 15%, but also reduces risk to occupants of any vehicle into which it crashes by 5%. The redesigned vehicle thus reduces risk to all occupants in any two-vehicle crash.

If new and old vehicles crash into each other, the risk ratio is 0.95/0.85 = 1.12, compared to a former value of 1.0. The driver of the old vehicle is now 12% more likely to die than the driver of the new vehicle, whereas formerly they had equal risks. Clearly, this does not mean that the new vehicle is "more aggressive" because it increased the risk ratio to the driver of the older vehicle by 12%. The literature is replete with inappropriate interpretations of risk ratios of the type that, in this case, would suggest that the new vehicle was reducing net safety when it is in fact increasing safety.

This example illustrates how available data do not necessarily provide answers to questions of high importance to public policy. There would be widespread agreement that if the redesign in the hypothetical example led to the hypothesized effects, it should be supported. However, there is no reliable way to estimate how the redesign affects the risks to both drivers. We can estimate only the ratio, which is subject to the misinterpretation discussed.

MORE ON DRIVERS TRANSFERRING TO DIFFERENT VEHICLES

Above we discussed the problem that when drivers transfer to different vehicles they cannot be assumed to adopt the same use and driver behavior patterns as those who previously chose such vehicles. There is yet another uncertainty. Vehicle characteristics may induce changes in driver behavior, including changes unknown to the driver. One vehicle characteristic that has been shown empirically to influence a driver's judgment of inter-vehicle spacing is the amount of roadway visible[25,15]. The same subject judged a vehicle in front to be nearer in a vehicle with a longer hood, which obscured more of the roadway. This implies that a driver transferring from a car to a vehicle with a shorter hood or higher seat will follow more closely when attempting to follow at the same headway.

Many drivers complain of being tailgated by SUVs. Perhaps SUV drivers are unknowingly tailgating because the view from the SUV makes following headways appear longer than they in fact are. Unlike some of the problems discussed in this paper, such a question can be reliably answered by straightforward experiments and observations. If SUV drivers are unknowingly placing themselves and others at risk by following closer than they think, countermeasures could be addressed. Even a simple warning "The vehicle you are following is closer than it seems", in analogy with the warning on convex rear-view mirrors, might be appropriate. It is also possible that the greater protection enjoyed by SUV drivers could lead to higher risk taking in the form of shorter following headways.

DISCUSSION AND CONCLUSIONS

CAFE and safety

The relationship between CAFE and safety involves much more than the relationship between vehicle mass reductions and safety. By lowering the fuel cost per mile of travel, CAFE will stimulate additional travel, with an expected consequent increase in traffic crashes and fatalities. If CAFE encouraged a move to SUVs away from cars, and SUVs have higher single-vehicle fatality rates and fatal rollover rates[13], this could increase deaths even as it increases fuel use.

One piece of the puzzle on which we can come to fairly confident conclusions is the relationship between vehicle mass reductions and safety.

More than half of occupant fatalities are in single-vehicle crashes. The evidence is compelling that fatality risk increases as the mass of a vehicle declines, so that there can be little doubt that any general reduction in vehicle mass will lead to an increase in fatalities. For two-vehicle crashes, reducing the mass of one of the vehicles increases the risk to its driver, but reduces the risk to the other involved driver. The net effect is the difference between a risk increase and a risk decrease, which can be computed for the case of two car crashes. Apart from some cases when the heavier car is made lighter, reducing the weight of one car increases the net risk in a two-car crash. While less is known about two-vehicle crashes involving vehicles other than cars, it is implausible to claim that any pattern of mass reductions could lead to a risk reduction that could come close to equaling the increase in risk from single-vehicle crashes, and likely risk increase from two-car crashes.

Safety in broader contexts

Vehicle mass has a larger influence on risk in a crash than any other vehicular factor[14,15,20,21]. Making vehicles lighter in response to CAFE is estimated to have killed an additional 1,300 to 2,600 Americans in 1993. Yet crashworthiness factors are overwhelmed in importance by driver factors. Crashworthiness factors are relevant only when crashes occur. Effective safety policy must place enormously more emphasis on preventing crashes – the approach that has been so dramatically successful for aviation safety. In terms of traffic deaths per million registered vehicles, the US has dropped from being the safest nation in the world in the early 1970s into thirteenth place, and still dropping[26,27]. If the US had matched the changes in fatality rates achieved by Australia, Canada or Britain in the last few decades, 15,000 fewer Americans would have been killed in US traffic in 2000[26,27]. In the last two decades 150,000 American deaths would have been prevented. The better-performing countries have not done anything that is either extraordinary or draconian – they have simply not fallen into the obsessive focus on vehicle factors that has dominated US safety policy since the 1970s. The better-performing countries surpass the US even though their vehicle fleet consists of smaller, and therefore less safe, vehicles.

Fuel use and CAFE

Higher CAFE standards for cars have made larger cars less available and more expensive. Many purchasers who have traditionally sought large cars have instead chosen light trucks to meet their personal transportation needs. When a vehicle buyer chooses a light truck rather than a large car, this choice increases the average fuel economy of the car fleet, and also increases the average fuel economy of the truck fleet. Although the choice increases the fuel economy of both fleets, it nonetheless leads to more fuel being used in the nation.

The reduction in the cost of travel that results from CAFE is expected to have long term effects, such as land-use changes due to longer commuting (and other) trips becoming more acceptable. When any vehicle travels more, it increases traffic congestion, thereby increasing fuel use per mile for other vehicles[28]. A simple comparison of the nation's fuel use before and after CAFE makes any claim that CAFE has reduced net fuel use hard to sustain.

The appropriate technical communities cannot agree whether CAFE led the nation to use more or less fuel. While there is near universal agreement that CAFE increased fatalities, even this has been disputed. Even if CAFE did reduce fuel, passing stricter CAFE standards can have no effect for many years. It will take time to pass complex legislation, and time to design vehicles to meet new regulations, so that many years will pass before the first affected vehicle appears in the showroom. After this, it will be another decade or so before nearly all of the fleet consists of vehicles sold under the new CAFE.

After the events of September 11, 2001 there is a need to reduce the flow of dollars to nations which might well use them to harm the US. It strains credulity to imagine that CAFE can play a role in the response to so urgent a national need.

While there seems to be no consensus among any of the professions involved in evaluating the effect of CAFE on fuel use, there is unanimity in another discipline. Economists agree that increasing the cost of a commodity reduces its consumption. For specific commodities, there is often disagreement about magnitude of the effect, or the elasticity – the percent drop in consumption per percent increase in price. However, there is never disagreement about the sign – if fuel costs more, less will be consumed. A detailed economic analysis of CAFE concludes "If policy-makers desire to reduce energy consumption, it would seem they should focus their attention on raising energy taxes"[29].

No major economic or social disruptions would follow if Congress were to add a nickel tax on a gallon of fuel at the end of each month. Innumerable self-motivated adjustments would follow in a gradual and orderly manner. Shoppers for new vehicles would attach more weight to fuel economy, sales of the many vehicles that have been offered for years that exceed 40 miles per gallon would increase, the automobile industry would respond to customer preference by offering a wider choice of high fuel economy models, drivers would be more likely to carpool or forgo marginal trips, etc. Our vehicle fleet would slowly evolve in the direction of vehicle fleets in Europe (which are not subject to any regulations resembling CAFE). If the public understood that the issue was national security, such an approach could be politically acceptable. The tax collected could be returned to voters to underline that the purpose of the policy was not to raise revenue but to protect the homeland. While I do not expect such a policy to be adopted, there can be little doubt that it would achieve the goal of energy independence, and additionally provide an environmental bonus. Failing any resolve to do anything that has any chance of being effective, I believe it is a sham to keep bringing up ineffective and possibly counterproductive programs like CAFE. Our political process refuses to discuss a tax increase, the only measure that can work. We are like a 300-pound patient asking a doctor how to lose weight but insisting that the answer must not mention eating or exercise.

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LIST OF TABLES AND FIGURES

Table 1. Risks of death in crashes between cars of different weights and other vehicles. When light cars and mopeds crash into each other, the moped driver is 139 times as likely to die as the car driver. When heavy cars and heavy trucks crash into each other, the car driver is 22 times as likely to die as the truck driver. Based on table[18] using FARS data 1975-89.

Other vehicle	**Mass class* of car**		
—	Light	Medium	Heavy
Moped	1/139	1/202	1/205
Motorcycle	1/42	1/85	1/153
Light car		1/3.1	1/7.7
Medium car	3.1		1/2.4
Heavy car	7.7	2.4	
Pick-up	7.1	2.7	1.3
Van	9.3	3.3	1.7
Medium truck	34	18	12
Heavy truck	44	29	22

*Definitions

Light car: Mass from 655 kg to 1227 kg, mean 1014 kg

Medium car: Mass from 1227 kg to 1599 kg, mean 1428 kg

Heavy car: Mass from 1600 kg to 2606 kg, mean 1833 kg

Medium truck: Gross Vehicle Weight (GVW) > 10 000 pounds (4536 kg), but not a heavy truck

Heavy truck: GVW > 26 000 pounds (11 794 kg), or tractor-trailer combination, or with cargo trailer(s), or truck tractor pulling no trailer.

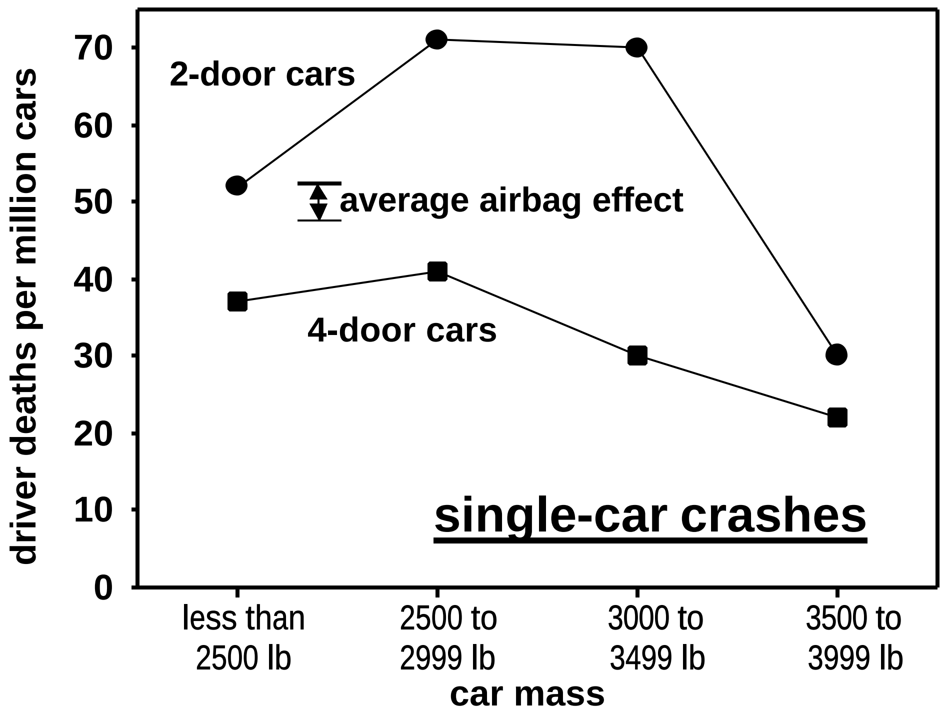

Fig. 1. Driver deaths in single-car crashes per million registered vehicle years for 1994-97 models during 1995-98. Data[14] from Insurance Institute for Highway Safety.

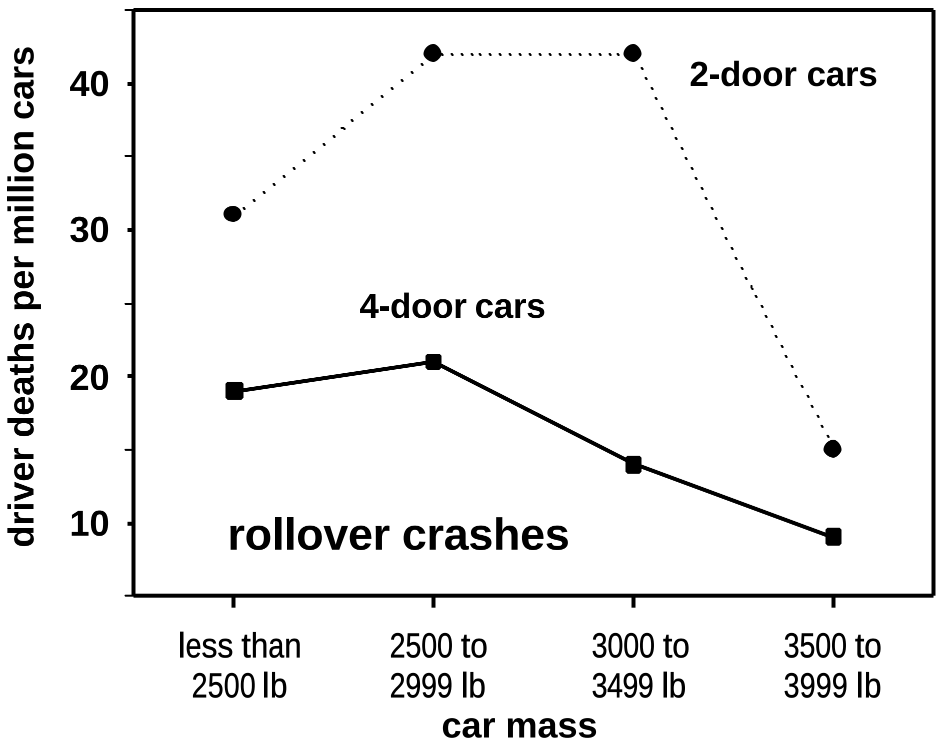

Fig. 2. Car-driver deaths in rollover crashes per million registered cars years for 1994-97 models during 1995-98. Data[14] from Insurance Institute for Highway Safety.

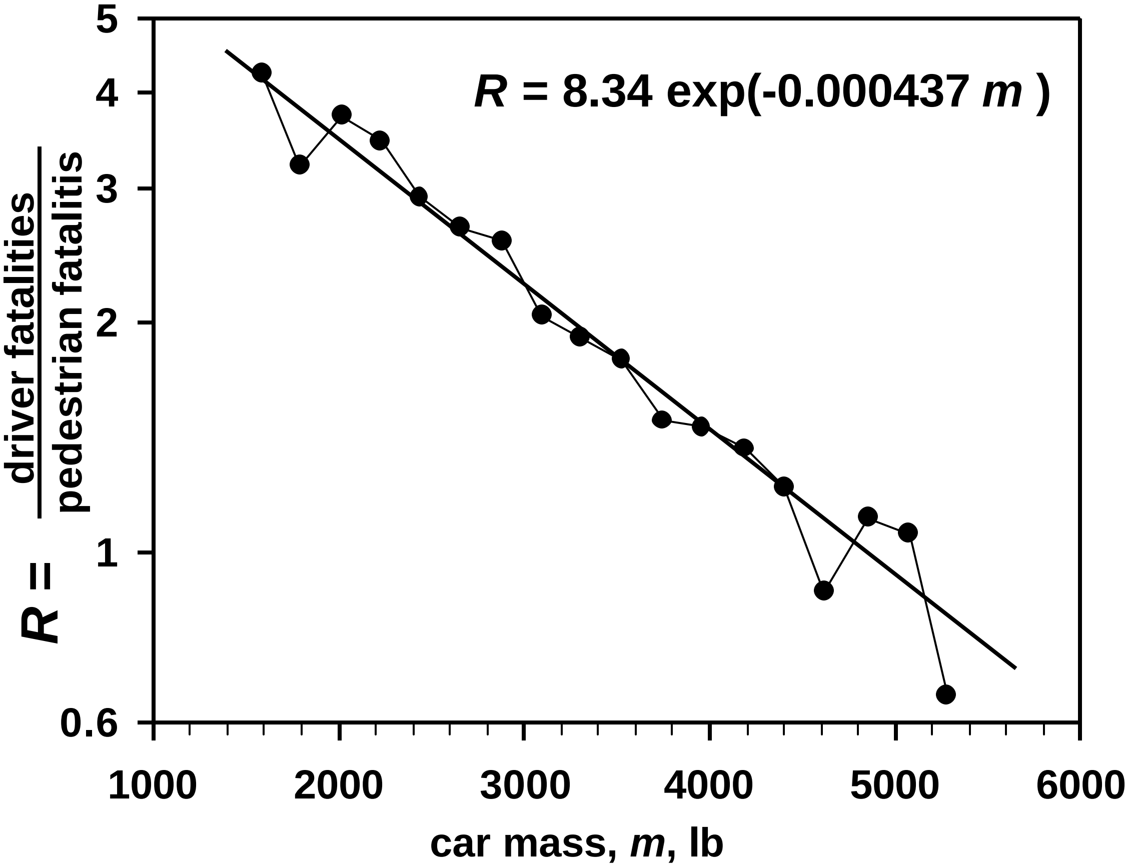

Fig. 3. The number of driver deaths in single-car crashes in cars with masses in a narrow range divided by the number of pedestrians killed in crashes involving cars in the same mass range[15,16,17].

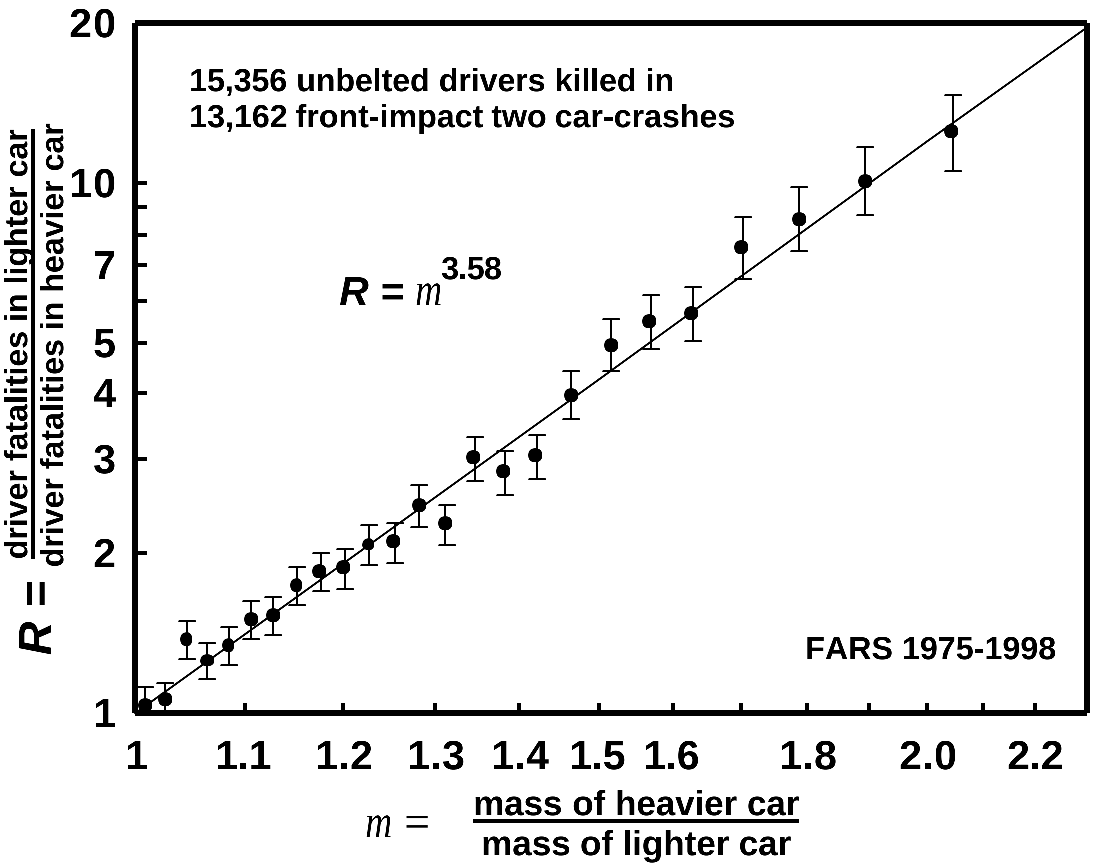

Fig. 4. The ratio, R, of driver fatalities in the lighter compared to in the heavier car versus the ratio, m, of the mass of the heavier to the mass of the lighter car for frontal crashes (both cars with principal impact point at 11, 12 or 1 o'clock). The relationship is the first of the two "laws" of two-car crashes.[21].

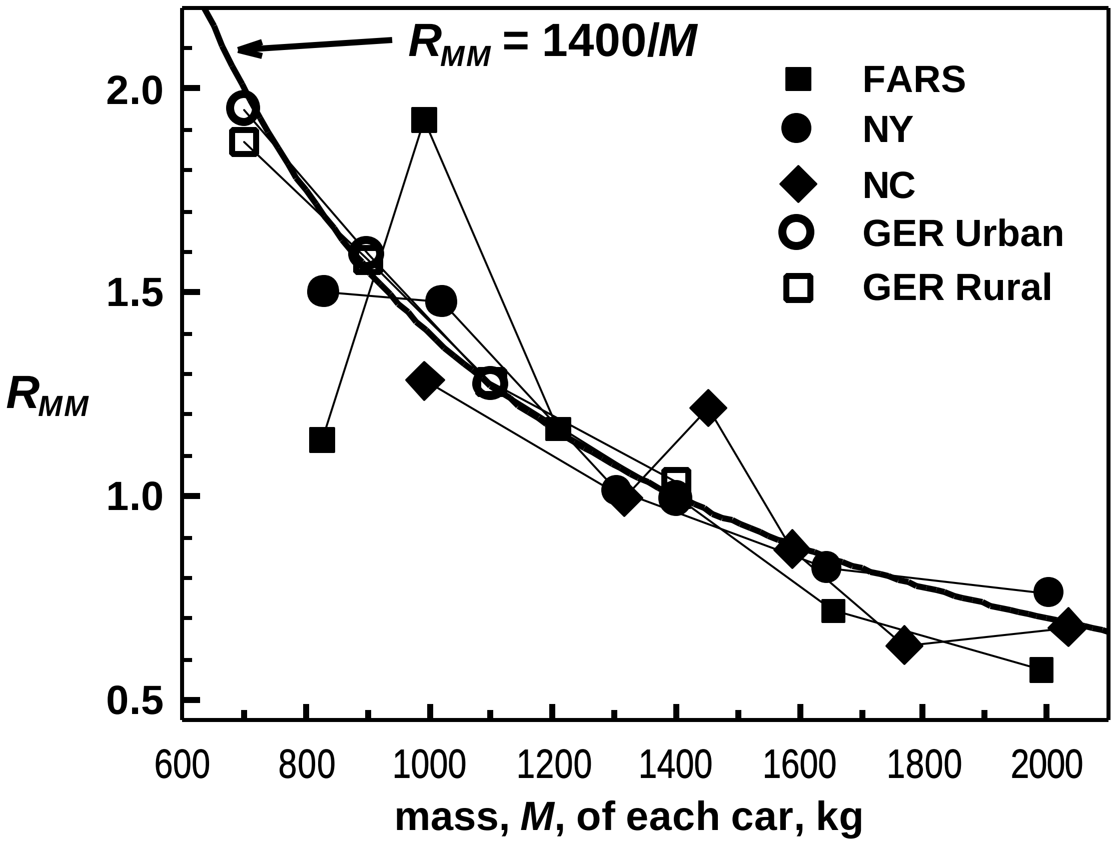

Fig. 5. Relative risk, R_{MM}, of driver injury or fatality when cars of similar mass crash head-on into each other versus M, the mass of each car. In all cases the data are scaled to assign a risk of 1 to M=1400 kg. The relationship is the second of the two "laws"[21].

FARS	Fatalities in US
NC	Injuries in North Carolina
NY	Injuries in New York State
GER Rural	Injuries on rural roads in Germany
GER Urban	Injuries on roads in built-up areas in Germany
Analytical curve	Computed from structural considerations, etc.

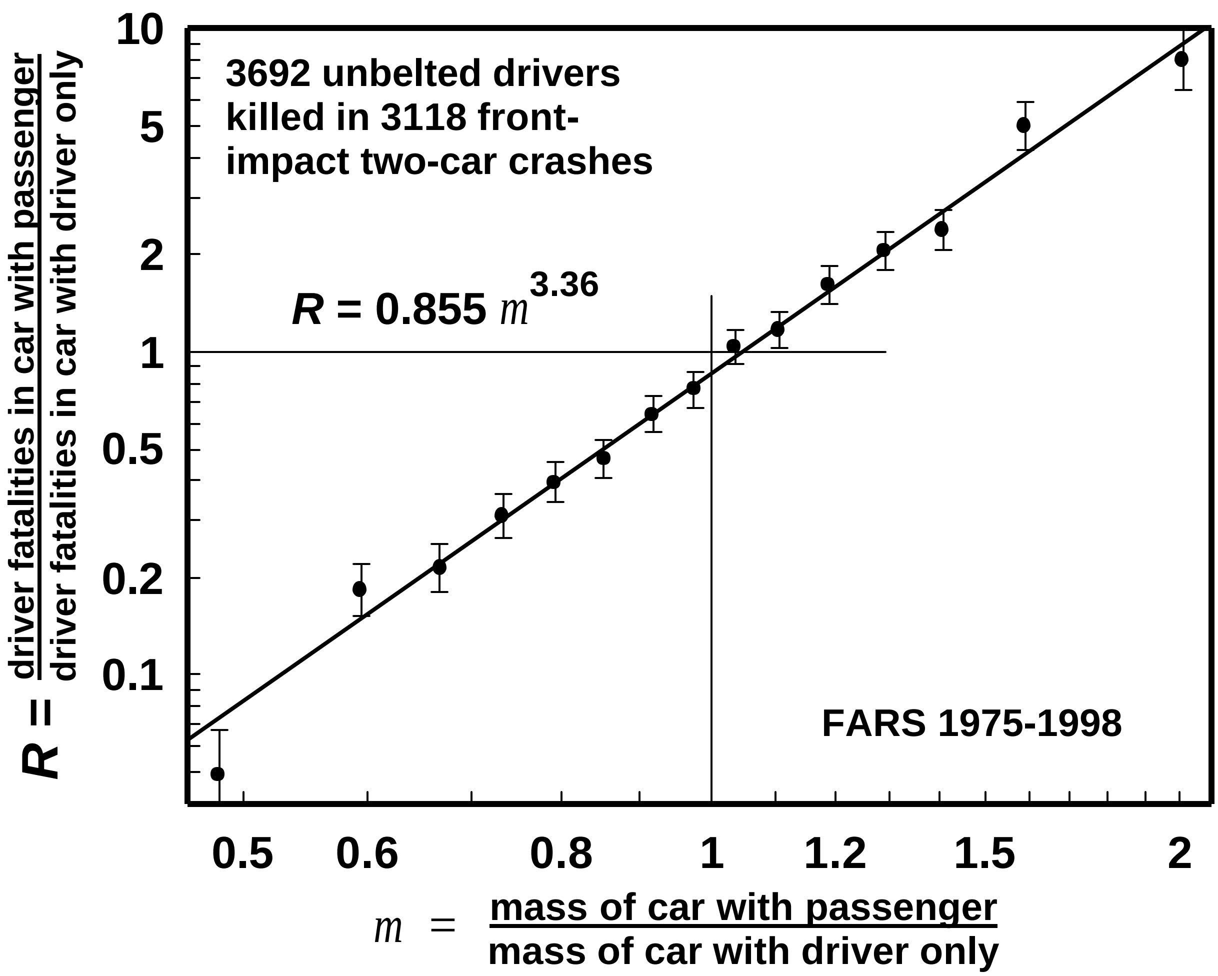

Fig. 6. The ratio, *R*, defined as the number of accompanied drivers killed divided by the number of lone drivers killed in the same crashes, versus μ, the curb mass of the lone drivers' cars divided by the curb mass of the accompanied drivers' cars. When the cars are of equal mass, the presence of a passenger is associated with a change in *R* of -14.5%[21]