Australasian Transport Research Forum 2011 Proceedings
28 - 30 September 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

Smaller cars: Not to be feared

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Abstract

Some people consider that small cars necessarily have low secondary safety, i.e., a relatively high probability of serious injury to their occupants. In collisions with other vehicles, this is true, as there is a strong effect of mass ratio. Beyond that, this paper will argue there is probably little or no further effect. Three lines of evidence are presented to support this.

- Theoretical analysis of the movement of occupants in collisions, and how injury occurs.
- There is no compelling evidence for an effect of car mass in data from the 1970's and 1980's. The most frequent reasons for rejecting claims based on that data are as follows. (1) Lack of relevance (e.g., the occupants were largely unrestrained). (2) Damage-only crashes were included in the denominator number of crashes (thus giving misleading results if the degree of under-reporting of damage-only crashes depends on size of car).
- We have recently analysed South Australian data on single-car crashes. Mass of car was found to have no effect. Allowance was made for some covariates: characteristics of driver (age, sex), geography (speed limit, in vs. outside the metro area), and time (night hours vs. daytime).

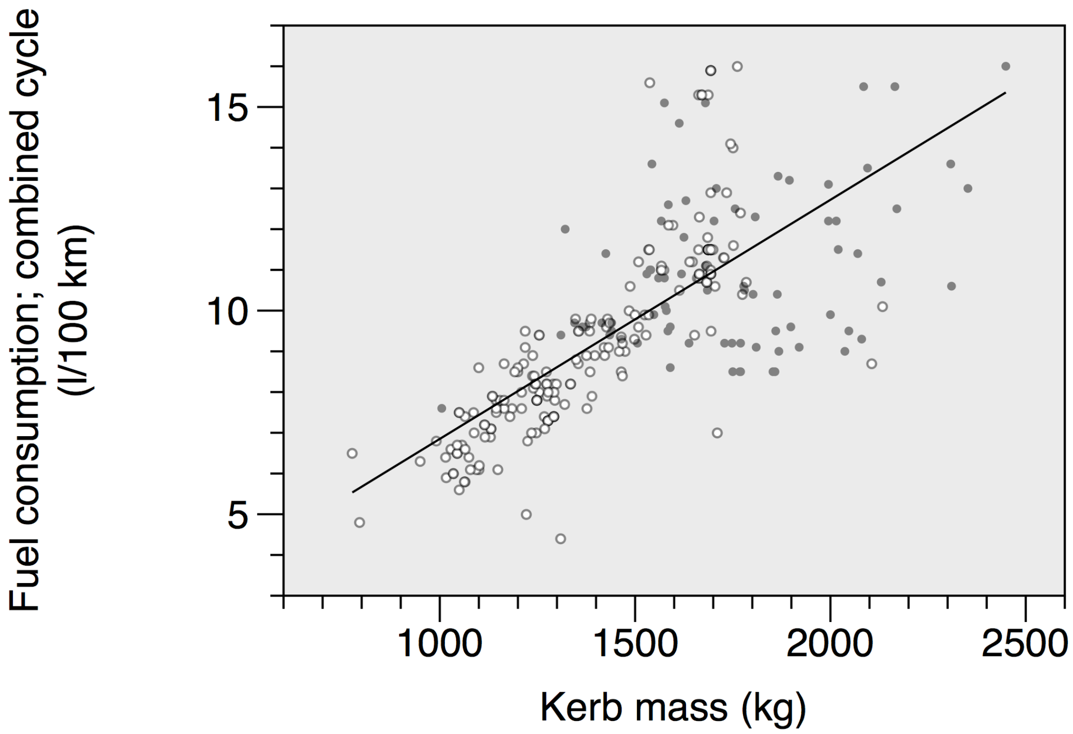
Naturally, if small cars were encouraged (explicitly, or by a substantial increase in fuel price), attention would need to be given to their safety. But at present, there is little evidence to support a conclusion that society should shy away from reducing the average mass of cars in its fleet.

1. Introduction

Small cars have obvious environmental and economic advantages. This is exemplified by the relation between mass and fuel consumption shown in Figure 1. The vehicles included were a random sample of 432 vehicles registered in South Australia in 2010 for which fuel consumption figures were available. As figures were consistently available only for models introduced post-2003, the vehicles approximate to a random sample of current models in the South Australian fleet in 2010. The slope of the best-fitting line indicates an increase of 0.58 litres per 100 km for an increase of 100 kg in mass. For decades, though, there have been concerns that small cars may not be as safe as large cars. There is discussion of the possible tension between fuel economy and safety in Noland (2005), for example.

In this paper, discussion will be of secondary safety (i.e., severity of injury in a crash), rather than primary safety (i.e., likelihood of getting into a crash). It is clear from basic theory that in collisions between two vehicles of different masses, the smaller vehicle undergoes a greater velocity change than the larger vehicle, and hence occupants tend to be more severely injured in the smaller vehicle. This effect is strong and well-known. The controversial issue is whether there is any further effect, for example, in collisions between two cars of equal mass, or in single-car crashes.

Figure 1: Relationship between car mass and fuel consumption (combined cycle, i.e., city/country). Open circles indicate regular passenger vehicles while the filled circles indicate SUV/4WD type vehicles. Data source: Registration sample from the South Australian Department of Transport, Energy and Infrastructure matched with vehicle specificications maintained by RL Polk Ltd



Section 2 describes the implications for this topic of the theory of car occupant movements in impacts. Sections 3 and 4 review empirical findings, and section 5 summarises our recent study of single-car crashes in South Australia. Section 6 discusses the findings.

2. How injury occurs to car occupants

The purpose of this section is to give some theoretical indication of how car size or mass is likely to affect injury severity. The velocity change of the car is taken as given, the model situation being a full frontal impact into a massive block.

Most injury occurs in frontal impacts. Separate consideration needs to be given to unbelted and belted occupants.

2.1 Unbelted occupants

An unbelted occupant continues moving forward as the car is decelerated. He or she strikes the interior of the car, decelerates over a distance of a few centimetres, and thus suffers injury. The relevant distances (of frontal crushing of the car, and from the occupant to the interior) are such that the relative speed of the interior impact approximately equals the velocity change of the car (Grime, 1966). If there is an airbag, some protection will be given by that.

The important point is that the mass, size, and crush characteristics of the front of the car are largely irrelevant. What is relevant is how structures of the interior crush when struck by an occupant. This is likely to be very similar in large cars and in small cars.

2.2 Belted occupants

An occupant restrained by an inextensible belt will decelerate over the crushing distance of the car. If the belt permits some movement forward, the deceleration distance will be greater. The movement of the occupant within the vehicle will be similar in large and in small cars. The crushing distance of the car, however, may be greater for large cars, in which case the deceleration of a belted occupant will be less, and hence so will injury.

The critical factor, then, is whether and how strongly crush distance is related to car size. On the basis of limited data, Grime and Jones (1970) considered there was no relationship. Hofferberth and Tomassoni (1974) found crush distance was approximately proportional to the cube root of mass. Recently, we also have found a weak relationship between crush distance and mass in U.S. crash test data (Hutchinson and Anderson, 2010), the exponent being approximately 0.28 when fitting a power function.

2.3 Other aspects of car design

It is sometimes said that larger cars are stronger, and are more likely to break fixed objects (Kahane, 2003, pp. 3-4). These comments are valid and relevant for crashes with an impact point close to an occupant (e.g., at the driver's door), or with something that is sufficiently strong to withstand impact by a small car but break when struck by a large car.

The greater floor height of large vehicles leads to intrusion into small vehicles, and furthermore larger cars are likely to have more advanced safety equipment. These effects may be quite important. However, they should respectively be considered issues of crash compatibility and of level of equipment and cost, rather than of vehicle size as such.

3. Data from the 1970's

Section 2 set out what is to be expected on theoretical grounds. In addition, various factors could potentially distort the comparison between large and small cars. These include driver characteristics, crash configuration, speed before braking, and braking effectiveness. Some of these are available in crash datasets, and it might be possible to make allowance for these, but usually not speed at impact.

Empirical studies performed in the 1970s continue to influence current thought about the effect of vehicle mass. In particular, a dataset on two-car collisions in North Carolina (1966, 1968-1971) was reported by Campbell and Reinfurt (1973), reanalysed by O'Neill et al. (1974), and features prominently in books by Evans (1991, Chapter 4; 2004, Chapter 4). According to Evans, when cars of the same mass crash into each other, the risk of driver injury is inversely proportional to car mass (Evans, 2004, p. 79).

Several features of the work cited are worth comment.

1. Campbell and Reinfurt (1973) thought that neither mass itself nor crush distance was responsible for the apparent effect of mass in their data, given the physics of the interior collision (as described above).
2. The lowest mass range in the two-car collision data of Campbell and Reinfurt is below 2700 lb. Forty five per cent were Volkswagens and 43 per cent were Ford Mustangs (Campbell and Reinfurt, 1973, Table 1). This raises a question about the validity of any general conclusion drawn from the data relating to this category, as individual models may be unusual in respects that are not captured in analysis. Possibilities would include the characteristics of the drivers, how the cars are driven, the environment of use, the relative numbers of different types of crash, the probability of a crash being reported, and so on.
3. Consider front-to-front crashes between two cars of equal mass.

(A) For the six mass ranges considered by Campbell and Reinfurt, the percentages of seriously or fatally injured drivers were (in order of increasing mass) 11, 5, 10, 6, 4, and 8. If the 11 per cent in the lowest mass range is omitted for reasons just given, the remaining sequence of percentages does not show a convincing dependence on car mass. These figures are based on Table I of O'Neill et al. (1974).

(B) However, the figures in Campbell and Reinfurt (1973, Table 6) are different, having been smoothed in such a way that the result is influenced by injury severity in crashes between cars of unequal mass. These figures are the ones used by Evans, and are 9, 7, 9, 6, 5, and 5. Even with the first of them omitted, there is a fairly convincing decline. But it is not clear why the smoothed percentages should be preferred when interest lies in crashes between two cars of equal mass.

(C) It may be added that the difference in impression conveyed by the two sequences of percentages rests on only a few casualties in the dataset. The 5 per cent and 7 per cent in the second mass range correspond respectively to 15 drivers and 22 drivers, and the 8 per cent and the 5 per cent in the sixth mass range correspond respectively to 14 drivers and 8 drivers.

4. Many damage-only crashes are included in the dataset. Results will be distorted if under-reporting of damage-only crashes differs for different masses of car. For example, it might be that larger cars tend to be more expensive to repair and the damage cost thus more easily reaches a reporting threshold. This was appreciated at the time of these studies (Milic, 1972).
5. All data from the 1970's is of only limited relevance to present-day Australia, where seat belt wearing rates are very high.

There were other datasets from the 1970's and 1980's considered by Evans (1991, Chapter 4; 2004, Chapter 4), and there are several others not discussed by him. Some refer to crashes between two cars of equal mass, and some to single-car crashes. None of these studies are compelling. In particular, comments 2, 4, and 5 above apply to many. Further information is given in Hutchinson and Anderson (2011a).

In contrast to the North Carolina findings, data from Great Britain (1969-1972) showed no, or very little, effect of car mass on injury risk, except for the well-known effect of mass ratio (Grime and Hutchinson, 1979a, 1979b, 1982).

4. Later data

Evans (2004, Figure 4-10) adds two more datasets to the three in Evans (1991, Figure 4-5). These refer to urban and rural areas of Germany (Ernst et al., 1991a,b), and show that the proportion of drivers killed or seriously injured was lower in large cars than in small cars. In this dataset, nearly all drivers were restrained. This data does support the view that larger cars are safer. However, serious damage-only crashes are included in the denominator of the proportion killed or seriously injured, and thus the fourth numbered point in section 3 applies here.

In Australia, driver injury severity has been plotted versus mass of car model by Newstead and Cameron (1997, Appendix C; 1999, Appendix B). The effect of mass was sufficiently weak that it was overwhelmed by model-to-model variation when all crashes were aggregated together (even though it must be present in the subset of crashes that are collisions with vehicles).

Mizuno et al. (1997) reported that the probability of death in single car crashes in Japan is positively related to car mass (their Figures 4 and 22). They attributed this to a positive relationship between car mass and crash speed. Such a relationship is found for single-car crashes, but no such relationship for head-on collisions (their Figure 10). Correcting for crash speed, they report (their Figure 26) that the probability of death or serious injury in single car crashes is negatively related to car mass in the range 500 kg to 1000 kg and unrelated in the range 1000 kg to 1800 kg; they do not report on whether there is any effect on the probability of death.

Trommer (2005) shows little effect of car mass on the proportion of killed or seriously injured drivers among all injured drivers in single-car crashes. This is 28 per cent and 26 per cent in the lightest 20 per cent of cars and the heaviest 20 per cent of cars, respectively. (The proportions fatal are about 5 per cent and 3 per cent.) For collisions between cars of about the same mass, Figure 40 of the same thesis shows an effect that the proportion of killed or seriously injured drivers among all injured drivers is about 44 per cent, 42 per cent, and 35 per cent in light, medium, and heavy cars, respectively. Taken overall, it seems fair to describe this as evidence for a slight improvement of secondary safety with increasing car size.

Some studies have looked for separate effects of car mass and linear dimensions. For example, Van Auken and Zellner (2005) report a number of regression analyses on data from the U.S.A., with car weight, wheelbase, and track as regressors (along with others). For "rollover" crashes and for "hit object" crashes, there are two effects in opposite directions, as greater mass leads to more fatalities per crash, and greater wheelbase leads to fewer fatalities per crash (their Table 13). It is difficult to know whether to regard these two effects as credible or not, in part because of instability of regression results when independent variables are highly correlated (Eyges and Padmanaban, 2009).

5. Recent data on single-car crashes in South Australia

5.1 Method

This study used routinely-collected police data on crashes in South Australia, 2007-2009. The crashes of interest were those in which a single car built in 1990 or later struck a fixed object or rolled over.

The dataset was supplemented with vehicle details from the proprietary database of RL Polk, using the registration number to get the VIN, with mass and other vehicle details being obtained from the VIN.

The analysis used logistic regression, with the dependent variable being the binary distinction being fatal vs. non-fatal injury. The independent variables of most interest were car mass and car year. Covariates were speed limit, crash location classified as within vs. outside the Adelaide metro area, time of day, driver sex, driver age, whether or not the vehicle was within a narrow definition of car (as distinct from a station wagon, SUV, etc.), and whether or not the vehicle overturned in the crash.

5.2 Results

The estimated coefficient of car mass was -0.04 per 100 kg of mass, not statistically significant at the 5 per cent level. Thus it is unlikely that car mass has a large effect.

Some other variables were statistically significant. Their estimated coefficients were as follows.

> Car year: -0.06 per year;
>
> Speed limit being 70 km/h or higher, rather than 60 km/h or lower: 1.1;
>
> Crash location being within the Adelaide metropolitan area, rather than outside: -0.8;

Car driver being male, rather than female: 1.4.

Thus the estimated effect of such a large car mass change as 400 kg is -0.16, and is much smaller than the effect of the car build year changing by 5 years (an effect of -0.30) and also much smaller than the effects of the three binary variables mentioned.

To be fair, we should note that the standard error associated with the coefficient of car mass was 0.06, and thus it could be said that this dataset is consistent with a coefficient of -0.15 per 100 kg of mass, for example, which is not negligible. We accept this, and note that our intention is not to disprove an effect of mass but to show the evidence for an effect is not conclusive.

We are preparing a fuller account of this analysis (Hutchinson and Anderson, 2011b).

6. Discussion

Studies of the association between vehicle size and injury risk should ideally account for the effects of crash speed in any analysis. Unfortunately, a major limitation with all of the relevant datasets is that the speeds of the impacts are not known, and in only a few datasets are there any estimates. Thus a lack of association between car mass and injury severity could be due to (for example) a positive association of crash speed with car mass, compensated by secondary safety being better for larger cars at any given speed, or to the opposite of these associations. There were no estimates of crash speeds in the British data analysed by Grime and Hutchinson. Campbell and Reinfurt did have estimates of the crash speeds for their North Carolina data, and their results for a given car mass are standardised to a reference population of crashes.

As an alternative to examining crash data, some studies have looked to the results of crash tests to examine the relationship between forces on the crash test dummy and car size. For example, Hutchinson and Anderson (2010) found weak negative correlations between chest acceleration and car mass and length. But vehicle-to-vehicle variation was much greater than the differences between large and small cars. Zachariadis (2008) found a weak negative correlation of EuroNCAP test points with car mass.

The theoretical work emphasises that vague appeals to strength are not sufficient to support the contention that bigger cars are safer (except where compatibility is also relevant). Indeed, for both unbelted and belted occupants, no strong effect of car size or mass on occupant injury severity is to be expected. For belted occupants, the empirical finding of little effect of mass on crush distance is an important factor in the argument. On the other hand, several considerations of secondary importance mean that a modest protective effect of car size is plausible. (In regard to the empirical data from the 1970’s, it is unlikely that mass had an effect, as most occupants were unbelted then, and car characteristics do not affect the speed with which the occupant strikes the interior.)

Fuel savings from smaller cars are potentially quite considerable, approximately 0.9 per cent per 1 per cent change in mass, according to the relationship in Figure 1. If smaller cars become preferred because of their environmental and economic advantages, the safety implications of this preference would require study, especially if the preference were explicit policy. However, it must also be considered that in a future fleet of cars, there will be benefits from additional primary and secondary safety features that will reduce both the incidence and severity of crashes. When considering other health effects, smaller cars having lower emissions and (because of their cheapness) being better competitors for walking and cycling would need to be included in the study, too.

Acknowledgements

We are grateful for financial support of this project from Austroads. The Centre for Automotive Safety Research receives core funding from both the South Australian

Department for Transport, Energy and Infrastructure and the South Australian Motor Accident Commission. The views expressed are those of the authors and do not necessarily represent those of the University of Adelaide or the funding organisations.

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