TRENDS IN AUSTRALIAN VEHICLE CRASHWORTHINESS BY YEAR OF VEHICLE MANUFACTURE WITHIN VEHICLE MARKET GROUPS

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ABSTRACT

This paper measures trends in the crashworthiness of the Australian passenger vehicle fleet by year of vehicle manufacture within four market groups. Crashworthiness is defined here as the risk of death or hospitalisation of a vehicle's driver given involvement in a crash and is estimated from police reported crash data on the injury status of 1.4 million vehicle drivers from 3 Australian states over the period 1987 to 1998. Results demonstrated clearly different trends in vehicle crashworthiness by year of manufacture from 1982 to 1998 between different vehicle market sectors of the Australian vehicle fleet, particularly for small and medium size vehicles.

Key Words: crashworthiness, accident analysis, statistics, vehicle age, market group

FOR A NUMBER OF YEARS, the Monash University Accident Research Centre (MUARC) has been monitoring trends in the crashworthiness of the Australian passenger vehicle fleet by year of vehicle manufacture. Crashworthiness is defined here as the risk of serious injury (death or hospitalisation) a vehicle poses to its driver given involvement in a crash of sufficient severity for at least one vehicle to be towed from the crash scene. Crashworthiness is estimated from mass data on crashes reported to police in Australia's three largest states. Data for estimation of crashworthiness by year of vehicle manufacture in the most recent Australian study (Newstead et al 2000) covers over 1.4 million drivers of passenger vehicles manufactured over the years 1964 to 1998 and crashing in the years 1987 to 1998.

Analysis of crashworthiness by year of vehicle manufacture by Newstead et al (2000) has shown significant improvement in vehicle safety associated with the introduction of Australian Design Rules and consumer vehicle safety rating programs, but has focused only on the Australian passenger car fleet as a whole. Figure 1, from Newstead et al (2000), shows the estimated trend in vehicle crashworthiness by year of manufacture for the Australian fleet along with the time points at which Australian Design Rules (ADRs) relating to vehicle passive safety and major consumer focused vehicle safety initiatives were introduced.

Newstead et al (2000) also estimates vehicle crashworthiness ratings by specific make and model of vehicle, with vehicles grouped within broad marketing categories for presentation. Examining trends in crashworthiness by vehicle year of manufacture amongst vehicles within each market grouping suggested that there was differential improvement in vehicle safety over time between the market groups. There was also some indication from new vehicle registration figures in Australia that the mix of the vehicle fleet in terms of vehicle size had changed over recent years, something that might also affect the total crashworthiness of the Australian fleet.

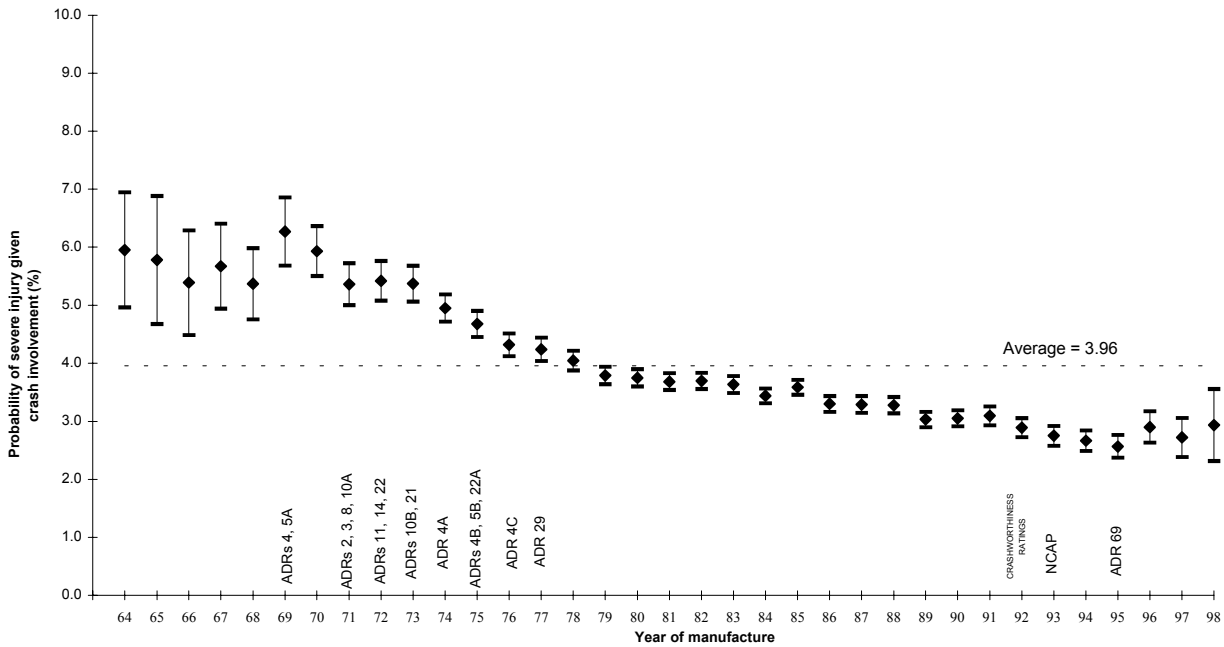

Fig. 1: Estimated vehicle crashworthiness by year of vehicle manufacture for the Australian passenger fleet

The aim of this study was to make a formal assessment of whether trends in vehicle crashworthiness by year of vehicle manufacture in Australia were uniform across all market sectors or whether some market groups had shown greater safety gains than others. A secondary aim was to assess possible reasons for differences in trends in crashworthiness by vehicle market group if found.

DATA

Real crash data from Australia's three most populous states, Victoria, New South Wales (NSW) and Queensland, used to produce the assessment of crashworthiness ratings by year of vehicle manufacture of Newstead et al (2000), covering vehicles manufactured over the period 1982-98 and crashing during the years 1987-98, was used here. In order to study crashworthiness by year of manufacture within individual vehicle market groups, vehicle model details had to be identified for vehicles appearing in the crash data. This could only be done for vehicles manufactured from 1982 onwards. Consequently, the data used for this study was the subset of that used in Newstead et al (2000) comprising vehicle manufactured from 1982 onwards. A description of the data assembled from each of the three Australian states' data available follows.

VICTORIAN CRASHES: Crashes are reported to the police in Victoria if a person is killed or injured, if property is damaged but names and addresses are not exchanged, or if a possible breach of the Road Traffic Regulations has occurred (Green 1990). The police reports cover all persons involved in crashes, regardless of whether the police officer recorded the person as injured or uninjured. To reliably identify injured drivers in the police reported data, personal injury insurance claims from all types of road users who were involved in crashes in the period 1987 to 1998 were merged with police crash reports. Cameron et al (1994a,b) describe the method of matching.

The merged files of personal injury insurance claims with police reports covered crashes during 1987-98, and represented 167,915 insurance claims for injury during 1987-98 of which 74,367 were injured drivers of cars, station wagons or taxis manufactured over the years 1964-98. Restricting the data to vehicles manufactured from 1982 onwards resulted in a file covering 37,554 injured drivers of 1982-98 model cars who had valid personal injury claims.

NEW SOUTH WALES CRASHES: Road crashes reported to the police in New South Wales (NSW) cover all crashes where at least one vehicle is towed from the scene, regardless of the injury status of the occupants. For the study of crashworthiness by vehicle year of manufacture of Newstead et al (2000), the NSW police reported crash data represented 1,273,403 drivers of cars, station wagons or taxis manufactured from 1964 to 1998 who were involved in tow-away crashes, of which 210,779 drivers were injured. Light passenger vehicles manufactured over the period 1982 to 1998, for which vehicle model could be identified, represented 517,824 cases in the NSW data. Of the drivers of these vehicles, 82,694 were injured. The presence of uninjured drivers in the NSW data file meant that it was suitable for measuring the risk of driver injury (in cars sufficiently damaged to require towing). This contrasted with the Victorian data file, which could not be used to measure injury risk directly because not all uninjured drivers were included.

QUEENSLAND CRASHES: Crashes in Queensland are also reported to the police if at least one vehicle requires towing from the scene. For the study of crashworthiness by vehicle year of manufacture by Newstead et al (2000), the Queensland data represented 163,114 drivers of cars, station wagons or taxis manufactured from 1964 to 1998 who were involved in tow-away crashes. Of these drivers, 33,054 were injured. The subset of this data representing vehicles manufactured from 1982 onwards, for which vehicle model details were identifiable, covered 131,005 light passenger vehicles of which 31,106 of the drivers were injured. As with the data from NSW, the presence of uninjured drivers in the data file meant that it was also suitable for measuring the risk of driver injury (in cars sufficiently damaged to require towing).

COMBINED DATA FROM THE THREE STATES: When the data on the injured drivers was combined for analysis, it covered 151,354 drivers of 1982-98 model vehicles who were injured in crashes in Victoria or NSW during 1987-98 or in Queensland during 1991-98. This information was used to assess the injury severity of the injured drivers of the vehicles in each market group. The information on the 648,829 drivers involved in tow-away crashes in 1982 to 1998 year of manufacture vehicles crashing in NSW during 1987-98 or Queensland during 1991-98 was used to assess the injury risk of drivers of vehicles in each market group.

ASSIGNMENT OF VEHICLE MARKET GROUP: In order to assign vehicles to specific market groups for analysis, it was necessary to identify the specific make and model of each vehicle appearing in the crash data. Vehicle make was recorded in each of the systems from which crash data was gathered along with either vehicle identification number (VIN) or information on vehicle mass and engine capacity, expressed as power units. A system of VIN decoding was used to identify specific vehicle model details for those vehicles with a valid VIN in the crash data, whilst a system of decoding specific model information from the registered vehicle make, mass and power units was used for the remainder of the vehicles. A full description of these systems appears in Newstead et al (2000). Vehicles were assigned to various market groupings according to a system used by the Australian Federal Chamber of Automotive Industries into three classes broadly distinguished by vehicle tare mass. The classes defined were small cars (<1100kg), medium cars (1100-1400kg), large cars (>1400kg) and 4 wheel drive vehicles (Sports Utility Vehicles, typically with masses >1400kg)).

METHODS

OVERVIEW OF THE MAIN ANALYSIS: The crashworthiness rating (C) is a measure of the risk of serious injury to a driver of a car when it is involved in a crash. It is defined to be the product of two probabilities (Cameron et al, 1992; Cameron et al 1995):

i) the probability that a driver involved in a crash is injured (injury risk), denoted by R; and
ii) the probability that an injured driver is hospitalised or killed (injury severity), denoted by S.

That is

$$C = R \times S.$$

Measuring crashworthiness in this two-step way was first developed by Folksam Insurance who publish the well-known Swedish ratings (Gustafsson et al, 1989). In this study, each of the two components of the crashworthiness rating was obtained by logistic regression modelling techniques (Hosmer & Lemeshow, 1989). Such techniques are able to simultaneously adjust for the effect of a number of factors (such as driver age and sex, number of vehicles involved, etc.) on the estimated injury risk and injury severity probabilities.

LOGISTIC MODELS FOR EACH COMPONENT:

Obtaining the Covariate Models: Before adjusted crashworthiness ratings could be obtained it was necessary to consider logistic models of each of the crashworthiness components separately to identify possible factors, other than vehicle design, that might have influenced the crash outcomes. A stepwise procedure was used to identify which factors had an important influence. This was done initially without considering the year of manufacture or market group of the vehicle in the logistic model as the aim was to determine which other factors were most likely to have had an influence across a broad spectrum of crashes.

Logistic models were obtained separately for injury risk and injury severity because it was likely that the various factors would have different levels of influence on these two probabilities. The factors considered during this stage of the analysis for both injury risk and injury severity were driver sex (male, female), driver age (≤25 years; 26-59 years; ≥60 years), speed limit at the crash location (≤ 75 km/h; ≥80 km/h), the number of vehicles involved in the crash (one vehicle; >1 vehicle), state of crash (Victoria, NSW or Queensland) and year of the crash (1987, 1988,…,1998). These influential variables were chosen for consideration because they were each part of the Victorian, Queensland and New South Wales databases. Other variables were only available from one source and their inclusion would have drastically reduced the number of cases that could have been included in the analysis. State and year of crash were included in the logistic models because of noted differences in average crash severity both between states and over time.

All data was analysed using the logistic regression procedure (PROC LOGISTIC) of the SAS statistical package. Regression parameters were obtained by maximum likelihood estimation with design variables for the various factors chosen in such a way that the estimated coefficients represented deviations of each of the variable levels from the mean for ease of interpretation. For both injury risk and injury severity all possible first and higher order interactions between the factors listed above were considered. A hierarchical structure was imposed so that interaction between two variables was included in the model only when the corresponding main effects were also included. The resultant logistic regression models were referred to as the "covariate" models or equations.

Assessing Year of Manufacture Differences by Market Group: Injury risk and injury severity by year of vehicle manufacture and vehicle market group were estimated after adding variables representing car year of manufacture (1982, 1983,..,1998) and market group (small, medium, large and 4WD) to the respective logistic "covariate" models and re-estimating all parameters in the combined model. The vehicle year of manufacture variable was treated as categorical to allow for the maximum flexibility of shape in the estimated trend in crashworthiness. Importantly, an interaction term between year of manufacture and vehicle market group was included in the logistic regression model to represent differing trends in crashworthiness by year of vehicle manufacture between the various market groups. Estimates of injury risk and injury severity probabilities were obtained by de-transforming the estimated logistic regression functions. Average estimates of injury risk and severity by year of manufacture and market group were obtained by setting all other factors in the logistic model, besides market group, year of manufacture and the market group by year of manufacture

interaction, to their average value. Computation of confidence limits on the resulting probabilities of injury risk and severity by year of manufacture and market group is straight forward and is described in Newstead et al (2000).

COMBINING THE INJURY RISK AND INJURY SEVERITY COMPONENTS: The final combined ratings of vehicle crashworthiness are given by:

Crashworthiness Rating = Injury risk x Injury severity.

For a given year of manufacture and market group, j, the crashworthiness rating, C_j, was therefore calculated as:

$$C_j = R_j \times S_j$$

where

R_j denotes the injury risk for year of manufacture and market group j, and

S_j denotes the injury severity for year of manufacture and market group j.

Let α_j and β_j be the values of the logistic regression function for injury risk and injury severity respectively for year of manufacture and market group *j* with all other factors set at their average level. Taking the natural log of the crashworthiness rating and using asymptotic statistical theory and assuming the estimates of α_j and β_j are independent, the asymptotic variance of the log of the crashworthiness rating is

$$Var(\log_e C_j) \approx \frac{Var(\alpha_j)}{(1+e^{\alpha_j})^2} + \frac{Var(\beta_j)}{(1+e^{\beta_j})^2}$$

The 95% confidence interval for the natural log of the crashworthiness rating is then

$$\log_e(C_j) \pm 1.96 \cdot \sqrt{Var\left(\log_e(C_j)\right)}.$$

The 95% confidence limit for the crashworthiness rating is obtained by taking the exponent of the confidence limit of the logged crashworthiness rating shown above. Because each of the two estimated crashworthiness components have been adjusted for the effect of other factors by logistic regression prior to their incorporation into the combined ratings, the resultant crashworthiness rating is also adjusted for the influence of these factors.

RESULTS

INJURY RISK: Injury risk was estimated from the data on 648,829 drivers involved in tow-away crashes in NSW and Queensland. This data set is referred to as the "involved drivers". The "covariate" model for injury risk was determined from the variables described above. The following covariates and interactions were statistically significantly associated with injury risk and were included in the logistic regression model.

Base effect terms: driver sex (sex), driver age (age), number of vehicles involved (nveh), speed zone of crash (speedzone), state of crash (state), year of crash (year).

First order interaction terms: sex*speedzone, speedzone*nveh, sex*nveh, speedzone*age, age*sex, nveh*state, age*state, age*nveh, speedzone*state.

No other variable or interaction term significantly improved the fit of the logistic covariate model. Terms for vehicle year of manufacture and market group, along with their interaction, were added to

the covariate model and the model re-estimated. The interaction term between year of manufacture and market group in the final model was statistically significant (chi-square=78.72, d.f.=48, p=0.003) indicating significantly different trends in injury risk by year of manufacture between the vehicle market groups assessed. The overall (average) injury risk for involved drivers in tow-away crashes in New South Wales and Queensland, after adjusting for the significant main effects and interactions described above, was 19.3%. In other words, the estimated average probability that a driver of a 1982-1998 model small, medium, large or 4 wheel drive vehicle involved in a tow-away was injured was 19.3%, after adjusting for other significant factors.

Figure 2 shows the estimates if injury risk by year of vehicle manufacture for each of the 4 market groups considered. Estimates have been smoothed using a linear smoothing function over a window of three years (the central year and a year either side). Smoothing of the estimates was carried out to better identify the trends in the data. Smoothing in this way also compensates for known error in the recording of the year of vehicle manufacture, an error typically up to one year from the true date of manufacture.

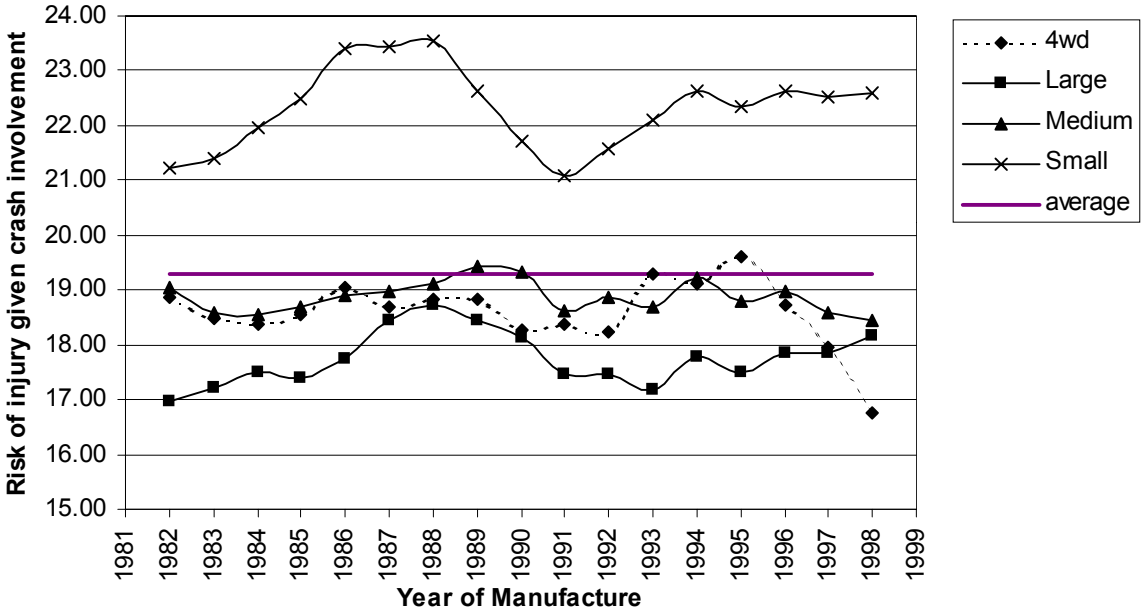

Fig. 2: Estimated injury risk by year of vehicle manufacture and market group

INJURY SEVERITY: The data for computation of injury severity covered 151,353 drivers of 1982-1998 small, medium, large or 4WD vehicles who were injured in crashes in Victoria or NSW during 1987-98 or Queensland during 1991-98. The "covariate" model for injury severity was determined from the variables described above and identified a number of statistically significant covariate effects. These were:

Base effect terms: driver sex (sex), driver age (age), number of vehicles involved (nveh), speed zone of crash (speedzone), state of crash (state), year of crash (year).

First order interaction terms: speedzone*nveh, sex*age, age*state, nveh*state, age*nveh, speedzone*age, speedzone*state, sex*state.

Second order interaction terms: Sex*State*Age, Age*Nveh*State, Speedzone*Nveh*State.

No other variable or interaction term significantly improved the fit of the logistic covariate model. Terms for vehicle year of manufacture and market group, along with their interaction, were added to the covariate model and the model re-estimated. The interaction term between year of manufacture and market group in the final model was statistically significant (chi-square=76.09, d.f.=48, p=0.006)

indicating significantly different trends in injury severity by year of manufacture between the vehicle market groups assessed. The overall (average) injury severity for injured drivers in crashes in Victoria, New South Wales and Queensland, after adjusting for the significant main effects and interactions described above, was 24.0%. In other words, the estimated average probability that a driver of a 1982-1998 model small, medium, large or 4 wheel drive vehicle injured in a crash in was severely injured was 24.0%, after adjusting for other significant factors.

Figure 3 shows the estimates if injury severity by year of vehicle manufacture for each of the 4 market groups considered. Estimates have again been smoothed to better identify the trends in the data.

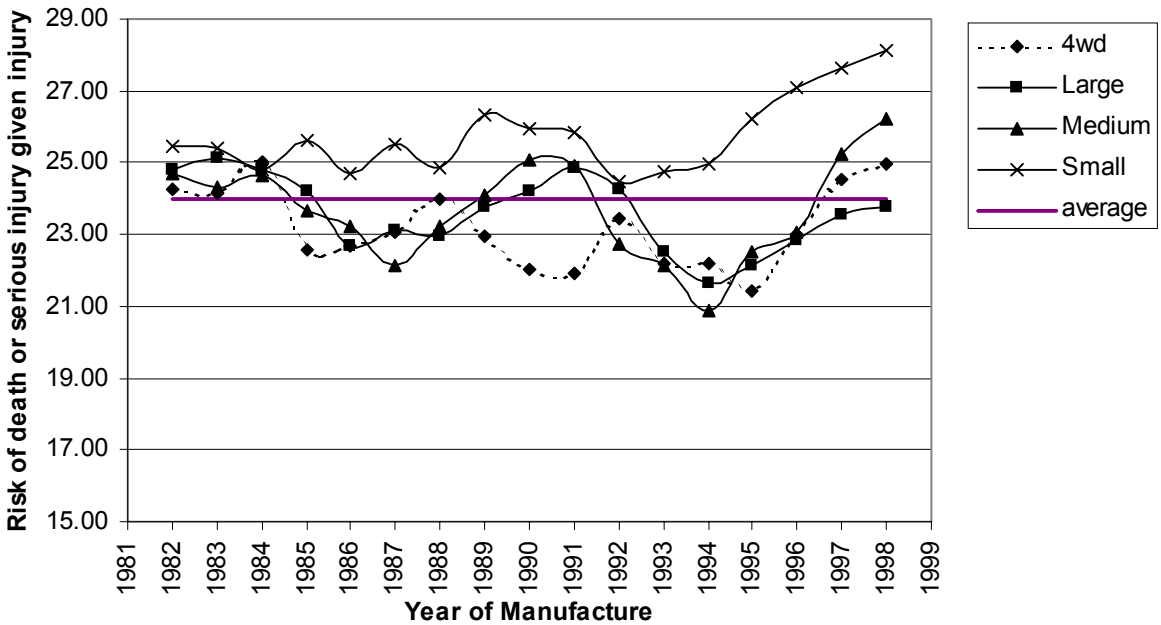

Fig. 3: Estimated injury severity by year of vehicle manufacture and market group

CRASHWORTHINESS BY YEAR OF MANUFACTURE BY MARKET GROUP: The crashworthiness estimates for each year of manufacture were obtained by multiplying the individual injury risk and injury severity estimates. Because each of the two components has been adjusted for the confounding factors, the resultant crashworthiness estimate is also adjusted for the influence of them.

Table 1 gives the crashworthiness estimates and the associated 95% confidence intervals (in brackets) for each of the years of manufacture from 1982 to 1998 by each of the four vehicle market groups considered. Each estimate is expressed as a percentage, representing the number of drivers killed or admitted to hospital per 100 drivers involved in a tow-away crash. The true risk of a driver being killed or admitted to hospital in a tow-away crash is only estimated by each figure, and as such each estimate has a level of uncertainty about it. This uncertainty is indicated by the 95% confidence limits. There is 95% probability that the confidence interval will cover the true risk of driver serious injury (death or hospital admission) in a vehicle of the particular year of manufacture and market group.

Year of Manufacture	4WD Vehicles	Large Vehicles	Medium Vehicles	Small Vehicles
1982	4.50 (3.74, 5.42)	3.96 (3.59, 4.36)	4.60 (4.13, 5.13)	5.52 (4.99, 6.09)
1983	4.58 (3.81, 5.51)	4.47 (4.04, 4.94)	4.79 (4.39, 5.23)	5.31 (4.89, 5.76)
1984	4.25 (3.65, 4.96)	4.57 (4.17, 5.01)	4.18 (3.78, 4.63)	5.47 (4.98, 6.01)
1985	4.92 (4.31, 5.62)	4.01 (3.67, 4.37)	4.76 (4.35, 5.21)	5.54 (4.98, 6.16)
1986	3.42 (2.82, 4.15)	4.07 (3.65, 4.54)	4.31 (3.85, 4.83)	6.25 (5.55, 7.03)
1987	4.67 (3.82, 5.73)	3.96 (3.40, 4.62)	4.11 (3.43, 4.92)	5.50 (4.27, 7.10)
1988	4.85 (4.11, 5.73)	4.76 (3.04, 7.46)	4.17 (3.73, 4.66)	6.16 (5.58, 6.80)
1989	4.03 (3.45, 4.71)	4.18 (3.79, 4.62)	5.05 (4.49, 5.69)	5.85 (5.13, 6.68)
1990	4.10 (3.48, 4.82)	4.21 (3.73, 4.76)	4.83 (4.30, 5.41)	5.88 (5.21, 6.64)
1991	3.93 (3.29, 4.69)	4.78 (4.19, 5.45)	4.66 (4.02, 5.40)	5.18 (4.38, 6.13)
1992	4.05 (3.37, 4.87)	4.03 (3.40, 4.78)	4.42 (3.54, 5.51)	5.29 (4.05, 6.92)
1993	4.87 (4.05, 5.85)	3.90 (2.73, 5.57)	3.70 (1.40, 9.77)	5.34 (4.85, 5.87)
1994	3.88 (3.10, 4.87)	3.63 (3.33, 3.96)	4.20 (3.89, 4.54)	5.75 (5.23, 6.32)
1995	3.93 (2.93, 5.27)	4.00 (3.61, 4.44)	4.09 (3.72, 4.51)	5.86 (5.37, 6.40)
1996	4.79 (3.45, 6.65)	3.98 (3.65, 4.36)	4.40 (3.99, 4.85)	5.95 (5.36, 6.60)
1997	4.20 (2.69, 6.56)	4.22 (3.78, 4.72)	4.63 (4.10, 5.22)	6.58 (5.73, 7.57)
1998	4.17 (1.93, 8.98)	4.40 (3.72, 5.22)	5.03 (4.05, 6.25)	6.15 (4.00, 9.46)

Table 1: Estimated crashworthiness by year of vehicle manufacture and market group with 95% confidence limits

The crashworthiness estimates are plotted for each year of manufacture and vehicle market group in Figure 4. Again, the values in Figure 4 have been smoothed for reasons given above. Table 1 gives the unsmoothed estimates. As indicated in the analysis of injury risk and injury severity above, there were statistically significant differences in trends in each of the components of crashworthiness by year of manufacture between the 4 vehicle market groups considered. Figure 4 shows that these different trends are reflected in the combined estimate. In the large and 4WD vehicle categories, Figure 4 shows general improvement in vehicle crashworthiness with increasing year of manufacture over the years considered. In contrast, for small vehicles, Figure 4 indicates worsening crashworthiness over the 1980s, some improvement through the early 1990s, with a steady worsening of average crashworthiness in this market group from 1993 onwards. Trends in the medium vehicle group are similar to those in the small car group, although the final trend of declining crashworthiness appears to have started later in around 1995. Reasons for the differential treads between the groups will be discussed below.

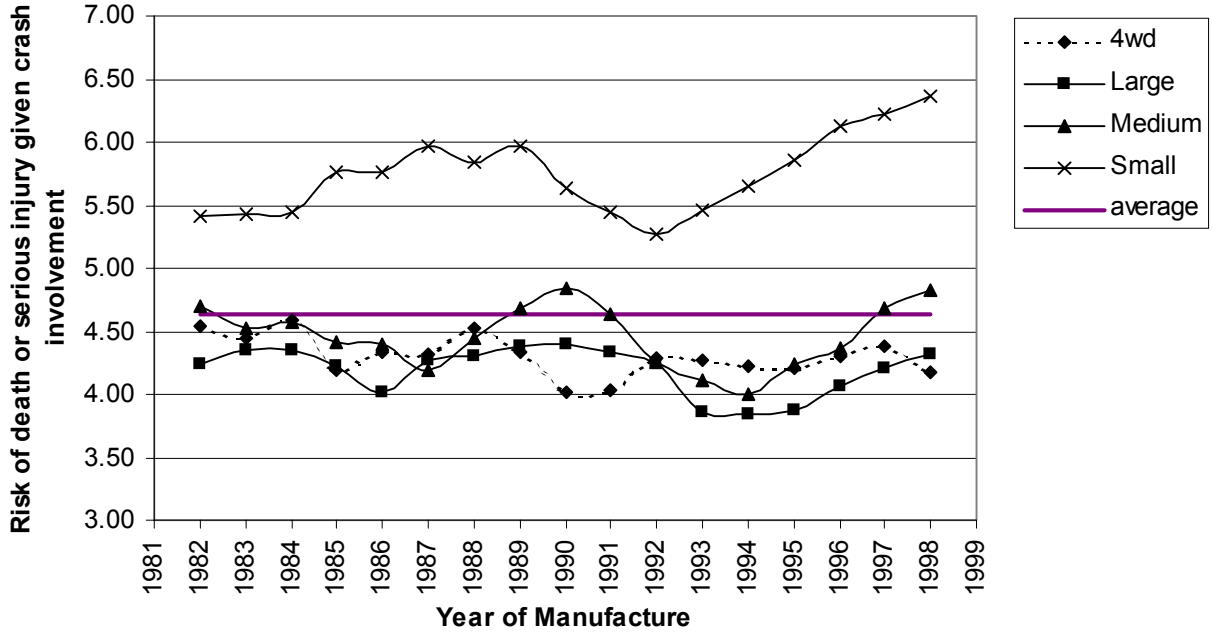

Fig. 4: Estimated crashworthiness by year of vehicle manufacture and market group

DISCUSSION

Analysis presented in this paper has demonstrated significant differences in the trends in crashworthiness by year of manufacture between the small, medium, large and 4WD market groups of Australian vehicles. Specifically, analysis has identified trends to poorer crashworthiness in the small car class from 1993 to 1998 in contrast to consistent or slightly improving crashworthiness in the large and 4WD vehicle classes. Trends in crashworthiness in the medium car class are similar to those in the small vehicle class from 1993 onwards.

For a number of reasons, it might have been expected that vehicle secondary safety levels, as measured by the crashworthiness ratings estimated here, would have shown improvements from the period 1992 onwards in all market segments. One of the major reasons is the drafting of Australian Design Rule (ADR) 69 specifying standards for frontal impact occupant protection in passenger cars as part of the Australian Motor Vehicle Standards Act. ADR 69 was approved as a national standard by the Minister for Land Transport on 16th December 1992, coming into effect for all newly released car models on 1st July 1995 and for all new passenger cars sold from 1st January 1996. Previous work (Cameron et al 1987; Cameron et al 1995) has shown the introduction of new ADRs to have a strong association with improvements in vehicle crashworthiness. Secondly, a number of programs were introduced in Australia during the 1990s to inform consumers of relative vehicle safety. Vehicle crashworthiness ratings based on real crashes that rated relative driver protection in individual makes and models of vehicles data were first published in 1992 and updated in 1994, 1996, 1997, 1998, 1999 and most recently 2000 (Newstead et al, 2000). The Australian New Car Assessment Program (ANCAP), which rates relative driver and front left passenger protection based on controlled laboratory impact testing of vehicles, first published test results in April 1993. ANCAP have continued their test program throughout the 1990s covering a large proportion of the Australian new car fleet by sales volume.

To understand why improvements in vehicle crashworthiness have not been seen across all market segments during the 1990s, it is useful to examine trends in new vehicle sales in Australia. New vehicle sales for both 1992 and 1998 have been obtained from the Australian Federal Chamber of

Automotive Industries. Analysis of new vehicle sales in the large market group shows that in both 1992 and 1998 the same two vehicle models, albeit different model years, accounted for around 70% of total sales in that market segment. Using the crashworthiness rating produced by Newstead et al (2000) for the two specific vehicle models dominating the large vehicle market segment, average crashworthiness for the 1992 model vehicles, weighted by sales volumes, was computed to be almost identical to the weighted average crashworthiness of the 1998 model year vehicles. This is consistent with the large vehicle group crashworthiness trends observed in Figure 4. Analysis of 1992 and 1998 sales volumes in the small car segment shows 5 vehicle models comprised around 50% of sales in this market segment in each year. There has, however, been a change in the 5 most popular small vehicle models between 1992 and 1998. In 1992, the 5 most popular small vehicle models were all of Japanese origin. By 1998, only three of these vehicle models remained as best sellers in the small car segment, joined by two low priced models imported from Korea that together made up 25% of the sales for the market segment. Again, using the model specific crashworthiness ratings of Newstead et al (2000), the sales weighted average crashworthiness of the 5 top selling small vehicles in 1998 was worse than that in 1992 by nearly 23%. This is consistent with the trends in crashworthiness for the small car segment shown in Figure 4 that rose around 22% between 1992 and 1998. It is interesting to note that the two Korean vehicle models that had become first and third best sellers in the small car segment by 1998 were also amongst those with the poorest crashworthiness ratings of all vehicle models rated by Newstead et al (2000).

It seems then that Australian small vehicle buyers shifting their purchase preferences towards vehicles with poor safety performance can explain the trend towards poorer crashworthiness in the small car group, seen in Figure 4 from 1993 onwards. A primary cause of this shift is most likely vehicle pricing. The vehicle models that have come to dominate the small car segment in Australia in 1998, particularly the Korean models mentioned above, are amongst the cheapest on the market. Fleet sales information suggests there is also a much higher proportion of sales to private buyers in the small car segment than in the large car segment. Private buyers are much more sensitive to vehicle pricing than are fleet buyers, who account for over 70% of new sales in the large car class. Whilst pricing appears to dominate the purchasing decisions of small car buyers, it is also apparent that consumer information and safety-based vehicle design regulations are not having the desired effect in improving vehicle crashworthiness of the small car segment. The results here show that those organisations producing vehicle safety information for consumer use, such as ANCAP, may have to be particularly vigilant in targeting buyers of small vehicles. Legislation also has an important role to play. Further tightening of vehicle safety standards through legislation seems warranted to ensure all vehicles on the Australian market, including those at the cheapest end of the market, improve their safety performance in the future.

Another interesting artefact of the Australian vehicle fleet exposed by analysis of sales figures is its polarisation to either small or large vehicles. In 1992, relative market shares in the small, medium and large vehicle classes were 29%, 24% and 28% respectively. In 1998 these figures were 32%, 9% and 37% respectively. It is possible this polarisation is having detrimental effects on the total safety of the Australian fleet by reducing vehicle compatibility in collisions, a particular problem for drivers of small vehicles. Issues of vehicle compatibility relevant to the polarisation of the Australian market have been discussed in Gabler and Hollowell (1998) and Cameron et al (1998). Issues discussed include mass polarisation leading to an increase in the number of adverse mass ratio collisions and hence higher collision severities for occupants of the lighter vehicles.

These results presented here also have implications for those advocating replacement of older vehicles in the fleet on safety grounds. The results suggest that if older vehicles were replaced with predominantly low cost, small new vehicles with comparatively poor safety performance, this could result in a net reduction in total safety of the Australian fleet as a whole. For such a replacement strategy to be effective, it would be necessary to ensure older vehicles were replaced with new vehicles with the best possible safety performance.

It is unclear if the trends in vehicle crashworthiness by year of manufacture within market groups would be observed in other countries outside of Australia. Some insight into the situation in Europe can be gained by examining the ratings of vehicles tested under the EuroNCAP program in Phases 1 to 7+. Examining the average EuroNCAP overall star rating for vehicles 1100kg and less and 1400kg and more shows the vehicle in the heavier weight class to have overall star ratings on average half a star more than those in the lighter class. More stars indicate higher secondary safety levels. Examination of the specifications of the tested vehicles shows those in the higher weight class are typically more expensive vehicles with higher levels of standard safety equipment than those in the lighter weight class. These results are consistent with the Australian findings. Comparison of vehicles tested under the EuroNCAP program with model years before and after 1998 by weight category suggests that in each mass class (including light vehicles), average safety was higher for the later model vehicles. This contrasts with the general finding from the Australian data here but it must be noted that the NCAP comparisons have been made on predominantly late and current model vehicles with none dating from 1992 as in the Australian study. Clearly, there is a need for further research to properly compare the Australian findings with those in other countries.

A number of assumptions have been made in producing the results presented in this paper. Firstly, it has been assumed that Victorian injury insurance claims records and NSW and Queensland police crash reports accurately recorded driver injury, hospitalisation and death. It is also assumed that there was no bias in the merging of injury insurance claims and Victorian police crash reports related to the model of car and factors affecting the severity of the crash. It is assumed crashed vehicle registration numbers were recorded accurately on police crash reports and that they correctly identified the crashed vehicles in the Victorian, NSW and Queensland vehicle registers. The form of the logistic models used to relate injury risk and injury severity with the available factors influencing these outcomes (including the car models) is assumed correct. Further, it is assumed the adjustments for driver sex, age, speed zone, the number of vehicles involved and the state and year in which the crash occurred crash removed the influences of the other main factors available in the data that affected crash severity and injury susceptibility. It should be noted that only driver crash involvements and injuries have been considered with passengers occupying the same model cars possibly having different injury outcomes. Other factors not collected in the data (eg. crash speed) may affect the results, however, earlier analysis has suggested that the different rating scores are predominantly due to vehicle factors alone (Cameron et al 1992).

CONCLUSIONS

This study has estimated relative trends in vehicle crashworthiness by year of vehicle manufacture across four market groups: small cars (<1100kg), medium cars (1100-1400kg), large cars (>1400kg) and 4 wheel drive vehicles (Sports Utility Vehicles). Crashworthiness is defined here as the risk of serious injury (death or hospitalisation) a vehicle poses to the driver of a vehicle given involvement in a crash of sufficient severity for at least one vehicle to be towed from the crash scene. It was estimated from mass data on crashes reported to police in Australia's three largest states.

Analysis has demonstrated clearly different trends in vehicle crashworthiness by year of vehicle manufacture between different vehicle market sectors of the Australian vehicle fleet. Results showed that whilst vehicles in the 4wd and large car groups had shown improvement in crashworthiness over time, vehicles in the medium and, particularly, the small car classes had shown deterioration in their crashworthiness performance as a class, especially in recent years. Reasons for the declining average crashworthiness of the small car classes in Australia are discussed and appear to be explained by a shift in preference of small car buyers towards cheap small vehicles with relatively poor safety performance. These shifts in small vehicle buyer preference have occurred despite the the introduction of Australian vehicle design rules and consumer vehicle safety information programs aimed at improving the safety of the Australian fleet, suggesting the urgent need for further action in these two areas.

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