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Paper Title: The Effectiveness of Anti-Lock Brake Systems: a statistical analysis of Australian data.

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ABSTRACT

This assesses the effect of anti-lock brake systems (ABS) on driver injury risk and injury severity through analysis of real crash outcomes reported by Police in Victoria, NSW and Queensland. Information on the presence or absence of ABS on crashed vehicles was provided by participating vehicle manufacturers and matched to the Police reported crash data. A total of 40,739 records were available for analysis.

The statistical analysis examined the effectiveness of ABS in terms of both primary and secondary safety. Primary safety effects have been assessed using induced exposure methods employing crashes where the focus vehicle is impacted in the side by another vehicle as the induced exposure measure. Secondary safety effects were evaluated using Poisson and logistic regression models that examined the effectiveness of ABS on the risk and severity of driver injury in the event of a crash whilst controlling for other factors that may affect the safety outcome such as driver age and sex, vehicle model and speed limit at the crash location.

ABS braking systems were generally found to have no statistically significant effects on secondary safety outcomes. In terms of primary safety, changes in the distribution of crash type for ABS equipped vehicles were detected as were changes in absolute risk for certain crash types. Vehicles fitted with ABS had lower risk of crashing with other vehicles. However, a higher risk of run of road type crashes for ABS equipped resulted in a net zero change in risk across all crash types. These results are consistent with those estimated in previous overseas studies.

1. Introduction

Since its introduction, ABS (Anti-lock Braking System) has been acclaimed as providing significant improvement to overall vehicle safety. ABS works to prevent wheel lock-up, thereby enabling the driver to maintain steering control during emergency braking and reducing stopping distances on some slippery surfaces.

Vehicle manufacturers have undertaken extensive marketing campaigns to promote the safety of their vehicles on the basis that they are equipped with ABS. Within the community there is a general perception that vehicles fitted with ABS are safer than those without. However, it is largely track experience and data that has shown the benefits of ABS in reducing stopping distances and maintaining steering control. It is these results, and not real-world crash data, that have driven the assumption that ABS has a positive net safety benefit. The effectiveness of ABS in reducing injuries in real-world crashes is less clear. The aim of this study is to investigate the effect of anti-lock brake systems (ABS) on vehicle occupant injury risk and injury severity through the analysis of real crash outcomes described in Australian mass crash data.

2. Data

Police reported crash data from Victoria, NSW and Queensland formed the basis of the crash data used in this study. The data covers 686,383 vehicles manufactured over the period 1982-98 and crashing during the years 1987-98. This data is a subset of that used to rate the crashworthiness of Australian passenger cars which is described in detail in Newstead et al (2000). It is noted that, injury outcome data is reliably available for the driver of a vehicle only, as injury outcome for vehicle occupants other than drivers is not reliably recorded in the crash data, particularly when the other occupants are uninjured. Consequently, measurement of secondary safety effects focus only on driver injury outcomes.

Vehicle model details were derived for vehicles appearing in the crash data used for crashworthiness ratings through a process of Vehicle Identification Number (VIN) decoding described in Newstead et al 2000. Using the decoded vehicle model information, it was then possible to identify the vehicle model series that had ABS as an option. However, in order to identify safety equipment fitted to a particular crashed vehicle it was necessary to return the VIN to the vehicle manufacturer to be compared against vehicle build information.

Twelve car manufacturers were initially approached to provide optional vehicle safety feature information on vehicles involved in real world crashes. Data from six car manufacturers (Ford, Holden, Honda, Mitsubishi, Toyota, and Volvo) ultimately proved useful in the analysis. Matching this data to the original crash data yielded 40,739 cases with an indicator of the presence or absence of ABS. This provided sufficient data to enable analysis of the effectiveness of ABS. At the request of the participating vehicle manufacturers, the performance of vehicle safety features in identified specific vehicle models is not reported.

3. Method

ABS is fundamentally considered a primary safety feature concerned with crash avoidance rather than injury mitigation given crash occurrence. It is possible, however that the provision of controlled maximum braking force by ABS may have some secondary safety effects in crashes by lowering impact speeds and hence total crash severity. Therefore, the potential benefits of ABS are analysed in terms of both primary and secondary safety.

Secondary safety

Secondary safety refers to injury outcome given that a crash event has occurred. The two measures of secondary safety used in this study are injury risk and injury severity. Injury risk refers to the probability of injury given involvement in a crash where at least one vehicle is towed from the scene or someone is injured. Injury severity is defined as the probability of death or serious injury (hospitalisation) given that an injury is sustained. As mentioned, only driver injury outcomes have been assessed.

In assessing the impact of ABS on secondary safety, the research question is whether injury risk and injury severity are equal for drivers of vehicles fitted with ABS and drivers of vehicles not fitted with ABS.

It was not sufficient to simply compare injury experience across drivers of all vehicles fitted with ABS with those not fitted with ABS. As the proportion of vehicles fitted with ABS was not equal across all vehicle models it was necessary to control for differences in average total safety between vehicle models. This was done by selecting crash involved vehicles of the same model in which ABS was present and absent and assessing differences in secondary safety between these vehicles. The average safety effect of ABS was obtained by averaging the effects across the individual vehicle models assessed. Individual vehicle models with small frequencies in each, or any, driver injury severity level were excluded from the analysis to ensure reliability of the results.

Assessment of differences in occupant injury risk and injury severity between crashed vehicles with and without ABS was made using a contingency table analysis. A log-linear model with Poisson error structure, appropriate for the variability in the counts of occupant casualties, was then fitted to the data, with the model form given by Equation 1. The log-linear model form of Equation 1 can easily be fitted in common statistical software packages such as SAS.

$$\ln(N_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{ijk} \dots \text{Equation 1}$$

In Equation 1, i is the vehicle model index, j is the ABS presence indicator (yes=1 or no=0), k is the injury level index (not injured=0 or injured=1 for the injury risk analysis or minor=0 or serious injury=1 for the injury severity analysis). The β values are the model parameters and N_{ijk} is the cell driver injury count. The percentage reduction in injury risk or severity associated with the presence of ABS in vehicle model i is given by Equation 2.

$$\Delta_i = 100 \times (1 - \exp(\beta_{i,j=1,k=1})) \% \dots \text{Equation 2}$$

Statistical significance of Δ_i is equal to the statistical significance of β_{i11} , obtained directly from the fitted log-linear model. Confidence limits for Δ_i are computed in the normal way using the estimated standard error of β_{i11} obtained from the fitted log-linear model and using the transformation given by Equation 2.

It should be noted that estimates of ABS effectiveness obtained from the log-linear model reflect a change in the odds of injury or odds of severe injury associated with ABS rather than the absolute change in the injury risk or severity measure directly. Injury risk odds are the ratio of injured to uninjured drivers whilst injury severity odds are the ratio of killed or hospitalised drivers to those with minor injuries. Estimates of ABS effectiveness presented in the results reflect percentage reductions in the injury or severity odds ratios associated with ABS presence.

Modification to the above model can be made to estimate average ABS effect across all represented vehicles. The modification required is shown in Equations 3 and 4.

$$\ln(N_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{jk} \dots \text{Equation 3}$$

$$\Delta = 100 \times (1 - \exp(\beta_{j=1,k=1})) \% \dots \text{Equation 4}$$

Assessing the secondary safety effects of ABS in the above way assumes that factors known to affect injury outcome, such as occupant age and sex and average

crash severity, are the same within each vehicle model for vehicles with and without ABS. Interrogation of the data on the available variables reflecting occupant and crash characteristics, being driver age and sex, speed zone of crash and number of vehicles involved, suggested this was true. Formal testing of this hypothesis was employed using logistic regression analysis. Results from the logistic regression analysis were used only to assess the assumption of balance of the listed factors between comparison vehicles. If the assumptions proved justified, the results from the Log-Linear analysis were considered the more definitive as this method gave greater statistical power due to fewer parameters being included in the models. A detailed description of the logistic regression framework is provided in Newstead et al (2000).

Primary safety

Primary safety refers to the ability of a vehicle to avoid a crash and is typically measured as crash risk per unit exposure. It is generally difficult to directly measure changes in primary safety as there is a lack of sufficiently detailed vehicle exposure information. The assessment of the primary safety effects of ABS have firstly been assessed by examining the difference in the distribution of ABS and non-ABS equipped vehicles across various crash types. Changes in absolute crash risk for various crash types have been assessed using induced exposure methods (Evans, 1998) using side impact crashes where the ABS equipped vehicle is the side impacted vehicle as the comparison crash type.

Comparison of Distributions

Within the available crash data, there are two different means of describing crash type. Victorian and Queensland data both use the Definition for Classifying Accidents (DCA) system whilst NSW use the Road User Movement (RUM) system. As it is not possible to re-code the categories in one system to be entirely compatible with the other, parallel rather than combined analysis of DCA and RUM crash data was conducted. Furthermore, due to small data quantities crash types were aggregated into 10 broad crash type groups for analysis based on the first two digits of the DCA code and the first digit of the RUM code.

Testing for differences in distribution by crash type between ABS and non-ABS equipped vehicles was carried out using a standard chi-squared test of independence.

Absolute Crash Risk

The methodology used to estimate the absolute risk of crash involvement follows closely that used by Evans in his study on the risks associated with different crash types (Evans, 1998). First, the ratio of the crash type of interest to side-impact crashes is calculated. This ratio is defined as:

$$R = \frac{N_{ABS(I)} \times N_{NABS(S)}}{N_{ABS(S)} \times N_{NABS(I)}} \dots \text{Equation 5}$$

where,

$N_{ABS(I)}$ the number of vehicles fitted with ABS involved in the crash type under examination where the driver was injured (N_I)

$N_{ABS(S)}$	the number of vehicles fitted with ABS involved in side impact crashes where the driver was injured (N_2)
$N_{NABS(I)}$	the number of vehicles not fitted with ABS involved in the crash type under examination where the driver was injured (N_3)
$N_{NABS(S)}$	the number of vehicles not fitted with ABS involved in side impact crashes where the driver was injured (N_4)

From this ratio it is possible to estimate the percentage change in risk associated with the presence of ABS using the following formula:

$$\Delta Risk = 100(1 - R)\% \dots \text{Equation 6}$$

In order to provide confidence limits on the estimated ratio of the crash type of interest to side impact crashes, it is necessary to consider the error structure. In this study, the choice of error structure is dictated by the natural bounds of the estimated ratio. To ensure that R is contained with the bounds 0 to infinity the logarithm of R is used to calculate the standard error. The standard error associated with the estimate of R is given by:

$$\sigma_{\ln(R)} = \sqrt{\sum_{i=1}^4 \frac{1}{N_i}} \dots \text{Equation 7}$$

and the 95 percent confidence limits by:

$$R_{\text{Lower Limit}} = \exp(\ln(R) - 2\sigma_{\ln(R)}) \dots \text{Equation 8}$$

$$R_{\text{Upper Limit}} = \exp(\ln(R) + 2\sigma_{\ln(R)}) \dots \text{Equation 9}$$

The confidence limits on the percentage change in risk associated with the presence of ABS can be easily derived from equations 6, 8 and 9.

4. Results

Secondary Safety

Sufficient data was available for seven vehicle models to enable assessment of the effects of ABS on driver injury severity using the contingency table analysis method. The presence of ABS braking systems was not associated with a statistically significant change in either injury risk or injury severity for any of the vehicle models individually or on average across the seven vehicle models. This result was the same for both the Poisson regression and logistic regression analysis. Due to space constraints, full results of these analyses are not presented here but are available in Burton et al (2004).

Primary Safety

Crash Distribution

Assessment of the primary safety effects of ABS brakes has been undertaken by examining differences in crash distribution between ABS equipped and non-equipped vehicles. As noted, due to the differences between the DCA and RUM system for describing crash configuration, analysis of ABS effects on crash type has been undertaken separately for each crash type definition.

The aggregated data are presented in Table 1 along with the percentage of data in each of the 10 broad DCA groupings for ABS and non-ABS equipped vehicles. The

percentages allow direct comparison of the distribution of crashes within each ABS category. It should be noted that the data in Table 1 includes only crashes involving injury in order to overcome the problem of different crash reporting criteria between Victoria (casualty crash reporting requirement) and Queensland (all tow-away crash reporting requirement). Failure to make this restriction may have resulted in bias in the analysis.

Table 1. ABS Brake Presence by DCA Crash Group: Victoria and Queensland

DCA Group	ABS Not Fitted	ABS Fitted	Total
Pedestrian	4 (0.15%)	1 (0.13%)	5
Vehicle Adjacent	530 (20.45%)	134 (17.01%)	664
Vehicle Opposing	495 (19.1%)	128 (16.24%)	623
Vehicle Same Direction	670 (25.86%)	176 (22.34%)	846
Manoeuvring	104 (4.01%)	26 (3.30%)	130
Overtaking	56 (2.16%)	22 (2.79%)	78
On Path	83 (3.20%)	30 (3.81%)	113
Off Path on Straight	397 (15.32%)	159 (20.18%)	556
Off Path on Curve	232 (8.95%)	101 (12.82%)	333
Passenger falling in/from vehicle and Miscellaneous	20 (0.77%)	11 (1.40%)	31
Total	2591 (100%)	788 (100%)	3379

A chi-squared test of independence of the data in Table 1 showed a statistically significant different distribution of crashes by crash type between ABS and non-ABS equipped vehicles ($\chi^2(9)=78.8$, $p<0.001$). From the relative percentages in Table 1, ABS equipped vehicles were under-represented in crashes coded as 'manoeuvring' or 'pedestrian' in comparison to non-ABS equipped vehicles. In contrast, ABS equipped vehicles were over-represented in comparison to non-ABS equipped vehicles in crashes where a vehicle left a straight or curved section of carriageway (i.e. 'off path on straight' or 'off path on curve'). It is noted that these results do not give any information about the relative crash risk of ABS and non-ABS equipped vehicles but only about the types of crashes in which they are involved.

Parallel analysis of NSW crash data using RUM codes produced similar results to those above. They are not presented in this paper due to space constraints.

Absolute Risk of Crash Involvement

To estimate the absolute risk of crash involvement it was necessary to obtain some measure of exposure. As there was a lack of sufficiently detailed exposure information available, side impact crashes, where the focus vehicle is impacted in the side by another vehicle, were selected for use as an induced exposure measure. These crashes were selected as it is believed that the frequency of this crash type is

unaffected by the presence or absence of ABS in the vehicle. The validity of this assumption is significant to the interpretation of the results. If side impact crashes are affected by ABS fitment, any deviation from unity of the ratio R (defined in the methods) cannot be interpreted as the change in absolute crash risk associated with ABS presence. It is believed that the incidence of side impacts will not be affected by ABS brake presence, as this impact direction is perpendicular to the direction of motion of the focus vehicle that can be altered by braking. Further, it is noted that side impact crashes have been used as an induced exposure measure in an evaluation of ABS by Evans (1998).

Side impact crashes used in the analysis were selected based on the impact direction for crashes occurring in Victoria and Queensland. As impact direction was not available for crash involved vehicles in NSW these crashes are not included in the analysis. Further, given the difference between crash reporting requirements in Victoria and Queensland, only those crashes involving injury have been considered in the analysis. Further, the analysis by individual crash type was not possible due to small data quantities in the defined cells. As for the analysis above, crash types were aggregated into the 10 broader crash type groupings for analysis based on the first two digits of the DCA code. The results of the analysis are presented in Table 2. It should be noted in Table 2 that the “Vehicles Adjacent” category excludes the side impact crashes used as the induced exposure measure.

Table 2. Estimation of Absolute Casualty Crash Risk for ABS equipped vehicles in Victoria and Queensland

Crash Type of Interest	R	Δ Risk Odds (%)*	90% Confidence Limits		95% Confidence Limits	
			Lower Limit	Upper Limit	Lower Limit	Upper Limit
Pedestrian	0.77	22.67	-138.15	74.89	-633.49	91.85
Vehicles Adjacent	0.78	21.80	8.48	33.18	-7.11	42.90
Vehicles Opposing	0.80	20.02	6.25	31.76	-9.88	41.78
Vehicles Same	0.81	18.75	5.58	30.08	-9.72	39.83
Manoeuvring	0.77	22.67	0.52	39.89	-27.98	53.28
Overtaking	1.22	-21.51	-60.86	8.21	-112.95	30.67
On Path	1.12	-11.80	-43.05	12.63	-83.04	31.72
Off Path on Straight	1.24	-23.88	-44.73	-6.03	-69.08	9.24
Off Path On Curve	1.35	-34.65	-59.93	-13.37	-89.96	4.55
Passenger falling in/from vehicle and Miscellaneous	1.70	-70.12	-152.60	-14.56	-275.09	22.85

* Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS. The shaded regions identify statistically significant results.

When testing at the 10 percent level, significant changes in the odds related to ABS presence were identified. In particular, the absolute risk of being involved in crashes involving vehicles colliding from adjacent, the same or opposing directions and manoeuvring crashes is estimated to be lower for ABS equipped vehicles than for non-ABS equipped vehicles. Statistically significant reductions in the odds related to ABS presence range from 19 percent for vehicles from the same direction to 23 percent for manoeuvring crashes. In contrast, the risk of involvement in crashes involving a vehicle leaving a straight or curved section of carriageway and passenger and miscellaneous crashes is higher for ABS equipped vehicles than for non-ABS equipped vehicles. Off path on straight and on curve crashes showed a statistically

significant increase in odds associated with ABS presence at the 10 percent level of significance of 24 and 35 percent respectively.

Run-off-the-road Crashes

As some earlier evaluations of ABS effectiveness have found evidence of an increased risk of involvement in run-off-the-road crashes associated with ABS, crashes of this nature were identified individually using all available data. This enabled analysis of the absolute risk of crash involvement for ABS vehicles involved in run-off-the-road crashes using data from all three states. The results are presented in Table 3.

Table 3. Estimation of Absolute Casualty Crash Risk for ABS Equipped Vehicles in Run-Off-the-Road Crashes

Crash Type of Interest	R	ΔRisk Odds (%)*	95% Confidence Limits	
			Lower Limit	Upper Limit
Run-off-the-road	1.35	-35.38	-13.55	-61.41

* Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS.

It is concluded that, the presence of ABS in a vehicle is associated with a 35 percent increase in the absolute risk of involvement in a run-off-the-road crash. This result is significant at the 5 percent level of significance. That is, the probability that the true increase in the absolute risk of involvement in a run-off-the-road crash associated with ABS lies between 14 percent and 61 percent is 0.95.

Vehicle-to-Vehicle Crashes

Hertz (1996) identified a decrease in the absolute risk of crash involvement associated with ABS fitment for vehicle-to-vehicle crashes. Combined analysis of these crash types was therefore conducted separately on both data sets. Vehicle-to-vehicle crashes were defined to include crashes involving vehicles from adjacent, opposing and the same direction and manoeuvring, overtaking and on path crashes. The results are presented in Table 4.

Table 4. Estimation of Absolute Casualty Crash Risk for ABS Equipped Vehicles in Vehicle-to-Vehicle Crashes

Crash Type of Interest	R	ΔRisk Odds (%)*	90% Confidence Limits		95% Confidence Limits	
			Lower Limit	Upper Limit	Lower Limit	Upper Limit
Vehicle-to-Vehicle (DCA)	0.82	17.65	5.88	27.94	-7.57	36.95
Vehicle-to-Vehicle (RUM)	0.96	4.13	-5.62	12.98	-16.37	21.01

* Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS. The shaded region identifies a statistically significant result.

The results from the analysis of Victorian and Queensland vehicle-to-vehicle crashes indicate that there is an estimated 18 percent decrease in the risk of involvement in this crash type associated with the presence of ABS with a significance probability of

between 90 and 95 percent. No such evidence could be found on the analysis of crashes occurring in NSW based on RUM codes at either the five or ten percent level of significance. However, the point estimates of the change in risk odds are consistent with those from the Victorian and Queensland analysis based on the confidence limit coverage.

5. Discussion

This study has attempted to quantify the effectiveness of ABS in terms of both primary and secondary safety. The requirement to examine only vehicle models where ABS is an option and not fitted as standard, has led to limited availability of data. As a result, none of the estimates of the effect of ABS with respect to its secondary safety effects have achieved statistical significance. Indeed, it cannot be concluded that ABS brakes have any significant effect on secondary safety through reduction in impact severity. Nevertheless, a number of the results are worthy of discussion, particularly in relation to primary safety effects of the feature and the results of other studies examining the effectiveness of ABS.

The US Insurance Institute for Highway Safety (IIHS) has conducted several studies aiming to determine if cars equipped with ABS are involved in more or fewer fatal accidents. A 1996 study (Hertz et al, 1996) found vehicles equipped with ABS were overall no less likely to be involved in fatal accidents than vehicles without. It found that cars with ABS were less likely to be involved in accidents fatal to the occupants of other cars but were more likely to be involved in accidents fatal to the occupants of the ABS equipped car, especially in single-vehicle accidents. There was much speculation about the reasons for this, including incorrect use of the ABS by the driver pumping the brakes or by releasing the brakes when they feel the system pulsing, leading to increased braking distance. Alternatively, it has been suggested that the retention of steering control during a panic stop may increase the likelihood of run off the road crashes. A more recent study (Farmer, 2001) indicates that the accident rates for ABS equipped cars are reducing, but there is still no conclusive evidence to show that ABS improves overall safety.

Overall, this study cannot show statistically significant changes in secondary safety associated with ABS brakes. It was not possible to examine fatalities alone in this study so it is not clear whether the results from this study are consistent with others with respect to fatal injury effects. Further analysis, based on larger quantities of data would be required in any attempt to show any secondary safety effects of ABS. However, it is expected any measured effects would be small based on the point estimates from analyses undertaken here.

Analysis of changes in crash type distribution associated with ABS in this study was consistent with findings by Hertz et al (1996). The distribution of crash involvement by crash type for ABS equipped vehicles was statistically significantly different from the distribution of crash involvement by crash type for non-ABS equipped vehicles. In particular, ABS equipped vehicles were found to be involved in fewer crashes with vehicles from adjacent, opposing or the same direction proportionately compared to non-ABS equipped vehicles. In contrast the proportion of ABS vehicles involved in run-off-the-road type crashes (i.e. 'off path on straight' and 'off path on curve') was greater than for non-ABS equipped vehicles. It is noted, however, that the results

looking only at crash distribution do not necessarily measure changes in absolute crash risk.

Estimates of changes in absolute crash risk by crash type associated with ABS brakes were obtained using induced exposure methods with side impact crashes as the reference crash type presumed to be unaffected by ABS fitment. Statistically significant results were obtained for a number of crash types. Most significantly, the analysis of the absolute risk of crash involvement for ABS-equipped vehicles was estimated to be approximately 35 percent greater than for non-ABS equipped vehicles in run-off-the-road crashes. Again, re-analysis of this question using a larger data set would be likely to decrease the width of the confidence limits attached to the estimates. Analysis of the data also identified an estimated 18 percent decrease in the absolute risk of vehicle-to-vehicle crash involvement for ABS-equipped. This result is consistent with that identified by Hertz (1996) in a study of the effectiveness of ABS braking systems.

6. References

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