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FOLLOWUP EVALUATION OF ELECTRONIC STABILITY CONTROL EFFECTIVENESS IN AUSTRALASIA

by

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Abstract:
The aim of this study was to evaluate the effectiveness of ESC systems in reducing crash risk in Australia and New Zealand. This was a follow up to an earlier evaluation, with the present study making use of a greater quantity and range of crash data to employ an improved induced exposure method for controlling the effect of confounding factors. More data also meant that effectiveness could be measured in terms of reductions in serious injury crashes and effectiveness could be measured for specific types of crashes, such as rollover crashes and head on crashes. Crash data from New Zealand and five Australian states, collected as part of the Used Car Safety Ratings project were analysed and consisted of 439,543 vehicles without ESC and 27,252 vehicles with ESC, with the latter group comprising of 175 different models.

The overall crash reduction estimates of this study were in general similar to those previously estimated. The effect of ESC on all types of crashes leading to driver injury was a significant 8% reduction in risk. ESC was associated with a significant 8% increase in the risk of multiple vehicle crashes, but this effect was not evident when restricted to crashes that resulted in the driver being injured. ESC was effective at preventing single vehicle crashes (by 28% for all severities and 32% for crashes leading to driver injury) and particularly effective at preventing rollover crashes. When fitted to 4WDs, ESC reduced the risk of rollover crashes by 82%. However, unlike studies from other countries, the results of this evaluation suggested that there was a trend that ESC was less effective at preventing serious single vehicle crashes than less serious single vehicle crashes. The reason for this is not clear but it is possible that in Australasia serious single vehicle crashes are not occurring in circumstances where ESC can successfully intervene after driver input, for example when the driver is asleep. Investigating whether the effectiveness of ESC may be mitigated by a risk compensation effect was suggested as a topic for future research.

Key Words:
Electronic Stability Control
Vehicle Fleet
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Preface

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EXECUTIVE SUMMARY

In 2008, Scully and Newstead (2008) employed an induced exposure methodology to show the reduced crash risk associated with Electronic Stability Control (ESC) systems in Australia and New Zealand was similar in magnitude to that previously demonstrated using data from Europe and the USA. A recommendation of that study was to conduct a follow up study when more data are available so that more accurate and crash specific estimates of effectiveness could be made. The primary aim of this study was to further evaluate the effectiveness of ESC systems in reducing crash risk in Australia and New Zealand on an expanded data set. This study aimed to test whether the preliminary evaluation of ESC by Scully and Newstead (2008) could be reproduced on more comprehensive data. The availability more comprehensive data allowed an improved methodology to be used which more effectively control for differences in the secondary safety of vehicles with and without ESC fitted. The effect of non-vehicle factors such as driver demographics could also be tested. Estimates of effectiveness in terms of reductions in serious injury crashes were also possible, along with estimates of effectiveness of specific types of crashes, such as rollover crashes and head on crashes.

The data used in the analysis were police-reported crash data from New Zealand and five Australian states which had been collected as part of the Monash University Accident Research Centre's Used Car Safety Ratings project. Only data for vehicles manufactured after 1998 that crashed in the period 2001-2008 were included in the analysis sample to ensure the group of ESC fitted vehicles and non-fitted vehicles were subject to similar design standards. The present analysis is based on 439,543 vehicles without ESC and 27,252 vehicles with ESC, with the latter group comprising 175 different models.

The induced exposure methodology was used for the study. It was assumed that the risk of being involved in a rear end impacts was not affected by ESC fitment to provide an estimate of relative vehicle exposure. This crash type has also been used to induce exposure in previous evaluations of ESC. Confounding factors were controlled for by matching ESC fitted vehicles with similar vehicles that did not have ESC using the year of manufacture of the crashed vehicles and their market group. The SAS statistical software was used to fit a Poisson regression model. The average effectiveness of ESC across all cohorts of vehicles was estimated, as well as separate estimates of effectiveness for different groups of vehicles.

The crash reduction estimates presented in this study were generally similar to those presented previously by Scully and Newstead (2008), confirming the validity of the previous evaluation. However the present study's estimates of effectiveness are representative of the effectiveness of ESC across a much broader group of vehicles as models and market groups (such as light cars and commercial vehicles) previously excluded due to low fitment rates could now be included in the analysis sample.

ESC fitment was associated with a significantly 8.2% ($p<.05$) reduction in crashes involving driver injury. Scully and Newstead (2008) had previously found that ESC was associated with reduced risk of driver injury crashes by a non-significant 9.8%. Investigations were also made regarding the effect of confounding factors, such as differences in the demographics of drivers of ESC fitted vehicles and non-fitted vehicles and differences in the secondary safety of ESC fitted vehicles and non-fitted vehicles. It was found that both the driver demographics and the superior secondary safety of ESC fitted vehicles had only a very small biasing effect on the reported estimates of effectiveness.

Similar to the previous evaluation, ESC was associated with a significant increase in multiple vehicle crashes of all severities, however the size of the effect was less than that previously estimated (7.9% compared to 14.8%). The increased risk associated with multiple vehicle crashes was not evident when restricted to driver injury crashes. For 4WDs, ESC was associated with a significantly reduced risk of head on collisions of 41.9% for crashes of all severities and of 47.3% when restricted to crashes resulting in the driver being injured.

It was found that the effect of ESC on the risk of single vehicle crashes was similar to that previously estimated by Scully and Newstead (2008). A significant 27.6% reduction for crashes of all severities and significant 32.3% reduction for single vehicle crashes involving driver injury was estimated. ESC was also associated with a significant 55.6% reduction in rollover crashes of all severities and a significant 59.6% reduction in rollover crashes resulting in driver injury. The effectiveness of ESC in preventing rollover crashes was even greater for 4WDs, reducing the risk of rollover crashes of all severities by 81.6% and rollover crashes resulting in driver injury by 79.8%.

Analysis results from this study also suggest that ESC may not be as effective in preventing serious single vehicle crashes as it is in preventing less serious single vehicles crashes. This is counter to what would be expected based on evaluations studies conducted in other countries. It is possible that serious single vehicle crashes in Australasia are different in some way to the crashes occurring in Europe or the USA. Perhaps in Australasia, serious single vehicle crashes may be occurring at a speed or in conditions that makes it difficult for ESC systems to regain control to avoid the crash from occurring or where the cause of the crash is not loss of control of the vehicle during active driver intervention. One example may be where fatigue is a cause of the crash and the driver is asleep. This potential requires further investigation.

FOLLOW UP EVALUATION OF ELECTRONIC STABILITY CONTROL EFFECTIVENESS IN AUSTRALASIA

1 INTRODUCTION

1.1 BACKGROUND

A 2008 study by Scully and Newstead employed an induced exposure methodology to determine whether Electronic Stability Control (ESC) systems reduced crash risk in Australasia. ESC is an in-vehicle technology designed to improve primary safety by assisting the driver from losing control of their vehicle. ESC continuously monitors a vehicle's direction of travel using sensors that measure lateral and rotational acceleration, steering wheel angle and the speed at which individual wheels are rotating. If a vehicle's direction of travel does not match the intended direction of travel, as indicated by the position of the steering wheel, ESC will apply the brakes to one or more of the vehicle's wheels or reduce engine power until control has been regained. Scully and Newstead's (2008) study suggested that the reduction in crash risk associated with ESC in the Australian and New Zealand fleet was of a similar magnitude to those predicted in the international literature.

One of the recommendations made by Scully and Newstead (2008) was that a follow-up study be conducted to increase the accuracy of reported measures of effectiveness. It was considered that the increased quantity of data that would be available in the future would mean that more accurate estimates of effectiveness could be made. Furthermore, the limited quantity of data available in 2008 meant that the original study could only measure effectiveness in terms of the reduction in risk of crashes of all severities and the reduction in the risk of crashes involving driver injury. With more data available for the current study, there was an opportunity to measure effectiveness in terms of reductions in serious injury crashes which is a measure relevant to the objectives of the road safety strategies of Australasian jurisdictions.

Since the 2008 evaluation, the range of vehicles fitted with ESC has also increased. This meant that estimates of the effectiveness of the technology when fitted to specific types of vehicles could be explored. Furthermore, the increased range of vehicle types fitted with ESC means that the effect of potential confounding variables could be investigated more rigorously. The increased quantity of data also potentially enabled estimates of effectiveness in terms of the extent to which ESC reduced the risk of specific types of crashes, such as rollover crashes or head on crashes.

1.2 REVIEW OF RECENT DEVELOPMENTS

ESC was first introduced as a primary safety vehicle on some passenger vehicles in 1998. Scully and Newstead (2008) provide a summary of the results of evaluations of ESC conducted prior to 2008 that used data from European and US jurisdictions. The following section provides a brief update of study results published since Scully and Newstead's (2008) evaluation. It is followed by sections detailing how government and industry have responded to estimates of effectiveness published in the scientific literature.

1.2.1 Summary of recent evaluations

Most of the ESC evaluations published prior to 2008 concluded that ESC was effective in reducing involvement in single vehicle crashes and that it was less effective in preventing multiple vehicle crashes. However the estimated degree of effectiveness differed between studies. This prompted Erke (2008) to conduct a meta-analysis of eight evaluations which confirmed that ESC does result in large reductions in single vehicle crashes and rollover crashes. However Erke (2008) concluded that the true magnitude of effect on single vehicle crashes had been exaggerated due to publication bias and outlier bias.

The effectiveness of ESC in preventing loss of control crashes has also been demonstrated empirically using a high-fidelity driving simulator. Papelis, Watson et al. (2010) used two vehicle models: a passenger vehicle and a 4WD (SUV). Both models could be configured so that ESC systems could either be included or omitted when modelling vehicle responses to driver inputs in scenarios where loss of control was possible. It was found that ESC helped drivers of both types of vehicles avoid losing control in all three scenarios considered.

Several recent international studies have evaluated ESC using local crash data. One example is the evaluation of ESC by Frampton and Thomas (2007) which used the United Kingdom's STATS19 database. An induced exposure methodology similar to that used by Scully and Newstead (2008) was used. Estimates of effectiveness included risk reduction for specific types of crashes. Effectiveness as a function of road surface condition revealed that ESC offered additional benefit on wet, snowy or icy roads. ESC was also found to be particularly effective at preventing single vehicle crashes, rollover crashes, side impact crashes and crashes that involved skidding. Frampton and Thomas (2007) also examined whether the level of effectiveness of ESC differed according to the sex of the driver but found no evidence.

Another study used in-depth real world crash data to determine how ESC intervenes to reduce the risk of high speed single vehicle crashes in the Australian rural environment (Mackenzie and Anderson 2009). In-depth data were used to recreate twelve crashes as computer simulations. In-depth data concerning each driver's attempts to prevent the crash (such as braking or steering) were simulated. Each vehicle's trajectory during the crash phase was simulated and compared to the trajectory that would have occurred if the vehicle had been fitted with ESC.

As the proportion of new cars fitted with ESC has increased, so too has the public's knowledge of the safety benefits of the technology. Just as the benefits of anti-lock braking systems (ABS) have been shown to have been mitigated by changes in driver behaviour (see Evans 1998; Burton, Delaney et al. 2004), drivers may drive more quickly or aggressively if they know their car is fitted with ESC. Two recent studies from Canada (Rudin-Brown, Jenkins et al. 2009) and Sweden (Vadeby, Wiklund et al. 2009) surveyed drivers regarding their knowledge of ESC. Vadeby, Wiklund et al. (2009) questioned drivers of ESC fitted vehicles about how they intended to behave in several critical driving situations and compared their responses with those from drivers of vehicles without ESC. Rudin-Brown, Jenkins et al. (2009) compared responses established preconditions necessary for negative behavioural adaptation to occur. Both studies found evidence that knowing a car was fitted with ESC increased risk taking behaviour and that the effect was stronger for males and young drivers.

Research has also attempted to evaluate different types of ESC systems. For example, Dang (2007) compared the effectiveness of two channel and four channel ESC systems and found that, for crashes of all severities, four channel ESC systems were significantly more effective at preventing single vehicle run off road crashes. Dang (2007) also validated the results from her earlier study (Dang 2004), and used an induced exposure methodology to demonstrate that ESC significantly reduced fatal run off road crashes and fatal crashes that involved a rollover event. These results also held for police reported crashes. One of the limitations of Dang's (2007) study was that the sample of vehicles used in the analysis was mainly restricted to luxury models.

A new area of research that has emerged since 2008 is measuring the effect of fitting ESC to heavy vehicles (see Barickman, Elsasser et al. 2009; Svenson, Grygier et al. 2009). Manufacturers of heavy vehicles are now offering ESC on many models. Estimating the benefits for heavy vehicles is a challenge as there is currently an insufficient quantity of real world crash to allow statistical studies employing a case control design. Another study investigated the potential for using ESC systems to prevent motorcycle crashes (Gail, Funke et al. 2009) and concluded that ESC only had potential to prevent a small sub-group of single vehicle crashes for motorcycles.

1.2.2 The effect of research on policy

Evidence that ESC reduced the incidence of single vehicle crashes influenced the National Highway Traffic Safety Administration to mandate that all light vehicles of mass 10,000 lbs or less manufactured from 2012 onwards must be fitted with ESC (National Highway Traffic Safety Administration 2007). Recent Canadian Motor Vehicle Safety Regulations also require that all passenger cars, multi-purpose passenger vehicles, trucks and buses of mass not exceeding 4,536 kg that are manufactured after 31st August 2011 must be fitted with ESC (Government of Canada 2009).

Weekes, Avery et al. (2009), reported that EuroNCAP first started publishing information on whether ESC was available on a particular vehicle in 2007 while in the same year the European Parliament voted that ESC should be available on all new models from 1st of November, 2011 and on all new vehicles from 1st of November 2014.

The Australian Federal Government released a new vehicle standard that required that all new models of passenger cars, forward control passenger vehicles and off road vehicles be fitted with ESC from the 1st of November 2011, while all new vehicles must be fitted with ESC from the 1st of November 2013 (Department of Infrastructure Transport Regional Development and Local Government 2009). The Australian state of Victoria has adopted a more immediate requirements by legislating that all passenger cars manufactured on or after 1st of January 2011 be fitted with ESC, irrespective of whether the vehicle is a new model (State Government of Victoria 2009).

1.2.3 Industry responses

The market penetration of ESC in Europe varies between different countries. For the UK, 53% of new cars had ESC as standard in 2008, up from 40% in 2006 (Weekes, Avery et al. 2009). In contrast, Krafft, Kullgren et al. (2009) reported that in December 2008, 97.9% of new cars sold in Sweden were fitted with ESC, an increase from 70% in 2005. Krafft, Kullgren et al. (2009) noted that Sweden was able to achieve impressive ESC penetration without legislation but by using a multi-faceted approach to shaping the new car market.

In Australia, ESC fitment rates have steadily increased since 2006. Data provided by the Transport Accident Commission (2010) show that in the first quarter of 2006, only 11% of new vehicles sold in Australia had ESC fitted as a standard feature, compared with 60% for the first quarter of 2010.

Data from the Insurance Institute for Highway Safety (2010) shows that in the US ESC fitment has steadily increased . For the 2010 model year ESC was fitted in 88% of passenger cars, 100% of SUVs and 62% of pickups (utilities) compared with48% of passenger cars, 66% of SUVs and 1% of pickups in 2006.

1.3 STUDY AIMS

The primary aim of this study was to further evaluate the effectiveness of ESC systems in reducing crash risk in Australia and New Zealand. This study aimed to test whether the preliminary evaluation of ESC by Scully and Newstead (2008) was accurate. Since the preliminary evaluation, a greater quantity of data are available for analysis, enabling the use of a methodology that more effectively controls for differences in the secondary safety (the ability of a vehicle to protect its occupants when a crash occurs) of ESC fitted vehicles and non-fitted vehicles. The increased quantity of data also allowed the effect of differences in non-vehicle factors, such as driver demographics, to be tested.

Another aim of the present study was to learn how the level of effectiveness of ESC differs for different driving situations. ESC effectiveness will be estimated for different crash types and different vehicle types. The study also aimed to measure effectiveness in terms of the extent to which ESC prevents crashes of different severities. Previously there were insufficient data to estimate the reduction in the risk of serious crashes for Australasia.

2 DATA

Crash data used in the study were police-reported crash data from New Zealand and five Australian states which had been collected as part of the Monash University Accident Research Centre's (MUARC's) *Used Car Safety Ratings* project. Newstead, Watson et al. (2009) provide a detailed description of these crash data. To ensure relatively homogeneous crash conditions, the sample of data analysed by Scully and Newstead (2008) was restricted to crashes occurring in the period 2001-2005. Three years of additional data were available for this study. The resulting analysis data included vehicles crashed in the period 2001-2008 covering records of 1,984,523 vehicles.

Vehicles without a valid Vehicle Identification Number (VIN) were excluded from the analysis sample as VINs were used to determine ESC fitment status. People movers (vehicles with more than 5 seats) were also excluded from the analysis as this group of vehicles had low fitment rates and including them would potentially bias estimates of effectiveness. The previous evaluation by Scully and Newstead (2008) also excluded light vehicles (< 1100kg tare mass), compact 4WDs (sport utility vehicles < 1700kg tare mass) and commercial vehicles for the same reason. However, ESC has since become more common in these types of vehicles allowing inclusion, leaving 1,323,025 vehicle records eligible for inclusion in the analysis.

The sample of crashed vehicles was also restricted to vehicles manufactured more recently than 1998 to ensure the group of ESC fitted vehicles and vehicles without ESC were of a similar age and subject to similar design standards, leaving 515,559 vehicles remaining in the sample.

2.1 DETERMINING ESC FITMENT STATUS

ESC fitment status was determined using the Redbook Lookup Guide (Automotive Data Services 2007) which provides data on the VIN and specifications of vehicles sold in Australia.

An SPSS syntax (SPSS 2009) was prepared to classify vehicles according to ESC fitment status based on their make and model as well as their year of manufacture and VIN. Using this syntax, 515,559 records were assigned to one of four categories: ESC fitted (n=27,252); not fitted (n=439,543); fitment status unknown (n=29,167); and VIN not recognised (n=19,597). The "unknown" category is models in which ESC was either offered as an optional extra or only on a trim level for which the VIN could not be used to identify from other trim levels. The cases in which the VIN was not recognised were probably cases in which either the VIN was incorrectly entered into the crash database or model variants not listed by Redbook. Vehicles for which the VIN could not be determined were excluded from the analysis.

Scully and Newstead's (2008) earlier evaluation of ESC in Australasia was based on 7,699 vehicles fitted with ESC and 203,186 without ESC. The present analysis was based on 27,252 vehicles with ESC and 439,543 without ESC. Furthermore, the sample of ESC fitted vehicles used in this analysis was comprised of 175 different models (see Appendix A), compared with only 90 different models for the earlier evaluation. Consequently, the statistical power of this analysis was greater than that of the previous evaluation, resulting in more accurate estimates of effectiveness. Furthermore, as the analysis sample now contained a greater range of vehicles with ESC, the estimates of effectiveness were more representative of ESC effectiveness for all vehicles, not just a limited range of models and market groups.

3 METHOD

3.1 ESTIMATING THE EFFECT OF ESC ON CRASH RISK

As suitable travel exposure data by environment and driver characterstic were not available, this evaluation used induced exposure to evaluate the effectiveness of ESC. The earlier evaluation of ESC in Australasia by Scully and Newstead (2008) also used induced exposure as have European (Lie, Tingvall et al. 2006; Page and Cuny 2006) and US (Dang 2004; Bahouth 2005) evaluations. Induced exposure has also been used to evaluate other vehicle technologies such as anti-lock braking systems (Evans 1998; Burton, Delaney et al. 2004).

Induced exposure approximates exposure by identifying a crash type for which crash risk is assumed not to be affected by ESC fitment. Several previous evaluations of ESC have assumed that the risk of being involved in a rear impact would be the same for ESC-fitted vehicles and vehicles without ESC (Lie, Tingvall et al. 2004; Bahouth 2005; Lie, Tingvall et al. 2006; Scully and Newstead 2008). Rear impacts were also used to induce exposure in this study.

Induced exposure uses the proportion of vehicles involved in rear impacts that have ESC to estimate the number of other types of crashes that would be expected if ESC had no effect on crash occurrence. Provided confounding factors are controlled for correctly, deviation from the expected number of crashes can be considered to be an effect of the fitment of ESC.

Like Scully and Newstead (2008), this evaluation controlled for confounding factors by matching ESC fitted vehicles with similar vehicles that did not have ESC. Scully and Newstead (2008) matched vehicles based on broad market group (passenger car or 4WD) and year of manufacture. The greater quantity of data available for this study enabled vehicles to be matched based on year of manufacture and nine specific market categories which included three categories of 4WDs (compact, medium and large); four categories of passenger cars (light, small, medium and large); and two categories of commercial vehicles (utilities and vans). Each market group and year of manufacture cohort is now a more homogeneous group of vehicles than the cohorts used in Scully and Newstead's (2008) evaluation.

Once the crash data were labelled by ESC fitment status, whether the crash was a rear impact and by cohorts defined by year of manufacture and market category, the SAS statistical software was used to fit a Poisson regression model. This model estimated the percentage reduction in crashes that could be attributed to ESC for each cohort of vehicles. A technique first demonstrated by Bruhning and Ernst (1985) was then used to estimate the average measure of effectiveness across all cohorts. Separate measures of effectiveness could also be defined for different groups of vehicles. A thorough explanation of the Poisson models used in this follow up evaluation can be found in Scully and Newstead (2008).

Scully and Newstead (2008) had sufficient data to be able to estimate the effectiveness of ESC in preventing single vehicle crashes and in multiple vehicle crashes as specific crash types as well as for all crashes. The increased quantity of data available for this study enabled the evaluation of effectiveness in terms of the reduction in risk of specific types of single and multiple vehicle crashes, including rollover crashes, head on crashes and side impact crashes. Scully and Newstead (2008) also derived estimates of effectiveness measured in preventing police-reported crashes of all severities (i.e. including property damage only crashes) and crashes in which the driver was injured (*driver injury crashes*). The quantity of data available for this study allowed estimation of effectiveness in terms of reductions in crashes resulting in the driver being hospitalised or killed (*serious injury crashes*).

In order for the Poisson models to converge, it was necessary to exclude some groups of vehicles to avoid large numbers of small or zero cell counts. Vehicles excluded from all analyses included: compact 4WDs and commercial utilities manufactured prior to 2006; medium 4WDs manufactured prior to 2002; commercial vans manufactured prior to 2004 and light cars manufactured prior to 2003. Commercial vans were also excluded when evaluating the effectiveness of ESC in terms of reductions in driver injury crashes, while the three 4WD market groups were merged into one category when estimating serious injury crash risk reduction.

When estimating effectiveness measured in terms of reductions in police-reported crashes of all severities, data from New Zealand and the Australian state of Victoria were excluded as these jurisdictions do not collect data on property damage only crashes, which reduced the sample of crashes available for analysis to 332,533. Similarly, since the Australian state of New South Wales does not distinguish between serious injury and minor injury in their crash data, data from New South Wales were excluded when measuring effectiveness in terms of reductions in crashes in which a driver was seriously injured. This reduced the sample of serious injury crashes available for analysis to 6,283. Data from all six jurisdictions were included when measuring effectiveness in terms of reductions in driver injury crashes.

3.2 DETERMINING CONFOUNDING EFFECTS

A limitation of the previous evaluation by Scully and Newstead (2008) was that no adjustment was made for the possible confounding effect of driver characteristics. However the increase in the quantity of data now available has enabled investigation of whether driver characteristics are likely to have had a confounding effect on estimates of effectiveness. This was done by matching ESC fitted vehicles with non-fitted vehicles using driver age and sex as well as vehicle characteristics. Estimates of effectiveness derived using both driver and vehicle characteristics were compared with estimates derived when only vehicle characteristics were used to match vehicles. From this the confounding influence of driver characteristics on the estimates of effectiveness could be quantified.

3.3 ESTIMATING THE EFFECT OF ESC ON SECONDARY SAFETY

In their evaluation of ESC in Great Britain, Frampton and Thomas (2007) acknowledged that differences in passive (or "secondary") safety of ESC fitted vehicles and vehicles without ESC may be inflating estimates of crash reduction attributed to ESC. If ESC fitted vehicles were more effective at reducing the risk of injury when a crash occurred or at reducing the severity of injuries to occupants, then the injury outcome for the same type of crash could be minor for a vehicle with ESC but serious for a vehicle without ESC. In the case of the ESC fitted vehicle, ESC did not prevent the crash from occurring but the crash was not counted as a serious crash due to the better passive safety of the ESC-fitted vehicle. This is a particular problem for the ESC evaluation in the UK where only crashes involving injury are reported to police.

The study reported here made efforts to ensure that the effect of differences in the secondary safety offered by ESC fitted vehicles was controlled. For example, the analysis sample was limited to vehicles manufactured in the last ten years and groups of ESC fitted vehicles were matched with non-fitted vehicle groups according to year of manufacture and market group. Using rear impacts to induce exposure also limited the biasing effect of differences in secondary safety between the two groups of vehicles. This section describes the method used to measure the biasing effect of differences in the secondary safety of the ESC fitted vehicles and non-fitted vehicles.

Logistic regression models were used to measure differences between the secondary safety provided by ESC fitted vehicles compared with non-fitted vehicles in rear end crashes and then in all other types of crashes. The parameters of these models were then used to estimate the extent to which the estimates of effectiveness in terms of crash risk reduction are a result of ESC fitted vehicles having better secondary safety.

The effect of ESC on the relative secondary safety ratings for rear end crashes and for other types of crashes was analysed using the *injury risk* and *injury severity* covariate models developed by Newstead, Watson et al. (2009) for their Used Car Safety Ratings. The injury risk model estimated the risk that a driver was injured when they were involved in a tow-away crash, while the injury severity model estimated the risk that an injured driver was seriously injured or killed.

These models contained main effects parameters as well as first, second and third order interaction terms involving driver (sex and age) and crash characteristics (year of crash, speed zone and jurisdiction of crash location, the number of vehicles involved and year of crash). By doing so the models adjusted for the effect of non-vehicle factors on injury outcomes. The process used to determine which non-vehicle related factor parameters were included in each covariate model is described in detail by Newstead, Watson et al. (2009).

Newstead, Watson et al. (2009) estimated injury risk given crash involvement and risk of that an injured driver was seriously injured for different vehicle models by adding a variable differentiating each distinct vehicle model to each covariate model. However instead of adding the variable distinguishing different models of vehicles, analysis in this study added the following six terms:

1) *Rearend*: a main effect term for the variable used to induce exposure;

2) *ESC*: another main effect term for ESC fitment status;

3) *Rearend*ESC*: a first order interaction between these two main effects variables;

4) *Mktgrp*: a main effect term indicating the market group;

5) *Yearman*: a main effect term indicating year of manufacture; and

6) *Mktgrp*Yearman*: a first order interaction term between market group and year of manufacture.

Parameters for the variables *Rearend, ESC,* and *Rearend*ESC* were then used to estimate the difference in the secondary safety of ESC fitted vehicles compared to non-fitted vehicles for rear impact crashes only and also for all other types of crashes. The final three terms listed were added to each covariate model to estimate the effect of matching ESC fitted vehicles with similar non-fitted vehicles.

As explained by Newstead, Watson et al. (2009), the values of parameters in a logistic regression model can be transformed to give estimated odds ratios for each of the independent variables. Where the independent variable is included as an interaction with another independent variable, the odds ratio for the independent variable depends on the value of the variable with which it interacting. Consider two independent variables, *F* and *X* and their interaction $F \times X$. The logit function in this case can be represented as

$$logit(F, X, Y_1, \ldots, Y_k) = \beta_0 + \beta_F F + \beta_X X + \beta_{FX} F * X + G(Y_1, \ldots, Y_k) \quad (1)$$

where β_0, β_F, β_X and β_{FX} are coefficients of the model and $G(Y_1, \ldots, Y_K)$ is the linear combination of model coefficients and main effect and interaction variables that do not involve variables *F* or *X*.

The odds ratio comparing two levels of *F* (e.g. $F = f_1$ versus $F = f_0$) is equal to the difference between the logit function of each level of *F*, i.e.

$$\exp(logit(f_1, x, Y_1, \ldots, Y_k) - logit(f_0, x, Y_1, \ldots, Y_k)) =$$

$$\exp\left(\beta_F (f_1 - f_2) + \beta_{FX} (f_1 - f_2) * x\right) \quad (2)$$

with confidence intervals equal to

$$\exp\left[\beta_F (f_1 - f_2) + \beta_{FX} (f_1 - f_2) * x \pm z_{1-\alpha/2} * \sqrt{Var\left(\beta_F (f_1 - f_2) + \beta_{FX} (f_1 - f_2) * x\right)}\right] \quad (3)$$

where

$$Var\left(\beta_F (f_1 - f_2) + \beta_{FX} (f_1 - f_2) * x\right) =$$

$$(f_1 - f_2) * Var(\beta_F) + (f_1 - f_2) * x * Var(\beta_{FX}) + 2 * (f_1 - f_2) * x * Cov(\beta_X, \beta_{FX}). \quad (4)$$

For each estimated odds ratio (OR), the percent reduction of in crashes associated with ESC status can then be estimated using the transformation

$$\%Reduction = (1 - OR) * 100. \quad (5)$$

This transformation can also be applied to the confidence limits of the odds ratio to derive the confidence limits for the estimated percent reduction.

Newstead, Watson et al. (2009) defined crashworthiness as “the measure of the risk of death or serious injury to a driver of that vehicle when it is involved in a crash” (p.2). The risk that a driver is seriously injured or killed when involved in a crash is a product of the risk that a driver is injured and the risk that an injured driver is seriously injured. Crashworthiness odds ratios can be derived by converting the injury risk and injury severity odds ratios into probabilities using the transformation

$$P(OR) = \frac{OR}{1 + OR}. \quad (6)$$

Multiplying the injury risk probability by the injury severity probability gives the risk of serious injury given involvement in a tow-away crash which can then be used to derive the crashworthiness odds ratio.

Newstead, Watson et al. (2006) describe how, once the crashworthiness odds ratios have been estimated, their confidence limits can be estimated by calculating the variance of the natural logarithm of the crashworthiness probability, which can be approximated by

$$\frac{Var(injury\ risk)}{(1+\exp(\alpha))^2} + \frac{Var(injury\ severity)}{(1+\exp(\beta))^2} \tag{7}$$

where $\exp(\alpha)$ is equal equation 2 with the injury risk parameters substituted, while $\exp(\beta)$ is equal to equation 2 with the injury severity parameters substituted. The variance terms can be derived using equation 4.

Applying equation 5 gives the crashworthiness risk reduction and its confidence interval.

The adjusted odds ratios calculated using the method described in Section 3.1 can be represented as

$$OR = \frac{A_{ESC} * R_{nonESC}}{A_{nonESC} * R_{ESC}} \tag{8}$$

where *R* is the number of vehicles involved in rear impact crashes, *A* is the number of other types of crashes and the subscripts indicate the ESC fitment status of the vehicle. If the secondary safety benefits of ESC, are adjusted for, the number of crashes involving ESC fitted vehicles would be

$$\overline{A}_{ESC} = {A_{ESC}}/{OR(A)} \quad \text{and} \quad \overline{R}_{ESC} = {R_{ESC}}/{OR(R)} \tag{9}$$

where *OR(R)* represents the odds ratio of injury (or serious injury) for ESC fitted vehicles compared with non-fitted vehicles when a rear end crash occurs and *OR(A)* represents the analogous odds ratio for all other types of impacts.

Therefore, the odds ratio associated only with the primary safety benefits of ESC can be expressed as

$$\overline{OR} = \frac{\overline{A}_{ESC} * R_{nonESC}}{A_{nonESC} * \overline{R}_{ESC}} = \left(\frac{A_{ESC} * R_{nonESC}}{A_{nonESC} * R_{ESC}}\right) * \left(\frac{OR(R)}{OR(A)}\right). \tag{10}$$

From Equation 10, the ratio of *OR(R)* to *OR(A)* is a measure of the bias in the estimates of the primary safety benefits of ESC caused by the secondary safety benefits of ESC fitted vehicles compared to vehicles without ESC.

4 RESULTS

4.1 OVERALL EFFECTIVENESS

Table 1 presents the estimates of effectiveness of ESC in reducing the risk of all types of crashes (using rear impacts as the induced exposure comparison). The measure of effectiveness estimated in Table 1 is the reduction in the risk of involvement in non-rear impact crashes associated with ESC fitment. As well as presenting results for crashes of all severities, Table 1 also presents measures of effectiveness in terms of driver injury crash reductions and serious injury crash reductions. Furthermore, separate estimates of effectiveness are presented for passenger cars, commercial vehicles and 4WDs.

Table 1: *Summary of the estimated percentage reduction in crash occurrence attributable to ESC (all crash types)*

	# vehicles	% Crash reduction		Stat.	95% CL	
	with ESC	Unadjusted	Adjusted	sig.	Lower	Upper
All vehicles						
All severities	24,235	2.90	-1.28	0.441	-4.61	1.94
Driver injury	4,204	13.96	8.17	0.028	0.90	14.90
Driver ser. inj.	401	11.82	5.34	0.732	-29.68	30.91
Cars only						
All severities	19,660	0.31	-5.10	0.007	-8.98	-1.36
Driver injury	3,596	12.61	3.28	0.426	-4.99	10.91
Driver ser. inj.	337	16.79	5.27	0.750	-32.08	32.05
Commercials only						
All severities	365	11.43	10.31	0.535	-11.34	27.75
Driver injury	42	30.54	29.28	0.281	-32.78	62.33
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	4,210	14.30	12.79	<0.001	5.89	19.19
Driver injury	566	43.66	34.04	<0.001	18.23	46.79
Driver ser. inj.	64	24.31	6.01	0.902	-151.18	64.83

*** There were insufficient data to measure reductions in serious injury crashes for commercial vehicles

The adjusted estimates of effectiveness were derived by fitting a Poisson regression model to the data so that the effects of year of manufacture and vehicle market were controlled. Also shown are the unadjusted crash reduction estimates from the aggregate data. The upper and lower 95% confidence limits of the adjusted crash reduction due to ESC are also presented as are the number of crashed ESC-fitted vehicles used to derive each estimate of effectiveness.

It was estimated that ESC was associated with a significantly reduced risk of driver injury crashes by 8.2%, with a 95% confidence limit ranging from 0.9% to 14.9%. The effectiveness estimates for crashes of all severities and for serious injury crashes were both not significant.

When the analysis was disaggregated by vehicle type, it can be seen that none of the three vehicle groups showed significant reductions in serious injury crashes. However, a significant 5.1% increase in crashes of all severities was noted for passenger cars. Estimates of effectiveness for 4WDs showed that ESC was associated with a significant 12.8% reduction in crashes of all severities and a 34.0% reduction in driver injury crashes. None of the estimates of effectiveness for commercial vehicles were significant and a low quantity of data meant that the estimated reduction in serious injury crashes was not calculated for commercial vehicles.

4.2 SINGLE VEHICLE CRASHES

Table 2 shows that ESC was estimated to be associated with reduced risk of involvement in single vehicle crashes of all severities by 27.3% (95% CI: 22.9% to 31.5%), while the 31.6% reduction (95% CI: 23.0% to 39.2%) estimated for single vehicle crashes resulting in driver injury was also significant. ESC was estimated to reduce serious injury crashes by 17.4%. However this reduction was not significant.

Table 2: *Summary of the estimated percentage reduction in SINGLE VEHICLE CRASH occurrence attributable to ESC*

	# vehicles	% Crash reduction		Stat.	95% CL	
	with ESC	Unadjusted	Adjusted	sig.	Lower	Upper
All vehicles						
All severities	11,643	27.58	27.33	<.0001	22.93	31.48
Driver injury	2,294	32.31	31.57	<.0001	23.01	39.17
Driver ser. inj.	188	22.32	17.40	0.307	-19.22	42.78
Cars only						
All severities	9,354	23.60	18.60	<.0001	13.06	23.78
Driver injury	1,949	30.96	22.81	<.0001	12.23	32.12
Driver ser. inj.	161	23.91	12.57	0.498	-28.94	40.71
Commercials only						
All severities	198	17.56	10.43	0.535	-26.81	36.73
Driver injury	29	19.95	14.85	0.684	-84.67	60.74
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	2,091	53.58	56.21	<.0001	49.49	62.04
Driver injury	316	69.78	64.73	<.0001	52.03	74.07
Driver ser. inj.	27	57.07	47.77	0.234	-52.36	82.09

For commercial vehicles, neither the 10.4% reduction in single vehicle crashes of all severities, nor the 14.9% reduction in single vehicle crashes resulting in driver injury, was significant. For passenger cars, ESC was associated with a significant 18.6% reduction in single vehicle crashes of all severities (95% CI: 13.1% to 23.8%) and a significant 22.8% (95% CI: 12.2% to 32.1%) reduction in single vehicle crashes resulting in driver injury. For 4WD vehicles, the estimated reduction in single vehicle crashes of all severities was a significant 56.2% (95% CI: 49.5% to 62.0%) while the reduction in single vehicle crashes resulting in the driver of a 4WD being injured was 64.7% (95% CI: 52.0% to 74.1%).

4.2.1 Rollover crashes

More than 90% of the rollover crashes identified in the analysis sample were single vehicle crashes. Therefore, for the purposes of this study, it is appropriate to examine rollover crashes as a specific type of single vehicle crash.

Table 3 shows that for all types of vehicles and for all levels of severity measured, ESC was associated with a decrease in the risk of rollover crashes. However, not all estimates of effectiveness were significant. For example, it was estimated that ESC reduced the risk of rollover crashes resulting in a driver being seriously injured by 31.4%, however this reduction was not significant with 95% confidence limits from 32.0% increase to a 64.4% reduction.

Table 3: *Summary of the estimated percentage reduction in ROLLOVER CRASH occurrence attributable to ESC*

	# vehicles	% Crash reduction		Stat.	95% CL	
	with ESC	Unadjusted	Adjusted	sig.	Lower	Upper
All vehicles						
All severities	9,789	45.95	55.60	<.0001	47.43	62.50
Driver injury	1,850	42.68	59.59	<.0001	47.56	68.85
Driver ser. inj.	94	25.43	31.44	0.259	-32.02	64.40
Cars only						
All severities	7,814	41.10	33.69	<.0001	19.27	45.55
Driver injury	1,571	45.17	45.62	<0.001	25.84	60.13
Driver ser. inj.	80	36.59	18.46	0.586	-70.01	60.89
Commercials only						
All severities	157	60.66	53.85	0.135	-27.10	83.24
Driver injury	22	20.99	19.22	0.709	-147.84	73.67
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	1,818	78.05	81.64	<.0001	73.78	87.15
Driver injury	257	79.20	79.80	<.0001	66.66	87.76
Driver ser. inj.	14	57.97	59.54	0.172	-48.19	88.96

ESC was associated with significant reductions in rollover crashes of all severities and rollover crashes resulting in driver injury. When all vehicles were considered, ESC was associated with a 55.6% reduction (95% CI: 47.4% to 62.5%) in rollover crashes of all severities and a 59.6% reduction (95% CI: 47.6% to 68.9%) in rollover crashes resulting in driver injury. For cars, ESC was associated with a significant 33.7% reduction (95% CI: 19.3% to 45.6%) in rollover crashes of all severities and a 45.6% reduction (95% CI: 25.8% to 60.1%) in rollover crashes that resulted in the driver being injured. For 4WDs fitted with ESC, the reduction in rollover crashes was estimated to be 81.6% (95% CI: 73.8% to 87.2%) for crashes of all severities and 79.8% (95% CI: 66.7% to 87.8%) for driver injury crashes.

4.3 MULTIPLE VEHICLE CRASHES

Table 4 shows that ESC was estimated to be associated with an increase in multiple vehicle crashes of all severities by a significant 7.9% (95% CI: 4.3% to 11.5%). For multiple vehicle crashes in which the driver was injured, ESC fitment was not associated with a significant increase or decrease in crash risk. This was also true for multiple vehicle crashes resulting in serious injury.

Table 4: *Summary of the estimated percentage reduction in MULTIPLE VEHICLE CRASH occurrence attributable to ESC*

	# vehicles with ESC	% Crash reduction		Stat. sig.	95% CL	
		Unadjusted	Adjusted		Lower	Upper
All vehicles						
All severities	22,195	-2.78	-7.86	<.0001	-11.54	-4.32
Driver injury	3,676	6.98	-1.06	0.799	-9.60	6.82
Driver ser. inj.	288	5.01	-4.68	0.789	-46.32	25.11
Cars only						
All severities	17,976	-4.91	-10.08	<.0001	-14.28	-6.04
Driver injury	3,161	6.02	-3.89	0.390	-13.36	4.78
Driver ser. inj.	244	12.45	1.09	0.952	-41.02	30.63
Commercials only						
All severities	320	9.62	10.94	0.319	-11.85	29.10
Driver injury	31	37.54	38.17	0.199	-28.80	70.32
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	3,899	2.14	-0.76	0.851	-9.06	6.91
Driver injury	484	21.37	12.81	0.249	-10.05	30.92
Driver ser. inj.	44	-28.81	-63.71	0.353	-362.97	42.11

4.3.1 Head on crashes

A head on crash was defined as a multiple vehicle crash in which two vehicles travelling in opposite directions collided such that the front of one vehicle struck the front of the other. Table 5 shows that, when vehicle types were aggregated, ESC was not associated with a significant change in the risk of head on crashes. This was true for each severity level considered.

However, when 4WDs were considered separately, the estimated reduction in head on crashes was a significant 41.9% (95% CI: 24.7% to 55.2%) for crashes of all severities and 47.3% (95% CI: 10.4% to 68.7%) for driver injury crashes.

For commercial vehicles, ESC was associated with a significant 70.4% reduction in the risk of head on crashes of all severities. However, ESC fitment was not associated with a change in head on crashes resulting in driver injury. This could be because there were only a small number of head on crashes in which a driver of a commercial vehicle fitted with ESC was injured.

Table 5: *Summary of the estimated percentage reduction in HEAD ON CRASH occurrence attributable to ESC*

	# vehicles with ESC	% Crash reduction Unadjusted	Adjusted	Stat. sig.	95% CL Lower	Upper
All vehicles						
All severities	10,073	8.80	4.74	0.406	-6.81	15.04
Driver injury	1,926	1.29	3.44	0.737	-18.47	21.30
Driver ser. inj.	101	8.78	19.22	0.476	-45.34	55.09
Cars only						
All severities	8,053	3.65	-12.89	0.066	-28.47	0.82
Driver injury	1,648	-0.45	-9.59	0.423	-37.12	12.40
Driver ser. inj.	86	26.54	25.60	0.379	-43.72	61.48
Commercials only						
All severities	156	72.98	70.41	0.039	5.92	90.69
Driver injury	20	19.71	8.03	0.913	-313.92	79.56
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	1,864	40.75	41.91	<.0001	24.74	55.17
Driver injury	258	47.28	47.03	0.018	10.35	68.70
Driver ser. inj.	15	-10.48	-15.48	0.837	-353.76	70.61

4.3.2 Side impact crashes

Side impact crashes refer to multiple vehicle crashes in which the side of one of the vehicles was struck by the front of another. For several of the jurisdictions contributing data to the study it was not possible to determine each vehicle's role in the crash. Consequently, when analysing the effect of ESC on side impact crashes, no distinction is made between the struck (side impacted) and the bullet (front impacted) vehicle. This may have limited the effect size of any reduction in side impact crashes associated with ESC and could explain why none of the estimates of effectiveness for side impact crashes were significant. Analysis results, presented in Table B1 of Appendix B, suggest that there is little evidence that ESC reduces the risk of side impact crashes.

4.4 CRASHES ON WET OR ICY ROADS

Data were also classified according to the road surface of the crash. There were very few crashes occurring on icy roads, so the wet and icy categories were combined into the one road surface category. When the effect of ESC on the risk of a crash on wet or icy roads was evaluated, it was found that, with the exception of results for 4WDs, none of the estimated reductions were significant. For crashes of all severities, ESC fitted 4WDs were 14.6% less likely be involved crashes occurring on wet roads ($p<.01$), while the reduction in driver injury crashes on wet or icy roads was 41.1% ($p<.005$). Table B2 of Appendix B shows detailed results for crashes on wet or icy roads.

4.5 CRASHES ON DRY ROADS

More than two thirds of the vehicles analysed were vehicles involved in crashes that occurred on dry roads. It is not surprising then that when the effectiveness of ESC in preventing crashes occurring on dry roads was estimated, the results were very similar to the overall effectiveness results presented in Table 1. Specific results for crashes occurring on dry roads are only presented in Table B3 of Appendix B.

4.6 TESTING FOR CONFOUNDING VARIABLES RELATED TO DRIVER CHARACTERISTICS

One of the limitations of the evaluation by Scully and Newstead (2008) was that it did not attempt to adjust for the possible confounding effect of driver characteristics. In this section, estimates of effectiveness are derived after ESC fitted vehicles are matched with non-fitted vehicles based on driver age and sex as well as the vehicle characteristics that were controlled for previously. Drivers of the crashed vehicles were categorised according to their sex and whether they were aged 16-25 years or 26 years or older.

The estimates of effectiveness derived using driver characteristics as well as vehicle characteristics are shown in Table 8 and can be compared with the estimates derived using vehicle characteristics only (Sections 4.1 to 4.3). Figures 1 to 3 graphically compare the two sets of estimates for all types of crashes, single vehicle crashes and multiple vehicle crashes respectively. It can be seen that the estimates of effectiveness derived when vehicle characteristics and driver characteristics were used to match ESC fitted vehicles and non-fitted vehicles are all very similar, within the bounds of statistical confidence, to those for when vehicle characteristics only were used in the matching process. This confirms that the results presented in the preceding sections do not need to be adjusted to account for driver demographic differences between ESC fitted vehicles and non-fitted vehicles.

Table 6: *Comparison of ESC crash reduction estimates derived when ESC fitted vehicles are matched to similar non-fitted vehicles based on vehicle characteristics only (market group and year of manufacture) compared to vehicle characteristics and driver characteristics (driver age and sex)*

	Characteristics used to match vehicles							
	Vehicle characteristics only				Vehicle and driver characteristics			
	% Red.	Stat. sig.	95% CL Lower	95% CL Upper	% Red.	Stat. sig.	95% CL Lower	95% CL Upper
All crashes								
All severities	-1.28	0.441	-4.61	1.94	1.44	0.410	-2.02	4.78
Driver injury	8.17	0.028	0.90	14.90	8.24	0.031	0.81	15.12
Driver ser. inj.	5.34	0.732	-29.68	30.91	0.98	0.954	-38.06	28.98
Single vehicle crashes								
All severities	27.33	<.0001	22.93	31.48	26.74	<.0001	22.07	31.13
Driver injury	31.57	<.0001	23.01	39.17	33.93	<.0001	25.19	41.66
Driver ser. inj.	17.40	0.307	-19.22	42.78	19.68	0.301	-21.70	46.98
Multiple vehicle crashes								
All severities	-7.86	<.0001	-11.54	-4.32	-4.68	0.012	-8.49	-0.99
Driver injury	-1.06	0.799	-9.60	6.82	-1.37	0.746	-10.11	6.67
Driver ser. inj.	-4.68	0.789	-46.32	25.11	-15.35	0.432	-64.76	19.23

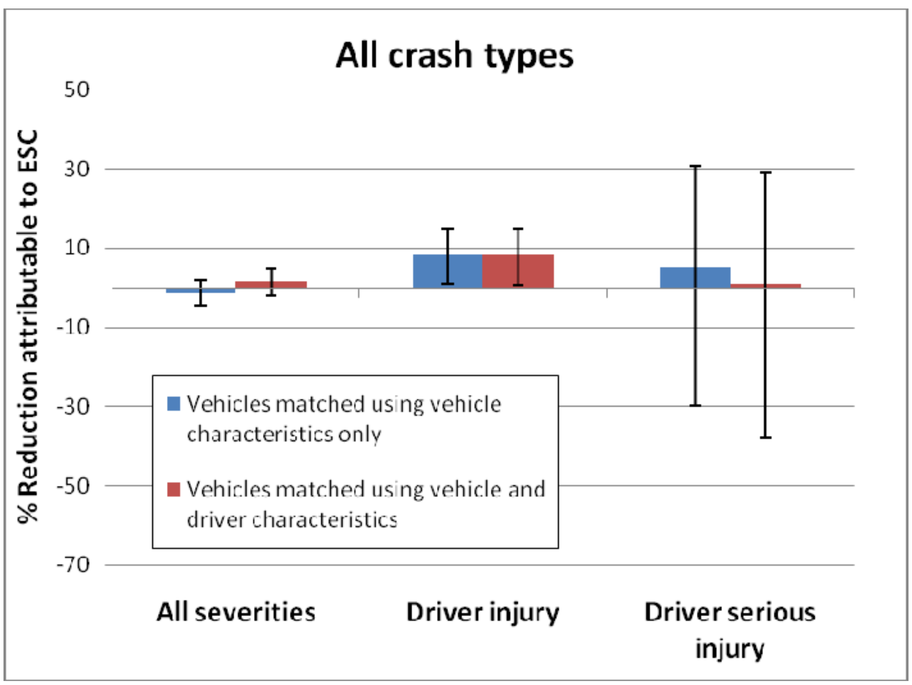

Figure 1: *Comparison of estimates of crash reductions attributable to ESC when only vehicle characteristics are used to match ESC fitted and non-fitted vehicles compared to when driver characteristics are also used in the matching process (all crash types)*

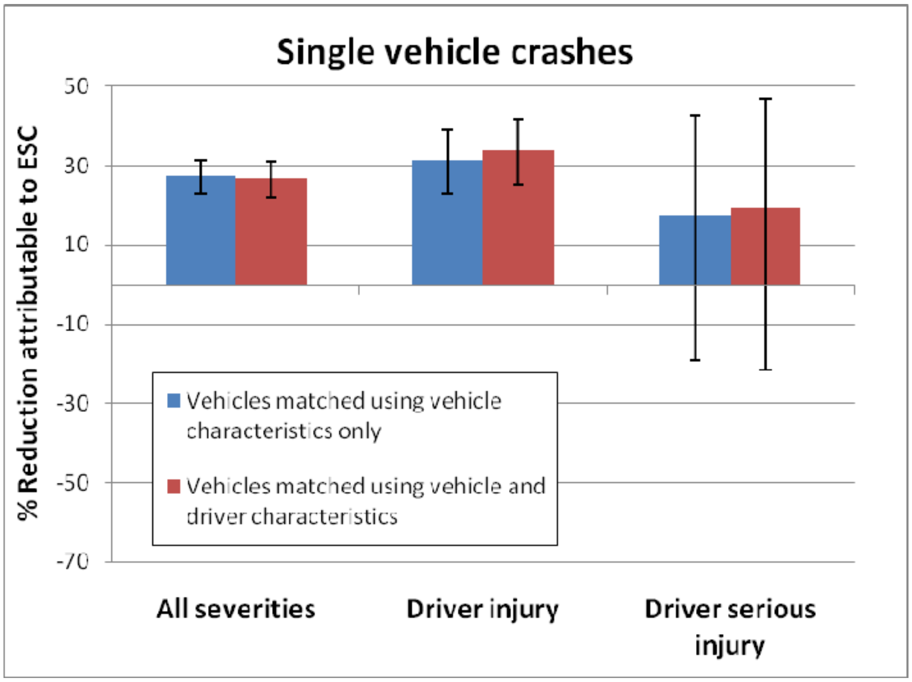

Figure 2: *Comparison of estimates of SINGLE VEHICLE crash reductions attributable to ESC when only vehicle characteristics are used to match ESC fitted and non-fitted vehicles compared to when driver characteristics are also used in the matching process*

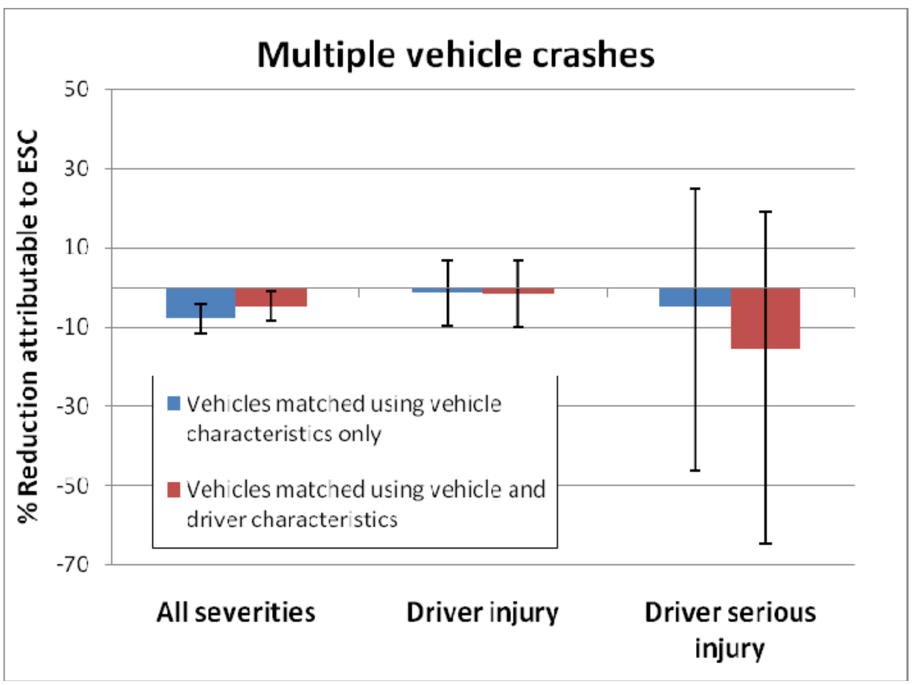

Figure 3: *Comparison of estimates of MULTIPLE VEHICLE crash reductions attributable to ESC when only vehicle characteristics are used to match ESC fitted and non-fitted vehicles compared to when driver characteristics are also used in the matching process*

4.7 TESTING FOR CONFOUNDING VARIABLES RELATED TO SECONDARY SAFETY

Table 7 shows the parameter coefficients, their standard errors and Wald statistics for the three variables added to the injury risk and injury severity covariate models developed by Newstead, Watson et al. (2009). These coefficients were used to determine the effect that differences in the secondary safety of ESC fitted vehicles and non-fitted vehicles had on estimates of the effectiveness of ESC in preventing crashes (Sections 4.1 to 4.7). Details for the parameters that Newstead, Watson and colleagues (2009) originally included in each covariate model and the variables related to market group and year of manufacture have not been included in this paper for reasons of brevity.

Table 7: *Parameters added to the injury risk and injury severity covariate models originally developed by Newstead, Watson et al. (2009) which were used to isolate the effect of ESC on secondary safety*

Parameter name	Categories	Est.	Std. Err.	Wald Chi sq.	Sig.	Exp(Est)
Injury risk model						
Rearend	Yes (1*), No (0)	0.1464	0.011	161.8	<.0001	1.16
ESC	Not-fitted (2*) Fitted (1)	-0.1642	0.031	27.7	<.0001	0.85
Rearend*ESC	Rear end and not-fitted	0.0502	0.043	1.4	0.2447	1.05
Injury severity model						
Rearend	Rear end (1)	-1.0213	0.035	847.4	<.0001	0.36
ESC	Not-fitted (2)	-0.0273	0.078	0.1	0.728	0.97
Rearend*ESC	Rear end and not-fitted	-0.1374	0.146	0.9	0.348	0.87

* Reference category

All data were analysed using the logistic regression procedure of the SAS statistical package, the coefficients of both models and their associated standard errors, were obtained by maximum likelihood estimation. The parameters presented in Table 9 were derived using a subset of the same data used in sections 4.1 to 4.7. However it was necessary to exclude cases that had missing values in one or more of the variables included in the original covariate models. Of the 332,533 cases used to evaluate the effectiveness of ESC in preventing crashes of all severities, 266,796 were included in the injury risk model, while of the 69,896 cases used to estimate the effectiveness of ESC in preventing driver injury crashes, 44,707 were included in the injury severity model.

If X is assumed to indicate whether the crash was a rear impact, and F indicates ESC status, the parameter coefficients of Table 9 can be substituted into equation 2 from the Method section to give the odds ratio for (serious) injury for drivers of ESC fitted vehicles compared to non-fitted vehicles for rear end crashes in addition to the analogous odds ratios for all other crashes.

The confidence of each odds ratio was obtained by substituting the model parameters into Equations 3 and 4 along with the following covariance terms (which was obtained from the SAS output for each model): $Cov(ESC, Rearend * ESC) = -0.00078$ for the injury risk model; and $Cov(ESC, Rearend * ESC) = -0.00469$ for the injury severity model.

Equation 5 was then used to obtain the percent reduction in crashes associated with the secondary safety benefits of ESC. These reductions and their confidence intervals are shown in Table 8.

Table 8: *Estimating the odds ratio and percent reduction in crashes attributable to the secondary safety of vehicles fitted with ESC compared to non-fitted vehicles for rear end crashes only as well as all other crashes*

	Logit difference		Odds Ratio	% Red.	95% CL	
	Estimate	Std. Err.			Lower	Upper
Injury risk						
Rear impact	-0.114	0.036	0.89	10.77	4.32	16.80
Other crashes	-0.164	0.031	0.85	15.14	9.79	20.18
Injury severity						
Rear impact	-0.164	0.135	0.85	15.19	-10.51	34.91
Other crashes	-0.027	0.079	0.97	2.69	-13.51	16.59
Crashworthiness						
Rear impact			0.78	22.05	-0.74	39.63
Other crashes			0.85	15.04	2.88	25.63

The method section describes how the odds ratio and reduction with respect to the *crashworthiness* of ESC fitted vehicles compared with non-fitted vehicles were estimated.

The fact that the injury risk, injury severity and crashworthiness odds ratios presented in Table 10 were all less than one indicates that even after matching ESC fitted vehicles and non-fitted vehicles using market group and year of manufacture variables, the ESC fitted vehicles offered better secondary safety than the non-fitted vehicles.

From equation 10 in the method section, if it is assumed that the odds ratio point estimates of Table 10 are accurate, the ratio *OR(R)* to *OR(A)* for the risk that a crash results in a driver injury is 1.05 (i.e. 0.89/0.85). Similarly the ratio for the risk that an injured driver was seriously injured or killed was equal to 0.87 (i.e. 0.85/0.97) and the odds that a crash-involved driver was seriously injured or killed was equal to 0.92 (0.78/0.85).

This means that when the effect of differences in the secondary safety of ESC fitted vehicles and non-fitted vehicles are adjusted for, the odds ratio of a serious injury crash not being a rear end impact for ESC fitted vehicles compared to non-fitted vehicles is actually less than that for when no compensation was made for the effect of secondary safety. Therefore, when the effect of differences in secondary safety between ESC fitted vehicles and non-fitted vehicles are removed, the percent reduction in serious injury crashes is actually greater than the estimates provided in Sections 4.1 to 4.7. However, the influence of secondary safety on the estimates presented in Sections 4.1 to 4.7 is relatively small: with the estimates of effectiveness in reducing the risk of serious injury crashes only likely to increase between four to eight percent.

By contrast, when the influence of differences in secondary safety are adjusted for, the odds ratio of a driver injury crash being a rear end impact for ESC fitted vehicles compared to non-fitted vehicles is greater than that for when no adjustment was made to remove the effect of secondary safety. However the estimates presented in Sections 4.1 to 4.7 are likely to only over-estimate of effectiveness of ESC in reducing driver injury crashes by between one and five percent.

A further important point to note is that the significance of the difference in the crashworthiness injury risk and severity for rear end crashes compared to all other crash types between ESC and non ESC equipped vehicles can be tested from the ESC*Rearend parameters in Table 7. Neither of these interactions are statistically significant validating the conclusions made from the odds ratios and their confidence limits shown in Table 8.

5 DISCUSSION

This paper is a follow up to an earlier evaluation of ESC conducted in 2008 (Scully and Newstead 2008). One aim of this study was to determine the accuracy of the outcomes of the earlier evaluation. With an additional three years crash data to that available for the previous study it was possible to employ a more rigorous methodology that considered confounders not previously controlled for while also enabling effectiveness to be estimated with a greater degree of accuracy.

Furthermore, as the analysis sample now contained market groups previously excluded from the evaluation (light vehicles and commercial vehicles), the estimates of effectiveness presented are more representative of ESC effectiveness for all vehicles, not just a limited range of market groups. Understanding how ESC presence in market groups with low fitment rates will affect their safety is important, as it will help quantify the advantages of accelerating fitment rates in these market groups.

The crash reduction estimates presented in the results section of this report were generally similar to those in the previous study, confirming the validity of the previous evaluation. Furthermore, the estimates of effectiveness presented here have much narrower 95% confidence limits than those previously obtained indicating higher statistical analysis power.

Another aim of the present study was to learn how the level of effectiveness of ESC differs for different types of crashes and different driving situations. The following sections highlight and discuss key results.

5.1 OVERALL EFFECTIVENESS

Scully and Newstead (2008) found that ESC was associated with a significant 7.1% increase in crashes of all severities, but a (non-significant) 9.8% reduction in crashes resulting in injury. One explanation for this result was that ESC fitted vehicles were probably more expensive models than the non-fitted models to which they were matched. This would mean that property damage only crashes involving ESC fitted vehicles would be more likely to be reported to police than property damage only crashes involving vehicles without ESC as damage to more expensive models would be more likely to exceed the minimum requirement for reporting in some jurisdictions (typically in the order of A$2,500 and above).

The results of this study show that the effect of ESC on the risk of crashes of all severities had reduced to a non-significant 1.3% increase, while the reduction in risk for driver injury crashes had remained comparatively unchanged (8.2%, $p<.05$). A greater range of vehicles are now fitted with ESC, including many lower-priced models. This means that the differential in value between the ESC fitted group and the non-fitted group is much reduced. Therefore, the reporting bias associated with ESC would also be much reduced. Lack of effect of ESC on crashes of all severities compared significant reductions for crashes involving injury may also suggest that ESC is not so effective in preventing crash occurrence all together but it is certainly effective at reducing crash severity which is a major positive benefit.

5.2 SINGLE VEHICLE CRASHES

It was found here that the effect of ESC on the risk of single vehicle crashes was similar to that previously estimated by Scully and Newstead (2008): a significant 27.6% reduction for crashes of all severities and significant 32.3% reduction for single vehicle crashes involving driver injury. The additional data available here compared to the previous study also allowed estimation of the effect of ESC on the risk of more-specifically defined crash types. In particular, ESC was associated with a significant 55.6% reduction in rollover crashes of all severities and a significant 59.6% reduction in rollover crashes resulting in driver injury. The effectiveness of ESC in preventing rollover crashes was even greater for 4WDs, reducing the risk of rollover crashes of all severities by 81.6% and rollover crashes resulting in driver injury by 79.8%. 4WDs when compared to regular cars have a higher centre of gravity which puts them at identified increased risk of a rollover event meaning that ESC has a greater potential for effect in 4WD vehicles.

5.3 MULTIPLE VEHICLE CRASHES

Like the previous evaluation, here ESC was estimated to be associated with a significant increase in multiple vehicle crashes when considering crashes of all severities. However the estimated effect in the present study was a 7.9% increase, compared to the previous study’s 14.8% increase. When considering driver injury crashes, there was neither a significant increase nor a significant decrease in multiple vehicle crashes. These results might be a reflection of ESC providing the ability to avoid a single vehicle crash but with some of these avoided single vehicle crashes becoming minor injury multi vehicle crashes instead. This potential needs investigating further on crash data allowing more in-depth analysis than was available here.

Whilst multiple vehicle crash benefits were no found for all vehicle types combined, there were significant benefits on this crash type for 4WD vehicles and commercial vehicles. ESC was found to be effective at reducing the risk head on crashes (a type of multiple vehicle impact) for 4WDs by 41.9% (95% CI: 24.7% to 55.2%) and for commercial vehicles by 70.4% (95% CI: 5.9% to 90.7%), but not for cars. Analysis also showed ESC in 4WDs significantly reduced the risk of head on crashes by 47.3% (95% CI: 24.7% to 55.2%) for driver injury crashes.

5.4 CRASHES ON WET OR ICY RAODS

Estimates of effectiveness were also investigated for crashes occurring on wet or icy roads. The estimates of effectiveness for reducing the risk of crashes occurring on wet roads were not significantly different for crashes occurring on dry roads, indicating that there is no evidence that ESC is more effective at preventing crashes on wet roads than on dry roads.

5.5 SERIOUS INJURY CRASHES

The additional data available for this study also enabled effectiveness to be estimated in terms of reductions in crashes with serious outcomes. The previous evaluation by Scully and Newstead (2008) were only able estimate the effectiveness of ESC in terms of reductions in crashes of all severities and reductions in crashes in which a driver was injured. Analysis results from this study show that for most crash types, ESC’s effectiveness in preventing serious injury crashes were relatively less than that its effectiveness in preventing driver injury crashes or crashes of all severities. For example, for single vehicle crashes, ESC was estimated to significantly reduce driver injury crashes by 31.6%, varying from 23% to 39% with 95% certainty. However for single vehicle crashes resulting in serious injury, the estimated 17.4% reduction was not significant (p=.307) and varied from a 19.2% increase to a 43.8% reduction with 95% certainty. The overlapping confidence intervals indicate that the two estimates were not significantly different. It should be noted that these differences were not significant due to the still limited quantities of serious injury data available for analysis.

Despite the lack of significance, these results suggest that ESC may be less effective in preventing single vehicles crashes that result in serious injury outcomes, conflicting with results from other jurisdictions. For example Dang (2007) found that the estimates of effectiveness for fatal run off road crashes were similar to those for police-reported run-off road crashes while Farmer (2006) found that ESC reduced fatal single vehicle crashes by 56% compared with a 41% reduction in single vehicle crashes of all severities. It is possible that serious single vehicle crashes in Australasia are different in some way to the crashes occurring in Europe or the USA. One possibility is that in Australasia, driver impairment may be a contributing factor in a greater proportion of serious single vehicle crashes when compared with serious single vehicle crashes in other jurisdictions. ESC can only be effective if drivers are aware that the path of their vehicle requires correction and that they have the capability of correcting their vehicle's path. If the driver is impaired in either being able to identify the need to correct the vehicle's path or being able to exert appropriate control over the vehicle's direction, ESC will provide no benefit.

One type of impairment that can affect a driver's ability to respond appropriately to a situation that could result in a single vehicle crash arises is fatigue. Fatigue is a gradual and cumulative process that results in tasks being performed with less effort and less efficiency (Meijman 1997). Another type of impairment that will affect a driver's ability to avoid a single vehicle crash is sleepiness, which refers to difficulty in staying awake and occurs because of sleep deprivation. It is difficult to estimate what proportion of serious crashes are caused by sleepiness or fatigue because it is difficult to determine the role that either played after a crash has occurred (Horne and Reyner 1999). Therefore making comparisons between jurisdictions of the proportion of serious single vehicle crashes in which fatigue or sleepiness are contributing factors is not recommended.

However, it is known that fatigue and sleepiness are more likely to be contributing factors when drivers have been driving for long periods and when exposed to a monotonous driving environment (Thiffault and Bergeron 2003). These risk factors are characteristic of long distance trips in Australia in particular. However more research is required to quantify differences between jurisdictions in terms of what proportion of motor vehicle travel is undertaken in environments and circumstances where there is a heightened risk of fatigue. Current travel surveys such as the Victorian Integrated Survey of Travel and Activity, the US's National Household Travel Survey and Great Britain's National Travel Survey do not classify roads in a manner that would allow such comparisons.

A review by Diamantopoulou, Hoareau et al. (2003) also stated that fatigue is more likely to be a contributing factor in crashes resulting in fatalities or serious injury than less serious crashes. This would also explain why, in the present study, ESC was found to be less effective at preventing crashes resulting in serious injury than less serious crashes.

These results point to a need to better understand the causal factors behind serious single vehicle crashes in Australasia. It also points to the potential for newly emerging lane departure and fatigue monitoring technologies in Australasian vehicles to assist in combating the single vehicle crash problem.

6 LIMITATIONS AND STRENGTHS OF THE STUDY

A limitation of the previous evaluation of ESC of Australasia (Scully and Newstead 2008) was that it did not adjust for possible confounding factors on the estimates of the effectiveness of ESC in reducing crash risk. In Section 4.8 the influence of differences in the sex and age of drivers of ESC-fitted vehicles and non-fitted vehicles were examined and it was shown that the estimates of effectiveness presented in the results section do not need to be adjusted to account for the confounding effect of differences in driver demographics.

The accuracy of the estimates of effectiveness presented in this report rely on groups of ESC fitted being as similar as possible to the groups of non-fitted vehicles to which they are matched. Ideally each matched group would only differ with respect to ESC fitment. The methodology employed did seek to make each matched group as similar as possible while keeping the analysis sample size large enough to provide meaningful estimates of effectiveness. These efforts included only considering vehicles manufactured in the last ten years and matching fitted and non-fitted groups using year of manufacture and market group. However the comparison of the secondary safety of ESC fitted vehicles and non-fitted vehicles showed that the matched groups of vehicles defined for the present study do differ in more ways than just ESC fitment. However it was also demonstrated that the biasing effect of these differences was negligible. Using induced exposure to estimate the primary safety benefits of ESC controlled for biases resulting from an imperfect matching strategy so that the estimates of effect reported in Sections 4.1 to 4.7 accurately reflect the primary safety benefits of ESC.

An area that has not been explored in the present study is whether the effectiveness of ESC is likely to be mitigated by a risk compensation effect, which has been demonstrated for other technologies such as anti-lock braking systems (Sagberg, Fosser et al. 1997). The increased risk of multiple vehicle crashes of all severities suggests that ESC may have some effect on driver behaviour, but, as previously explained, this could also be caused by ESC fitted vehicles being more expensive than non-fitted vehicles. The latter theory is also supported by the fact that there is no evidence of increased risk of multiple vehicle impacts resulting in injury. Nevertheless, the fact that the public are becoming more knowledgeable about how ESC works means that evidence suggesting risk compensation behaviour should be monitored.

Finally, the study demonstrated that when data from Australasia were used to measure the effectiveness of ESC, estimates of effectiveness for some types of crashes were different to those derived in studies which used data from Europe or the USA. In particular, it was found that ESC was not as effective at preventing serious single vehicle crashes in Australasia as it is overseas, thus demonstrating the importance of evaluating a technology using data from local vehicle fleets. Each vehicle fleet is unique and the introduction of new countermeasures can have unexpected outcomes. However a limitation of the study is that it could only speculate that this unexpected outcome was due to fatigue being a contributing factor in a greater proportion of serious single vehicle crashes in Australasia than in Europe or the USA. This hypothesis remains untested.

7 CONCLUSIONS

This study has been able to provide a further evidence base for the effectiveness of vehicle electronic stability control (ESC) systems in reducing crash risk in Australasia. It was able to employ greater quantities of real world crash data relating to a wider range of vehicles in terms of specific makes and models and market groups. It was also able to investigate the effects of ESC on risks of a range of specific types of crashes including rollover crashes and head-on crashes.

The overall crash reduction estimates of this study were in general similar to those previously estimated. The effect of ESC on all types of crashes leading to driver injury was a significant 8% reduction in risk. ESC was associated with a significant 8% increase in the risk of multiple vehicle crashes, but this effect was not evident when restricted to crashes that resulted in the driver being injured. ESC was particularly effective at preventing single vehicle crashes (by 28% for all severities and 32% for crashes leading to driver injury) and rollover crashes. When fitted to 4WDs, ESC reduced the risk of rollover crashes by 82%. However, unlike studies from other countries, the results of this evaluation suggested that there was a trend that ESC was less effective at preventing serious single vehicle crashes than less serious single vehicle crashes. The reason for this is not clear but it is possible that in Australasia serious single vehicle crashes are not occurring in circumstances where ESC can successfully intervene after driver input, for example when the driver is asleep. Investigating whether the effectiveness of ESC may be mitigated by a risk compensation effect was suggested as a topic for future research.

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APPENDIX A – THE LIST OF VEHICLES FITTED WITH ESC

Table A.1: A list of the market group, make, model, year of manufacture values of the 27,252 vehicles identified as having Electronic Stability Control in the analysis sample used in this report

Market Group	Make and Model	Year of Manufacture	Number of Vehicles
4WD - Compact	MITSUBISHI OUTLANDER	2006-2008	78
	JEEP PATRIOT	2007-2008	9
	JEEP COMPASS	2007	2
	MAZDA CX-7	2006-2008	150
	NISSAN X-TRAIL	2008	1
	HONDA CR-V RE	2007-2008	28
	LANDROVER FREELANDER 2	2007-2008	6
	SUZUKI GRAND VITARA JT	2008	2
	TOYOTA RAV4 30 SERIES	2006-2008	327
4WD - Large	AUDI Q7	2006-2008	19
	BMW X5 E53	2000-2008	671
	JEEP CHEROKEE GRAND WJ/WG	2005	17
	JEEP CHEROKEE GRAND WH	2005-2008	60
	JEEP COMMANDER	2006-2008	31
	MAZDA CX-9	2007-2008	22
	MERCEDES M-CLASS W163	1999-2007	712
	MERCEDES M-CLASS W164	2001-2008	110
	MERCEDES R-CLASS W251	2006-2007	7
	PORSCHE CAYENNE	2003-2008	44
	RANGE ROVER 95 on	2002	4
	RANGE ROVER 02-05	2002-2006	81
	RANGE ROVER III	2005-2008	47
	TOYOTA LANCRUISER >=98	2000-2006	42
	TOYOTA LANDCRUISER 200 SER	2007-2008	41
	VOLKSWAGEN TOUAREG 03-05	2003-2008	106
4WD - Medium	DODGE NITRO	2007-2008	12
	FORD TERRITORY SX	2008	42
	HOLDEN ADVENTRA	2002-2007	173
	HOLDEN CAPTIVA	2006-2008	255
	HUMMER H3	2007	3
	HYUNDAI SANTA FE	2006-2008	72
	HYUNDAI SANTA FE CM	2007-2008	4
	MITSUBISHI PAJERO NM / NP	2006-2007	96
	NISSAN MURANO	2004-2008	168
	HONDA MDX	2003-2006	120
	SUBARU TRIBECA	2006-2008	30
	TOYOTA KLUGER	2007-2008	134
	TOYOTA PRADO 120 SERIES	2003-2008	504
	LEXUS RX330	2002-2006	281

	LEXUS RX350/400h	2006	9
	VOLVO XC90	2002-2007	168
Commercial - Ute	HOLDEN COMMODORE VE UTE	2007-2008	51
	MITSUBISHI OUTLANDER CW	2006-2008	158
Commercial - Van	MERCEDES VITO VAN	2004-2008	195
	MERCEDES SPRINTER W903/904	2007	13
	VOLKSWAGN CRAFTER	2007-2008	5
Large	ALFA 166	2005	1
	AUDI A5/S5	2007-2008	2
	AUDI A8 SERIES 2	2003-2006	8
	BMW 6 SERIES E63	2004-2006	5
	BMW 7 95-01	1999-2001	20
	BMW 7 02 on	2002-2007	85
	CHRYSLER 300C	2005-2008	87
	SSANGYONG CHAIRMAN	1999-2006	3
	FAIRLANE & LTD BA 03 on	2003-2006	184
	HOLDEN COMMODORE VY/VZ	2001-2006	177
	HOLDEN STATESMAN/CAPRICE WK/WL	2001-2006	147
	HOLDEN COMMODORE VE	2000-2008	2201
	HOLDEN STATESMAN/CAPRICE WM	2006-2008	60
	HYUNDAI GRANDEUR TG	2005-2007	19
	JAGUAR XJ8 98-03	1999-2003	5
	JAGUAR XK8	2003	1
	JAGUAR S-TYPE	2002-2007	109
	JAGUAR XJ X350	2003-2004	4
	JAGUAR XK	2006-2007	3
	MERCEDES S-CLASS W129	1999-2001	4
	MERCEDES S-CLASS W220	1999-2005	199
	MERCEDES CL500/600 W215	2000-2005	11
	MERCEDES S-CLASS R230	2002-2007	38
	MERCEDES SLK W171	2004-2006	52
	MERCEDES CLS W219	2005-2008	24
	MERCEDES S-CLASS W221	2004-2008	17
	MERCEDES CL W216	2007	1
	NISSAN MAXIMA J31	2003-2008	507
	HONDA LEGEND KB	2006	1
	PEUGEOT 607	2001-2003	14
	SAAB 9-5 II 06 on	2000-2006	48
	LEXUS LS430	2000-2006	57
	LEXUS ES300 II	2001-2005	121
	LEXUS SC430	2001-2006	29
	LEXUS GS 190 SERIES	2005-2007	45
	TOYOTA AURION	1999-2008	547
	TOYOTA CAMRY 40 SERIES	2008	69
	LEXUS LS460	2007	4
	VOLVO 850/S70/V70/C70	1999-2007	48
	VOLVO S80	2000-2005	71

	VOLVO S80 A	2007	3
	VOLVO V70 / XC70 00-07	2000-2007	66
	VOLVO V70 / XC70	2008	1
Medium	ALFA 156	2003	45
	ALFA 147	2001-2008	297
	ALFA 159 / BRERA	2005-2008	29
	AUDI TT 8J	2007-2008	5
	AUDI A6/S6 95-04	2001-2004	16
	AUDI A6/S6 05 on	2005-2008	22
	AUDI A4	1999-2004	237
	AUDI TT	2000-2007	120
	BMW Z3	1999-2002	63
	BMW Z4	2003-2008	66
	BMW 5 SERIES E60/61	2001-2008	211
	BMW 3 SERIES E90/91/92	1999-2008	448
	BMW 3 99-06	1999-2006	3925
	BMW 5 96-03	1999-2003	553
	CHRYSLER CROSSFIRE	2003-2007	22
	CHRYSLER SEBRING	2007-2008	8
	CITROEN C5	2002-2007	31
	DODGE AVENGER	2007-2008	5
	HYUNDAI ELANTRA XD	2006-2008	209
	HYUNDAI TIBURON	2000-2007	115
	HYUNDAI SONATA NF	2005-2008	115
	JAGUAR X-TYPE	2008	2
	KIA MAGENTIS	2006-2008	26
	MAZDA 6	2008	1
	MAZDA RX8	2003-2008	273
	MERCEDES C-CLASS W202	1999-2000	297
	MERCEDES CLK W208	1999-2005	259
	MERCEDES E-CLASS W210	1999-2006	174
	MERCEDES SLK W170	2000-2004	62
	MERCEDES C-CLASS W203	1999-2007	1315
	MERCEDES CLK C209	1999-2008	300
	MERCEDES E-CLASS W211	2001-2008	379
	MERCEDES C-CLASS W204	1999-2008	41
	NISSAN 350Z	2003-2007	43
	HONDA ACCORD EURO	2003-2008	1608
	HONDA ACCORD EURO 08 on	2008	3
	PEUGEOT 407	2004-2008	83
	PORSCHE BOXSTER	2007	1
	RENAULT GRAND SCENIC	2006-2007	5
	RENAULT LAGUNA 02-08	2005-2006	12
	SAAB 900/ 9-3 94-02	2002	1
	SAAB 9-5 98-05	2004-2005	12
	SAAB 9-3 II 03 on	2001-2008	190
	SUBARU LIBERTY 99-03	2000-2003	162

	SUBARU LIBERTY 03 on	2004-2008	170
	LEXUS IS200	2001-2003	60
	LEXUS IS250 / IS F	1999-2008	172
	VOLVO S60	2000-2007	160
	VOLVO C30	2007-2008	5
	VOLKSWAGEN PASSAT 98-05	2003-2006	87
	VOLKSWAGN PASSAT 3C	2006-2008	85
	VOLKSWAGN EOS	2007-2008	22
	SKODA OCTAVIA	2007-2008	4
Small	AUDI CABRIOLET	2001-2007	47
	AUDI A3 GEN2	2004-2008	79
	AUDI A4 B6	1999-2008	633
	BMW 1 SERIES E87	2003-2008	189
	CITROEN C4	2005-2008	74
	CITROEN XSARA	2003-2004	8
	DODGE CALIBER	2006-2008	10
	FORD FOCUS LS / LT	2006-2008	750
	HOLDEN ASTRA AH	2006-2008	30
	MITSUBISHI LANCER CG/CH	2005-2008	474
	MAZDA 3	2007-2008	705
	MAZDA MX5 02 on	2006-2008	45
	MERCEDES A-CLASS W168	1999-2005	466
	MERCEDES A-CLASS W169	2000-2008	46
	MERCEDES B-CLASS W245	2005-2008	45
	HONDA S2000	2006	1
	HONDA CIVIC GEN 8	2007-2008	34
	PEUGEOT 307	2002-2008	173
	RENAULT MEGANE II	2005-2008	21
	RENAULT MEGANE II CABRIOLET	2007	6
	SUBARU IMPREZA 2001-2007	2004-2007	178
	SUBARU IMPREZA 2008 on	2008	26
	TOYOTA MR2 ZZW30R	2003-2004	22
	VOLVO S40/V50	2004-2008	107
	VOLVO V40/S40	2000-2006	69
Light	MITSUBISHI COLT Z2	2006-2008	130
	PEUGEOT 207	2007	9
	PEUGEOT 206	2003-2006	40
	RENAULT CLIO	2004-2005	19
	SMART CITY-COUPE	2003-2006	30
	SMART ROADSTER	2003-2005	9
	SMART FORFOUR	2004-2006	5
	SUZUKI SWIFT RS415	2008	8

APPENDIX B – OTHER RESULTS

Table B1: Summary of the estimated percentage reduction in SIDE IMPACT CRASH occurrence attributable to ESC

	# vehicles with ESC	% Crash reduction Unadjusted	% Crash reduction Adjusted	Stat. sig.	95% CL Lower	95% CL Upper
All vehicles						
All severities	14,958	3.57	-1.16	0.591	-5.50	3.00
Driver injury	2,616	12.40	2.82	0.583	-7.64	12.27
Driver ser. inj.	180	3.08	-21.19	0.327	-77.96	17.47
Cars only						
All severities	12,053	1.59	-3.56	0.143	-8.53	1.17
Driver injury	2,234	13.32	1.13	0.839	-10.40	11.47
Driver ser. inj.	153	12.52	-13.72	0.537	-71.05	24.39
Commercials only						
All severities	232	2.87	1.15	0.936	-31.14	25.50
Driver injury	25	15.43	15.23	0.719	-108.15	65.48
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	2,673	9.93	8.94	0.069	-0.72	17.67
Driver injury	357	17.85	12.03	0.377	-16.89	33.80
Driver ser. inj.	27	-45.36	-97.64	0.255	-538.59	38.83

Table B2: Summary of the estimated percentage reduction in WET OR ICY ROAD CRASH occurrence attributable to ESC

	# vehicles with ESC	% Crash reduction Unadjusted	% Crash reduction Adjusted	Stat. sig.	95% CL Lower	95% CL Upper
All vehicles						
All severities	13,251	20.50	2.09	0.382	-2.65	6.61
Driver injury	2,317	24.44	7.82	0.174	-3.66	18.02
Driver ser. inj.	140	30.44	15.73	0.431	-29.01	44.96
Cars only						
All severities	10,718	17.80	-0.56	0.834	-5.97	4.57
Driver injury	1,993	22.30	1.07	0.867	-12.22	12.80
Driver ser. inj.	124	32.39	17.87	0.392	-28.88	47.67
Commercials only						
All severities	208	2.42	-2.79	0.867	-41.82	25.50
Driver injury	24	27.15	26.98	0.520	-90.37	72.00
Driver ser. inj.	***	***	***	***	***	***
4WDs only						
All severities	2,325	28.24	14.56	0.008	3.99	23.98
Driver injury	300	52.41	41.09	0.002	17.46	57.95
Driver ser. inj.	16	40.82	-5.05	0.942	-300.08	72.42

Table B3: Summary of the estimated percentage reduction in DRY ROAD CRASH occurrence attributable to ESC

	# vehicles with ESC	% Crash reduction		Stat. sig.	95% CL	
		Unadjusted	Adjusted		Lower	Upper
All vehicles						
All severities	20,445	-4.88	-3.08	0.086	-6.71	0.43
Driver injury	3,645	9.96	8.26	0.037	0.53	15.39
Driver ser. inj.	335	4.92	1.30	0.936	-36.00	28.37
Cars only						
All severities	16,517	-7.77	-7.61	<0.001	-11.85	-3.51
Driver injury	3,111	8.83	3.24	0.461	-5.59	11.32
Driver ser. inj.	280	10.91	1.13	0.947	-38.71	29.52
Commercials only						
All severities	303	16.76	16.91	0.121	-4.98	34.22
Driver injury	36	31.08	30.26	0.294	-36.67	64.41
Driver ser. inj.						
4WDs only						
All severities	3,625	9.32	12.48	0.001	5.07	19.32
Driver injury	498	40.80	34.05	<0.001	17.31	47.39
Driver ser. inj.	55	19.49	2.76	0.956	-163.87	64.17