DOES ALL-WHEEL-DRIVE (AWD) ON PASSENGER CARS HAVE ANY SAFETY BENEFITS ON ROADS COVERED WITH ICE OR SNOW? ANALYSIS OF REAL-WORLD CRASHES INVOLVING AWD CARS WITH ESC (ELECTRONIC STABILITY CONTROL)

Matteo Rizzi
Anders Kullgren
Folksam Research and Chalmers University of Technology
Sweden

Johan Strandroth
Swedish Transport Administration and Chalmers University of Technology
Sweden

Anders Ydenius
Folksam Research
Sweden

Paper Number 17-0260

ABSTRACT

In 2016, 30% of new cars sold in Sweden were fitted with All-Wheel-Drive (AWD). However, there is limited research on the real-life safety effects of AWD. The objectives of the present study were to: (i) calculate whether AWD reduces the risk of involvement in injury crashes among cars fitted with Electronic Stability Control (ESC); (ii) evaluate if AWD has any influence on impact severity and speed; (iii) investigate the winter tire fitment among AWD cars involved in injury crashes.

Swedish police records for the period 2003-2016 were used (STRADA). Only cars with ESC were included. AWD cars (n=5220) were identified and matched with the 2-Wheel-Drive (2WD) version of the same car models (n=21827) or other similar 2WD cars (n=8799).

Different methods were used for each objective. (i) To calculate the risk of being involved in an injury crash, an induced exposure approach was used, where AWD-sensitive to AWD-non-sensitive crashes and road conditions were matched in relation to cars with AWD and 2WD. (ii) To estimate the impact severity and speed, the paired comparison method for 2-car crashes was used. The relative injury risk for each group of cars was calculated by comparing the injury outcome for that group with the injury outcome for the vehicles they collided with. The relative difference between the impact severity for AWD and 2WD cars was translated into a difference of impact speed using the Power Model. (iii) To investigate the winter tire fitment, the present data were merged with a previous study also based on STRADA. In that study, additional information on winter tires fitment was collected from a sample of drivers using a questionnaire; 290 cases were included in the present study population.

The results for roads covered with ice or snow showed that injury crashes increased by 19-31% with AWD. Similar results were found for head-on and single-vehicle crashes. No significant difference was found between Permanent and Automatic AWD. On icy or snowy roads, AWD cars had a 13-15% higher impact severity than 2WD cars, which corresponded to an 8-10% increase of impact speed for AWD cars. On dry or wet roads, no differences were found between AWD and 2WD. Although based on a limited material, the survey indicated that AWD and 2WD cars had similar distributions of winter tires.

The results suggested that AWD may lead drivers to underestimate the level of available friction on icy or snowy roads and therefore to drive at faster speeds than they would do with a 2WD car. Therefore it is recommended that AWD should not be advertised as a safety feature. The necessity of fitting AWD on a wide range of car models should be carefully reconsidered. AWD technologies should be further developed so that slippery road conditions are not disguised by the increased traction provided by AWD.

INTRODUCTION

Several vehicle technologies have been introduced aimed at reducing the number of car crashes or mitigating impact severity, for example Electronic Stability Control (ESC) and Autonomous Emergency Braking (AEB). Previous research has shown significant safety benefits with ESC (Aga et al, 2003; Farmer 2004), especially on icy or snowy roads (Lie et al, 2006) and SUVs (Dang 2004; Green et al, 2006). As of November 2014, ESC is mandatory on all new cars sold in Europe (EC 2008). Furthermore, it is estimated that ESC-fitted cars accounted for 85% of the total car mileage in Sweden in 2015 (STA 2016).

AEB has been shown to have large safety benefits in real-life conditions. Several studies have reported significant reductions of rear-end injury crashes with AEB (Cicchino 2016; Fildes et al, 2015; Isaksson-Hellman et al, 2015; Rizzi et al, 2014). It is reported that in 2015 approximately 65% of new cars sold in Sweden were fitted with standard low-speed AEB (Folksam 2016a).

All-Wheel-Drive (AWD) has also been considered to have safety benefits in terms of improved vehicle stability, especially on roads covered with ice or snow (Kubota et al, 1995; Williams 2006; Al Khoory Automobiles 2017; Audi 2017). While different nomenclatures are used to refer to AWD in general terms (Four-Wheel-Drive, 4x4) or brand-specific AWD technologies (Quattro, 4Motion, xDrive, etc.), there are basically 3 different types of AWD:

- *Permanent, or full-time AWD*: all wheels are powered at all times.
- *Automatic, or on-demand AWD*: the car is Two-Wheel-Drive (2WD) under normal conditions, AWD is activated automatically when wheel-slipping is detected (or expected as in the proactive automatic AWD).
- *Selectable, or part-time AWD*: AWD is manually activated by the driver by a lever or a button.

While the terms Four-Wheel-Drive or AWD vehicle are sometimes used to refer to SUVs (Broyles et al, 2001; Broyles et al, 2003; Walker et al, 2006), several studies have shown that SUVs pose greater injury risks to pedestrians (Simms et al, 2005), to the occupants of other light passenger vehicles (Gabler et al, 1998; Broyles et al, 2003; Wenzel et al, 2005; Newstead et al, 2006) as well as their propensity to rollover due to their higher center of gravity (Keall et al, 2006). On the other hand, it has been shown that the risk of injury crash involvement with SUVs is similar to other car classes (Wenzel et al, 2005; Keall et al, 2008).

However, to the authors' knowledge there is limited previous research on the real-life safety effects of AWD itself, regardless of car size. A study from the Swedish Road Administration (SRA 2005) showed that AWD cars accounted for 9% of fatal crashes on roads covered with ice or snow during 2000-2004, although the share of AWD among new cars during 1988-2004 was only 4%. However, no further analysis on this issue was performed, thus leaving the question of causality between AWD fitment and increased crash rate on icy or snowy roads still open. In spite of this fact, in 2016 14% of new cars sold in Europe were fitted with some kind of AWD. In Sweden, a 30% figure is reported (ACEA 2017), which stresses the need for new research on the safety effect of AWD on passenger cars.

Another issue often reported by consumer organizations and magazines is that some drivers may believe that an AWD car may not need to be fitted with winter tires during the winter season (Auto Motor Sport 2013; Consumer Reports 2015). However, to the authors' knowledge there is limited research on the choice of winter tires among drivers of AWD cars.

OBJECTIVES

The objectives of the present paper were as follows.

1) Calculate whether AWD reduces the risk of involvement in injury crashes among cars fitted with Electronic Stability Control (ESC), especially on roads covered with ice or snow.
2) Evaluate if AWD has any influence on impact severity and speed, compared to similar 2WD cars with ESC.
3) Investigate the winter tire fitment among AWD cars involved in injury crashes.

MATERIAL AND METHODS

Material

Police records including vehicle data for the period 2003-2016 were acquired from the Swedish national accident database (STRADA). Only cars with ESC were included in the study (with one exception, see later section "*consistency checks*").

Cars with AWD were identified and matched with the 2WD version of the same car models. This control group is later referred to as "*2WD group 1*". Other cars in the same classes, but only available with 2WD, were also included in the analysis as further controls, later referred to as "*2WD group 2*". For the sake of clarity, an example is presented. A common AWD car in the present material was the Volvo V70 II AWD. This car would be compared with:

- 2WD group 1 − Volvo V70 II 2WD
- 2WD group 2 − Saab 9-5 (98-09)

To ensure the comparability of AWD and 2WD cars, high-performance and police versions were excluded (these accounted for 7% of the material). Furthermore, Selectable AWD, which is mostly fitted on large SUVs and pick-up trucks, was also excluded due to the limited number of cases involving the 2WD versions of those cars. A detailed list of all car models included in the analysis is given in Table B in the Appendix. In total, more than 80 car models from 22 different manufacturers were analyzed.

Table 1.
Number of injury crashes used in the analysis

	AWD	2WD group 1	2WD group 2
all injury crashes	5220	21827	8799
2-car injury crashes	2146	8602	3530

Objective 1: calculating the risk of being involved in an injury crash

The present study used an induced exposure approach to compare the risk of being involved in an injury crash with and without AWD. This method is suitable when the true exposure is unavailable (Evans 1998; Lie et al, 2006; Strandroth et al, 2012) and is based on identifying at least one crash type or condition in which AWD can be reasonably assumed (or known) to be ineffective. Then, the relation between cars with and without AWD in a non-affected situation would be considered as the true exposure relation. The effect of AWD is considered to be zero if R in Equation 1 is equal to 1.

$$R = \frac{A_{AWD}}{N_{AWD}} \div \frac{A_{no-AWD}}{N_{no-AWD}} \qquad \text{(Equation 1)}$$

A_{AWD} = number of crashes *sensitive* to AWD, involving cars *with* AWD

A_{no-AWD} = number of crashes *sensitive* to AWD, involving cars *without* AWD

N_{AWD} = number of crashes *non-sensitive* to AWD, involving cars *with* AWD

N_{no-AWD} = number of crashes *non-sensitive* to AWD, involving cars *without* AWD

The effectiveness in reducing crashes in relation to non-sensitive crashes was calculated as follows:

$$E = 100 \times (1 - R)\% \qquad \text{(Equation 2)}$$

The standard deviation of the effectiveness was calculated on the basis of a log odds ratio variance, see below (Evans 1998).

$$Sd\,(\ln R) = \sqrt{\frac{1}{A_{AWD}} + \frac{1}{A_{no-AWD}} + \frac{1}{N_{AWD}} + \frac{1}{N_{no-AWD}}} \qquad \text{(Eq. 3)}$$

The 95% confidence limits are given below.

$$R_{LOWER} = R \times \exp(1{,}96 \times Sd) \qquad \text{(Equation 4)}$$

$$R_{UPPER} = \frac{R}{\exp(1{,}96 \times Sd)} \qquad \text{(Equation 5)}$$

In the present study, these calculations were performed on specific crash types as well as on all injury crashes (i.e. a crash leading to at least one injured road user, not necessarily the occupants of the studied cars). Similarly to previous studies on ESC (Lie et al, 2006), rear-end crashes were considered to be non-sensitive to AWD. Different road conditions were analysed, as the largest difference between AWD and 2WD was expected on roads covered with ice or snow.

Consistency checks

In order to verify the strength of the present material, the effectiveness of ESC in reducing injury crashes was calculated using one specific car model (Volvo V70/XC70/S80 00-06). This was done using the same induced exposure method explained above, for the AWD as well as 2WD versions of that particular car, see Table 2. The results were then compared with a previous study also based on STRADA (Lie et al, 2006).

Table 2.
Number of injury crashes involving the Volvo V70/XC70/S80 00-06

	AWD	2WD
ESC	403	2254
no ESC	865	5272

Objective 2: estimating the impact severity and impact speed

The calculation method is described in detail by Hägg et al (1992; 2001). A brief description is outlined below.

The impact severity was calculated using the paired comparison method for 2-car crashes. By studying 2-car crashes in which both cars have been involved in the same impact, the paired comparison method can control for variation in impact severity apart from the influence of car mass. The relative injury risk for a specific group of vehicles is calculated by comparing the injury outcome for that group with the injury outcome for the vehicles they collided with. In 2-car crashes, mass differences can influence the relative injury risk, because they alter the impact severity distribution between the groups. This can be taken into account in the model and the influence of mass on the relative injury risk can be controlled for.

Using the paired comparison method, crash outcomes in 2-car crashes are grouped as follows (see Table 3), where:

- *x1* is the number of crashes with injuries in both cars
- *x*2 is the number of crashes with injuries in the case car only
- *x*3 is the number of crashes with injuries in the other vehicle only
- *x4* when no one is injured in the crash (often little or no data are available here)

In calculating relative risk, *x4* is not used because it does not add any important extra information. The collision partners are considered to be a sample of the whole car population and therefore provide the exposure basis to allow comparisons across all case vehicles.

Table 3.
Grouping of crashes into *x*1, *x*2, and *x*3 sums

		Other vehicle	
		Injured	Not injured
Case vehicle	Injured	*x1*	*x2*
	Not injured	*x3*	*x4 (unknown)*

Some factors, apart from the design, may influence the relative injury risk for a car model. Three factors can be introduced:

s = impact severity factor
m = mass relation factor
a = structural aggressivity factor

The mass of a particular car model will have an influence of its relative injury risk in 2-car crashes. The change of velocity for a car model will be lower than the change of velocity for its collision partner if its mass is higher than its collision partner. It will result in an advantage for the case car and a disadvantage for the collision partner. The disadvantage for the other car can be regarded as aggressivity due to the increased mass of the case car. The aggressivity due to the structure and geometry of the case car may influence the results as well. Here, it is defined as the influence on injury risk for the other vehicle due to the structure and geometry of the case vehicle.

The estimate *x1/(x1+x2)* of the injury risk for the other vehicle (*p2*) was used to calculate the impact severity factor (*s*). The differences in the measured ratio will differ depending on the influence of the three factors *m*, *a* and *s*. As the estimate of the injury risk for the other vehicle should be equal for all car models, the difference between the *average* estimate and the one for *each car group* depends on the three factors. Since the AWD and 2WD cars were very similar (if not the same), the aggressivity factor was assumed to be equal. The mass factor *m* was calculated as shown in Hägg (2001). The impact severity factor *s* was calculated as follows:

$$s = \frac{p_{2\,car}}{p_{2\,average}} \times m \qquad (Equation\ 6)$$

Where *p2 car* is the injury risk for the other vehicle in crashes involving a specific group of car models, and *p2 average* is the injury risk for the other vehicle in all 2-car crashes.

The relative difference between the impact severity factor *s* for AWD and 2WD cars was calculated. Finally, that relative difference was directly translated into a difference of impact speed using the Power Model. This model is thoroughly described in several publications (Nilsson 2004; Elvik 2009; Elvik 2013) and just a brief description is given here. The Power Model describes a mathematical relationship between changes in the mean speed of traffic and changes in the number of crashes or injured road users. The general form of the Power Model is as follows (Elvik 2013):

$$crashes_{\,after} = crashes_{\,before} \times \left(\frac{speed_{\,after}}{speed_{\,before}}\right)^{EXPONENT} \qquad (Equation\ 7)$$

Where the exponent to use depends on whether the number of crashes or injured road users are being calculated, and on their severity. For all injury crashes regardless of traffic environment, the best estimate of the exponent is reported to be 1,5 (Elvik 2009), see Table 4.

Table 4.
The Power Model based on a 1,5 exponent

change in speed	change in injury risk
1 %	1,5 %
2 %	3,0 %
3 %	4,5 %
4 %	6,1 %
5 %	7,6 %
6 %	9,1 %
7 %	10,7 %
8 %	12,2 %
9 %	13,8 %
10 %	15,4 %
11 %	16,9 %
12 %	18,5 %
13 %	20,1 %
14 %	21,7 %
15 %	23,3 %

Objective 3: winter tires fitment
STRADA does not include any information on type of tires. Therefore, data from a previous study based on STRADA were merged with the present AWD fitment data (Strandroth et al, 2015). In that study, police-reported rear-end injury crashes involving passenger cars during 2008-2014 were included. The study was limited to crashes occurring in the winter period in Sweden (October-March). Winter tires are mandatory on roads covered with ice or snow in the period December 1st to March 31st. In Strandroth et al (2015), only 2-car crashes were included (n=4239). Additional information was collected from a sample of drivers using a questionnaire designed as a postcard (A5-size) with four questions. The overall response rate was 17 %, thus providing information on winter tires fitment for 717 2-car injury crashes, 290 of which were included in the present study population.

To ensure confidentiality of the respondents, only information regarding the winter tire fitment was transferred from the survey responses to the crash data sample. Respondents and crashes were matched with an identification key which was later deleted. Ethical approval was given on March 4, 2013.

RESULTS

Objective 1: calculating the risk of being involved in an injury crash
Overall, the induced exposure calculations showed a negative effect of AWD on roads covered with ice or snow (Table 5), and no difference in dry or wet surfaces (Table 6). More specifically, injury crashes were found to increase by 19-31% with AWD on icy or snowy roads. Similar results were found for head-on and single-vehicle crashes. No significant difference was found between Permanent and Automatic AWD on roads covered with ice or snow, with a negative point estimate around 25% for both technologies. The specific results for mid-size and large cars were in line with the overall results, although with lower statistical power.
On dry or wet roads, no differences were found between AWD and 2WD, regardless of crash type, car class or AWD type.

Table 5.
The reduction of injury crashes with AWD on roads covered with ice or snow, for different crash types, car classes and AWD types. Negative values indicate an increase of injury crashes (see Eq. 1-5)

roads covered with ice or snow										
car class	**non-sensitive crashes**	**sensitive crashes**	**AWD type**	**2WD type**	**2WD group 1**			**2WD group 2**		
					E	95% CI		E	95% CI	
all	rear-end struck	all other injury crashes	all	all	-23%	-52%	-1%			
			all	FWD only	-30%	-61%	-5%	-30%	-65%	-2%
all	all rear-end	all other injury crashes	all	all	-19%	-41%	-1%			
			all	FWD only	-21%	-44%	-1%	-31%	-59%	-8%
all	rear-end struck	head-on and single-vehicle	all	all	-15%	-44%	9%			
			all	FWD only	-21%	-53%	5%	-41%	-84%	-8%
all	rear-end struck	all other injury crashes	permanent	FWD only	-24%	-70%	9%	-24%	-73%	11%
			automatic	FWD only	-25%	-64%	4%	-25%	-67%	6%
all	rear-end struck	head-on and single-vehicle	permanent	FWD only	-20%	-70%	15%	-40%	-102%	3%
			automatic	FWD only	-13%	-52%	16%	-31%	-81%	5%
mid-size and large cars	rear-end struck	all other injury crashes	all	all	-22%	-54%	4%			
			all	FWD only	-31%	-69%	-2%	-30%	-70%	1%
mid-size and large cars	rear-end struck	head-on and single-vehicle	all	all	-15%	-49%	12%			
			all	FWD only	-25%	-66%	5%	-47%	-99%	-9%

Table 6.
The reduction of injury crashes with AWD on dry or wet roads, for different crash types, car classes and AWD types. Negative values indicate an increase of injury crashes (see Eq. 1-5)

dry or wet roads										
car class	**non-sensitive crashes**	**sensitive crashes**	**AWD type**	**2WD type**	**2WD group 1**			**2WD group 2**		
					E	95% CI		E	95% CI	
all	rear-end struck	all other injury crashes	all	all	4%	-4%	11%			
			all	FWD only	1%	-8%	9%	2%	-8%	11%
all	all rear-end	all other injury crashes	all	all	0%	-7%	7%			
			all	FWD only	-3%	-11%	5%	5%	-3%	13%
all	rear-end struck	head-on and single-vehicle	all	all	2%	-8%	11%			
			all	FWD only	-1%	-12%	9%	1%	-10%	12%
all	rear-end struck	all other injury crashes	permanent	FWD only	0%	-14%	13%	1%	-14%	14%
			automatic	FWD only	2%	-9%	12%	3%	-9%	13%
all	rear-end struck	head-on and single-vehicle	permanent	FWD only	-2%	-20%	13%	1%	-17%	16%
			automatic	FWD only	0%	-14%	12%	2%	-12%	14%
mid-size and large cars	rear-end struck	all other injury crashes	all	all	3%	-7%	12%			
			all	FWD only	-2%	8%	-13%	2%	-10%	12%
mid-size and large cars	rear-end struck	head-on and single-vehicle	all	all	0%	-12%	11%			
			all	FWD only	-8%	-22%	5%	1%	-13%	13%

Consistency checks

The analysis showed that the effectiveness of ESC in reducing all injury crashes ranged between 17% in dry or wet surfaces to 29% on icy or snowy conditions. The overall reduction of all injury crashes was 20% (see Table 7). These results were well in line with previous research also based on STRADA: Lie et al (2006) reported a 17% (± 9%) reduction of all crashes (excluding rear-end) with ESC.

Table 7.
The effectiveness of ESC in reducing injury crashes involving the Volvo V70/XC70/S80 00-06. Estimates are in relation to all rear-end crashes

	E	**95% CI**	
roads covered with ice or snow	29%	1%	49%
dry or wet roads	17%	6%	26%
all road conditions	20%	11%	28%

Although the statistical power was limited, further analysis of the Volvo V70/XC70/S80 00-06 showed that AWD without ESC increased the number of injury crashes on icy or snowy roads by 11% (see Figure 1), compared to 2WD. Interestingly, it was also found that on ice or snow the R-value (see Eq. 1) for the 2WD version without ESC was very similar to the AWD version with ESC.

On dry or wet roads, no differences between AWD and 2WD were found for this particular car model.

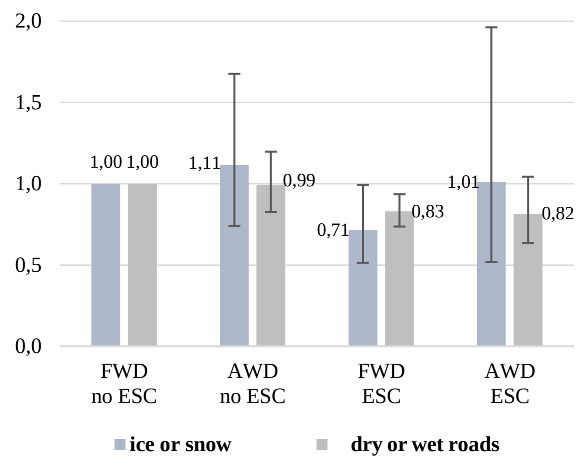

Figure 1. R-values (see Eq. 1) for the 2WD and AWD versions of the Volvo V70/XC70/S80 00-06 with and without ESC (all injury crashes).

Objective 2: estimating the impact severity and impact speed

Overall, the results showed higher impact severity for AWD cars on roads covered with ice or snow: compared to the 2WD group 1, the relative difference ranged between 13% and 15% (see Table 8). This corresponded to an 8-10% higher impact speed for AWD cars on icy or snowy roads. The findings of mid-size and large cars were in line with the overall results.

On dry or wet roads, no differences between AWD and 2WD were found.

Table 8.
Impact severity and difference in impact speed for AWD and 2WD cars for different crash types, car classes and road conditions. Relative differences were calculated in relation to "2WD group 1"

car class	crash types	road condition		n crashes	mean curb weight (kg)		impact severity		difference in impact speed
					case car	other car	factor (s)	rel diff group 1	
all	all	roads covered with ice or snow	AWD	479	1746	1497	1,12	15%	10%
			2WD group 1	1330	1571	1480	0,97	-	-
			2WD group 2	604	1476	1473	0,97	0%	0%
all	all	dry or wet roads	AWD	1571	1760	1486	0,95	1%	1%
			2WD group 1	6870	1570	1475	0,94	-	-
			2WD group 2	2742	1468	1469	0,98	4%	2%
all	all excl. rear-end struck	roads covered with ice or snow	AWD	416	1744	1496	1,17	14%	9%
			2WD group 1	1111	1573	1480	1,03	-	-
			2WD group 2	515	1477	1473	1,04	1%	1%
all	all excl. rear-end struck	dry or wet roads	AWD	1221	1756	1485	1,04	1%	1%
			2WD group 1	5314	1569	1476	1,02	-	-
			2WD group 2	2154	1467	1471	1,07	4%	3%
mid-size and large cars	all	roads covered with ice or snow	AWD	360	1743	1503	1,14	14%	9%
			2WD group 1	983	1629	1475	1,00	-	-
			2WD group 2	441	1493	1477	1,01	-3%	-2%
mid-size and large cars	all	dry or wet roads	AWD	1065	1747	1481	0,94	0%	0%
			2WD group 1	5030	1626	1470	0,94	-	-
			2WD group 2	1981	1483	1467	0,97	4%	2%
mid-size and large cars	all excl. rear-end struck	roads covered with ice or snow	AWD	310	1743	1501	1,19	13%	8%
			2WD group 1	824	1631	1474	1,06	-	-
			2WD group 2	372	1495	1476	1,04	-1%	-1%
mid-size and large cars	all excl. rear-end struck	dry or wet roads	AWD	839	1745	1482	1,03	2%	1%
			2WD group 1	3907	1624	1470	1,01	-	-
			2WD group 2	1562	1482	1470	1,05	4%	3%

Objective 3: winter tires fitment
The survey showed very similar distributions of tire types across the included AWD and 2WD cars. Overall, studded winter tires were the most common (approximately 50%), followed by non-studded winter tires. Only a few cases included all-season tires. Surprisingly, the share of summer tires was 10% for AWD cars and 18% for 2WD cars, respectively.

Table 9.
Distribution of tire types among AWD and 2WD cars with ESC in the survey

	AWD	2WD
studded winter tires	50%	46%
non-studded winter tires	38%	30%
all season tires	0%	2%
summer tires	10%	18%
unknown	2%	3%
Total %	100%	100%
Total n	42	248

DISCUSSION

It is important to evaluate the safety benefits of vehicle technologies in real-life conditions to make prioritization decisions and provide guidelines for consumers. Many safety systems have been proven to be effective, for instance ESC and AEB, while others have been shown to give limited benefits or none at all, for example ABS on passenger cars (HLDI 1994, Kullgren et al, 1994). While several studies have investigated different safety concerns related to SUVs (Broyles et al, 2003; Walker et al, 2006; Simms et al, 2005; Gabler et al, 1998; Wenzel et al, 2005; Newstead et al, 2006; Keall et al, 2008), to date no study has analyzed the real-life safety effects of All-Wheel-Drive (AWD), compared with Two-Wheel-Drive (2WD). While the Swedish Road Administration (2005) has reported an overrepresentation of AWD cars in fatal crashes on roads covered with ice or snow, the causality between AWD fitment and crash rate was not investigated. Using an induced exposure approach, the present study clearly showed that AWD gave a negative effect on roads covered with ice or snow, with a statistically significant increase of injury crashes ranging between 19% and 31%. On dry or wet roads, however, no significant difference was found.

To be able to understand and explain why, further analyses were performed (Objective 2). By using paired comparisons, it was possible to show that AWD cars had 13-15% higher impact severity on roads covered with ice or snow, compared to the same 2WD models. By using the Power Model (Elvik 2013), it was calculated that AWD cars crashed on ice or snow with an 8-10% higher impact speed, compared with similar 2WD cars. Clearly, this would imply higher injury risks for the occupants of the other vehicles as well. On dry or wet roads, however, no differences between AWD and 2WD were found.

A possible explanation for these results is some kind of behavioral adaptation. Since AWD is an optional feature on the cars included in this study, it is well-understood that drivers who chose to purchase these technologies may be different from those who did not (i.e. selective recruitment). For instance, it could be hypothesized that drivers of AWD cars could generally be more aggressive drivers. If this was the case, though, it would be logical to expect at least the same (or even greater) differences in crash rate and impact speed on dry road surfaces. However, this was not case, thus suggesting that AWD may lead drivers to underestimate the level of available friction on icy or snowy roads and therefore to drive at faster speeds than they would do with a 2WD car. Previous research that supports this explanation (Kubota et al, 1995) measured the maximum speed at which 6 drivers were subjectively comfortable driving on a closed test track with different road conditions. It was found that the comfort zone with AWD implied a 10% higher driving speed than with 2WD, and it was concluded that AWD improves driver confidence and a feeling of driving safety. While these were conceivable conclusions, the question is whether that translates in an actual safety improvement? Based on the results of the present study, the answer is negative. Clearly, it should be kept in mind that under normal driving conditions an AWD car cannot decelerate more effectively than a 2WD car.

Theoretically, the present results could be explained by different fitment of winter tires among AWD cars. For example, a larger share of summer tires among AWD cars during the winter season could explain, at least in part, why AWD cars had a larger injury crash involvement on icy/snowy roads and the same on dry/wet roads. On the other hand, it could be less intuitive to explain that the higher impact severity among AWD cars on ice and snow was due to a larger share of summer tires among AWD cars. To clarify this issue, a previous survey was used (Objective 3, see Strandroth et al, 2015), showing almost identical distributions of tire types. Although based on a limited number of cases, at this stage there is no reason to believe that the winter tire fitment confounded the overall results to any large degree.

To further verify the consistency of the present material, additional checks were made by calculating the effectiveness of ESC in reducing injury crashes. Comparison with previous research based on the same source (STRADA) indicated that the results were very similar, thus suggesting that the present material did not include any major miscoding or bias. However, there are some limitations that are important to discuss. First of all, police data were used. While these are known to suffer from a number of quality issues (Farmer 2003), it was assumed that these limitations would affect both the AWD and 2WD groups equally, therefore it was not expected to affect the overall results to any large degree.

Often a critical issue in real-life evaluations of safety technologies is to obtain the exposure. In the present paper, indirect methods were used, i.e. the exposure was derived from the actual crash data. While it may be possible to obtain data based on real exposure, the data may include confounding factors, for instance selective recruitment, as mentioned above, or age, gender and use in different geographical regions. If crash rates are calculated based on real exposure (i.e. number of crashes divided by number of registered vehicle, or vehicle mileage) it is essential to control for possible confounders, as done in for instance Teoh et al (2011). However, adopting an induced exposure approach would normally address this issue, as the result was given by the relative differences within the AWD and 2WD crash populations. Basically, even though a variable is known to affect the overall crash or injury risk (say driver age), the same variable can only confound the induced exposure results by deviating from the overall sensitive/non-sensitive ratio. If this is found to be the case, the case group can be stratified into different subgroups for further analysis. The induced exposure calculations can be adjusted for confounders, as suggested by Schlesselman (1982), for instance by calculating the weighted average of the individual odds ratios. However, it was argued that this procedure was not necessary in the present research; the cases and controls were very similar in terms of age, speed areas etc. (see Table A in the Appendix), and therefore it would not have had any major effect on the overall results.

A limitation is that the questionnaire did not ask participants about the brand of their tires. Consumer tests have shown that, given a certain type of winter tire, there may be great differences between premium and budget brands (Folksam 2016b). Also, certain vehicle types with AWD have large or wide wheel dimensions. AWD cars may also be more sensitive for uneven wear between tires. The cost for new tires on those cars can be high and it may be tempting to choose budget or all season tires with less braking performance on snow and ice. While these aspects could not be investigated with the present material, it is recommended that future research should look deeper into this issue.

While the present findings showed no difference between Permanent and Automatic AWD (see Table 5 and 6), it should be kept in mind that Selectable AWD was not included in the study. This was mainly due to the limited number of cases involving the 2WD versions of SUVs and pick-up trucks with Selectable AWD. A further reason was that it was not possible to known whether those cars were used in 2WD or AWD mode at the time of the crash.

In summary, the present paper analyzed the real-life safety effects of AWD on passenger cars and found consistent evidence suggesting that AWD leads drivers to underestimate the level of available friction on icy or snowy roads, thus increasing their injury crash rate by 19-31%. While these important results imply that AWD shall not be considered as a safety feature, it should be kept in mind that AWD does have benefits in terms of improved traction compared to 2WD cars, for instance on icy up-hills, snowdrifts and, depending on the vehicle, in off-road driving. In some regions of the world these aspects may be very important and therefore should not be regarded as secondary. However, further research is needed to gain a better understanding of the behavioral adaptation mechanisms which may lay behind the present findings and to develop effective countermeasures. Theoretically, it should be possible to further develop AWD technologies so that slippery road conditions are not disguised by the AWD traction. For instance, it is possible that AWD with only low-speed functionalities (i.e. the car is strictly 2WD at higher speeds) could address this issue by giving drivers more direct feedback on the actual friction and still detain the AWD traction at low speeds. It is also possible that already existing Selectable AWD systems without center differential (designed mostly for low-speed driving on surfaces with low friction) could somehow have this functionality when properly used. Unfortunately, these technologies could not be included in the present study and should be further investigated in future research. Another possible countermeasure to help drivers of AWD cars understanding the level of available friction on icy or snowy roads could be a low-friction warning system. While such technologies still need to be developed and implemented, previous research based on driving simulator tests has reported promising results (Kircher et al, 2009). It is recommended that the future development of AWD technologies should focus on finding a proper solution to address the need for traction in certain conditions without sacrificing safety in all others.

CONCLUSIONS AND RECOMMENDATIONS

In the present study, Swedish police records were analyzed and expanded with a limited survey to obtain information regarding the fitment of winter tires. Only ESC-fitted cars were analyzed. The findings were as follows.

- On roads covered with ice or snow, injury crashes increased by 19-31% with AWD. Similar results were found for head-on and single-vehicle crashes. No significant difference was found between Permanent and Automatic AWD.
- On icy or snowy roads, AWD cars had a 13-15% higher impact severity, compared to 2WD cars. Based on the Power Model, this corresponded to an 8-10% higher impact speed for AWD cars.
- On dry or wet roads, no differences were found between AWD and 2WD, regardless of crash type, car class or AWD type.
- Although based on a limited material, the survey indicated that AWD and 2WD cars had similar distributions of winter tires.
- Overall, the results suggested that AWD may lead drivers to underestimate the level of available friction on icy or snowy roads and therefore to drive at faster speeds than they would do with a 2WD car.
- Based on these findings, it is recommended that car manufacturers should not advertise AWD as a safety feature.
- The necessity of fitting AWD on a wide range of car models should be carefully reconsidered. AWD technologies should be further developed so that slippery road conditions are not disguised by the improved traction provided by AWD.
- At the present stage, consumers should be advised to purchase an AWD car only because of particular needs (for instance driving up icy hills)

- and should receive clear information regarding the safety drawback of AWD on roads covered with ice or snow (i.e. higher speeds).
- Insurance companies should consider including drivetrain among the parameters influencing the car insurance premium, at least in those regions where snow or ice are common.

ACKNOKWLEDGMENTS

Many thanks to Prof. Claes Tingvall (ÅF and Chalmers University of Technology) and Maria Ohlin (University of Gothenburg) for their important contribution and support.

REFERENCES

ACEA, European Automobile Manufacturers Association (2017) Statistics on 4x4 penetration. Available at: http://www.acea.be/statistics/article/share-of-new-cars-4x4s Accessed March 23, 2017.

Aga M, Okada A (2003) Analysis of Vehicle Stability Control (VSC)'s effectiveness from accident data. In proceedings of the 18th ESV Conference; Nagoya, Japan; paper number 03-0541.

Al Khoory Automobiles (2017) Symmetrical AWD, effects of the drivetrain on drivability. Webpage: http://www.subaru-uae.com/tec_awd.html Accessed March 23, 2017.

Audi (2017) Quattro All-Wheel-Drive. Webpage: http://www.audi.com.au/au/brand/en/discover_audi/technology_design/quattro_all-wheel_drive.html Accessed March 23, 2017.

Auto Motor Sport (2013) Vad är bäst – vinterdäck eller 4WD? In Swedish. Webpage: http://www.mestmotor.se/automotorsport/artiklar/nyheter/20130202/vad-ar-bast-vinterdack-eller-4wd Accessed March 23, 2017.

Broyles RW, Clarke SR, Narine L, Baker DR (2001) Factors contributing to the amount of vehicular damage resulting from collisions between Four-Wheel-Drive vehicles and passenger cars. Accident Analysis and Prevention 33(5):673-678.

Broyles RW, Narine L, Clarke SR, Baker DR (2003) Factors associated with the likelihood of injury resulting from collisions between Four-Wheel-Drive vehicles and passenger cars. Accident Analysis and Prevention 35(5):677-681.

Cicchino C (2016) Effectiveness of Forward Collision Warning Systems with and without Autonomous Emergency Braking in reducing police-reported crash rates. IIHS, Insurance Institute for Highway Safety, Arlington, VA.

Consumer Reports (2015) Do you really need AWD in the snow? Webpage: http://www.consumerreports.org/cro/magazine/2015/09/do-you-really-need-awd-in-the-snow/index.htm Accessed March 23, 2017.

Dang JN (2004) Preliminary results analyzing the effectiveness of Electronic Stability Control (ESC) systems. Report no. DOT-HS-809-790. U.S. Department of Transportation, Washington, DC.

Elvik R (2009) The Power Model of the relationship between speed and road safety. Update and new estimates. Report 1034. Institute of Transport Economics, Oslo, Norway.

Elvik (2013) A re-parameterization of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims. Accident Analysis and Prevention 50:854-860.

Evans L (1998) Antilock Brake Systems and risk of different types of crashes in traffic. In proceedings of the 16th ESV Conference; Windsor, Ontario, Canada; paper number 98-S2-O-12.

European Commission (2008) Proposal for a regulation of the European Parliament and the Council concerning type-approval requirements for the general safety of motor vehicles. COM (2008) 316 final. European Commission, Brussels, Belgium.

Farmer CM (2003) Reliability of police-reported information for determining crash and injury severity. Traffic Injury Prevention 4(1):38-44.

Farmer CM (2004) Effect of Electronic Stability Control on automobile crash risk. Traffic Injury Prevention 5:317-325.

Fildes B, Keall M, Bos N, Lie A, Page Y, Pastor C, Pennisi L, Rizzi M, Thomas P, Tingvall C (2015) Effectiveness of low-speed Autonomous Emergency Braking in real-world rear-end crashes. Accident Analysis and Prevention 81:24-29.

Folksam (2016a) Fitment rates of Autonomous Emergency Braking (AEB) in Sweden. In proceedings of the 2016 Annual Conference of the

Research Council for Automobile Repairs (RCAR); Seoul, South Korea.

Folksam (2016b) Däckval viktigt för säkerheten även med fyrhjulsdrift. In Swedish. Available at: https://www.folksam.se/media/i-trafiken-dackval-rapport_tcm5-24184.pdf Accessed March 23, 2017.

Gabler HC, Hollowell WT (1998) The aggressivity of light trucks and vans in traffic crashes. 1998 International Congress and Exposition; Detroit, Michigan. SAE Paper 980908.

Green P, Woodrooffe J (2006) The estimated reduction in the odds of loss-of-control type crashes for sport utility vehicles equipped with Electronic Stability Control. Journal of Safety Research 37:493-499.

HLDI, Highway Loss Data Institute (1994) Collision and property damage liability losses of passenger cars with and without Antilock Brakes. Insurance special report; Arlington, VA.

Hägg A, v Koch M, Kullgren A, Lie A, Nygren Å, Tingvall C (1992) Folksam car model safety rating 1991–1992. Folksam Research. Stockholm, Sweden.

Hägg A, Krafft M, Kullgren A, Lie A, Malm S, Tingvall C, Ydenius A (2001) Folksam car model safety rating 2001. Folksam Research. Stockholm, Sweden.

Isaksson-Hellman I, Lindman M (2015) Evaluation of rear-end collision avoidance technologies based on real world crash data. In proceedings of the 3rd International Symposium on Future Active Safety Technology towards zero traffic accidents; Gothenburg, Sweden.

Keall MD, Newstead S, Watson L (2006) Four-Wheel-Drive vehicle crash involvement patterns. Monash University Accident Research Centre, Melbourne.

Keall MD, Newstead S (2008) Are SUVs dangerous vehicles? Accident Analysis and Prevention 40(3):954-963.

Kircher K, Thorslund B (2009) Effects of road surface appearance and low friction warning systems on driver behavior and confidence in the warning system. Ergonomics 52(2):165-176.

Kubota M, Ushijima T, Brown J (1995) Correlation of driver confidence and dynamic measurements and the effect of 4WD. 1995 International Congress and Exposition, Detroit, Michigan. SAE Paper 950972.

Kullgren A, Lie A, Tingvall C (1994) The effectiveness of ABS in real-life accidents. In proceedings of 14th ESV Conference; Munich, Germany.

Lie A, Tingvall C, Krafft M, Kullgren A (2006) The effectiveness of Electronic Stability Control (ESC) in reducing real-life crashes and injuries. Traffic Injury Prevention 7:38-43.

Newstead S, Cameron M, Watson L (2006) Vehicle safety ratings estimated from police reported crash data: 2006 update Australian and New Zealand crashes during 1987–2004. Report 248. Monash University Accident Research Centre, Melbourne.

Nilsson G (2004) Traffic safety dimensions and the Power Model to describe the effect of speed on safety. Bulletin 221. Lund Institute of Technology, Lund, Sweden.

Rizzi M, Kullgren A, Tingvall C (2014) Injury crash reduction of low-speed Autonomous Emergency Braking (AEB) on passenger cars. In proceedings of the 2014 IRCOBI Conference; Berlin, Germany.

Schlesselman J (1982) Case-control studies: design, conduct, analysis. Oxford University Press, NY.

Simms C, O'Neill D (2005) Sports utility vehicles and older pedestrians. British Medical Journal 331:787-788.

Strandroth J, Rizzi M, Olai M, Lie A, Tingvall C (2012) The effects of studded tires on fatal crashes with passenger cars and the benefits of Electronic Stability Control (ESC) in Swedish winter driving. Accident Analysis and Prevention 45:50-60.

Strandroth J, Rizzi M, Ohlin M, Eriksson J, Lie A (2015) Analysis of different types of winter tires in rear-end injury crashes and fatal loss-of-control crashes with ESC. In proceedings of the 24th ESV Conference; Gothenburg, Sweden.

SRA, Swedish Road Administration (2005) Halkolyckor med dödlig utgång. Analys av Vägverkets djupstudiematerial 2000-2004. In Swedish. Publication number 2005:83. Borlänge, Sweden.

STA, Swedish Transport Administration (2016) Analysis of road safety trends 2014. Management by objectives for road safety work towards the 2020 interim targets. Publication number 2015:103. Borlänge, Sweden.

Teoh E (2011) Effectiveness of Antilock Braking Systems in reducing motorcycle fatal crash rates. Traffic Injury Prevention 12(2):169-173.

Walker L, Williams J, Jamrozik K (2006) Unsafe driving behavior and Four-Wheel-Drive vehicles: observational study. British Medical Journal 333(7558), 71.

Wenzel TP, Ross M (2005) The effects of vehicle model and driver behavior on risk. Accident Analysis and Prevention 37(3):479-494.

Williams R (2006) 4WD-AWD market trends in vehicles and technology differences and similarities, from 1997 to 2004 primarily in the US Market, and also some Global Comparisons. SAE Technical Paper 2006-01-0822.

APPENDIX

Table A.
Overview of the material used for analysis

	all injury crashes			**2-car injury crashes**		
	AWD	**2WD group 1**	**2WD group 2**	**AWD**	**2WD group 1**	**2WD group 2**
n	5220	21827	8799	2146	8602	3530
Car class						
Supermini	<1%	<1%	-	<1%	<1%	-
Small car	8%	24%	27%	8%	23%	28%
Mid-size car	24%	22%	49%	24%	22%	48%
Large car	46%	50%	24%	46%	51%	24%
Large MPV	0%	1%	-	0%	1%	-
Small SUV	14%	3%	-	14%	3%	-
Large SUV	8%	<1%	-	8%	<1%	-
Total %	100%	100%	100%	100%	100%	100%
mean MY	2008,0	2007,4	2007,4	2008,3	2007,5	2007,4
mean power/curb weight (kW/kg)	0,073	0,070	0,066	0,073	0,070	0,066
Driver age						
18-24	12%	14%	10%	12%	14%	10%
25-34	17%	20%	19%	18%	21%	19%
35-44	25%	22%	22%	26%	23%	23%
45-54	21%	19%	17%	20%	19%	18%
55-64	14%	13%	15%	14%	13%	15%
65-74	6%	6%	9%	6%	6%	9%
75+	2%	2%	4%	2%	2%	4%
unknown	3%	3%	3%	2%	2%	2%
Total %	100%	100%	100%	100%	100%	100%
Speed area (km/h)						
<50	6%	7%	6%	5%	6%	6%
50-60	32%	35%	36%	38%	41%	41%
70-80	24%	23%	24%	24%	22%	23%
90	10%	9%	10%	9%	8%	8%
100+	11%	9%	8%	9%	8%	7%
unknown	18%	17%	16%	15%	14%	14%
Total %	100%	100%	100%	100%	100%	100%
Crash type						
Head-on	10%	8%	8%	14%	12%	12%
Intersection	23%	22%	23%	43%	41%	43%
Rear-end striking	13%	14%	13%	17%	19%	17%
Rear-end struck	21%	22%	22%	21%	22%	21%
Single-vehicle	12%	13%	12%	0%	0%	0%
Pedestrian/bicycle	14%	15%	16%	0%	0%	0%
Wildlife	2%	2%	2%	0%	0%	0%
Other	5%	5%	5%	5%	6%	6%
Total %	100%	100%	100%	100%	100%	100%

Table B.
Car models used for analysis

Car model	Car class	AWD	2WD group 1		2WD group 2	AWD model	AWD type	Limit for performance version	kW/curb weight
			FWD	RWD	FWD				
Alfa Romeo 156 98-05	small car	1	20			Q4	permanent	156 2,5 V6 24	0,100
Audi A3 97-03	small car	35	747			Quattro	automatic	S3	0,102
Audi A3 03-13	small car	70	393			Quattro	automatic	A3 3,2	0,109
Audi A3 12-	small car	9	38			Quattro	automatic	S3	0,144
Audi A4 01-07	mid-size car	637	496			Quattro	permanent	A4 2,0 TS	0,104
Audi 08-15	mid-size car	260	374			Quattro, Allroad	permanent	A4 3,0 TDI	0,102
Audi A5 07-	mid-size car	40	79			Quattro	permanent	A5 Coupe 3,0 TDI	0,104
Audi A6 98-05	large car	266	161			Quattro, Allroad	permanent	A 6 3,2 FSI	0,106
Audi A6 05-11	large car	212	405			Quattro, Allroad	permanent	A6 3,2 FSI	0,109
Audi A6 11-	large car	61	97			Quattro, Allroad	permanent	A6 2,0 TFSI	0,103
Audi TT 98-02	supermini	4	36			Quattro	automatic	TT 1,8 Q	0,109
Audi TT 06-14	supermini	2	1			Quattro	automatic	TT Coupe 2,0T	0,110
BMW 3 Series 98-05	mid-size car	12		733		xi, xd	permanent	330CI Coupe	0,113
BMW 3 Series 05-12	mid-size car	68		692		xi, xd, xDrive	automatic	330 D	0,107
BMW 3 Series 12-	mid-size car	2		126		xDrive	automatic	330	0,108
BMW 5 Series 04-09	large car	49		598		xi, xd, xDrive	automatic	530 I	0,114
BMW 5 Series 10-	large car	28		213		xDrive	automatic	530 D	0,111
BMW X1 10-15	small SUV	59		17		xDrive	automatic	-	-
Chevrolet Captiva 07-11	large SUV	38	5			AWD	automatic	-	-
Chevrolet Trax 13-	small SUV	2	1			AWD	automatic	-	-
Citroen Berlingo/Peugeot Partner 08-	small car	6	369			4x4	permanent	-	-
Ford Focus II 05-11	mid-size car				969	only FWD	-	Focus ST	0,119
Ford Focus III 11-	mid-size car				169	only FWD*	-	Focus ST	0,121
Ford Kuga 13-	small SUV	2	3			4x4	automatic	-	-
Ford Mondeo 07-14	large car				319	only FWD	-	Mondeo 2,5 T	0,103
Honda CR-V 12-	small SUV	20	2			4WD	automatic	-	-
Hyundai I30 07-11/Kia Ceed 07-11	small car				782	only FWD	-	-	-
Hyundai I30 12-/Kia Ceed 12-	small car				212	only FWD	-	Ceed GT	0,108
Hyundai I40 11-/Kia Optima 12-15	large car				66	only FWD	-	-	-
Hyundai IX35 10-/Kia Sportage 11-15	small SUV	70	113			4WD	automatic	-	-
Mazda 6 13-	mid-size car	1	13			AWD	automatic	-	-
Mazda CX-5 12-	small SUV	16	3			AWD	automatic	-	-
Mercedes B Class 12-	small car	2	83			4Matic	permanent	B 250	0,105
Mercedes C Class 00-06	mid-size car	4		396		4Matic	permanent	C 280	0,104
Mercedes C Class 07-13	mid-size car	1		267		4Matic	permanent	C 350	0,120
Mercedes E Class 96-01	large car	5		383		4Matic	permanent	E 320 V6	0,104
Mercedes E Class 02-09	large car	17		618		4Matic	permanent	E 350	0,106
Mercedes E Class 09-	large car	5		287		4Matic	permanent	E 350	0,124
Mitsubishi Outlander/Citroen C-Crosser/Peugeot 4007 08-	small SUV	95	2			4x4, AWD	selectable w/ auto opt	-	-
Nissan Juke 11-	small SUV	5	51			4x4	selectable w/ auto opt	-	-
Nissan Qashqai 07-13	small SUV	75	220			4x4	selectable w/ auto opt	-	-
Nissan Qashqai 14-	small SUV	1	28			4x4	selectable w/ auto opt	-	-
Nissan X-trail 04-07	small SUV	105	1			4x4	selectable w/ auto opt	-	-
Opel Insignia 09-	large car	18	72			4x4	automatic	Insignia 2,8 V6 T	0,107
Opel Mokka 12-	small car	1	11			AWD	automatic	-	-
Peugeot 307 01-	small car				1144	only FWD	-	-	-
Peugeot 308 07-12	small car				189	only FWD	-	308 GTI	0,100
Peugeot 308 13-	small car				51	only FWD**	-	-	-
Saab 9-3 03-12	mid-size car	6	1112			9-3X	automatic	9-3 Aero	0,100
Saab 9-5 98-09	large car				1253	only FWD	-	9-5 Aero 2,3 TS	0,105
Saab 9-5 10-12	large car	3	6			XWD	automatic	9-5 Turbo6 2,8T	0,111
Seat Leon III 12-	small car	1	26			4Drive	automatic	-	-
Skoda Octavia 05-12	small car	112	694			4x4, Scout	automatic	Octavia RS 2,0 TFSI	0,099
Skoda Octavia 13-	mid-size car	25	42			4x4, Scout	automatic	Octavia RS TSI	0,114
Skoda Superb 09-15	large car	65	93			4x4	automatic	Superb V6	0,110
Skoda Superb 15-	large car	1	2			4x4	automatic	-	-

Skoda Yeti 10-	small car	45	26		4x4	automatic	-	-
Subaru Impreza 08-12	small car	16			all models	permanent	Impreza WRX STI	0,140
Subaru Legacy/Outback 03-09	mid-size car	31			all models	permanent	Outback 3,0 R	0,113
Subaru Legacy/Outback 09-14	mid-size car	127			all models	permanent	Outback 3,6 R	0,112
Subaru Outback 14-	large car	3			all models	permanent	-	-
Suzuki Swift 11-	supermini	1	71		AllGrip	permanent	Swift 1,6 Sport	0,090
Suzuki SX4 06-	small SUV	28	27		4x4	selectable w/ auto opt	-	-
Toyota Avensis 03-08	large car			253	only FWD	-	-	-
Toyota Avensis 09-15	large car			229	only FWD	-	-	-
Toyota Prius 04-09	mid-size car			511	only FWD	-	-	-
Toyota Prius 09-16	mid-size car			204	only FWD	-	-	-
Volvo S40/V50 04-12	mid-size car			2448	only FWD***	-	S40 T5	0,111
Volvo S60 00-09	large car	5	396		AWD	automatic	S60 T5	0,119
Volvo S60/V60 10-	mid-size car	47	515		AWD	automatic	V60 T5	0,108
Volvo V40 12-	small car	3	164		AWD	automatic	V40 T5	0,114
Volvo V70/S80 00-06 (ESC)	large car	403	2254		AWD	automatic	V70 T5	0,112
Volvo V70/S80 00-06 (no ESC)	large car	865	5272		AWD	automatic	V70 T5	0,110
Volvo V70/S80 07-	large car	487	2550		AWD	automatic	S80 3,2	0,105
Volvo XC60 08-	small SUV	254	140		AWD	automatic	XC60 T6	0,114
Volvo XC90 02-15	large SUV	367	1		AWD	automatic	XC90 V8	0,107
VW Caddy 04-	small car	18	768		4motion	automatic	-	-
VW Golf/Jetta 04-08	small car	20	723		4motion	automatic	Golf GTI	0,100
VW Golf 08-12	small car	39	982		4motion	automatic	Golf GTI	0,104
VW Golf 12-	small car	18	231		4motion	automatic	Golf R	0,147
VW Passat 97-05	large car	132	941		4motion	permanent	Passat V6 Syncro	0,091
VW Passat 05-07	large car	147	658		4motion	automatic	Passat GT Sport	0,103
VW Passat 08-14	large car	470	1083		4motion	automatic	Passat V6 GT Sport	0,103
VW Passat 15-	large car	23	16		4motion, Alltrack	automatic	-	-
VW Sharan/Seat Alhambra/Ford Galaxy 96-	large MPV	3	99		4x4, Syncro, 4motion	automatic	Alhambra 2,8 V6	0,081
VW Sharan/Seat Alhambra 10-	large MPV	16	53		4Drive, 4motion	automatic	-	-

* excluding 2,3 EcoBoost RS
** excluding R Hybrid
*** excluding T5 AWD