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Can electronic stability control replace studded tyres?

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ABSTRACT

Based on recent studies, this paper examines whether an increased use of electronic stability control can replace studded tyres. A re-analysis of a study that evaluated the effects on accidents of changes in the use of studded tyres in major cities in Norway is presented. It is found that if all cars have electronic stability control, the use of studded tyres can be reduced to about 15 percent before any increase in the number of accidents occurs. Even if studded tyres were eliminated entirely, any increase in the number of accidents is likely to be considerably smaller than it would have been if electronic stability control had never been invented.

Key words: studded tyres; electronic stability control; evaluation study

1 INTRODUCTION

The use of studded tyres in winter is still allowed in the Scandinavian countries. Use has been reduced in Norway in recent years, partly as a result of policies in major cities discouraging the use of studded tyres (Elvik et al. 2013). It remains high in Sweden and Finland. There is, however, growing concern about the adverse environmental impacts of studded tyres and the potential health effects of micro-particles torn off the road surface by studded tyres and increasing the dispersion of dust in the air. This paper will examine whether electronic stability control is associated with the same change in safety as studded tyres, permitting studded tyres to be phased out without adverse changes in safety. Before examining this question, it is put into a broader context by means of a review of relevant literature.

2 LITERATURE REVIEW

It has long been known that driving in winter involves an increased risk of accident (Bjørnskau and Høye 2013). A Swedish study (Norrman et al. 2000) defined ten different classes of slippery roads. All of them were associated with an increased risk of accident compared to non-slippery roads. The most hazardous condition was rain falling on a frozen road, forming ice almost instantly. In this condition, the accident rate was more than 15 times higher than on non-slippery roads. While winter road maintenance can reduce the risk (Usman et al. 2010, 2012), it is difficult to fully prevent it from increasing. Spreading salt may prevent snow from sticking to the road, but only at certain temperatures and only on roads with enough traffic to help keep the road surface free from snow.

Drivers adapt behaviour to road surface conditions (Kilpeläinen and Summala 2007), primarily by slowing down during adverse weather or when the road is slippery, but the behavioural adaptation is not sufficient to prevent the accident rate from increasing. To maintain a high level of mobility and safety, highway agencies try to keep at least the major roads free of snow and ice in winter. Two measures can contribute to this: salt and studded tyres. Unfortunately, both these measures are associated with adverse environmental impacts. Studded tyres tear up micro-particles; the smallest of these can be inhaled and cause respiratory diseases (Gustafsson et al. 2008, Kim et al. 2015). Salt damages vegetation close to the road, corrodes concrete structures such as bridges, corrodes cars and is associated with increased mortality in birds who eat the salt (Bjørnskau and Høye 2013).

There is thus a very sharp trade-off between improving safety and protecting the environment with respect to measures designed to improve the safety of winter driving. While the safety effects of salt can be debated (Elvik 2003, Bjørnskau 2011), it seems clear that studded tyres provide a safety benefit (Elvik 1999, Hjort and Jansson 2010, Strandroth et al 2012, Hjort 2013, Elvik et al. 2013, Strandroth et al. 2015).

A Swedish study (Strandroth et al. 2012) found that studded tyres reduce fatal accidents in winter. The same study also found that electronic stability control (ESC) reduced fatal and serious injury accidents in winter. The study outlined a scenario in which policies designed to reduce the use of studded tyres should go in phase with the increase in the share of traffic performed by cars with electronic stability control. This suggests that electronic stability control might, in the long run, replace studded tyres. None of the cars included in the evaluation of studded tyres had electronic stability control, while it is reasonable to assume that a majority of the cars included in the study of electronic stability control had studded tyres. In other words, having studded tyres did not eliminate the effects of electronic stability control. Table 1 summarises the estimates of effect presented in the study. The overall estimate for all road surface conditions was obtained by assuming that 50 percent of accidents in winter are on snow- or ice-covered roads and 50 percent on dry or wet bare roads. Swedish accident statistics (Strandroth et al. 2012) confirms that these assumptions are reasonable.

Table 1 about here

A conservative interpretation of the effects of electronic stability control is that these are the additional effects of the system, given that the car already has studded tyres. A more liberal interpretation is that these are the effects of electronic stability control for all cars, no matter whether they have studded tyres or not. Either way, the estimated effects of electronic stability control were a little smaller than those of studded tyres. Hence, it would perhaps be optimistic to expect electronic stability control to be a perfect substitute for studded tyres.

A recent study (Strandroth et al. 2015) confirmed that cars with studded tyres are less involved in accidents than cars without studded tyres. There was a particularly large difference for fatal loss-of-control accidents, which were 65 percent lower with studded tyres than without studded tyres for cars without ESC. An even larger difference was found for cars with ESC, suggesting that ESC provides an additional safety benefit for cars using studded tyres.

A meta-analysis of studies that have evaluated the effects on accidents of electronic stability control (Høye 2011) confirm the results of the Swedish studies. The meta-analysis found that ESC reduces fatal accidents by about 40 percent. The effect on injury accidents was smaller; for accidents defined as "ESC-related" (typically accidents involving loss of control) a reduction of about 20 percent was found.

Tests performed in controlled conditions on a winter test track (Hjort 2013) found that a double evasive manoeuvre could be performed at a slightly higher speed without losing control when ESC was activated than when ESC was de-activated. The same study found that ESC greatly improved manoeuvrability on a slippery road surface for cars equipped with so called "Central European" un-studded winter tyres. Cars equipped with studded tyres had better manoeuvrability than cars with un-studded tyres and there was no clear additional gain if ESC was activated.

Studded tyres produce an external safety benefit which electronic stability control does not. Studded tyres tear away snow or ice and thus reduce the share of traffic taking place on snow- or ice-covered road surfaces. This benefits cars not using studded tyres. A key question is how many cars need to use studded tyres in order to produce this effect. A Finnish study (Tuononen and Sainio 2014) tried to determine this under controlled conditions. The study concluded that if 25-50 percent of cars use studded tyres, that would prevent the road from becoming too slippery for cars not using studded tyres. In other words, if less than about 25 percent of cars use studded tyres, the external safety benefits may be reduced and a further reduction in the use of studded tyres may be associated with a larger increase in the number of accidents than, say, a reduction in the use of studded tyres from 60 to 30 percent.

It therefore remains an open question whether an increased use of electronic stability control can fully compensate for a reduced use of studded tyres, since electronic stability control does not tear away snow or ice from the road surface.

3 RESEARCH PROBLEM

This paper tries to shed light on the following questions:

1. Does inclusion of a variable showing the share of vehicle kilometres driven by cars with electronic stability control influence estimates of the effects on accidents of changes in the share of cars using studded tyres?
2. To what extent can an increased use of electronic stability control offset the effect on accidents of a reduced use of studded tyres?
3. Can the impacts of more slippery roads when the use of studded tyres becomes very low be quantified, given that one controls for the use of electronic stability?

These questions will be examined by means of a re-analysis of the aggregate results of the long-term evaluation of changes in the use of studded tyres in major Norwegian cities reported in 2013 (Elvik et al. 2013).

4 A RE-EXAMINATION OF ELVIK ET AL. (2013)

Elvik et al. (2013) presented the results of two studies made eleven years apart in Norway (Fridstrøm 2000, Elvik and Kaminska 2011) to evaluate the effects on accidents of changes in the use of studded tyres. The first of these studies included four major cities in Norway, the second included five major cities. The unit of analysis was city and day. The chief reason for doing the analysis at this level was to include weather effects, which are quite important for the number of accidents in winter. Negative binomial regression models including more than 20 variables were fitted to the data. For each day in each city, these models produced an estimate of the number of accidents expected to occur. Model estimates per city per day were aggregated by means of the sample enumeration method, producing an estimate of the total number of accidents expected to occur in each city during the season when use of studded tyres is permitted.

In each city, the model-estimated number of accidents in the first year was used as baseline. All subsequent years were compared to the first year. Model-based estimates of changes in the number of accidents per city per year were plotted against changes in the use of studded tyres. The purpose of this analysis was to determine whether there was a dose-response relationship between changes in the use of studded tyres and changes in the number of injury accidents during the season when the use of studded tyres is permitted. The results when both studies were combined are shown in Figure 1, which is identical to Figure 3 in Elvik et al. (2013).

Figure 1 about here

It is seen that a clear dose-response relationship was found. Data points highlighted by red or yellow circles represent less than 25 percent use of studded tyres. These data points indicate a larger increase in the number of accidents than the other data points, thus confirming the Finnish study (Tuononen and Sainio 2014) suggesting that less than 25 percent use of studded tyres would reduce the effects on road surface conditions that benefit all cars. All these data points were observed in the most recent of the two studies.

In Figure 1, the data points show the percentage change in the number of accidents associated with a certain percentage point of change in the use of studded tyres. Thus the uppermost of the data points in the Figure are associated with a reduction in the use of studded tyres of a little more than 20 percentage points. However, Figure 1 suggests that showing changes in the use of studded tyres in terms of percentage points can be un-informative. The leftmost data point in Figure 1 was associated with a reduction of almost 50 percentage points in the use of studded tyres; yet the increase in the number of accidents was quite small. If only the size of the change mattered, this data point ought to be associated with a large increase in the number of accidents, whereas the data points surrounded by red circles ought to be associated with smaller changes in the number of accidents.

The study by Tuononen and Sainio (2014) suggests that it is the share of cars using studded tyres that matters most for the effect on accidents, not the size of changes from one year to another. In Figure 2, the results in Figure 1 have been plotted according to a different scale. The abscissa shows the use of studded tyres following a reduction. Only the levels of use following reductions have been included in Figure 2. The rationale is that concerns about adverse impacts on safety are related to reductions in the use of studded tyres, in particular reductions leading to a use of less than 25 percent.

Figure 2 about here

A trend line has been fitted to the results of the first study (Fridstrøm 2000). It predicts a considerably greater increase in the number of accidents when the use studded tyres drops below 25 percent than what was found in the second study (Elvik and Kaminska 2011). All data points in the second study are located inside the triangle indicated in Figure 2 and all are located well below the trend line based on the first study. What happened between the first and second study? Why did the increase in accidents implied by the results of the first study not materialise?

It is suggested that the increase in accidents associated with the low levels of use of studded tyres found in the second study was partly prevented by an increase in the share of cars equipped with electronic stability control.

5 GROWTH IN USE OF ELECTRONIC STABILITY CONTROL (ESC)

Figure 3 shows changes from 1991 to 2009 in the percentage of vehicle kilometres performed in Norway by cars with electronic stability control. It is seen that the percentage increased from 0 in 1991 to 52.3 percent in 2009.

Figure 3 about here

A projection of the trend shown in Figure 3 indicates that by 2024, 96 percent of all vehicle kilometres in Norway will be performed by cars with electronic stability control (ESC). One would expect the growth of ESC in Norway to offset some of the increase in the number of accidents that would otherwise have been associated with a low use of studded tyres.

6 A REVISED MODEL

An analysis of the data points shown in Figure 2 was performed in order to determine whether an effect of the increasing use of ESC could be found in these data. Use of ESC was indicated as the percentage of vehicle kilometres driven by cars with ESC, see Figure 3. These data may not be exactly correct for each city. However, city-specific data on the use of ESC are not available. It is unlikely that use of ESC in each city could be very different from average use in the country as a whole.

The variables of principal interest are use of studded tyres and use of ESC. Both were stated as percentages. Different functional forms were tested in order to reproduce, at least qualitatively, the trend line shown in Figure 2. This trend line represents the effects of reduced use of studded tyres when few cars use ESC. The highest share of ESC in the first study was 9.8 percent.

Following exploratory testing, it was concluded that the best model fit was obtained by including both use of studded tyres, stated as a percentage, and the natural logarithm of the use of studded tyres in the model. These variables are obviously highly correlated, but nevertheless produced meaningful and reasonably precise coefficient estimates. The final model had the form:

Percentage change in accidents = Constant term + Use of studded tyres (%) + Ln(Use of studded tyres) + Use of ESC (%)

A logarithmic transformation of use of ESC was tested, but did not improve model fit. Table 2 shows estimated model coefficients and their standard errors. Overall goodness-of-fit is also indicated. A potential problem in fitting regression models to time-series data is autocorrelation of the residuals. However, as indicated at the bottom of Table 2, no strong autocorrelation of the residual terms was found.

Table 2 about here

Two versions of the model were run. In the first version, data points were equally weighted. In the second version, data points were weighted in proportion to their statistical precision. As can be seen from Table 2, coefficient estimates were highly similar in the two versions, but the standard errors of the coefficients were considerably smaller in the weighted analysis than in the un-weighted analysis.

Use of ESC was stated as a percentage. The coefficients therefore imply that a 100 percent use of ESC will be associated with a 9-10 percent reduction in the number of injury accidents during the season when the use of studded tyres is permitted. Estimated changes in the number of accidents are shown in Figure 4.

Figure 4 about here

The data points are indicated by circular symbols. The curved line shows estimated changes in the number of accidents with no use of ESC. The squares show estimated changes in the number of accidents with the actual use of ESC in each year. It is seen that the estimates including actual use of ESC are quite close to many of the data points, in particular when the use of studded tyres is less than 30 percent. A more formal analysis of residuals is presented in Figure 5.

Figure 5 about here

Figure 5 shows standardised residuals. Only two of these are outside plus or minus two standard errors, which is quite normal for 44 residuals. The residuals are normal up to an increase of about 4 percent in the number of injury accidents. For larger increases, all residuals are positive (i.e. model predictions are too low). This suggests that ESC may not be fully able to compensate for the slippery roads effect that is likely to arise when very few cars use studded tyres. Thus, the net effect on accidents of changes in the use of studded tyres is the result of three partial effects:

1. The effect of reduced use of studded tyres, given a constant use of ESC.
2. The effect of increased use of ESC, given a constant use of studded tyres
3. The effect of roads becoming more slippery at low levels of use of studded tyres

The next section tries to identify the contributions of these effects.

7 DECOMPOSING EFFECTS

The relative contributions of the three factors listed above is of particular interest when the use of studded tyres gets low. If increased use of ESC can fully offset the impacts of reduced use of studded tyres, one need not worry about roads becoming more slippery. If, on the other hand, the substitution effect is less than complete, it may be wise to aim for the continued use of studded tyres by a certain proportion of cars in order to reduce the slipperiness effect.

To assess the extent to which ESC can substitute studded tyres, three estimates of the change in the expected number of accidents have been developed for the nine observations for which the use of studded tyres was less than 25 percent:

1. The estimate made in the original study (Elvik et al. 2013), which did not include use of ESC explicitly, but nevertheless to some extent reflects the effects of ESC as an omitted variable (to the extent it is correlated both with an included independent variable and the dependent variable. This is the case: use of ESC is negatively correlated both with the use of studded tyres and the number of accidents).
2. An estimate assuming zero use of ESC. This shows the "pure" effect of reduced use of studded tyres, with no offsetting impact from ESC.
3. An estimate including the actual level of use of ESC. This shows the degree to which ESC substitutes studded tyres at a given level of use of ESC.

Figure 6 shows the three estimates for nine data points referring to a less than 25 percent use of studded tyres. For these data points, the use of studded tyres varied between 9.9 and 23.8 percent.

Figure 6 about here

Trend lines have been fitted to the data points. Unsurprisingly, the uppermost curve shows the changes in the number of accidents expected to occur if no car has ESC. Starting at the rightmost data point, the estimated increase in the number of accidents is 11.3 percent (at 9.9 percent use of studded tyres). If all cars had ESC, the number of accidents would be reduced by 9.1 percent (the coefficient 0.091 in Table 2 multiplied by 100). This would leave a net increase of 2.2 percent even if all cars had ESC. Moving to the next data point, at 16.2 percent use of studded tyres, the no ESC effect (pure studded tyres effect) is estimated as an increase of 8.1 percent in the number of accidents. A hundred percent use of ESC, reducing the number of accidents by 9.1 percent, will fully offset this.

It is therefore only when the use of studded tyres drops below about 15 percent that a hundred percent use of ESC will no longer be able to compensate for the increase in accidents associated with reduced use of studded tyres.

8 DISCUSSION

Is safety sacrificed by discouraging, and possibly prohibiting, the use of studded tyres? Until now, the answer has been that, yes, if we eliminate studded tyres we should be prepared for an increase of the number of accidents in winter, in the order of 5-10 percent. This answer becomes less obvious if the effects of ESC are considered. An increasing proportion of cars have ESC, and this system is a nearly perfect substitute for studded tyres.

ESC is, however, likely to be only a nearly perfect substitute for studded tyres. ESC does not tear away snow or ice from the road surface, the way studded tyres do. If studded tyres are eliminated, then so is the beneficial effect they have in rubbing away snow and ice and thus increasing road surface friction. Tuononen and Sainio (2014) suggested that roads will become noticeably more slippery if the use of studded tyres goes below 25 percent. The analyses presented in this paper suggest that if all cars have ESC, the critical lower level for the use of studded tyres drops to about 15 percent.

The chief argument for banning studded tyres is avoiding their adverse impacts on environment and health. The chief argument for keeping them is the safety benefit. The safety argument for studded tyres is weakened by the introduction of ESC, but perhaps not undermined entirely. While ESC has a safety effect which is almost as large as the effect of studded tyres, it has this effect irrespective of whether the car has studded tyres or not. Studded tyres prevent some, but not all cases of skidding and losing control. Electronic stability control provides an additional effect. Thus, by keeping both systems, one gets the effects of both. By abandoning one system, one no longer gets this “double” safety effect.

9 CONCLUSIONS

The main conclusions of the research presented in this paper can be summarised as follows:

1. An increasing use of electronic stability control has partly offset adverse impacts on the number of accidents of a reduced use of studded tyres in Norwegian cities in recent years.
2. If all cars have electronic stability control, the number of injury accidents in the season when the use of studded tyres is permitted may be reduced by 9-10 percent.
3. The effect of a hundred percent use of electronic stability control may fully substitute for a reduced use of studded tyres down to about 15 percent use of studded tyres.

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REFERENCES

Bjørnskau, T. 2011. Sikkerhetseffekter av salting (Safety effects of road salting in winter road maintenance). Rapport 1171. Oslo, Transportøkonomisk institutt.

Bjørnskau, T., Høye, A. 2013. Vinterdrift av veger (Winter maintenance of roads). Kapittel 2.6 i Trafikksikkerhetshåndboken. Oslo, Transportøkonomisk institutt.

Elvik, R. 1999. The effects on accidents of studded tires and laws banning their use: a meta-analysis of evaluation studies. Accident Analysis and Prevention, 31, 125-134.

Elvik, R. 2003. Assessing the validity of road safety evaluation studies by analysing causal chains. Accident Analysis and Prevention, 35, 741-748.

Elvik, R., Fridstrøm, L., Kaminska, J., Meyer, S. F. 2013. Effects on accidents of changes in the use of studded tyres in major cities in Norway: A long-term investigation. Accident Analysis and Prevention, 54, 15-25.

Elvik, R., Kaminska, J. 2011. Effects on accidents of reduced use of studded tyres in Norwegian cities. Report 1145. Oslo, Institute of Transport Economics.

Fridstrøm, L. 2000. Piggfrie dekk i de største byene. Rapport 493. Oslo, Transportøkonomisk institutt.

Gustafsson, M., Blomqvist, G., Gudmundsson, A., Dahl, A., Swietlicki, E., Bohgard, M., Lindbom, J., Ljungman, A. 2008. Properties and toxicological effects of particles from the interaction between tyres, road pavement and winter traction material. Science of the Total Environment, 393, 226-240.

Hjort, M. 2013. Measuring tyre performance in ESC intervention situations. Proceedings of the international conference Science meets Tires: Perspectives for Tire Technology, Aachen, September 11-12, 2013.

Hjort, M., Jansson, J. 2010. Handling of buses in slippery roads during the influence of side wind – a study of the effects of different tyres. Accident Analysis and Prevention, 42, 972-977.

Høye, A. 2011. The effects of Electronic Stability Control (ESC) on crashes – An update. Accident Analysis and Prevention, 43, 1148-1159.

Kilpeläinen, M., Summala, H. 2007. Effects of weather and weather forecasts on driver behaviour. Transportation Research Part F, 10, 288-299.

Kim, K-H., Kabir, E., Kabir, S. 2015. A review on the human health impact of airborne particulate matter. Environment International, 74, 136-143.

Norrman, J., Eriksson, M., Lindqvist, S. 2000. Relationships between road slipperiness, traffic accident risk and winter road maintenance activity. Climate Research, 15, 185-193.

Strandroth, J., Rizzi, M., Ohlin, M., Eriksson, J., Lie, A. 2015. Analysis of different types of winter tyres in rear-end injury crashes and fatal loss-of-control crashes with ESC. Proceedings of 24th Experimental Safety Vehicle Conference.

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.

Tuononen, A. J., Sainio, P. 2014. Optimal proportion of studded tyres in traffic flow to prevent polishing of an icy road. Accident Analysis and Prevention, 65, 53-62.

Usman, T., Fu, L., Miranda-Moreno, L. F. 2010. Quantifying safety benefit of winter road maintenance: Accident frequency modelling. Accident Analysis and Prevention, 42, 1878-1887.

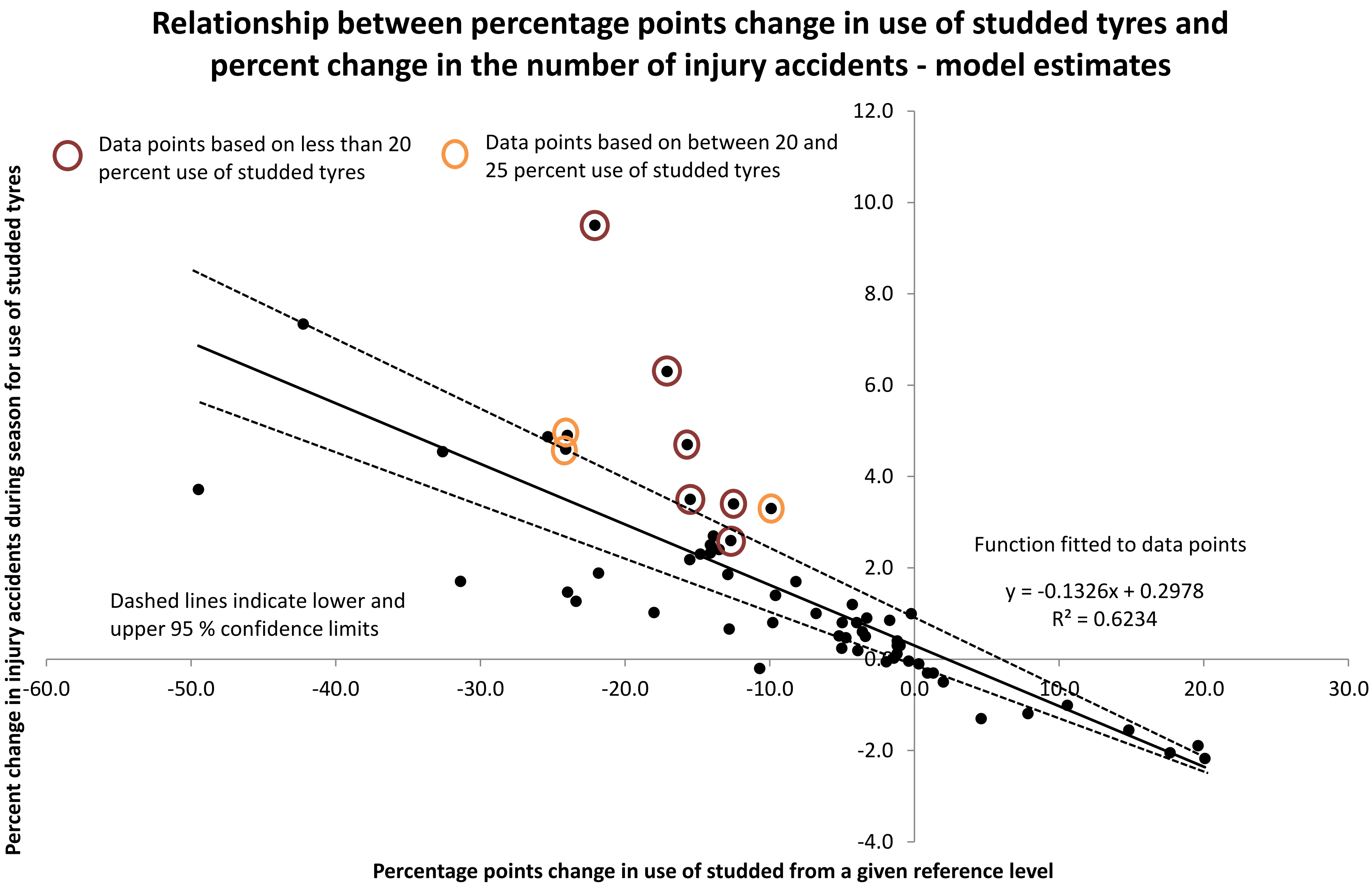
Usman, T., Fu, L., Miranda-Moreno, L. F. 2012. A disaggregate model for quantifying the safety effects of winter road maintenance activities at an operational level. Accident Analysis and Prevention, 48, 368-378.

LIST OF FIGURES AND TABLES

Table 2:

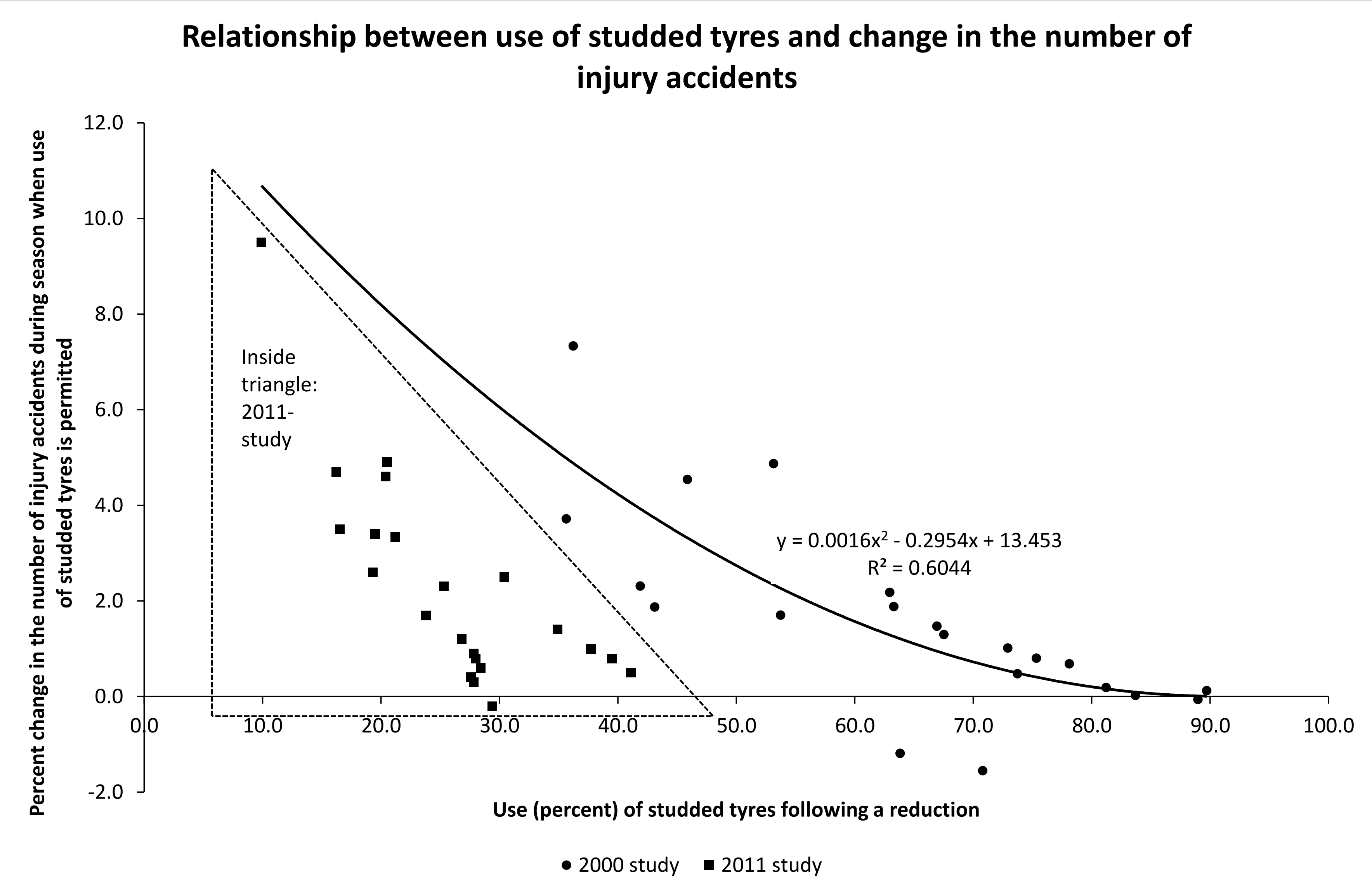
Estimated coefficients for studded tyres and electronic stability control in simple and weighted regression

Figure 1:



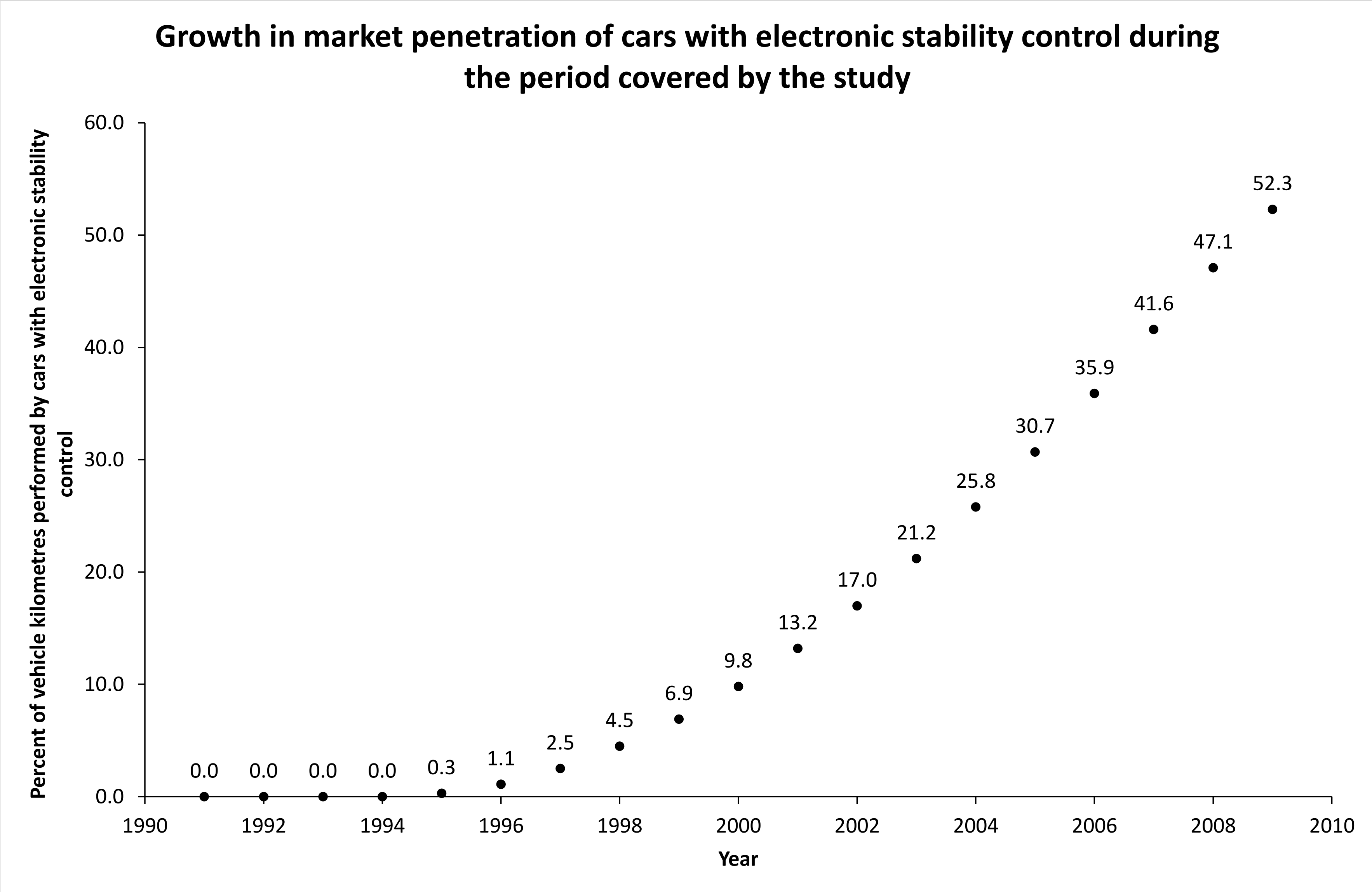
Relationship between percentage points change in use of studded tyres and percent change in the number of injury accidents - model estimates
Data points based on less than 20 percent use of studded tyres
Data points based on between 20 and 25 percent use of studded tyres
Function fitted to data points
y = -0.1326x + 0.2978
R² = 0.6234
Dashed lines indicate lower and upper 95 % confidence limits
Percent change in injury accidents during season for use of studded tyres
Percentage points change in use of studded from a given reference level
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0

Figure 2:



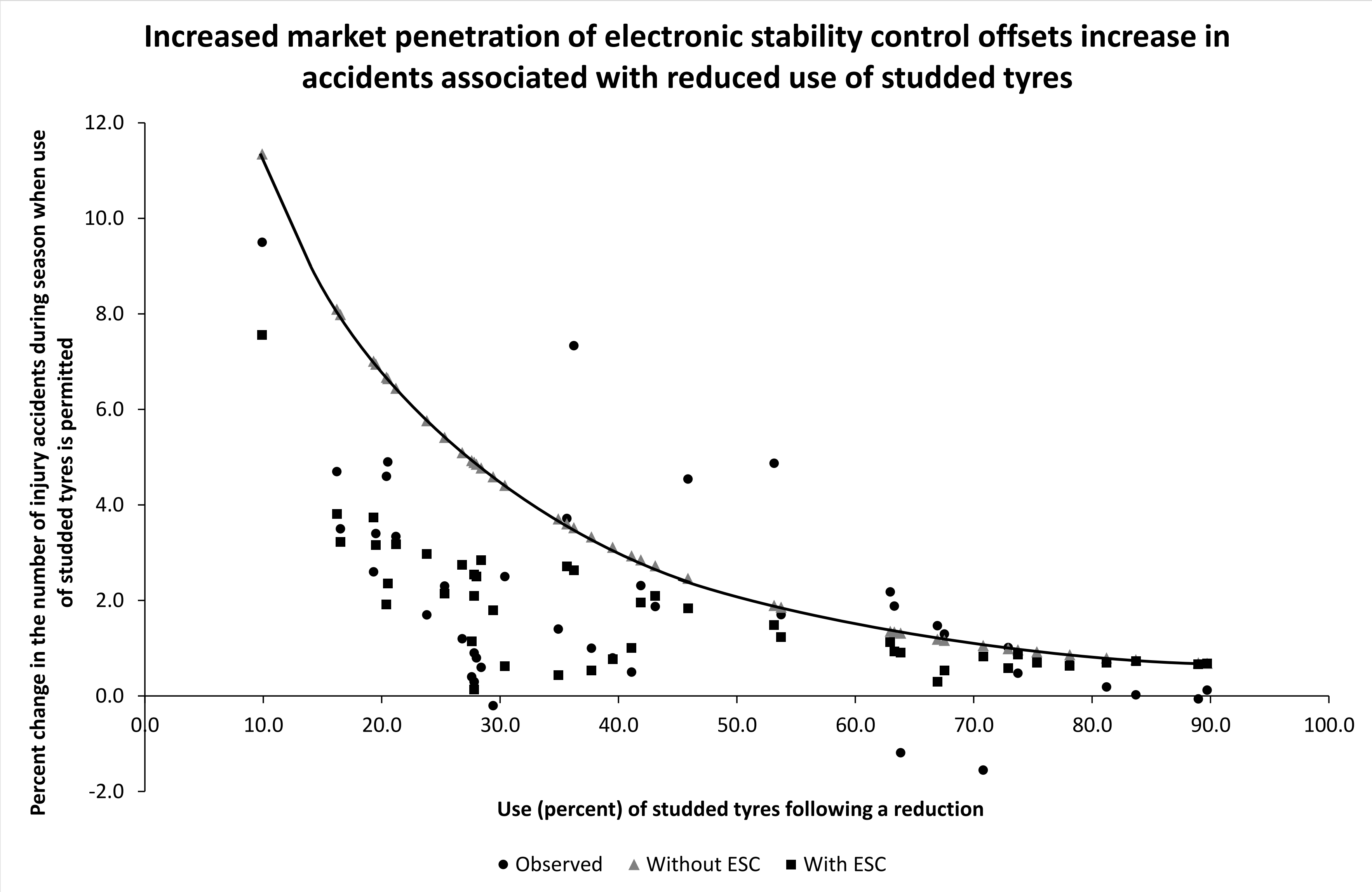
Relationship between use of studded tyres and change in the number of injury accidents
Percent change in the number of injury accidents during season when use of studded tyres is permitted
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
Inside triangle: 2011-study
y = 0.0016x² - 0.2954x + 13.453
R² = 0.6044
Use (percent) of studded tyres following a reduction
2000 study
2011 study

Figure 3:



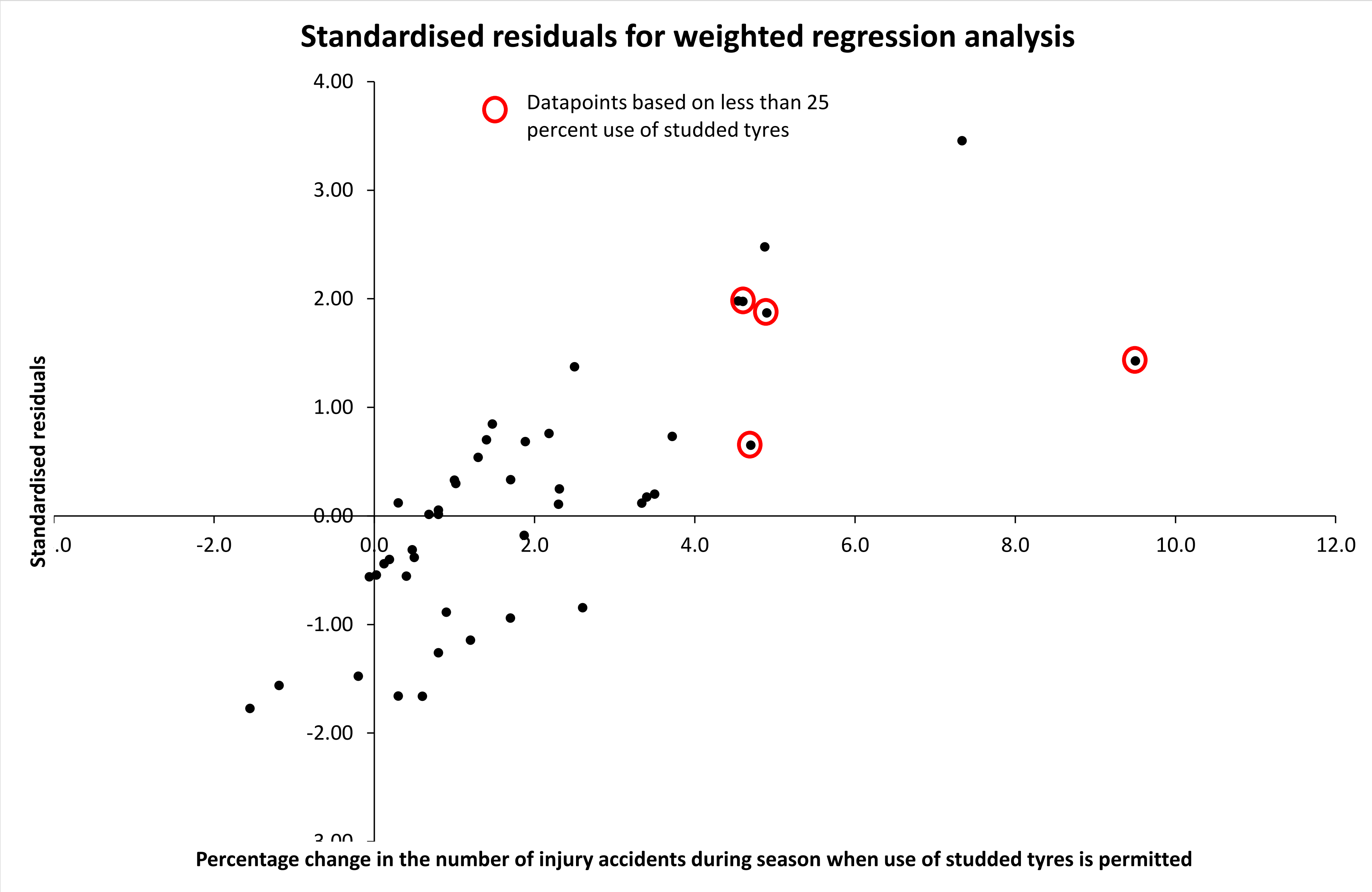
Growth in market penetration of cars with electronic stability control during the period covered by the study
Percent of vehicle kilometres performed by cars with electronic stability control
Year
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
0.0
0.0
0.0
0.0
0.3
1.1
2.5
4.5
6.9
9.8
13.2
17.0
21.2
25.8
30.7
35.9
41.6
47.1
52.3

Figure 4:



Increased market penetration of electronic stability control offsets increase in accidents associated with reduced use of studded tyres
Percent change in the number of injury accidents during season when use of studded tyres is permitted
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
Use (percent) of studded tyres following a reduction
Observed
Without ESC
With ESC

Figure 5:



Standardised residuals for weighted regression analysis
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
3.00
Datapoints based on less than 25 percent use of studded tyres
Standardised residuals
.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Percentage change in the number of injury accidents during season when use of studded tyres is permitted

Figure 6:

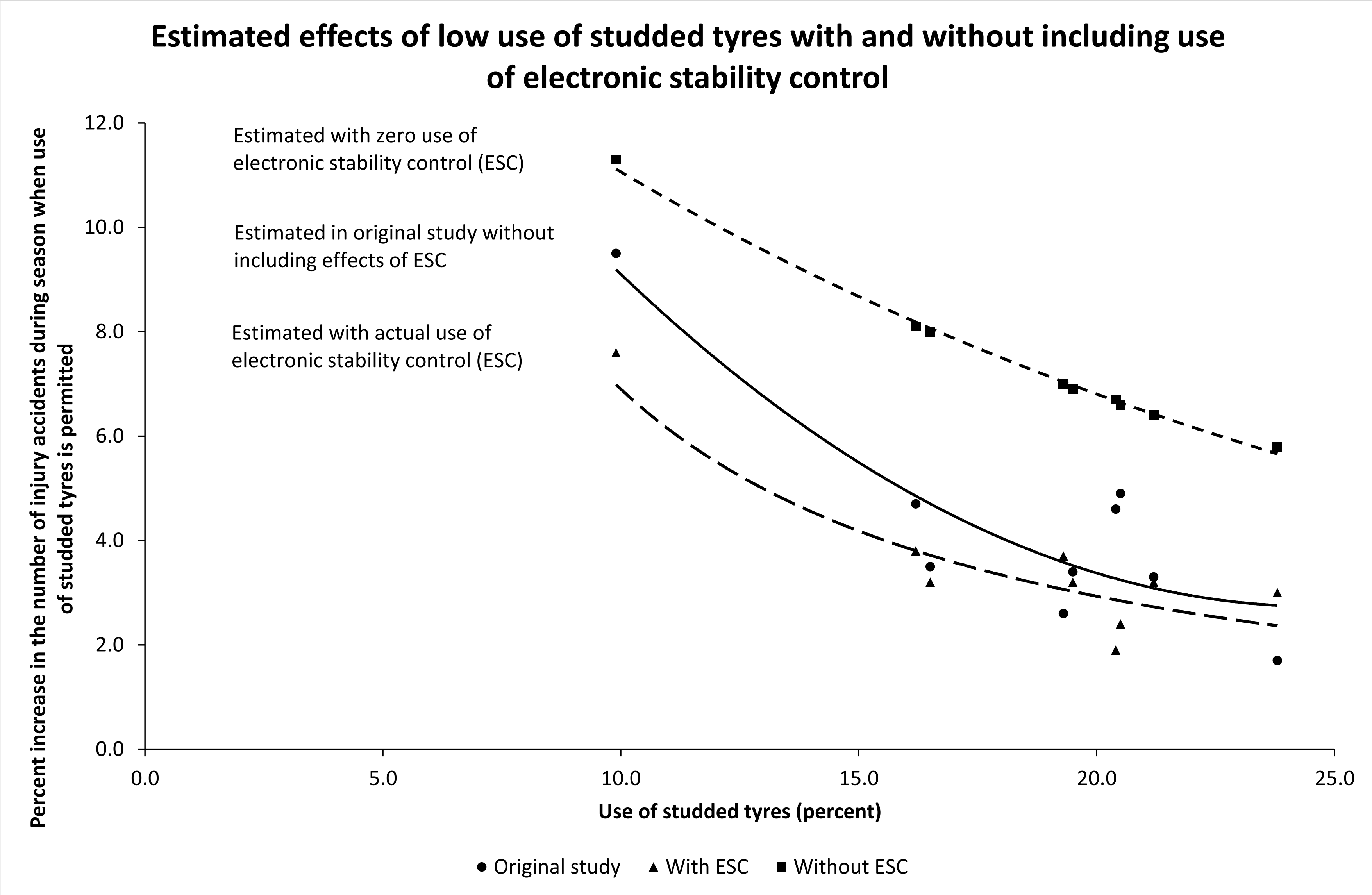


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Table 1:

Percent change in the number of fatal accidents during winter season		Percent change in the number of fatal and serious injury accidents during winter season	
Studded tyres	**Estimate of effect (95 % confidence limits)**	**Electronic stability control**	**Estimate of effect (95 % confidence limits)**
Roads covered by snow or ice (50%)	-42 (-36, -48)	Roads covered by snow or ice (50%)	-32 (-20, -44)
Dry or wet bare roads (50%)	+6 (-24, +36)	Dry or wet bare roads (50%)	+8 (-33, +49)
All road surface conditions (100%)	-18 (-36, 0)	All road surface conditions (100%)	-12 (-39, +15)

Table 2:

	Un-weighted regression			Weighted regression		
Terms	**Estimate**	**Standard error**	**P-value**	**Estimate**	**Standard error**	**P-value**
Constant	29.021	6.012	0.000	27.920	0.633	0.000
Use of studded tyres	0.068	0.043	0.121	0.075	0.004	0.000
Ln (Use of studded tyres)	-7.702	1.973	0.000	-7.553	0.202	0.000
Use of electronic stability control	-0.096	0.031	0.004	-0.091	0.003	0.000
Goodness-of-fit (R-squared)	0.483			0.496		
Mean value of autocorrelation of residuals for lags 1-16	-0.058			-0.034		