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Does the influence of risk factors on accident occurrence change over time?

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ABSTRACT

A large number of studies have been made to assess the relationship between risk factors and accident occurrence. A risk factor is any factor that makes an accident more likely to occur. Very many risk factors have been identified, for example, being under the influence of alcohol while driving, driving on slippery roads, entering complex junctions, or driving in hours of darkness. Few studies have been made to determine whether the associations between risk factors and accident occurrence remain stable over time. This paper presents examples of studies that have replicated estimates of risk. All these studies were made within a given country, using the same method, to ensure that estimates of risk are comparable. The risk factors included in the paper are: daylight, horizontal curves, junctions, road surface conditions, precipitation, drinking and driving and driver age. For all these risk factors, their association with accidents has changed over time, mostly becoming weaker. A protective factor, snow depth, is also included. Its protective effect has become smaller over time. Possible reasons for the weakening influence of risk factors are discussed.

Key words: risk factor; changes over time; daylight; horizontal curves; junctions; precipitation; driver age; drinking and driving

1 INTRODUCTION

Studies evaluating the effects of road safety measures are often amenable to a formal synthesis by means of meta-analysis. Studies of the risk factors that contribute to accidents or injuries are often quite heterogeneous and not as easy to summarise. As an example, Johansson, Wanvik and Elvik (2009) listed 13 studies of the risk of accident associated with darkness. The studies differed with respect to country of origin, types of accidents included, accident severity, type of traffic environment and technique used to control for other risk factors that may be correlated with darkness, such as slippery roads. The studies were judged to be too different to apply meta-analysis to summarise their findings. Besides, not all studies reported the information needed to be included in a meta-analysis.

Little is known about changes over time in the association between risk factors and accident occurrence. While, for example, darkness is a risk factor found all over the world, its relationship to accidents may vary both between countries and over time. It is known that the risk of pedestrian accidents increases more in darkness than the risk of accidents involving motor vehicles only. Hence, if there are fewer pedestrians at night, risk may change. Likewise, the standard of road lighting and of vehicle headlights may change over time and influence the risk associated with darkness. It is by no means certain that the risk associated with darkness remains the same over time. Similar points of view can be put forward with regard to many risk factors.

The objective of this paper is to explore whether the association between some risk factors and accident occurrence is stable over time. The study is exploratory and only intended to give examples that may motivate others to do more research regarding the stability over time of the associations between risk factors and accident occurrence.

2 LITERATURE REVIEW

The idea that the association between risk factors and accident occurrence may change over time is not new. Minter (1987) described the improvement of road safety in some highly motorised countries as a process of learning and fitted learning curves developed in psychology to time-series data on the number of traffic fatalities per registered car. These curves described the overall decline over time in the number of accidents per registered car, but did not identify the factors contributing to the decline.

Qiu and Nixon (2008) reviewed studies of the effect of adverse weather on traffic crashes. They reported that the increase in accident rate associated with snow appears to have been reduced over time. The mean increase in accident rate associated with snow was 113 percent in studies reported between 1950 and 1979, 71 percent in studies reported between 1980 and 1989 and 47 percent in studies reported between 1990 and 2005. The increase in accident rate associated with rain also changed in the same decades, but did not decline consistently. Rain was associated with an 80 percent increase in accident rate between 1950 and 1979, a 29 percent between 1980 and 1989 and a 71 percent increase between 1990 and 2005. Qiu and Nixon also reported that both rain and snow were associated with a smaller increase in the risk of injury accidents and fatal accidents than the overall increase in the risk of accidents of all levels of severity.

In recent years, improvement in both the active and passive safety of cars has made an important contribution to reducing accident rates. Broughton (2012) shows how new cars registered recently in Great Britain are safer than cars registered 20-30 years ago. It is likely, as will be discussed later in the paper, that some new safety features on cars have contributed to reducing the risk associated with some environmental risk factors, such as rain or snow.

A factor that probably has been contributing to reducing accident rates for a long time, is the increasing collective experience of the population of drivers. A 60 year old driver today is likely to have had a longer driving career than a 60 year old driver 40-50 years ago. Cicchino (2015) reports that fatality rates among older drivers in the United States have declined, which is consistent with the fact that these drivers have had a longer driving career than any other group of drivers and thus more opportunities to learn safer driving.

Christophersen et al. (2016), giving detailed statistics for five countries, show that drinking and driving has been reduced in all these countries. In discussing why this trend is found, the authors note that decades of enforcement, information campaigns and fairly strict penalties for drinking and driving may have caused a change in social norms, making drinking and driving an unacceptable behaviour for most people. Whatever the underlying mechanisms, it seems clear that the contribution of drinking and driving to accidents has declined over time.

3 IDENTIFICATION OF STUDIES

Given the exploratory nature of this study, it is limited to a few risk factors for which the author knows that at least two studies, performed at least ten years apart, have been made. Studies that fulfilled the following criteria were identified:

1. Successive studies of the same risk factor should have been made in the same country.
2. The studies should employ the same method, or at least highly similar methods.
3. The studies should refer to the same level of accident or injury severity.

Studies fulfilling these criteria were identified for the following risk factors:

1. The length of daylight, as determined by the times of sunrise and sunset.
2. The radius of horizontal curves on rural two-lane roads.
3. The number of legs in junctions located in rural or urban areas.
4. Road surface conditions in winter (dry road, wet road, snow- or ice-covered road).
5. Precipitation in the form of rain or snow in millimetres during 24 hours.
6. The frequency of drinking and driving.
7. The relative accident rate of older drivers compared to all drivers.

Studies of these risk factors have been made in Norway, Denmark, Sweden and the United States. Furthermore, a factor which has been found to be protective against injury accidents (i.e. it does not prevent accidents, but makes them less severe), snow depth, was included. Studies of this factor have been reported in Norway and Sweden.

4 EXAMPLES OF CHANGES IN ESTIMATES OF RISK

4.1 Daylight

Two Norwegian studies made eleven years apart (Fridstrøm 2000, Elvik and Kaminska 2011) to evaluate the effects on accidents of changes in the use of studded tyres in major cities in Norway included a variable measuring the length of daylight. This varies enormously in Norway; north of the Arctic Circle there is midnight sun in summer and no sun at all in winter. In the city of Oslo, the share of the day with sunlight varies between 0.246 and 0.785.

Negative binomial regression models were developed in both studies, including more than 20 variables (Elvik et al. 2013). The dependent variable was the number of accidents per day per city. The first study covered the period 1991-2000 (median year 1996). The second study covered the period 2002-2009 (median year 2006). Figure 1 shows the relative number of accidents on the day with the shortest period of daylight compared to the day with the longest period of daylight in 1996 and 2006 for the four cities that were included in both studies.

Figure 1 about here

The day with the shortest period of daylight has more accidents than the day with the longest period of daylight. This was found in both studies. However, in three of the four cities, the difference in the number of accidents between the day with the shortest duration of daylight and the day with the longest duration of daylight became smaller from 1996 to 2006. Moreover, the differences between the cities with respect to the variation in the number of accidents were smaller in the second study than in the first. The results thus indicate that the risk associated with darkness has become smaller and more uniform over time. The reasons for this tendency are not known. Road lighting may have been upgraded to a higher and more uniform standard in all the cities and car headlights may have been improved.

4.2 Horizontal curves

Accident prediction models for horizontal curves have been developed more than once in the United States. In general, these models describe the relationship between characteristics of a curve, like radius, length, and the presence of transition curves and the expected number of accidents. The Highway Safety Manual (AASHTO 2010) presents a model developed by Zegeer et al. (1992), based on data for two-lane rural roads in the state of Washington. These data were, however, quite old (1976-1982). An updated accident prediction model, also based on data for two-lane rural roads in the state of Washington, was developed by Bauer and Harwood (2013). This model did not have exactly the same mathematical form as the model developed by Zegeer et al., but served the same function and included the same variables. Estimates based on the two models are therefore regarded as comparable. Figure 2 shows how the relative accident rate (i.e. number of accidents for a given traffic volume) depends on curve radius (metres) according to the two models.

Figure 2 about here

The estimated relationships are very close until curve radius is less than about 200 metres. For curves with radius less than 200 metres, the oldest function predicts a considerably larger increase in accident rate than the most recent function. It would thus seem that sharp curves have become less of a risk over time. The reasons for this are not known, but possible reasons include improvements in vehicle steering and handling, improved signing of sharp curves, and a trend for the population of drivers to become more experienced.

4.3 Junctions

Accident prediction models for junctions have been fitted in four rounds in Denmark (Vejdirektotatet 2015). The first versions of these models were based on data for the years 1995-1999 (median year 1997). The most recent versions of the models were based on data for the years 2007-2011 (median year 2009). All generations of the models have the same form:

Expected number of accidents = $\alpha \cdot Q_{maj}^{\beta_1} \cdot Q_{min}^{\beta_2}$

The models include traffic volume only, stated in terms of daily entering volume (Q) from the major road (maj) and the minor road(s) (min). Prior to fitting the models, junctions were classified into ten groups. The models were fitted in each of these ten groups. Figure 3 compares the estimated relative number of accidents in different types og junctions for the oldest and most recent versions of the models. It was assumed that 5,000 vehicles per day enter from the major road and 2,500 vehicles per day enter from the minor road.

Figure 3 about here

A three-leg junction in a rural area, with no channelization, was classified as the least complex junction. The other types of junctions listed in Figure 3 are intended to be listed in increasing order of complexity. The idea is that if complexity is a risk factor, the predicted number of accidents should increase as one moves to the right in Figure 3. The number of accidents predicted for the simplest junction (to the left in Figure 3) has been set to 1.00 and the predicted number of accidents in the other types of junctions stated as multiples of this value.

It is seen that the predicted number of accidents, for a given traffic volume, increases as one moves from left to right in Figure 3. However, the model-predicted increase in the number of accidents is, in most cases, smaller in 2009 than in 1997. Although this pattern is not entirely consistent, it indicates that, on the whole, the differences in risk associated with different types of junctions have become smaller in the recent 15 years.

Repeated studies of safety in junctions have also been made in Norway (Johannessen and Heir 1974, Vodahl and Giæver 1986, Kvisberg 2003). In these studies, no accident prediction models were developed, but accident rates (number of accidents per million entering vehicles) were estimated for different types of junctions. Figure 4 summarises the main findings of the studies.

Figure 4 about here

Junctions have been sorted according to the number of legs (three or four) and speed limit (50, 60/70 or 80/90 km/h). It is seen that the oldest study, based on data from 1968-1972 (Johannessen and Heir 1974) found considerable differences in accident rate between the different types of junctions. Accident rate in four leg junctions with a speed limit of 80 or 90 km/h was more than eight times as high as in three leg junctions with a speed limit of 50 km/h. The second of the three studies (Vodahl and Giæver 1986) found much smaller differences in accident rate between the different types of junctions. The third study (Kvisberg 2003) indicated larger differences in accident rates than the second, but smaller than the first study.

Thus, the Norwegian studies do not show that the differences in accident rates have consistently become smaller over time. The smallest differences were found in the second of the three studies. All the studies were based on a sample of junctions. The samples were quite small and differences between the studies with respect to how the samples were obtained (they must all be classified as convenience samples) may explain some of the differences in results. At any rate, junction type and complexity do seem to involve a smaller increase in risk today than more than 40 years ago.

Several accident prediction models for junctions based on negative binomial regression have been developed in the United States. The models developed by Vogt and Bared (1998) (data from 1981-1985) and by Oh, Washington and Choi (2004) (data from 1991-1998) have been selected for closer examination. By comparing estimates based on these models, one may assess whether the difference in accident rates between three-leg junctions and four-leg junctions has become smaller over time. To make estimates as comparable as possible, all junctions were, based on Oh et al. (2004), assumed to have 13,000 entering vehicles per day from the major approach, and 650 entering vehicles per day from the minor approach. The number of accidents expected to occur at this volume was estimated by applying the constant term and the coefficients for entering volume. Coefficients for other variables were not included. Based on data for 1981-1985, it was found that four-leg junctions had 12.04 times as many accidents (at the given entering volume) as three-leg junctions. Based on the data for 1991-1998, this difference had been reduced to 2.08 times as many accidents. The models therefore suggest that the added complexity of four legs is associated with a declining increase in risk.

Do the trends found in the three countries have anything in common? To assess this, rural three-leg and four-leg junctions were selected, as these types of junctions were studied in all countries. The relative accident rate in four-leg junctions was then estimated as: accident rate in four-leg junctions/accident rate in three-leg junctions. This accident rate ratio shows how many times more accidents there are in four-leg junctions compared to three-leg junctions at a given traffic volume. By comparing the accident rate ratio at different points in time, one may see whether the differences in risk have become greater or smaller. The relevant accident rate ratios are presented in Figure 5.

Figure 5 about here

It is seen that in all countries, the differences in accident rate between four-leg junctions and three-leg junctions have become smaller over time. Reasons for this trend are not known, but one can imagine that skill in handling complex traffic situations may improve as drivers gain experience, at least up to a certain age.

4.4 Road surface conditions in winter

Two studies made more than 20 years apart estimated accident rates associated with different types of road surface conditions in Sweden (Brüde and Larsson 1980, Niska 2006). Both studies identified three types of road surface conditions: (1) Dry road surface, (2) Wet road surface, and (3) Road surface covered by snow or ice. The number of accidents per million vehicle kilometres was estimated for these road surface conditions in three regions of Sweden: the south, the middle and the north.

The first study made estimates for 1973 and 1977. The second study made estimates for a number of winter seasons from 1993 to 1997, with 1995 as the median year of the period covered by the data. A dry road surface was found to be the safest in all studies. Figure 6 shows the relative accident rate on a wet road surface, compared to a dry road surface (accidents per million vehicle kilometres on wet roads/accidents per million vehicle kilometres on dry roads).

Figure 6 about here

There are small changes over time. The estimate for all of Sweden for 1973 (1.10) was almost the same as for 1995 (1.16). Unlike the other risk factors that have been surveyed so far, the risk associated with a wet road surface does not seem to have declined over time. Qiu and Nixon (2008) found that the increase in risk associated with rain was almost as large in the period 1990-2006 (70 percent increase) as it was in the period 1950-1979 (80 percent increase).

Figure 7 shows relative accident rate on snow- or ice-covered roads compared to dry roads.

Figure 7 about here

The most striking tendency is that the differences between the regions have become smaller over time. There is also a weak tendency for the relative accident rate on snow- or ice-covered roads in Sweden as a whole to decline over time. The accident rate ratio (snow-or ice/dry) was 4.92 in 1973 and 4.74 in 1995. The increase in accident rate associated with snow or ice is considerably greater than the increase in accident rate associated with a wet road surface.

4.5 Precipitation

The two Norwegian studies quoted above (Fridstrøm 2000, Elvik and Kaminska 2011) estimated the effects on accidents of precipitation in the form of rain or snow. The models developed in the two studies have been presented in a previous paper (Elvik et al. 2013). Both models were negative binomial regression models using the number of accidents per city per day in the largest cities in Norway as dependent variable. With minor exceptions, not affecting the precipitation variables, all independent variables were identically defined in the two studies. Both models contained more than 20 independent variables.

Figure 8 shows the relationship between rain during the last 24 hours and the number of injury accidents for rainfall up to 20 millimetres. It rarely rains more than 20 millimetres during 24 hours. It is seen that the number of accidents increases, but the increase was larger in first study than in the second, although the studies were made only eleven years apart. The median year of the period covered by the first study (1991-2000) was 1996, the median year of the period covered by the second study (2002-2009) was 2006.

Figure 8 about here

Why did rainfall become less of a hazard in a period of merely ten years? The answer is not known, but one can think of a number of reasons. In the first place, it rains more often than before and previous studies (Eisenberg 2004) indicate that a learning effect may be associated with this: the more often it rains, the more accustomed drivers get to driving in rain. In the second place, many cars now have intelligent window wipers that sense the amount of rain and automatically adapt their speed of operation to this. In the third place, modern car tyres may drain rain more effectively than older tyres.

Figure 9 shows the association between snow and the expected number of injury accidents. The difference between the risk curve for 1996 and 2006 is even more dramatic than for rain. The increase in risk associated with snow was considerably smaller in 2006 than in 1996. Indeed, in 2006 the increase in risk associated with rain was marginally greater than the increase in risk associated with snow.

Figure 9 about here

Again, one may think of several reasons why snow became a less important risk factor during this period. A recent study (Elvik 2015) found that electronic stability control reduces the number of accidents in winter. The share of cars having electronic stability control increased considerably from 1996 to 2006. Statistics (Elvik et al. 2013) show that expenditures on road maintenance have grown fast, indicating that roads are maintained to a higher standard than before; in particular the use of salt to keep the road surface free from snow has increased. Finally, the quality of winter tyres, both studded and non-studded, has probably improved.

4.6 Drinking and driving

Roadside surveys made in Norway at different points in time (Bø 1972, Christensen et al. 1978, Glad 1985, Gjerde et al. 2008, 2013) show that the percentage of drivers testing positive for alcohol in roadside surveys has declined over time. Reviews of the percentage of killed drivers in which alcohol was found in autopsy (Christophersen et al. 2016) also show a decline over time. Figure 10 shows these trends.

Figure 10 about here

Both the curves in Figure 10 refer to a blood alcohol content of 0.05 percent or more. The statutory limit for blood alcohol concentration when driving in Norway was lowered to 0.02 percent in 2001, but to maintain comparability over time, the results in Figure 10 refer to the old limit of 0.05 percent.

As noted earlier, the decline in drinking and driving in Norway is not unique; similar trends have been found in other countries. There are now strong social norms against drinking and driving in Norway.

4.7 Relative accident rate of older drivers

Travel behaviour surveys are made regularly in Norway. By combining data on travel behaviour based on these surveys with official accident statistics, accident rates for various modes of transport and various groups of car drivers can be computed. Car driver injury accident rates have repeatedly been found to be highest among the youngest and oldest drivers, but a tendency can be seen for the accident rates of older drivers to decline over time. Figure 11 shows this tendency based on six travel behaviour surveys in Norway (Bjørnskau 1993, 1998, 2003, 2008, 2011, 2015).

Figure 11 about here

Older drivers have been defined as all drivers who are 65 years old or older. In 1992 these driver had an injury accident rate which was 70 percent higher than the average injury accident rate for driver of all ages (including 65 and above). In 2014, there was no longer any difference in the injury accident rate between older drivers and driver of all ages. As noted above, a similar tendency has been found in the United States

(Cicchino 2015), and it would not be surprising if it could be found in more countries.

4.8 Snow depth

A Swedish study (Brorsson, Ifver, Rydgren 1988) based on data for 1978-1984 (median year 1981) found that snow depth was a protective factor for single vehicle accidents in winter. Deep snow creates a snow wall along the road. This can dampen the impact if a vehicle runs off the road. The Swedish study found a large protective effect of snow depth on single vehicle injury accidents during the months January, February, March and December in all regions of Sweden. The lower curve in Figure 12 shows the protective effect of snow depth found in Sweden.

Figure 12 about here

The two Norwegian studies evaluating the use of studded tyres also included snow depth as a variable (Elvik et al. 2013). Single vehicle accidents were not identified, but a protective effect was estimated for all injury accidents in winter. The estimates of the two studies are shown as the upper curves in Figure 12. It is seen that the protective effect of snow depth has been reduced over time. Even if one were to adjust the curve based on the Swedish study, assuming that there is no protective effect for multi vehicle accidents, it is likely that it would still be located below the two curves based on the Norwegian studies. This example shows that even protective factors have become less protective over time.

The most likely reason for this is that other protective systems have replaced snow depth. Around 1980, seat belts were not worn as often as today, they did not have modern pre-tensioners, airbags were not standard equipment and vehicle crashworthiness was poorer.

5 DISCUSSION

The predominant tendency in the studies reviewed above is that the associations between the risk factors and accidents have become weaker over time. This tendency is not entirely consistent, but when estimates of risk made at two points in time are compared, it is much more often than not the case that the most recent estimate indicates a smaller increase in risk. The reasons for this tendency are not well known, but for some of the risk factors discussed in this paper, it seems likely that innovations in car safety systems may have contributed to it. It also seems likely that the population of car drivers has become more experienced over time. Novice drivers contribute to a smaller share of kilometres driven nowadays than they did 30-40 years ago, at least in Norway.

The risk factors reviewed in this paper are either environmental (daylight, road surface conditions, precipitation, snow depth), related to infrastructure elements (horizontal curves, junctions) or related to road user behaviour and characteristics (drinking and driving, driver age). In nearly all cases, the increase in risk associated with a certain factor has become smaller over time. Driving on a wet road surface is an exception. The increase in risk associated with a wet road surface has not declined over time. The fatality risk associated with drinking and driving (with a blood alcohol content above 0.05 percent) in Norway has also remained fairly stable since about 1980.

Little is known about changes over time is the risks associated with road user behaviour. Is speeding, for example, associated with the same risk today as twenty or thirty years ago? We do not know.

Many road safety measures are intended to influence a specific risk factor or group of factors. Winter road maintenance, for example, is intended to clear roads from snow. But if the risk associated with snow is not as great as before, winter road maintenance may become less effective. There is probably a two-way relationship here. It is reasonable to think that improvements in weather forecasts, de-icing methods and other elements of winter road maintenance has made it more effective, which could be one of the reasons why the risk associated with snowfall has declined. On the other hand, if other factors, like electronic stability control, have also contributed to lowering the risk, winter road maintenance may ultimately become less effective. The fact that the associations between risk factors and accidents change over time therefore underlines the need for continuous updating of knowledge regarding the effects of road safety measures.

6 IMPLICATIONS FOR EVALUATION STUDIES

The fact that many risk factors seem to be more weakly associated with accidents now than only some 10-20 years ago can have a number of implications for studies designed to evaluate the effects of road safety measures.

In the first place, if the risk factors a road safety measure is intended to influence are not associated with the same increase in risk as before, the effects of the measure may become smaller. If, for example, darkness is not associated with the same increase in risk as before, road lighting may become less effective.

In the second place, to reliably detect small effects, larger accident samples are needed. However, the downward trend in the number of accidents makes this increasingly difficult.

In the third place, accounting for trends is very important in before-and-after studies in order to get unbiased estimates of the effects of road safety measures. To control adequately for trends is becoming more difficult, as the trends are no longer stable, but seem to be accelerating in many countries, in particular with respect to traffic fatalities.

In the fourth place, detecting interactions between road safety measures is increasingly important. As an example, electronic stability control prevents loss of control and may thus make both studded tyres and winter road maintenance less effective than before.

In the fifth place, since new vehicle safety feature spread quite rapidly, knowledge gets outdated more quickly than before and updating evaluation studies frequently becomes more important.

7 CONCLUSIONS

This paper reports a small exploratory study of the stability over time of the association between risk factors and accident occurrence. The following results were found regarding the risk factors that were studied:

1. The difference in the number of accidents between the day with the shortest duration of daylight and the day with the longest duration of daylight in Norway has become smaller over time.
2. The increase in accident rate in sharp curves (radius less than 200 metres) has become smaller over time in the United States.
3. The increase in accident rate associated with increasing complexity of junctions has become smaller over time in Denmark, Norway and the United States, although the tendency is a little noisy.
4. The increase in risk associated with driving on a wet road surface during winter in Sweden has not declined over time.
5. The increase in risk associated with driving on a snow- or ice-covered road surface during winter in Sweden has become slightly smaller over time and the regional differences in risk have become substantially smaller.
6. The increase in risk associated with rain and snow has become smaller over time in Norway.
7. The percentage of traffic involving drinking drivers, and the percentage of killed drivers who had a blood alcohol concentration of 0.05 percent or more have declined over time in Norway.
8. The relative injury accident rate of older drivers (65 or more), compared to all drivers, has declined over time in Norway.
9. The protective effect of snow depth has become smaller over time in Sweden and Norway.

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ACKNOWLEDGEMENT

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Figure 1:

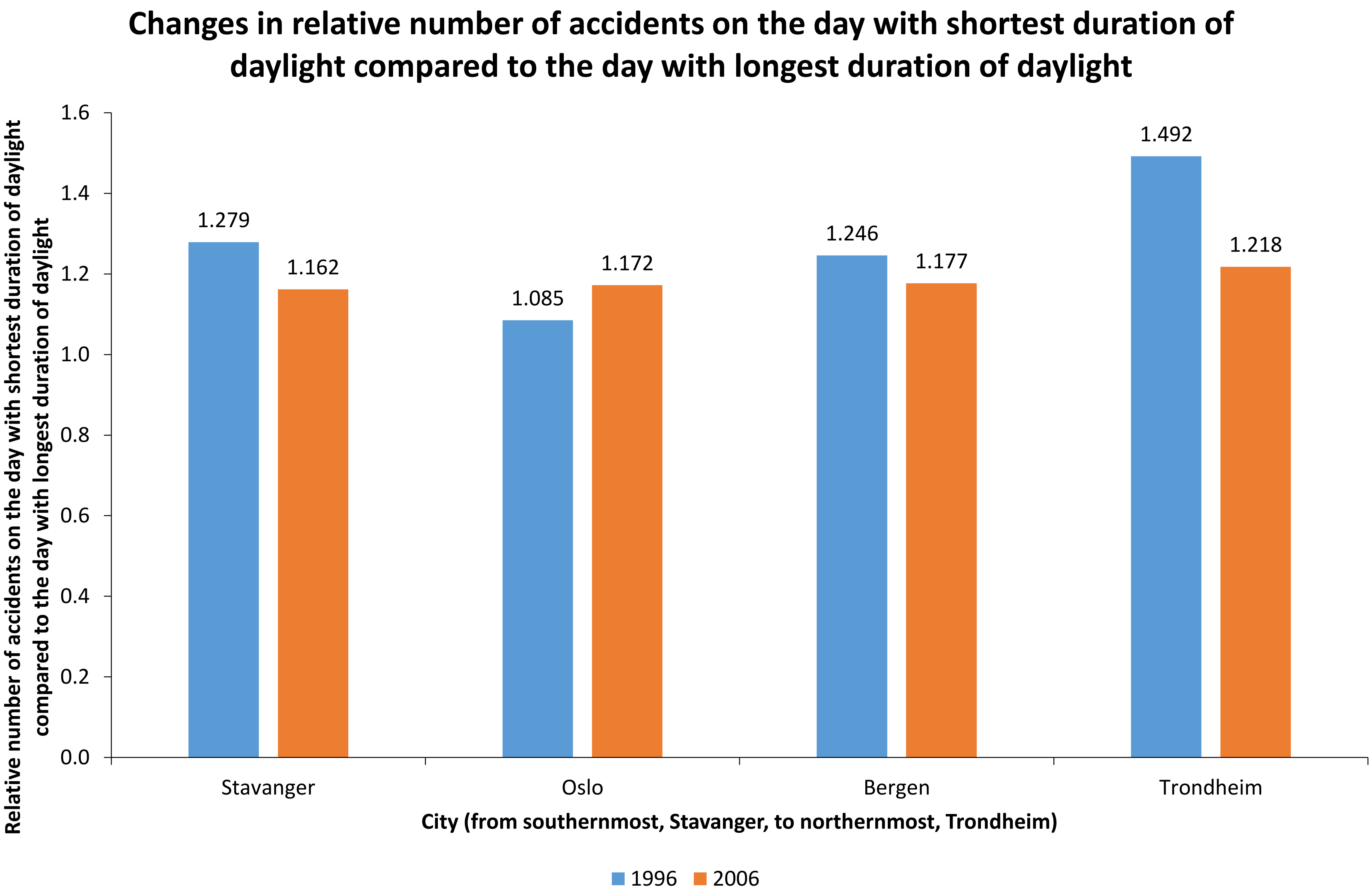
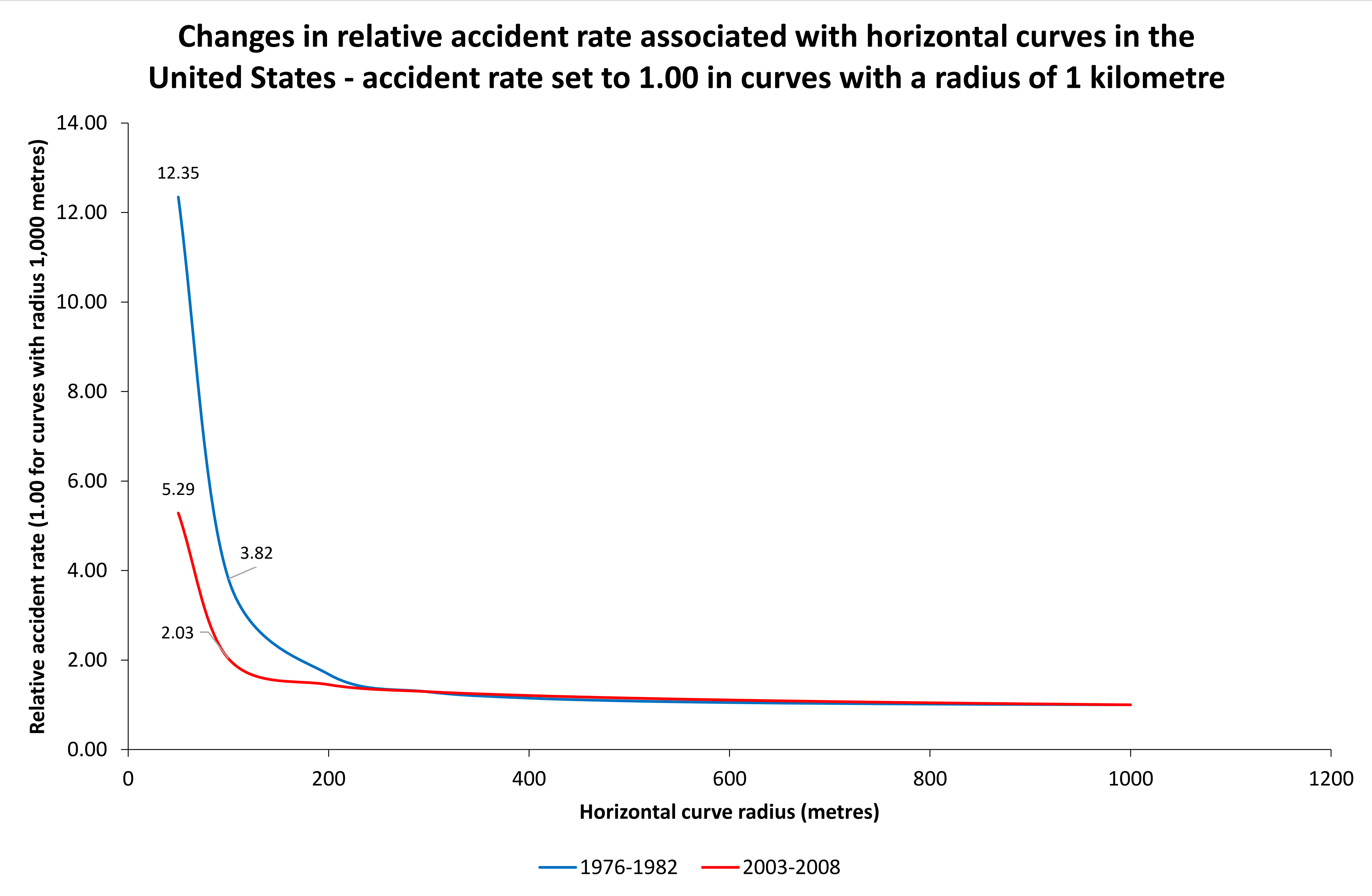

Changes in relative number of accidents on the day with shortest duration of daylight compared to the day with longest duration of daylight
Relative number of accidents on the day with shortest duration of daylight compared to the day with longest duration of daylight
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.279
1.162
1.085
1.172
1.246
1.177
1.492
1.218
Stavanger
Oslo
Bergen
Trondheim
City (from southernmost, Stavanger, to northernmost, Trondheim)
1996
2006

Figure 2:



Changes in relative accident rate associated with horizontal curves in the United States - accident rate set to 1.00 in curves with a radius of 1 kilometre
Relative accident rate (1.00 for curves with radius 1,000 metres)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
12.35
5.29
3.82
2.03
0
200
400
600
800
1000
1200
Horizontal curve radius (metres)
1976-1982
2003-2008

Figure 3:

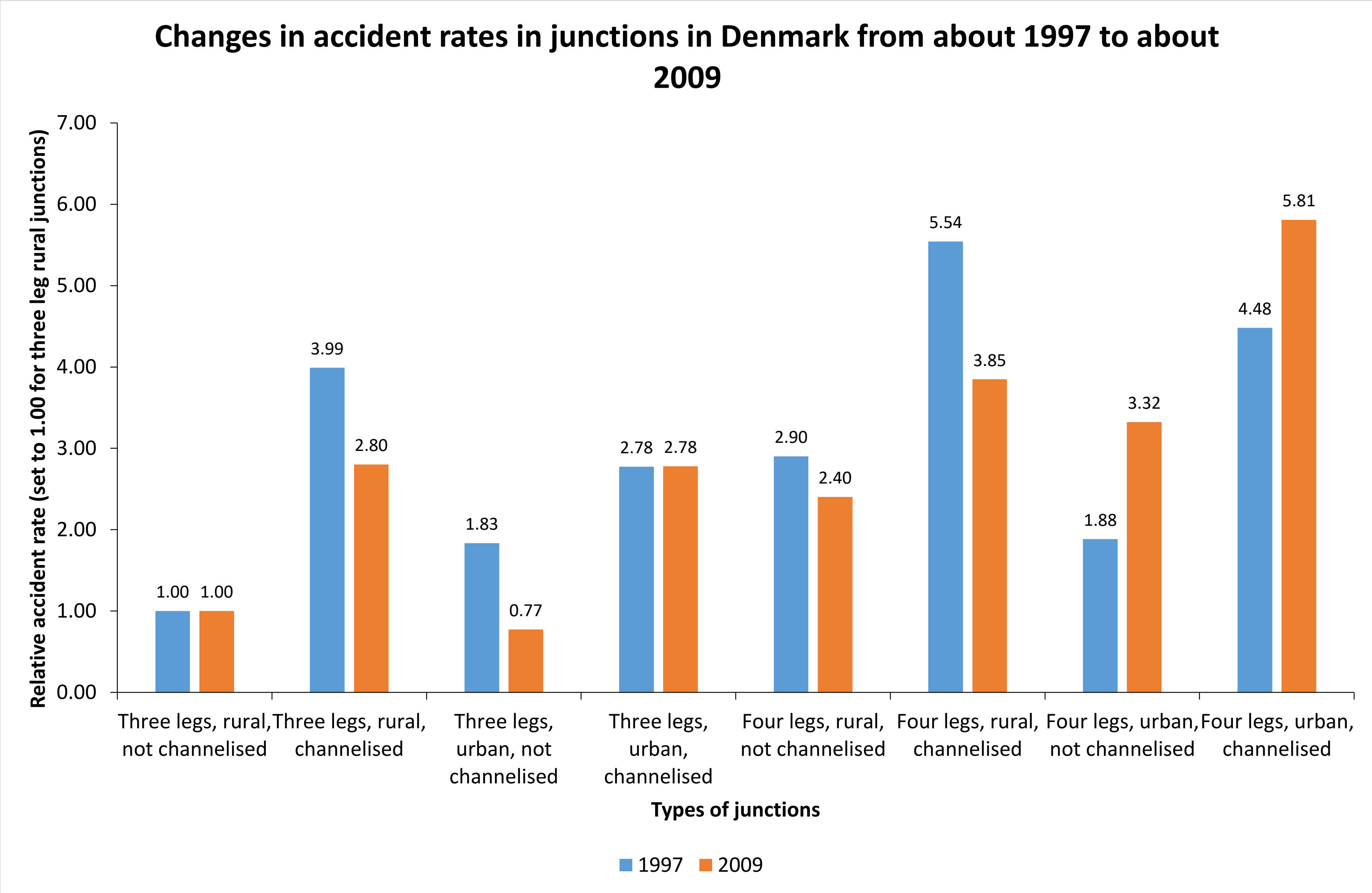
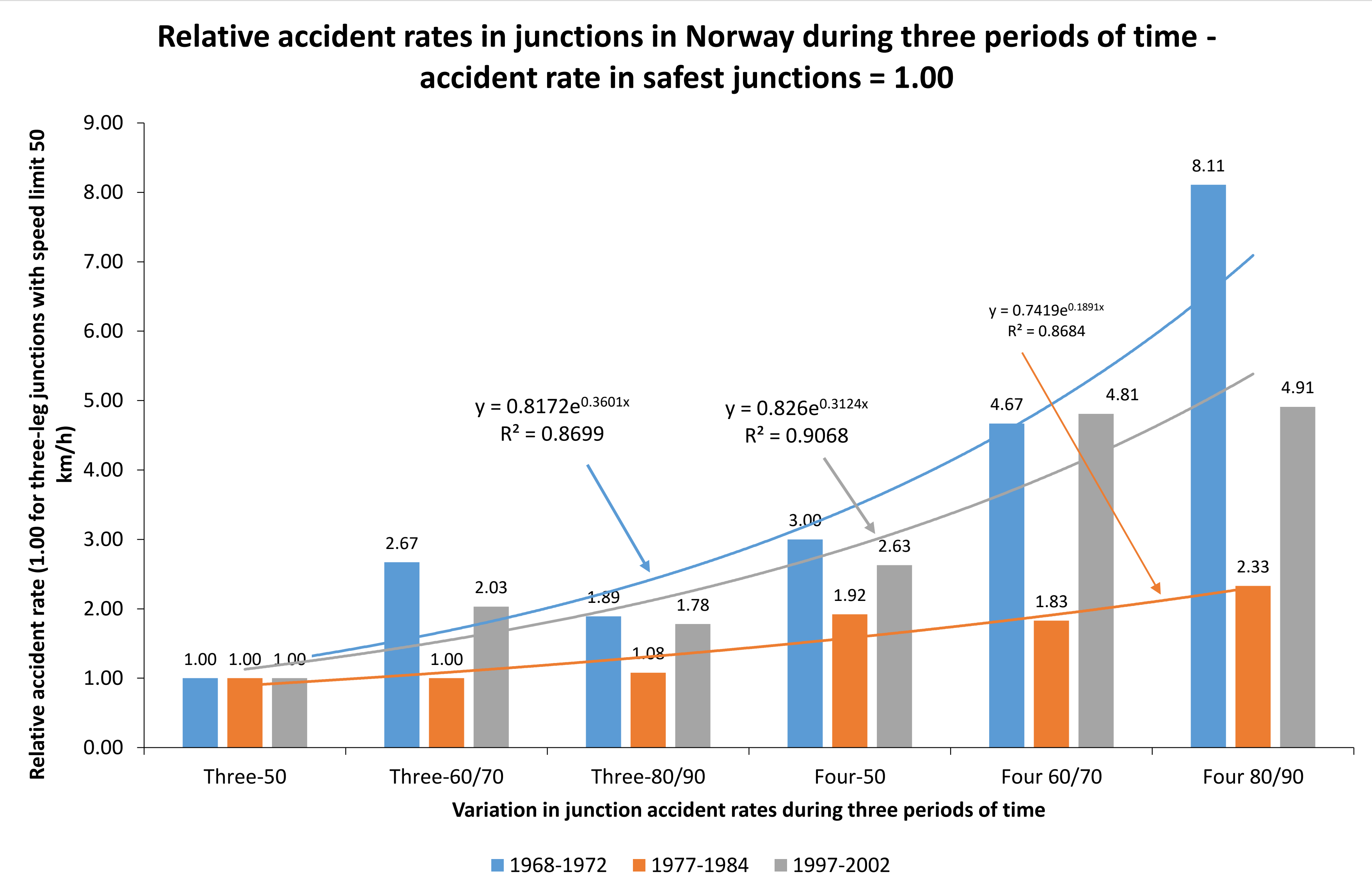
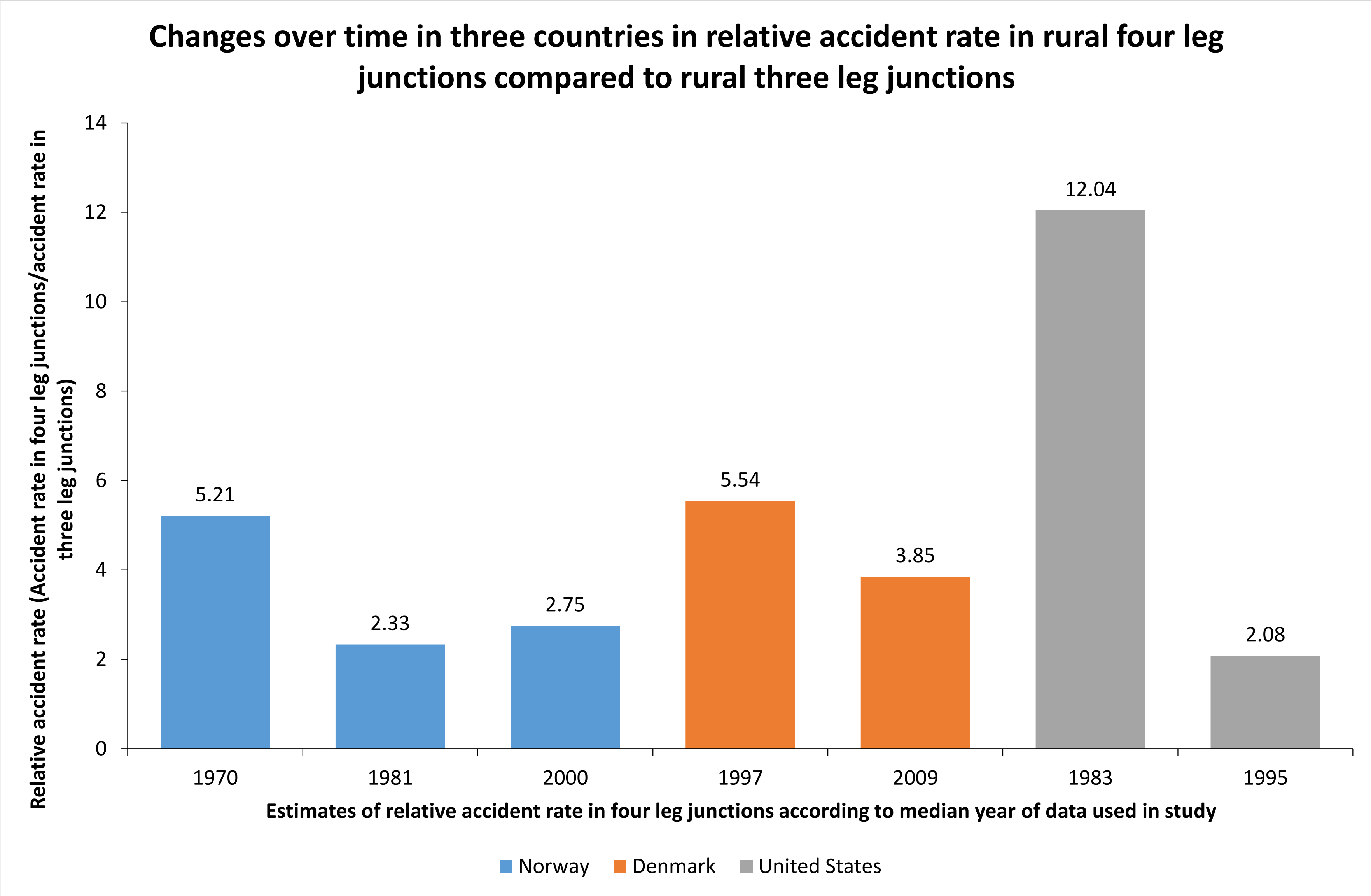

Changes in accident rates in junctions in Denmark from about 1997 to about 2009
Relative accident rate (set to 1.00 for three leg rural junctions)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.00
1.00
3.99
2.80
1.83
0.77
2.78
2.78
2.90
2.40
5.54
3.85
1.88
3.32
4.48
5.81
Three legs, rural, not channelised
Three legs, rural, channelised
Three legs, urban, not channelised
Three legs, urban, channelised
Four legs, rural, not channelised
Four legs, rural, channelised
Four legs, urban, not channelised
Four legs, urban, channelised
Types of junctions
1997
2009

Figure 4:



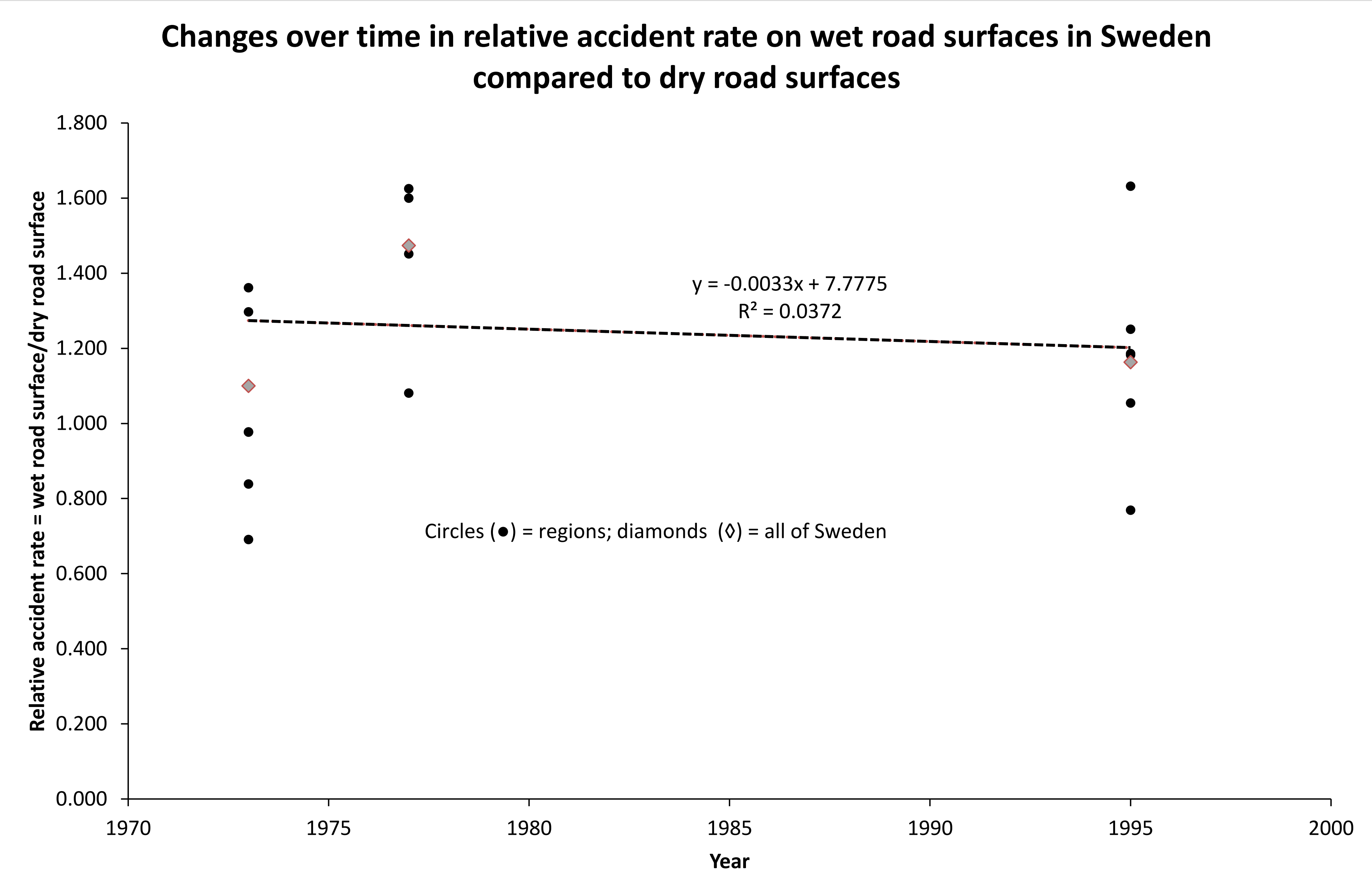
Relative accident rates in junctions in Norway during three periods of time - accident rate in safest junctions = 1.00
Relative accident rate (1.00 for three-leg junctions with speed limit 50 km/h)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
y = 0.8172e^0.3601x
R² = 0.8699
y = 0.826e^0.3124x
R² = 0.9068
y = 0.7419e^0.1891x
R² = 0.8684
1.00
1.00
1.00
2.67
1.00
2.03
1.89
1.08
1.78
3.00
1.92
2.63
4.67
1.83
4.81
8.11
2.33
4.91
Three-50
Three-60/70
Three-80/90
Four-50
Four 60/70
Four 80/90
Variation in junction accident rates during three periods of time
1968-1972
1977-1984
1997-2002

Figure 5:



Changes over time in three countries in relative accident rate in rural four leg junctions compared to rural three leg junctions
Relative accident rate (Accident rate in four leg junctions/accident rate in three leg junctions)
14
12
10
8
6
4
2
0
5.21
2.33
2.75
5.54
3.85
12.04
2.08
1970
1981
2000
1997
2009
1983
1995
Estimates of relative accident rate in four leg junctions according to median year of data used in study
Norway
Denmark
United States

Figure 6:



Changes over time in relative accident rate on wet road surfaces in Sweden compared to dry road surfaces
Relative accident rate = wet road surface/dry road surface
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
1970
1975
1980
1985
1990
1995
2000
Year
y = -0.0033x + 7.7775
R² = 0.0372
Circles (●) = regions; diamonds (◊) = all of Sweden

Figure 7:

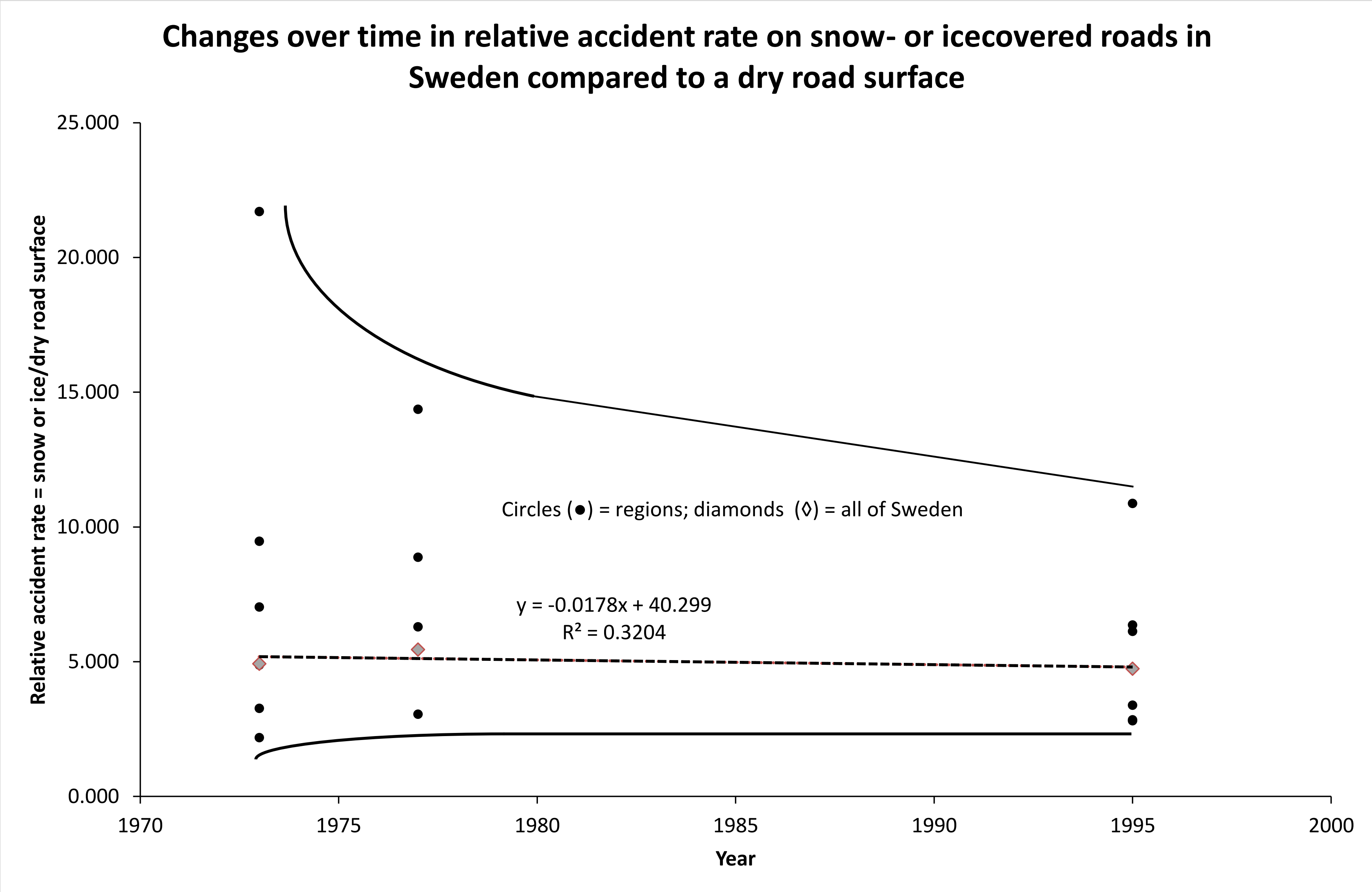
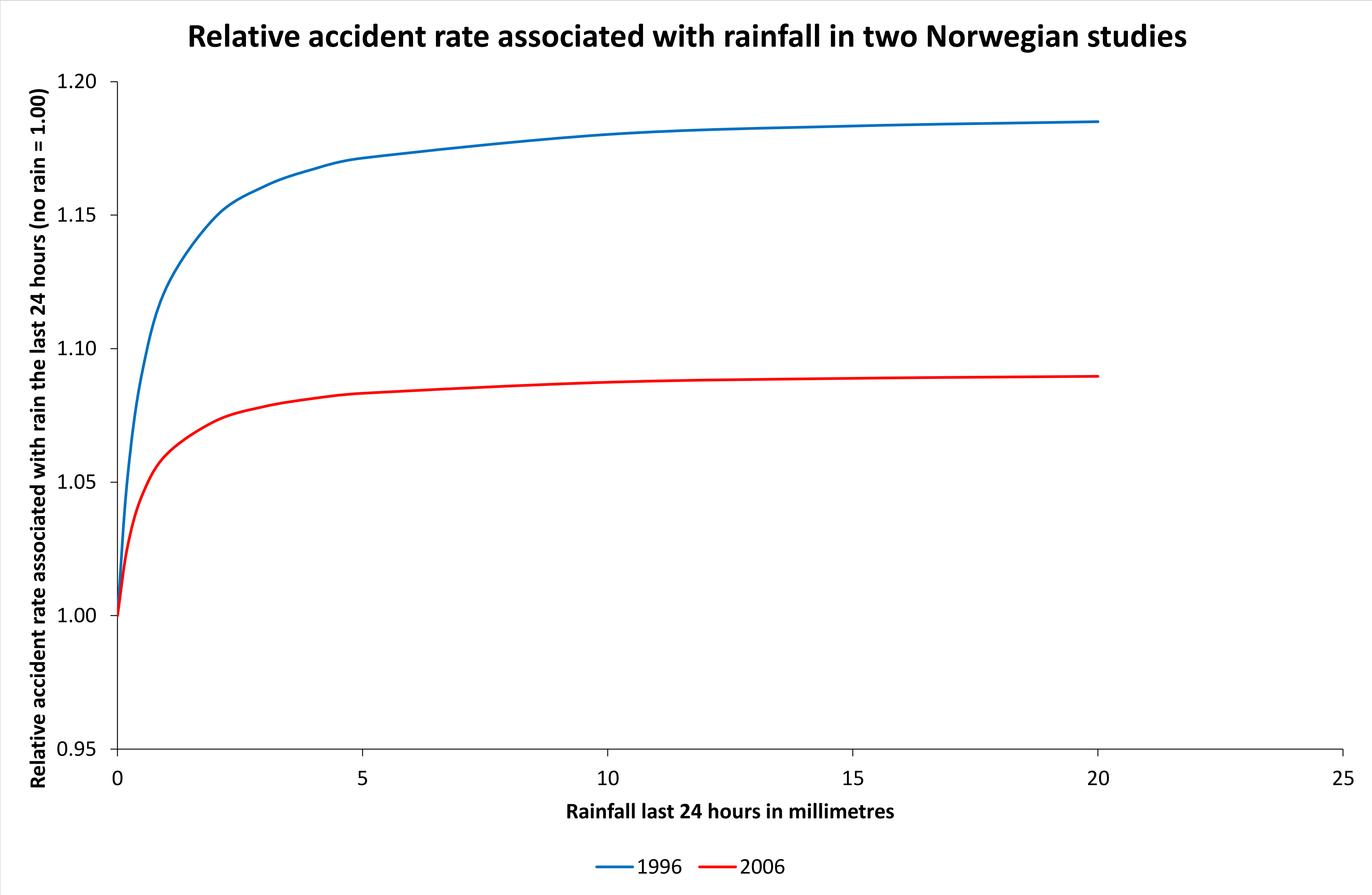

Changes over time in relative accident rate on snow- or icecovered roads in Sweden compared to a dry road surface
Relative accident rate = snow or ice/dry road surface
25.000
20.000
15.000
10.000
5.000
0.000
1970
1975
1980
1985
1990
1995
2000
Year
Circles (●) = regions; diamonds (◊) = all of Sweden
y = -0.0178x + 40.299
R² = 0.3204

Figure 8:



Relative accident rate associated with rainfall in two Norwegian studies
Relative accident rate associated with rain the last 24 hours (no rain = 1.00)
1.20
1.15
1.10
1.05
1.00
0.95
0
5
10
15
20
25
Rainfall last 24 hours in millimetres
1996
2006

Figure 9:

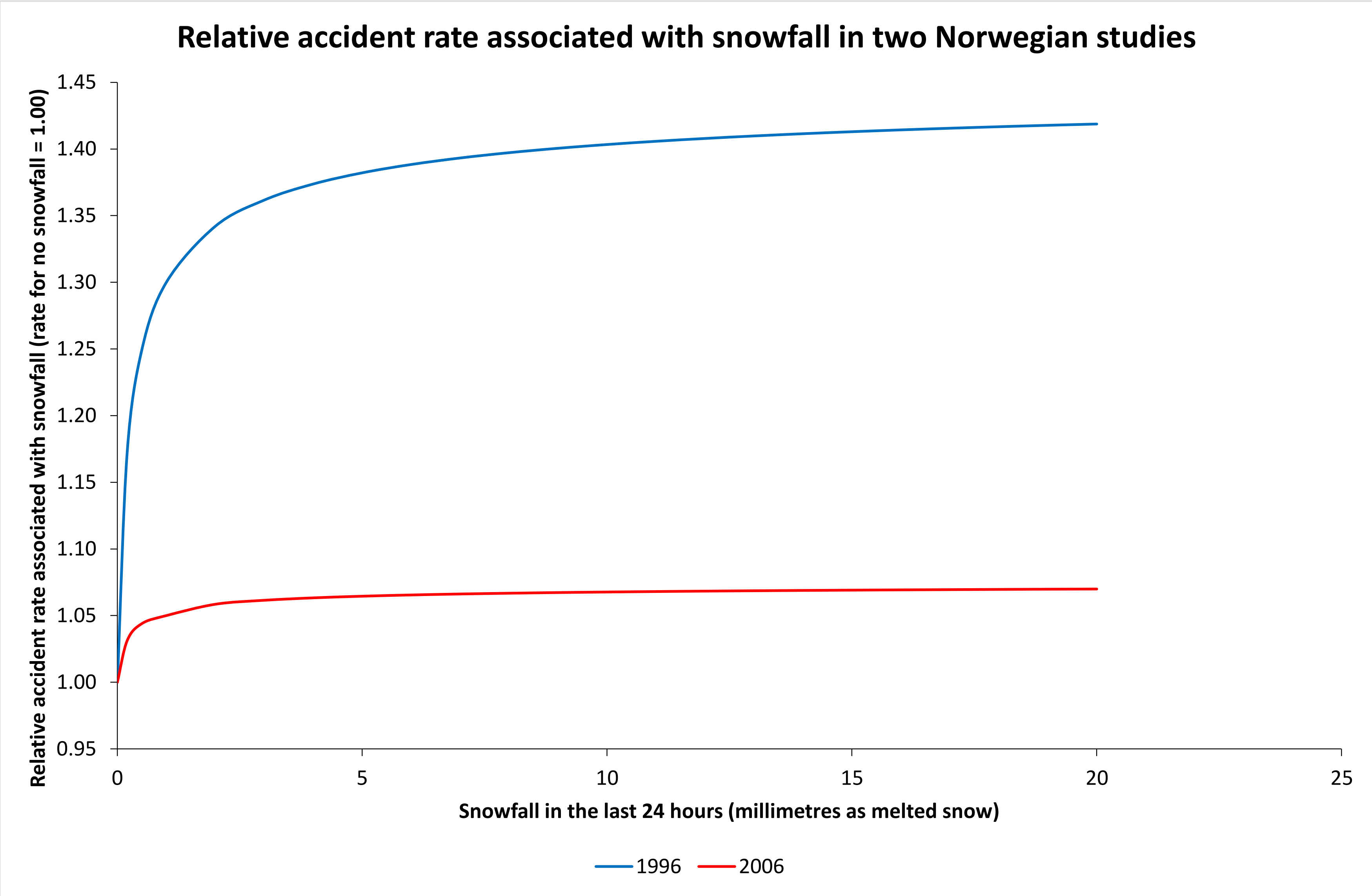
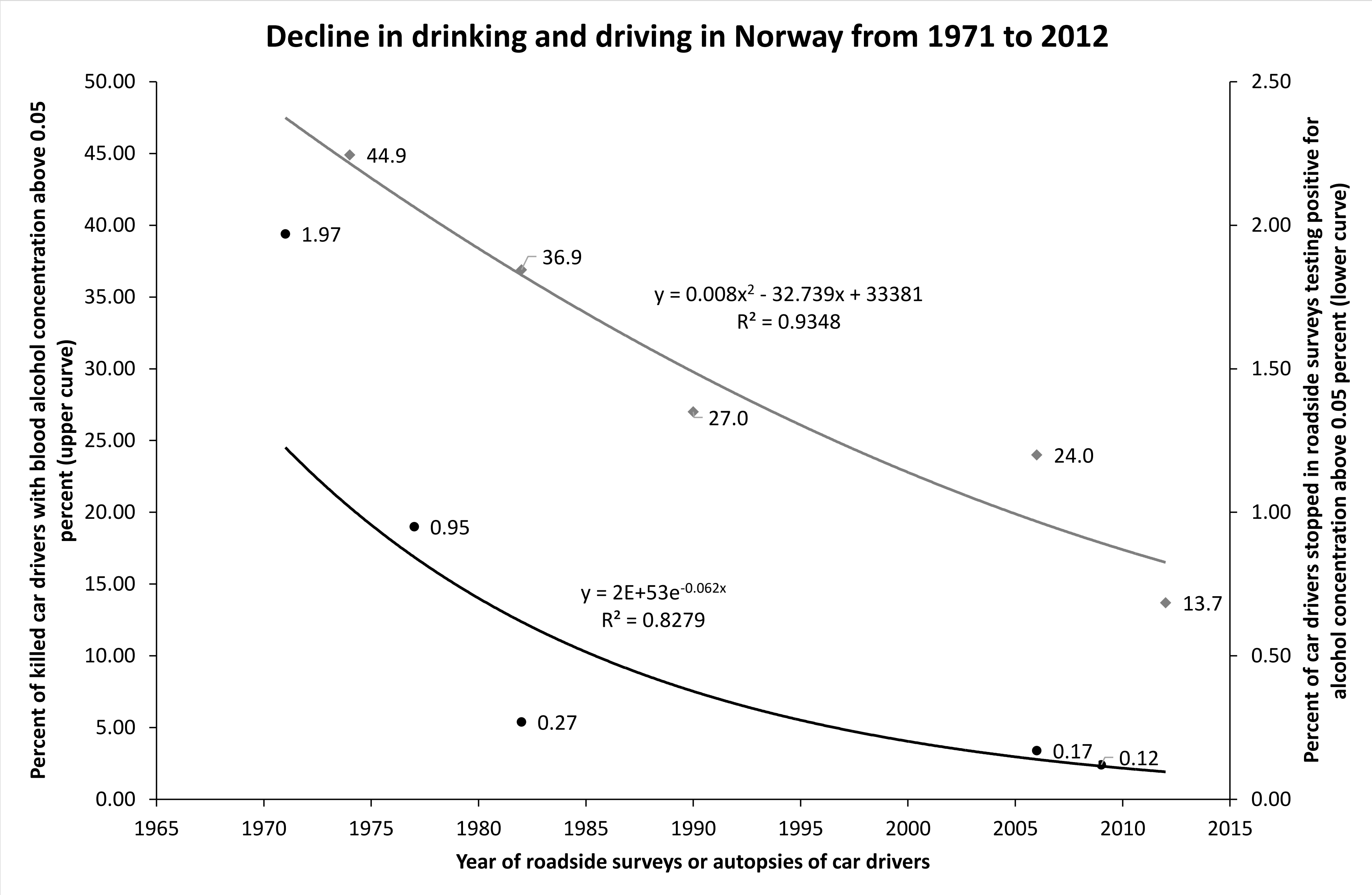

Relative accident rate associated with snowfall in two Norwegian studies
Relative accident rate associated with snowfall (rate for no snowfall = 1.00)
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0
5
10
15
20
25
Snowfall in the last 24 hours (millimetres as melted snow)
1996
2006

Figure 10:



Decline in drinking and driving in Norway from 1971 to 2012
Percent of killed car drivers with blood alcohol concentration above 0.05 percent (upper curve)
Percent of car drivers stopped in roadside surveys testing positive for alcohol concentration above 0.05 percent (lower curve)
Year of roadside surveys or autopsies of car drivers
44.9
36.9
27.0
24.0
13.7
1.97
0.95
0.27
0.17
0.12
y = 0.008x² - 32.739x + 33381
R² = 0.9348
y = 2E+53e^-0.062x
R² = 0.8279
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
2.50
2.00
1.50
1.00
0.50
0.00
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Figure 11:

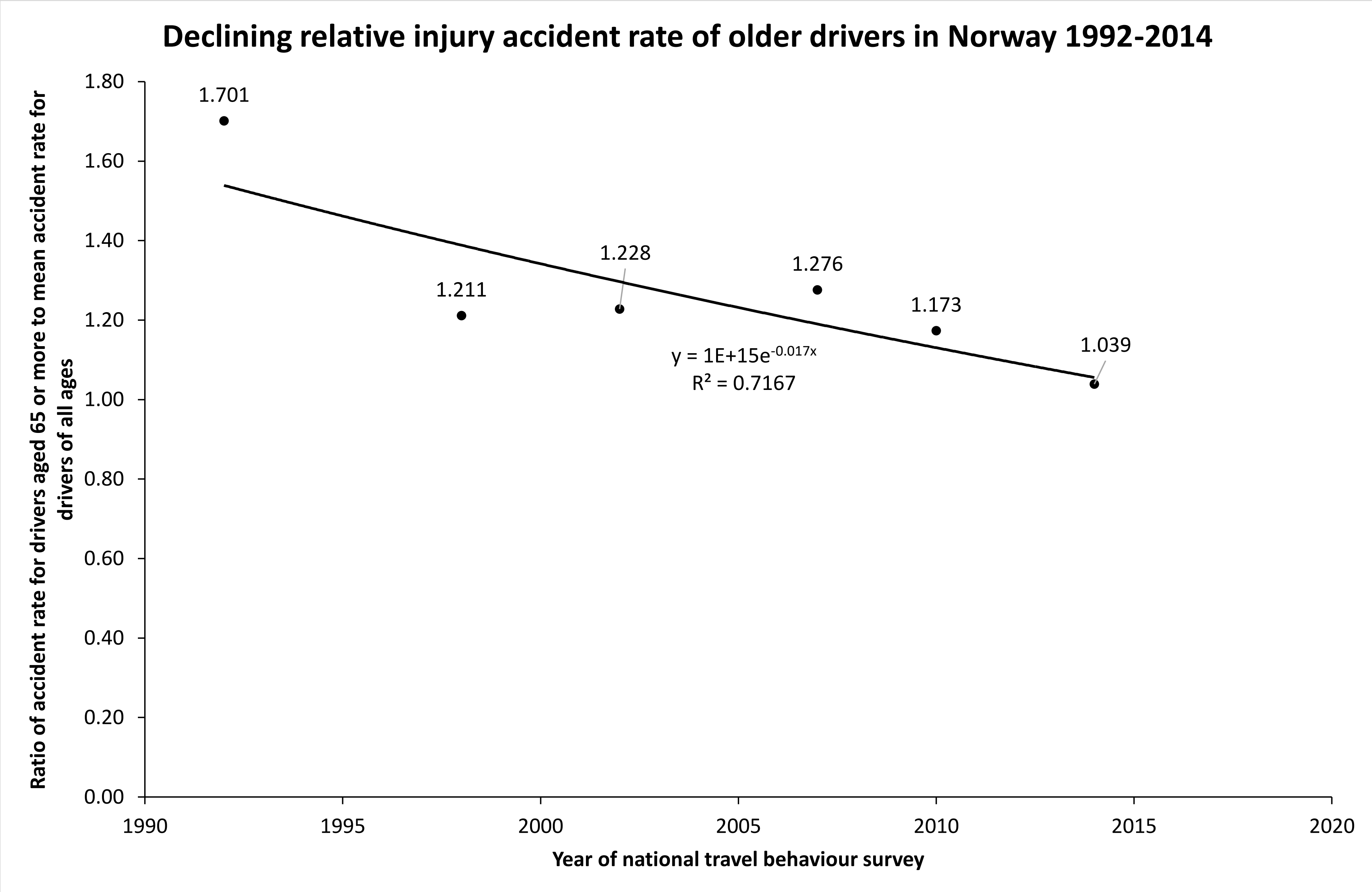
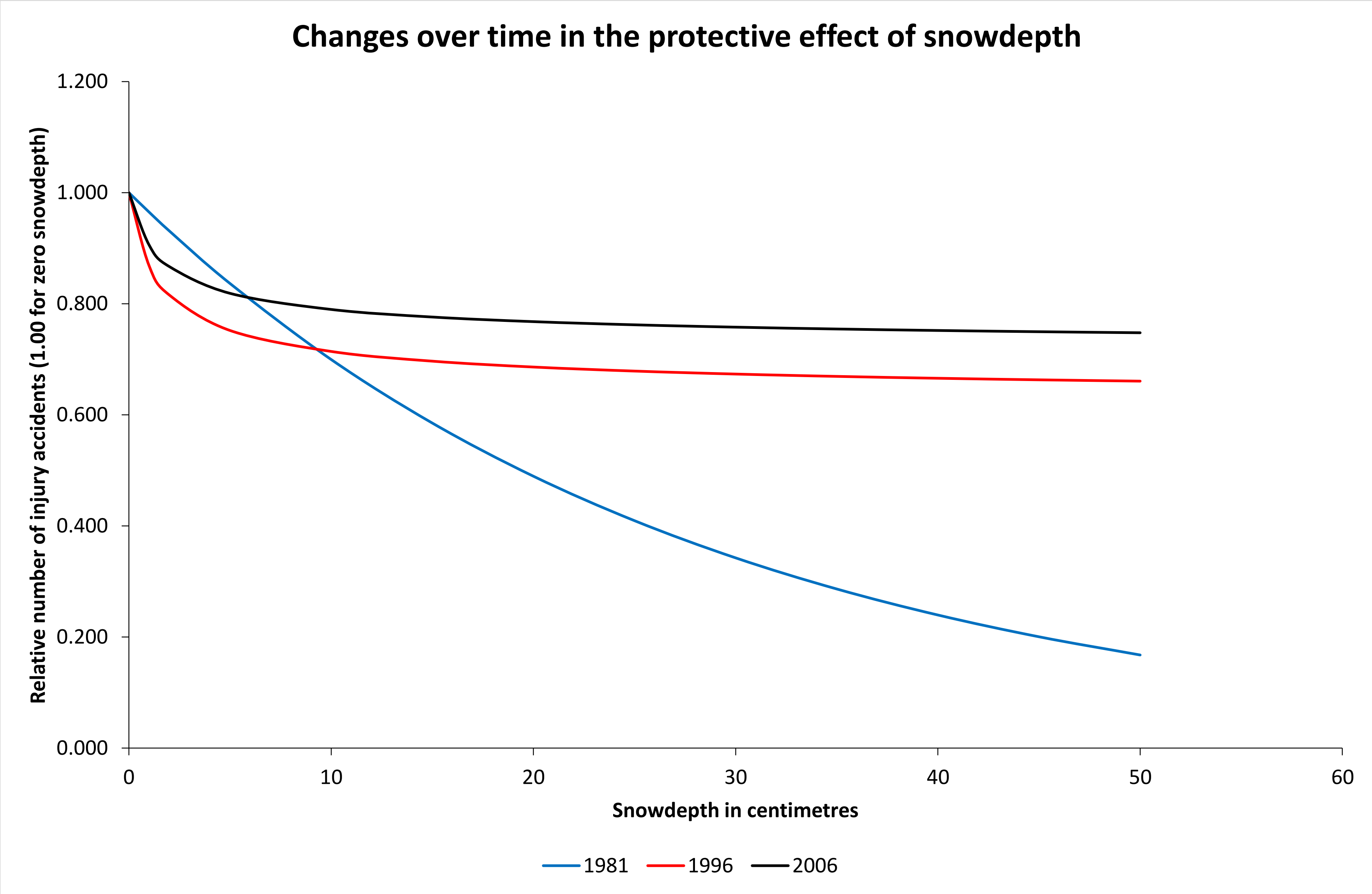

Declining relative injury accident rate of older drivers in Norway 1992-2014
Ratio of accident rate for drivers aged 65 or more to mean accident rate for drivers of all ages
Year of national travel behaviour survey
1.701
1.211
1.228
1.276
1.173
1.039
y = 1E+15e$^{-0.017x}$
R^2 = 0.7167
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1990
1995
2000
2005
2010
2015
2020

Figure 12:



Changes over time in the protective effect of snowdepth
Relative number of injury accidents (1.00 for zero snowdepth)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
10
20
30
40
50
60
Snowdepth in centimetres
1981
1996
2006