Rune Elvik
Joanna Kaminska
TØI report 1145/2011

Institute of Transport Economics
Norwegian Centre for Transport Research

Effects on accidents of reduced use of studded tyres in Norwegian cities

Analyses based on data for 2002-2009

TØI report
1145/2011

Effects on accidents of reduced use of studded tyres in Norwegian cities

Analyses based on data for 2002-2009

Rune Elvik
Joanna Kaminska

This report is covered by the terms and conditions specified by the Norwegian Copyright Act. Contents of the report may be used for referencing or as a source of information. Quotations or references must be attributed to the Institute of Transport Economics (TØI) as the source with specific mention made to the author and report number. For other use, advance permission must be provided by TØI.

ISSN 0808-1190
ISBN 978-82-480-1223-8 Paper version
ISBN 978-82-480--1222-1 Electronic version

Oslo, April 2011

Title: Effects on accidents of reduced use of studded tyres in Norwegian cities

Author(s): Rune Elvik, Joanna Kaminska

Date: 04.2011

TØI report: 1145/2011

Pages 45

ISBN Paper: 978-82-480-1223-8

ISBN Electronic: 978-82-480-1222-1

ISSN 0808-1190

Financed by: Swedish Transport Administration

Project: 3642 Effects on accidents of reduced use of studded tyres in Norwegian cities

Project manager: Rune Elvik

Quality manager: Marika Kolbenstvedt

Key words: Evaluation study; Road accidents; Studded tyres

Summary:

The effects on accidents of reduced use of studded tyres in five Norwegian cities have been evaluated. The five cities are Oslo, Drammen, Stavanger, Bergen and Trondheim. The study period is from 1.1.2002 until 31.8.2009. Except for the city of Stavanger, the use of studded tyres has been reduced in all cities. It is estimated that this has caused a 2 percent increase in the number of injury accidents. The number of property damage accidents is almost unchanged. The results are highly consistent with those of a previous study, reported in 2000.

Language of report: English

Tittel: Virkninger på trafikkulykker av redusert bruk av piggdekk i norske byer

Forfattere: Rune Elvik, Joanna Kaminska

Dato: 04.2011

TØI rapport: 1145/2011

Sider 45

ISBN Papir: 978-82-480-1223-8

ISBN Elektronisk: 978-82-480-1222-1

ISSN 0808-1190

Finansieringskilde: Trafikverket (Sverige)

Prosjekt: 3642 Effects on accidents of reduced use of studded tyres in Norwegian cities

Prosjektleder: Rune Elvik

Kvalitetsansvarlig: Marika Kolbenstvedt

Emneord: Evalueringsstudie; Piggdekk; Trafikkulykker

Sammendrag:

Virkninger på trafikkulykker av redusert bruk av piggdekk i fem norske byer er undersøkt. De fem byene er Oslo, Drammen, Stavanger, Bergen og Trondheim. Undersøkelsen omfatter perioden 2002-2009. Med unntak av Stavanger var det en klar tendens til redusert bruk av piggdekk i alle byene. I gjennomsnitt er det beregnet at redusert bruk av piggdekk har ført til 2 prosent flere personskadeulykker i piggdekksesongen. Antall ulykker med materiell skade er praktisk talt uendret. Resultatene stemmer godt overens med resultater av en tilsvarende undersøkelse som ble gjort i 2000.

Institute of Transport Economics
Gaustadalleen 21, 0349 Oslo, Norway
Telefon 22 57 38 00 - www.toi.no

Transportøkonomisk Institutt
Gaustadalleen 21, 0349 Oslo
Telefon 22 57 38 00 - www.toi.no

Copyright © Transportøkonomisk Institutt
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961
Ved gjengivelse av materiale fra publikasjonen, må fullstendig kilde oppgis

Preface

This report presents a study evaluating the effects on accidents of reduced use of studded tyres in five Norwegian cities. The five cities are Oslo, Drammen, Stavanger, Bergen and Trondheim. The study covers the period from January 1, 2002 to August 31, 2009. The study is a replication of a similar study published by the Institute of Transport Economics in 2000.

The study was commissioned by the Swedish Transport Administration (Trafikverket). There is currently a discussion in Sweden regarding the effects of studded tyres on safety, pollution and public health. There is a concern that safety will deteriorate if the use of studded tyres is reduced. The Swedish Transport Administration therefore wanted to learn what the effects have been in Norway of the reduced use of studded tyres observed in most large cities in Norway located near the coast.

Contact person for the study at the Swedish Transport Administration has been Magnus Ljungberg. Project manager at the Institute of Transport Economics has been Rune Elvik. Several other people have made important contributions to the study, including:

Jostein Mamen and Ketil Isaksen, of the division of Climate Research at the Norwegian Institute of Meteorology, by supplying weather data and providing guidance regarding extraction and interpretation of data from the e-Klima web-based database.

Tuomo Saloranta, of the Norwegian Water Resources and Energy Directorate (NVE) by providing weather data.

Harald Moseby, of the Norwegian Association of Finance (FNO), by providing data on accidents reported to insurance companies (mostly property damage accidents).

Arild Engebretsen, of the Public Roads Administration (Vegdirektoratet), by providing data on injury accidents, traffic volume and the mean speed of traffic.

Nils Gaute Voll, Institute of Transport Economics, by merging the data provided from the various data sources into a single file for use in multivariate analysis.

Joanna Kaminska, Department of Mathematics, Wroclaw University, Poland, by contributing to the statistical analyses.

Lasse Fridstrøm, Institute of Transport Economics, by clarifying important details regarding the study reported in 2000, so as to enable as exact a replication of that study as available data made possible. The present study is not an exact replication of the former study in every detail, but it comes fairly close to that.

Marika Kolbenstvedt, Institute of Transport Economics, by performing internal peer-review of the study and quality controls.

Unni Wettergreen, Institute of Transport Economics, by finishing the editing of the text and preparing the report for printing and electronic publication.

We thank all these people warmly for their contribution to the study.

Oslo, April 2011
Institute of Transport Economics

Lasse Fridstrøm	*Marika Kolbenstvedt*
Managing Director	Head of Department

Contents

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Summary:

Effects on accidents of reduced use of studded tyres in Norwegian cities

TØI Report 1145/2011
Author(s): Rune Elvik, Joanna Kaminska
Oslo 2011, 45 pages English language

Reduced use of studded tyres in five Norwegian cities from 2002 to 2009 has not had a major impact on the number of road accidents. The five cities are Oslo, Drammen, Stavanger, Bergen and Trondheim. Changes in the use of studded tyres and changes in the number of accidents have been studied in these five cities for the period from January 1, 2002 until August 31, 2009. The use of studded tyres was reduced in all cities except Stavanger. For all five cities as a group, the number of police reported injury accidents increased by 2 percent during the winter season as a result of reduced use of studded tyres. The number of insurance reported accidents (of which more than 90 percent are property damage only accidents) was almost unchanged. The results of the study are highly consistent with the results of a similar study reported by the Institute of Transport Economics in 2000.

Background and research problem

The background of this study is an ongoing discussion in Sweden regarding the impacts of studded tyres. Recently, attention has focused on the potential impacts of studded tyres on public health, arising from the spread of micro-particles that can be inhaled and may cause, or worsen, respiratory diseases. There is a political desire to reduce the use of studded tyres in major cities in Sweden. There is, however, concern that a reduced use of studded tyres may lead to an increase in the number of road accidents.

The Swedish Transport Administration (Trafikverket) therefore contacted the Institute of Transport Economics in order to commission an update of a study reported by the institute in 2000 (Fridstrøm 2000). That study included the cities of Oslo, Stavanger, Bergen and Trondheim. It covered the period from 1991 (1992 in Trondheim, 1993 in Oslo) to 2000. The study modelled changes in the use of studded tyres during this period and evaluated the effects on accidents of these changes by means of a negative binomial regression model. The use of studded tyres was reduced in all cities. The study estimated that reducing the use of studded tyres by 50 percent (e.g. from 70 percent to 35 percent) would lead to an increase of about 3 percent in the number of police reported injury accidents during the season when the use of studded tyres is permitted (from November 1 to the first Monday after Easter). For accidents reported to insurance companies (most of which are property-damage-only accidents), the effect of reduced use of studded tyres was considerably smaller; an estimated increase of less than 0.5 percent.

The use of studded tyres has continued to decline in most major cities in Norway after the year 2000. Only in the city of Stavanger did the use of studded tyres remain virtually constant between 2002 and 2009. The question the Swedish Transport Administration wanted the Institute of Transport Economics to investigate was whether the reduced use of studded tyres was associated with an increase in the number of accidents. The objective was to replicate the study reported in 2000 as closely as possible.

Sources of data and methods

The study presented in this report is, as far as available data permit, a replication of the study reported in 2000. It employs the same sources of data and the same approach to data analysis as the former study. The study relies on a multivariate negative binomial regression analysis of a large number of factors that influence the number of accidents. Data were taken from multiple sources and were supplied by, among others, the Public Roads Administration, the Norwegian Meteorological Institute and the Norwegian Association of Finance.

The study includes the cities of Oslo, Drammen, Stavanger, Bergen and Trondheim. It covers the period from January 1, 2002 to August 31, 2009. The unit of observation is day per city. The complete data set includes 2,800 days in each city, for a total of 14,000 in the five cities. The effects on accidents of reduced use of studded tyres were estimated by means of a negative binomial regression model containing 23 independent variables. This approach was chosen because it controls statistically for a large number of factors that influence accidents in addition to the use of studded tyres.

In addition to studying the effects on accidents, road user behavioural adaptation in terms of changes in the mean speed of traffic was studied. This study was included in order to estimate how road users adapt speed to factors like traffic volume, the length of daylight and changes in the weather.

A third multivariate analysis was performed in order to determine the effects of factors influencing the use of studded tyres, including the introduction of a tax for using studded tyres.

Results

The use of studded tyres has been reduced in all cities, except in Stavanger. The use of studded tyres in the city of Stavanger was marginally lower in 2009 than in 2002, but fluctuated randomly in the years between, with no clear long-term trend. In Oslo, the use of studded tyres (in the season when it is permitted) was 32.0 % in 2002, declining to 16.5 % in 2009. The corresponding figures for Drammen were 40.1 % (2002) and 30.5 % (2009); for Bergen: 31.1 % (2002) and 14.0 % (2009); for Trondheim 44.5 % (2002) and 20.4 % (2009).

Model estimates show that the number of police reported injury accidents goes down when the use of studded tyres increases (as it did some years in Stavanger

Copyright © Institute of Transport Economics,2011

and on a few occasions in the other cities), and increases when the use of studded tyres is reduced. The largest decline in the number of injury accidents observed was 1.3 %. The largest increase observed was 9.5 %. For all five cities as a group, the number of injury accidents increased by 2 %. Figure S.1 shows the relationship between percentage points of change in the use of studded tyres using 2002 as baseline and change in the number of police reported injury accidents.

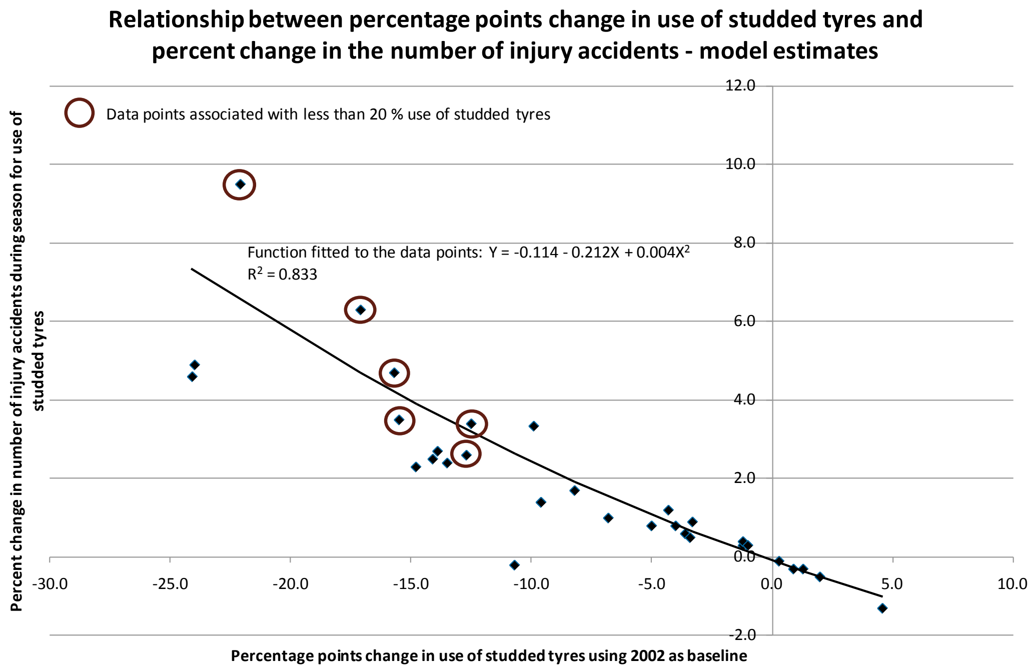


Figure S.1: Relationship between percentage points of change in use of studded tyres and percent change in the number of police reported injury accidents

There was no meaningful change in the number of insurance reported accidents (property damage accidents). The results are highly consistent with those reported in the study published in 2000.

Speed is reduced when traffic becomes denser. Speed is reduced considerably when snow is falling. If the ground is covered by snow, speed is reduced even in fine weather, although not as much as when snow is falling. Road user adaptation in terms of speed was not sufficient to fully offset the adverse effects of bad weather on the number of accidents.

Introducing a fee for the use of studded tyres was found to reduce the use of such tyres by four percentage points (e.g. from 26 to 22 percent).

Discussion and conclusions

The main source of uncertainty in a study of the kind reported here, is whether one has been able to successfully control for all potentially confounding variables, thus supporting a claim that the changes in the number of accidents were caused by changes in the use of studded tyres, and not something else. Unfortunately, there is a potentially important omitted variable in this study. That is changes in winter road maintenance. Data on winter road maintenance are not available in a form that permits inclusion of this variable in a multivariate analysis.

Copyright © Institute of Transport Economics, 2011

Aggregate data on municipal expenditures suggest that road maintenance has been increased from 2002 to 2009 in all cities except for the city of Trondheim. Expenditures on road maintenance have grown considerably more than wage expenditures for municipal employees. It is therefore possible that a higher standard of road maintenance may have prevented an increase in the number of accidents that would otherwise have happened. It is, however, not possible to estimate the effect on accidents of changes in road maintenance in a meaningful way.

Changes in road maintenance should, however, only be treated as an omitted variable if these changes did not occur in response to changes in the use of studded tyres. If winter maintenance of roads was changed in order to compensate for the effects of reduced use of studded tyres, it is an effect of reduced use of studded tyres that should not be controlled for in statistical analyses.

The fact that the results, at least for injury accidents, display a very clear dose-response pattern (see Figure S.1), and that they agree very well with the results of the previous study suggest as the most reasonable conclusion that reduced use of studded tyres is associated with a quite modest increase in the number of injury accidents. For insurance reported accidents (mostly property damage only accidents), no effects could be detected.

Copyright © Institute of Transport Economics,2011

Sammendrag:

Virkninger på trafikkulykker av redusert bruk av piggdekk i norske byer

TØI rapport 1145/2011
Forfatter(e): Rune Elvik, Joanna Kaminska
Oslo 2011, 45 sider

Redusert bruk av piggdekk i fem av de største byene i Norge i perioden 2002-2009 har i liten grad påvirket antall trafikkulykker. De fem byene er Oslo, Drammen, Stavanger, Bergen og Trondheim. Utviklingen i bruk av piggdekk og trafikkulykker i disse byene er studert for perioden fra 1.1.2002 til 31.8.2009. I alle byer unntatt Stavanger er bruken av piggdekk redusert. For alle byer sett under ett, har antallet politirapporterte trafikkulykker med personskade i piggdekksesongen økt med 2 prosent som følge av redusert piggdekkbruk. Antall forsikringsmeldte ulykker (mer enn 90 prosent av disse er med kun materiell skade) er praktisk talt uendret. Studien bekrefter resultatene av en tilsvarende tidligere studie, utført av Transportøkonomisk institutt i 2000.

Bakgrunn og problemstilling

Bakgrunnen for denne studien er en pågående diskusjon i Sverige om virkninger av piggdekk. De mulige virkningene av høy bruk av piggdekk på folkehelsen, i form av spredning av mikropartikler som kan pustes inn og gi, eller forverre, luftveissykdommer har fått økt oppmerksomhet. I de største byene i Sverige er det derfor et politisk ønske om å redusere bruken av piggdekk. Det hersker imidlertid bekymring for at dette kan føre til flere trafikkulykker.

Trafikverket kontaktet på denne bakgrunn Transportøkonomisk institutt med sikte på å få oppdatert en studie som ble gjort i 2000 om virkninger av redusert bruk av piggdekk i de største byene i Norge (Fridstrøm 2000). Studien omfattet byene Oslo, Stavanger, Bergen og Trondheim i perioden fra 1991 til 2000 (fra 1992 i Trondheim og 1993 i Oslo). I løpet av denne perioden ble bruken av piggdekk redusert i alle byene. Studien beregnet at en halvert bruk av piggdekk ville gi om lag 3 prosent flere personskadeulykker i piggdekksesongen. Den beregnede virkningen på antall forsikringsmeldte ulykker var uhyre liten, mindre enn 0,5 prosent økning.

I perioden etter 2000 har nedgangen i bruk av piggdekk fortsatt i de fleste store byer i Norge. Kun i Stavanger er bruken praktisk talt uendret fra 2002 til 2009. Spørsmålet Trafikverket ønsket svar på var hvilke virkninger for trafikksikkerheten den fortsatte nedgangen i bruk av piggdekk i norske byer har hatt.

Datakilder og metode

Studien som legges fram i denne rapporten er, så langt mulig, en kopi av studien som ble gjort i 2000. De samme datakilder og statistiske analyseteknikker er benyttet. Studien bygger på en multivariat analyse av data om en lang rekke forhold som påvirker antall trafikkulykker. Data er hentet fra ulike kilder, blant dem Statens vegvesen (personskadeulykker, trafikkmengde, fart), Finansnæringens Fellesorganisasjon (forsikringsmeldte ulykker) og Meteorologisk institutt (værdata).

Studien omfatter byene Oslo, Drammen, Stavanger, Bergen og Trondheim. Den dekker perioden 1.1.2002 – 31.8.2009. Årene 2000 og 2001 kunne ikke inkluderes fordi data om trafikkmengde og fart manglet. Virkninger på ulykkene av endret bruk av piggdekk er beregnet ved hjelp av en negativ binomial regresjonsmodell med 23 forklaringsvariabler. Denne metoden ble valgt for å kunne kontrollere statistisk for flest mulig av de faktorer som påvirker ulykkene i tillegg til bruken av piggdekk.

I tillegg til virkninger på ulykkene, inngår en studie av faktorer som påvirker trafikkens gjennomsnittsfart. Denne studien er tatt med for å finne ut i hvilken grad trafikantene tilpasser sin atferd til faktorer som værforhold, dagslys, trafikkmengde og andel som bruker piggdekk.

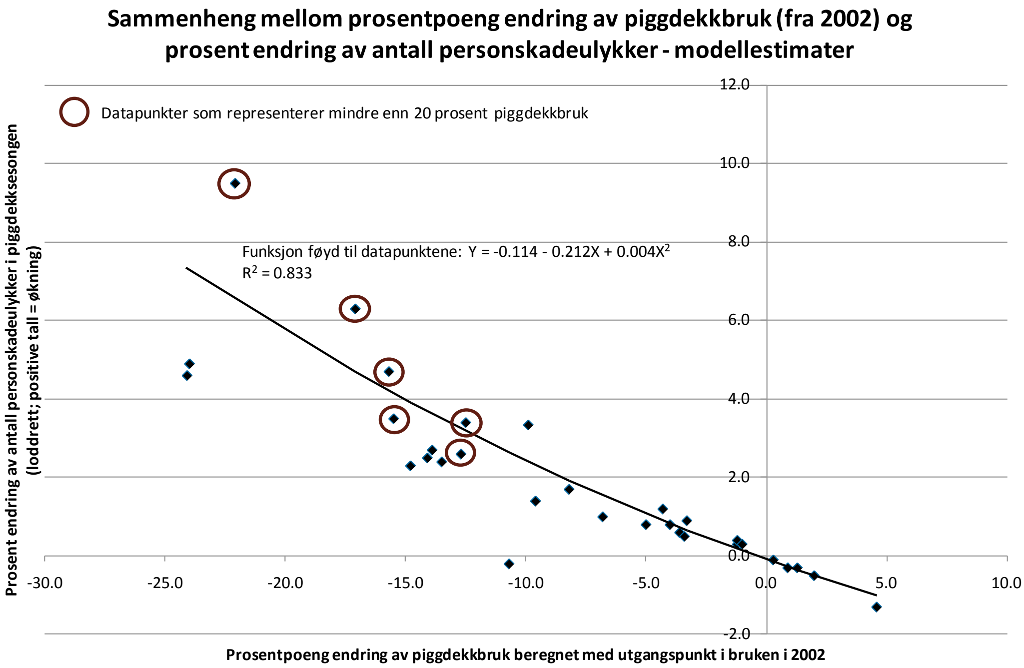
En tredje multivariat analyse ble utført for å identifisere faktorer som påvirker bruken av piggdekk. Her ble det spesielt undersøkt om innføring av et gebyr for bruk av piggdekk fører til redusert bruk av slike dekk.

Resultater

Bruken av piggdekk er redusert i alle fem byer, unntatt Stavanger. I Stavanger var bruken av piggdekk ubetydelig lavere i 2009 enn i 2002 og svingte i årene mellom tilfeldig opp og ned uten noen klar tendens. I Oslo gikk bruken av piggdekk ned fra 32 % i 2002 til 16,5 % i 2009. Tilsvarende tall for Drammen var 40,1 % (2002) og 30,5 % (2009). For Bergen var tallene 31,1 % (2002) og 14,0 % (2009) og for Trondheim var de 44,5 % (2002) og 20,4 % (2009).

Beregninger viser at antall personskadeulykker i piggdekksesongen går ned når bruken av piggdekk øker og går opp når bruken av piggdekk går ned. Det er en tydelig dose-responssammenheng. Denne sammenhengen fremkommer etter at det er kontrollert for alle andre forklaringsfaktorer som inngår i studien. Den største økningen i ulykker med personskade i løpet av piggdekksesongen som kan knyttes til redusert bruk av piggdekk er på 9,5 %. Den største nedgangen i antall personskadeulykker som kan knyttes til økt bruk av piggdekk er på 1,3 %. I gjennomsnitt for alle byer er antall personskadeulykker i piggdekksesongen økt med 2 %. Figur S.1 viser sammenhengen mellom antall prosentpoeng endring av piggdekkbruk (beregnet med utgangspunkt i bruken i 2002) og prosent endring av antall personskadeulykker i piggdekksesongen. Piggdekksesongen er definert som alle døgn der beregnet bruk av piggdekk var mer enn 0 prosent.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961



Figur S.1: Sammenheng mellom prosentpoeng endring av piggdekkbruk (med utgangspunkt i bruken i 2002) og prosent endring av antall personskadeulykker i piggdekksesongen

Endringene i antall forsikringsmeldte ulykker (stort sett materiellskadeulykker) er usystematiske og betydelig mindre enn endringene i antall personskadeulykker.

Resultatene av undersøkelsen med hensyn til trafikkulykker stemmer svært godt overens med resultatene av undersøkelsen som ble lagt fram i 2000.

Undersøkelsen viser at farten går ned når trafikken blir tettere. Farten synker betydelig når det snør. Hvis det ligger snø på bakken, reduseres også farten litt, selv i pent vær. Fartstilpasningene er imidlertid ikke store nok til å kompensere fullt ut for virkningene på ulykkesrisikoen av nedbør i form av regn eller snø og variasjoner i dagslysets lengde.

Innføring av gebyr for bruk av piggdekk reduserer i gjennomsnitt bruken av piggdekk med 4 prosentpoeng.

Drøfting og konklusjoner

Den viktigste kilden til usikkerhet ved denne typen undersøkelser er hvor godt man klarer å isolere og måle på en riktig måte virkningene av den faktoren man ønsker å måle virkninger av, i dette tilfellet endret (i hovedsak redusert) bruk av piggdekk. Studien kontrollerer statistisk for svært mange andre faktorer som påvirker trafikksikkerheten. En viktig faktor har det likevel ikke vært mulig å kontrollere for. Det er endringer i standarden på vintervedlikeholdet av vegene.

I prinsippet er det ikke mulig å utelukke at de endringer i ulykkestall som ifølge studien tilskrives endret bruk av piggdekk delvis kan ha sammenheng med endringer i vintervedlikehold. Data om endringer i vintervedlikehold foreligger ikke i en slik form at de kunne inngå i den multivariate analysen.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

En nærliggende antakelse er at redusert vintervedlikehold forverrer føreforholdene og gir flere ulykker. Omvendt kan det antas at bedre vintervedlikehold gir færre ulykker. For å få et bilde av mulige endringer i standarden på vintervedlikeholdet av gater og veger i de fem byene, er kommunale utgiftstall hentet fra databasen KOSTRA, som er tilgjengelig på Statistisk Sentralbyrås hjemmeside. Utgiftstallene skiller dessverre ikke mellom sommervedlikehold (asfaltering, oppmerking) og vintervedlikehold (brøyting, salting). I alle byer unntatt Trondheim er imidlertid utgiftene til vegvedlikehold økt betydelig fra 2002 til 2009, langt mer enn økningen i lønnsutgifter til kommunalt ansatte. Det tyder på at standarden på vegvedlikeholdet er økt. I prinsippet kan dette tenkes å ha motvirket en ytterligere økning av ulykkene som kunne ha skjedd dersom vedlikeholdet ikke var blitt forsterket.

Tilgjengelige data gjør det ikke mulig å beregne virkningene på ulykkene av økt vegvedlikehold. Resultatene tyder uansett ikke på at redusert bruk av piggdekk er forbundet med noen stor økning i trafikkulykkene. De beregnede økningene er langt fra statistisk signifikante, men mønsteret i resultatene er likevel meget systematisk, i det minste for personskadeulykkene.

Det bør dessuten påpekes at dersom endringer i vintervedlikeholdet er et resultat av endringer i bruken av piggdekk, det vil si at disse endringene er iverksatt for å kompensere for redusert bruk av piggdekk, er det ikke riktig å kontrollere statistisk for endringer i vintervedlikehold når man skal beregne virkningene av endret bruk av piggdekk. Endringene i vintervedlikehold vil i et slikt tilfelle være en del av virkningene av endret bruk av piggdekk, ikke en feilkilde det skal kontrolleres for.

Det klare mønsteret i resultatene, samt det faktum at resultatene i stor grad samsvarer med en tidligere undersøkelse utført med samme metode tyder på at den mest rimelige konklusjonen er at redusert bruk av piggdekk fører til en beskjeden økning av antall personskadeulykker om vinteren. For forsikringsmeldte ulykker (materiellskadeulykker) kan ingen virkning påvises.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

1 Background and research problem

1.1 Background

The use of studded tyres on motor vehicles during winter is common in Norway, Finland and Sweden. Studded tyres are mainly intended to enhance friction and thereby improve safety. A meta-analysis of studies reported before 1999 (Elvik 1999) concluded that cars using studded tyres have a slightly lower accident rate per kilometre of driving during winter than cars using other types of tyres. The difference in accident rate was not statistically significant at conventional levels. The study found that the effect attributed to studded tyres was strongly related to study quality. Larger effects were reported in studies with poor control for potentially confounding factors than in more well-controlled studies.

The meta-analysis also summarised the findings of studies that have evaluated the effects of laws banning the use of studded tyres. Such laws have been passed in some states in the United States of America, some provinces in Canada and the northern part of Japan. Banning the use of studded tyres was associated with a small increase in the number of accidents in winter, roughly 4 %, according to the most recent evidence from Hokkaido in Japan.

In 2000, a study evaluated the effects on safety of reduced use of studded tyres in four Norwegian cities (Fridstrøm 2000): Oslo, Bergen, Trondheim and Stavanger. During the period from 1993 to 2000, use of studded tyres was reduced from about 80 % to about 35 % in Oslo. In Bergen, the use of studded tyres went down from about 70 % in 1991 to about 45 % in 2000. In Trondheim, the use of studded tyres was reduced from roughly 90 % in 1992 to roughly 70 % in 2000. In Stavanger, the use of studded tyres initially increased from about 55 % in 1991 to around 75 % during 1993-1995, but then declined to about 40 % in 2000.

The study estimated that halving the use of studded tyres, e.g. reducing the share of cars using such tyres from 70 % to 35 %, was associated with an increase of the number of injury accidents during winter of some 2-5 %, and very small changes in the number of property-damage-only accidents of less than 1 %.

Thus, studies performed before 2000 agree that the use of studded tyres does confer a small safety benefit. Reducing the use of studded tyres was found to be associated with a small increase in the number of accidents. However, in view of the fact that these effects were small and uncertain, recent discussion about the use of studded tyres in Norway has focused more on the environmental impacts of studded tyres. Studded tyres wear down the road surface and tear up micro-particles that can be inhaled and cause health problems, particularly for individuals who have respiratory diseases. Several cities in Norway have therefore introduced measures to discourage the use of studded tyres. In Oslo, Bergen and Trondheim, car owners have to pay a fee for using studded tyres. The use of studded tyres has gone down in all these cities in the last few years (Muskaug et al. 2009).

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

1.2 Recent studies of safety aspects of studded tyres

The environmental impacts of studded tyres are debated in Sweden as well as Norway, but in Sweden concern about adverse impacts on road safety if the use of studded tyres is reduced appears to be stronger than in Norway. A search of the TRANSPORT literature database, using “studded tires” as search term identified 113 studies, but only 34 of these studies had been published after 2000 (i.e. in the years from 2001 to 2010). Most of the studies dealt with environmental impacts of studded tyres. Few studies were found that shed new light on the safety effects of studded tyres.

An American study (Scheibe 2002) compared the stopping distance from a speed of 40 km/h for different types of tyres. Three types of tyres were compared: (1) studded tyres, (2) Non-studded winter tyres (the “Blizzak” tyres manufactured by Bridgestone and Firestone), and (3) All season tyres. Three types of road surface were compared: (1) Packed snow, (2) Ice, (3) Bare road surface. Results of trials made in Fairbanks, Alaska are shown in Figure 1.

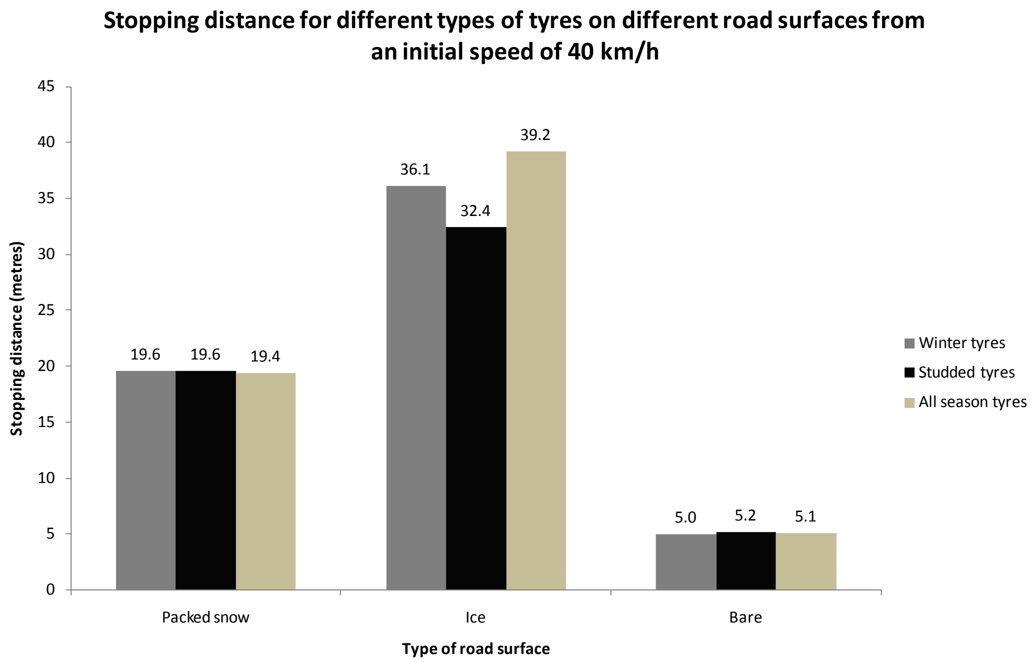


Figure 1: Stopping distance on different road surfaces with different types of tyres. Source: Scheibe 2002, Figure 9

The stopping distances were almost identical for the three types of tyres on packed snow and bare road surfaces. It was only on an ice-covered road surface that studded tyres provided an advantage. This study indicates that a safety improvement associated with using studded tyres can only be expected on ice-covered road surfaces.

A Japanese study (Asano et al. 2002) evaluated costs and benefits of the ban on studded tyres in Sapporo in Japan. The principal focus of the study was on environmental impacts, but safety impacts were also included in the cost-benefit analysis. Unfortunately, the presentation of safety impacts is rather confusing and incomplete. It is difficult to interpret the information presented, but the figures given in Table 2 of the paper are perhaps intended to show the number of accidents per million vehicle kilometres of driving (the text in the relevant

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

columns of the table is meaningless). There appears to have been an increase from 0.136 accidents per million vehicle kilometres of driving before the ban on studded tyres to 0.237 accidents per million vehicle kilometres of driving after the ban on studded tyres. This is an increase of 74 %, which is considerably more than the modest increase of about 4 % reported in earlier studies of the ban. However, as the text given in the table is confusing, it is not clear that this interpretation is correct. The paper is, in general, not well-presented and it is a bit surprising that it was accepted for publication.

Öberg and Möller (2009) estimated how a reduced use of studded tyres in Sweden might influence road safety in winter. The current use of studded tyres was estimated to be 70 %. The effects on safety of reducing the use of studded tyres to 50 % or 20 % were estimated. On roads covered by snow or ice, reducing the use of studded tyres to 50 % was associated with an expected increase of 3% in the number of injury accidents. If the use of studded tyres was reduced to 20 %, injury accidents were expected to increase by 7.5 %. On roads covered by ice, reducing the use of studded tyres to 50 % was associated with an increase of 9 % in the number of injury accidents. Reducing the use of studded tyres to 20 % was associated with an estimated increase of 11 % in the number of injury accidents. Considering the fact that not all accidents during winter occur on roads that are covered by snow or ice, the increase in the total number of accidents during winter is smaller than the percentages stated above, and not altogether out of line with the effects estimated by Fridstrøm (2000). The report also assessed whether the estimated increase in the number of accidents could be prevented by increasing winter road maintenance. It was concluded that it was not possible to compensate for reduced use of studded tyres by stepping up road maintenance.

A recent study by Strandroth et al. (2011), so far unpublished, estimated the effect of studded tyres on fatal accidents to be a reduction of 42 % on roads covered by snow or ice and an increase of 6 % on dry or wet road surfaces. The overall effect for all road surface conditions combined can be estimated as an accident reduction of 38 % (by deriving statistical weights from confidence intervals provided). No previous study has reported the effect of studded tyres on fatal accidents. It is therefore difficult to compare the findings of this study to previous studies. If real, however, the estimated impacts do justify a concern that safety could be jeopardised if the use of studded tyres is reduced.

The Swedish Transport Administration has commissioned the Institute of Transport Economics to update the study made in 2000 concerning the effects on safety of reduced use of studded tyres in Norwegian cities. Ten years have passed since that study was reported. In the meantime, the trend towards less use of studded tyres has continued in all the cities that were included in the original study. This report presents the results of an updated analysis of the effects on road safety of reduced use of studded tires in a sample of Norwegian cities.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

1.3 Research problem

The main problem to be answered in this report is:

What are the effects on road safety of a reduced use of studded tyres in major cities in Norway?

The report seeks to answer this question by replicating, as far as available data permit, the study reported in 2000 (Fridstrøm 2000). This allows for a direct comparison of the results of the two studies. In addition to the main research problem, a number of other questions are also of interest:

- Do the effects of reduced use of studded tyres vary according to accident severity?
- Are there signs of a "threshold" effect on accidents with respect to the share of traffic performed by cars using studded tyres?
- What are the effects of weather, daylight and calendar events on accidents?

In the study published in 2000, there was evidence of a larger effect of less use of studded tyres on injury accidents than on property-damage-only accidents. In the present study, the same two levels of accident severity have been applied.

The use of studded tyres is likely to influence the safety not just of the cars using such tyres, but also the safety of cars not using studded tyres. The reason is that the studs tear down snow or ice and thus clears the road surface more quickly of snow or ice than if studded tyres were not used (Krokeborg 1998). This means that a higher share of traffic takes place on bare road surfaces, which is an advantage for the safety of cars not using studded tyres. There is a concern that if the share of cars using studded tyres becomes very small, the benefits of the studs in wearing down snow or ice will be lost. More of traffic will then be performed on roads covered by snow or ice and this could lead to a higher overall accident rate in winter (i.e. a higher mean accident rate for all road surface conditions combined).

Road safety in winter is influenced by a large number of factors in addition to the use of studded tyres. Weather and daylight are known to have large effects; these effects must be controlled for when estimating the effects of studded tyres. If, for example, a winter is very mild, this could benefit safety. If, at the same time, the use of studded tyres was reduced, a simple study of the relationship between the use of studded tyres and the number of accidents might mistakenly conclude that less use of studded tyres is good for safety, when in fact this was an effect of a mild winter. Although the primary focus of this report is on the effects of studded tyres, the effects of the other factors are also of some interest.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

2 Data and methods

2.1 Replication of earlier study

The study reported in 2000 was a multivariate analysis based on a negative binomial regression model. As part of the study, two main models were developed. The first model was intended to estimate the daily rate of use of studded tyres. This model was based on the combined information about the use of studded tyres given in several sources of data. Model estimates indicated a very rapid increase in the use of studded tyres once the season started or once the first snowfall occurred. Both events had a strong effect on the use of studded tyres. Once the season permitting the use of studded tyres ended, use fell abruptly. Figure 2 shows estimated use of studded tyres in the four cities that were included in the study.

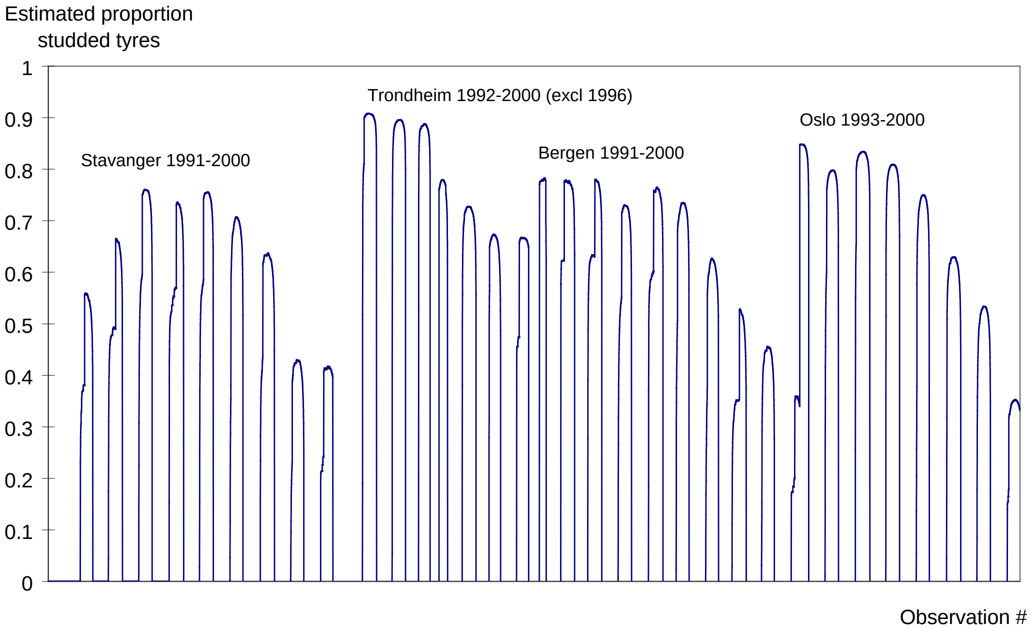


Figure 2: Estimated use of studded tyres (proportion using studded tyres) in the four largest Norwegian cities 1991-2000. Source: Fridstrøm 2000.

As can be seen from Figure 2, the columns are virtually rectangular, with only a slightly rounded shape close to the peak values. If available data regarding the use of studded tyres can be treated as showing peak use during the season, no great error would therefore seem to be made by treating the use of studded tires as constant throughout most of the season.

The second model developed by the study reported in 2000, was a comprehensive model of the effects on accidents of changes in the use of studded tires. This model was run on three different data sets, differing in terms of the variables that were included in them. The main result is shown in Figure 3. It shows the

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

estimated percentage change in the number of accidents during the season when the use of studded tyres is permitted associated with reducing the use of studded tyres by 50 % (e.g. from 70 to 35 %).

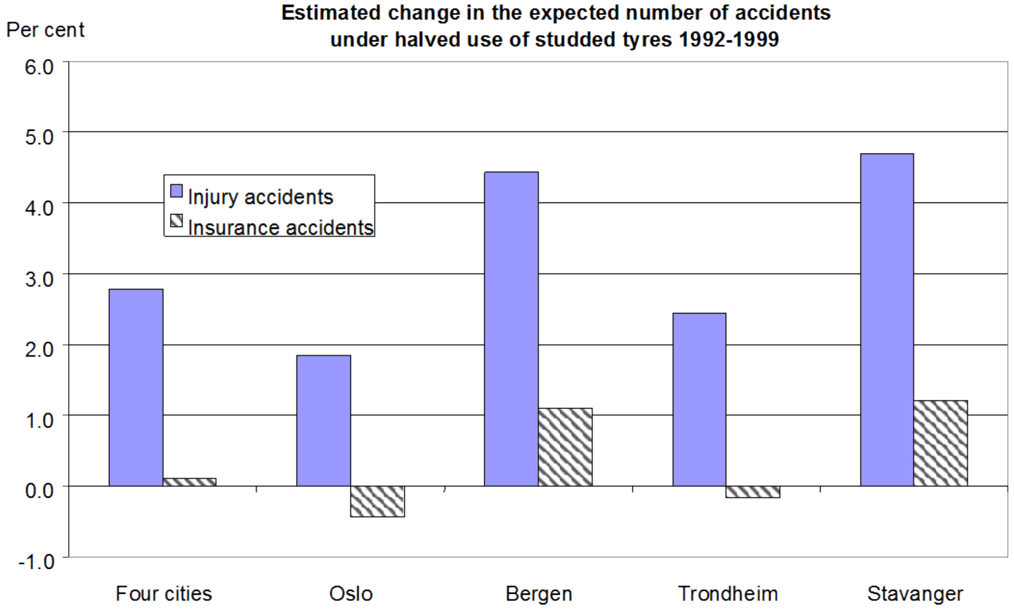


Figure 3: Estimated percentage change in the number of accidents associated with a 50 % reduction of the use of studded tires. Source: Fridstrøm 2000

As can be seen, reducing the use of studded tyres by half was estimated to lead to a small increase of the number of injury accidents in all four cities. Estimated effects on insurance reported accident (more than 90 % of which are property-damage-only accidents) were less consistent, but considerably smaller than the effects on injury accidents.

2.2 Sample of cities and variables included in the study

Based on the annual counts of the use of studded tyres reported by the Public Roads Administration, it was decided to include the following cities in the study:

1. Oslo
2. Bergen
3. Trondheim
4. Stavanger
5. Drammen

The first four cities were included in the study reported in 2000. The city of Drammen was added because counts show that the use of studded tyres in that city has declined considerably from 2000 to 2009.

In each city, the period covered by the study was from 1.1.2002 to 31.8.2009, i.e. almost eight years. It was originally planned to use 2000 as the first year of this study. However, as data on traffic volume and the mean speed of traffic could not be obtained for the years 2000 and 2001, it was decided to use 2002 as the first year of the study period. The study period ended before the 2009-2010 winter season, as counts of the use of studded tyres from February 2010 have not yet

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

been published. It was therefore not possible to estimate the use of studded tyres in the final months of 2009.

The variables included in the study can be placed in four groups:

1. Dependent variables, describing road safety
2. Independent variables, describing the use of studded tyres
3. Confounding variables, describing important factors that may influence road safety in addition to the use of studded tyres.
4. Mediating variables, describing the causal chain by which studded tyres influence road safety.

Figure 4 presents a causal diagram showing the relationships expected between these variables. The dependent variables, the number of accidents (two levels of severity), are influenced by large number of variables in addition to the variable of principal interest in this study, the proportion using studded tyres.

There are two dependent variables in the study:

1. The number of police reported injury accidents per day per city
2. The number of insurance reported accidents per day per city.

These variables are count variables taking on the values 0, 1, 2, etc. With respect to insurance reported accidents, accidents when backing up, accidents involving parked vehicles and accidents of unknown type were omitted. Many of these accidents tend to happen in parking areas and are in that sense not traffic accidents.

The independent variable of principal interest in the study is the use of studded tyres. This is represented by:

1. The proportion of cars using studded tyres according to counts made by the Public Roads Administration. These counts are made in second week of February each year and are assumed to represent the maximum use during the season when using studded tyres is permitted. Use of studded tyres outside the season was set to zero.
2. A dummy variable taking on the value of 1 each day during the season for using studded tyres and 0 the rest of the year. The season always begins on November 1, but the last day of the season varies from year to year. The last day of the season is the first Sunday after Easter.

The potentially confounding variables in the study can be placed in four categories:

1. Traffic volume
2. Daylight
3. Weather
4. Passage of time and calendar events

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

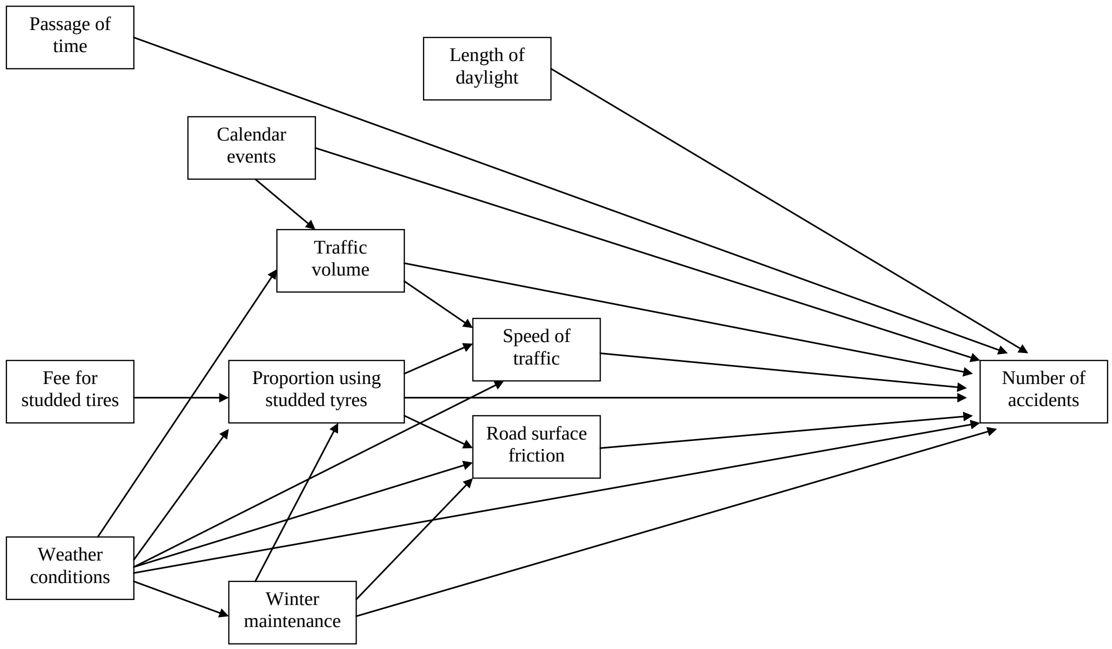


Figure 4: Causal diagram of main groups of variables influencing road safety in winter

Traffic volume is one of the most important factors influencing the number of accidents and typically explains 60-80 % of the systematic variation in the number of accidents (Fridstrøm et al.1995). Traffic volume is known to vary systematically over time. There is, for example, usually less traffic on Saturdays and Sundays than on other days of the week. Severe weather may influence traffic volume, by leading to the cancellation of non-essential trips. To accurately capture the effect of traffic volume, it is therefore necessary to obtain data on daily traffic volume.

The length of daylight varies enormously throughout the year in Norway and from the southernmost to the northernmost part of the country. The length of daylight can be estimated based on the known times of sunrise and sunset and the duration of twilight. The length of daylight is stated as the proportion of 24 hours that have daylight. Thus, if the sun is up for 8 hours, the variable takes the value of 0.33.

The variables representing weather are the same in this study as in the study reported in 2000. The weather variables include:

1. Daily precipitation in the form of snow (in millimetres)
2. Daily precipitation in the form of rain or mixed rain/snow (in millimetres)
3. Current snow-depth (centimetres)
4. Whether the temperature crossed the freezing point (0 degrees Celcius) at least once in a day or not (i.e. stayed either above or below 0 degrees Celcius the whole day)

The calendar events specified in the analysis (as dummy variables) include:

1. Sundays or other public holidays
2. Saturdays
3. Easter week (8 days)
4. Whitsun weekend (4 days)

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

5. Ascension weekend (5 days)
6. Christmas and New Year (10 days)
7. Time trend

The time trend is measured as the number of years that have elapsed since January 1, 2002 (with decimals). Passage of time can be viewed as a variable that captures long-term trends that influence safety, such as the gradual turnover of the fleet of motor vehicles. Table 1 lists the variables included in the study and their units of measurement. Comments will be given with respect to some of the variables.

Data on insurance reported accidents (mostly property-damage accidents) were obtained in the form of a list of claims filed each day in each city. The number of claims does not equal the number of accidents, as each party involved in a multi-vehicle accident is likely to send a claim. There will therefore be more claims than accidents. The number of accidents was estimated as follows:

1. Claims involving backing up, hitting a parked vehicle or unknown type of accident were omitted.
2. Claims in which the counterpart was a car, truck, moped, motorcycle or other motor vehicle were divided by two.
3. Claims in which the counterpart was a pedestrian, cyclist, tram, train, animal, fixed object or no counterpart were counted as one accident.

The passage of time was included by a variable identifying the year, and by a count variable counting the number of years elapsed since January 1, 2002. This variable takes the value of 0.5 half way through 2002, 1 at the end of the year, etc. Three dummy variables were formed on the basis of daily minimum- and maximum temperatures. These were days when the temperature stayed below zero degrees Celcius the whole day (24 hours), days when the temperature stayed above zero the whole day and days when the temperature crossed zero at least once. It is expected that roads are most slippery when the temperature crosses zero, least slippery when the temperature stays above zero the whole day.

Cities were identified by dummy variables. The mean speed of traffic is not treated as a confounding variable. It is a mediating variable, which is influenced by the weather, traffic volume and the proportion using studded tyres. It is one of the variables through which the use of studded tyres influences the number of accidents. The other main variable influenced by studded tyres, road surface friction, is identified in Figure 4, but no data have been obtained regarding this variable, as road surface friction is not measured on a daily basis. Winter maintenance measures are also not recorded on a daily basis and are therefore not included.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 1: Variables included in the study of effects of reduced used of studded tyres in Norwegian cities and their units of measurement

Category	Name of variable	Unit of measurement
Dependent		
D1	Police reported injury accidents	Number per day
D2	Insurance reported accidents (mostly property damage)	Estimated number per day
Independent		
I1	Estimated percentage using studded tyres	Percent of vehicles
I2	Season when use of studded tyres is allowed	Dummy = 1 in season
Confounding		
C1	Traffic volume	Automatic count per day
C2	Year	2002, 2003, etc
C3	Years elapsed since January 1, 2002	Decimal count
C4	Sundays and public holidays	Dummy
C5	Saturdays	Dummy
C6	Easter	Dummy (8 days)
C7	Ascension day	Dummy (4 days)
C8	Whitsun	Dummy (5 days)
C9	Christmas	Dummy (10 days)
C10	Length of daylight	Share of 24 hours
C11	Minimum temperature	Degrees Celcius
C12	Maximum temperature	Degrees Celcius
C13	Days with temperature consistently below zero	Dummy
C14	Days with temperature consistently above zero	Dummy
C15	Days with temperature crossing zero	Dummy
C16	Precipitation as rain	Millimetres
C17	Precipitation as snow	Millimetres
C18	Snow depth	Estimated in centimetres
C19	First snow	Date of first snow (dummy)
C20	Last snow	Date of last snow (dummy)
C21	City identifier for Oslo	Dummy
C22	City identifier for Drammen	Dummy
C23	City identifier for Stavanger	Dummy
C24	City identifier for Bergen	Dummy
C25	City identifier for Trondheim	Dummy
Mediating		
M1	Mean speed of traffic per city per day	Kilometres per hour
Other		
O1	Fee for use of studded tyres	Dummy

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

2.3 Sources of data

Several sources of data were combined. Data on the number of police reported injury accidents were taken from the STRAKS accident record, which is kept by the Public Roads Administration. Complete data were obtained. The Public Roads Administration also provided data on traffic volume and the mean speed of traffic. These data are recorded by automatic traffic counting devices based on inductive loops buried in the road surface. Data on traffic volume and speed were missing for 2000 and 2001. For the years from 2002 to 2009, there were some gaps in the data about traffic volume and traffic speed. These gaps were filled by inserting estimated values based on seasonal variation curves for years that had complete data.

Data on insurance reported accidents (mostly property-damage-only accidents) were taken from the TRAST file, kept by the Norwegian Association of Finance. The unit in this file is a claim. As noted above, the number of accidents was estimated. Complete data were obtained.

Data on the use of studded tyres were taken from the counts made by the Public Roads Administration. These are assumed to represent the peak use of studded tyres during the season. Complete data were obtained.

The length of daylight was estimated according to the times of sunrise and sunset in each city. The length of daylight was computed as the number of hours and minutes between sunrise and sunset. The twilight periods before sunrise and after sunset were not included in the length of daylight. The values for the city of Drammen were set equal to those for the city of Oslo, as the two cities are located very close to each other.

Data on daily minimum and maximum temperatures were downloaded from the eKlima website, hosted by the Norwegian Institute of Meteorology. This website is freely accessible and contains time-series of data recorded at all weather stations in Norway. Temperature data for the city of Drammen are missing for part of the period, as the main weather station was moved from Drammen, Marienlyst to Drammen, Berskog, in 2003-2004, leading to a discontinuity in the data.

Data on precipitation and snow depth were obtained from the Norwegian Water Resources and Energy Directorate (NVE). These data were complete.

2.4 Estimation of the use of studded tyres

In the study reported in 2000 (Fridstrøm 2000) there were several sources of data regarding the use of studded tyres. By combining these sources of data, it was possible to develop day-by-day model estimates of the percentage of vehicles using studded tyres. In this study, there is only one source of data regarding the use of studded tyres – the annual counts made by the Public Roads Administration in the second week of February. The results of these counts probably indicate the peak use of studded tyres during a winter season. Thus, the count made in February 2009 probably indicates maximum use of studded tyres in the 2008-2009 winter season.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

In the absence of other sources of data, variation in the use of studded tyres throughout the season has been estimated by applying the following rules:

1. The use of studded tyres measured in February represents peak use of studded tyres. This level of use is assumed to be constant from December 1 to February 28 (29 in leap years), unless exceptional weather conditions prevail (see below for a case of this). The rationale for this assumption is that there are probably very few car owners who change tyres during the season, once the studded tyres have been put on.
2. If there is snowfall before or on November 1 (the first day when studded tyres are permitted), 40 % of peak use (i.e. 8 % if peak use is 20 %) is reached the following day, or the first Monday after. The reason for assuming a delay from Sunday to Monday is that many car owners seek professional help for changing tyres, and businesses offering this are more accessible on weekdays than during the weekend.
3. If there is another snowfall the following week, use increases to 90 % of the peak level. It then increases linearly to 100% of peak use by December 1.
4. If there is no snowfall the following week, use increases to 50 % of the peak level. It then increases to 90 % following the next snowfall and then to 100 % of peak use by December 1.
5. If there is no snowfall before November 1, use increases to 40 % of peak level on November 1 or 2. If there is snow the following week, use increases to 90 % of peak level and then linearly to 100 % of peak level by December 1.
6. If there is no snowfall in the first week after November 1, use of studded tyres increases to 50 % of peak level during this week. It then increases to 90 % of peak level following the first snowfall, and then linearly to 100 % of peak level by December 1.
7. If there is no snow the first week after Easter, use of studded tyres falls linearly from 100 % of the peak level to 0 %.
8. If there falls snow during the first week after Easter, the removal of studded tyres is shifted by one week.
9. A special case is the city of Stavanger in the 2007-2008 season. The first snow did not occur until March 24, 2008. It was assumed that 40 % of the peak level was reached on November 1, then there was a linear increase to 100 % of the peak level by January 1, 2008. Since March 24 is close to end of the season, it was assumed that nobody put on studded tyres following the snowfall, but preferred to wait for the snow to melt (which it would normally do in a matter of few days in Stavanger at this time of the year).

These rules give results that resemble those obtained by Fridstrøm by means of the model he developed.

2.5 Variable transformations

Some of the variables have been transformed. These transformations are the same as those made in the first study (Fridstrøm 2000).

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Readings of precipitation are normally taken only once per day (as opposed to temperature which is recorded several times per day). Precipitation is normally recorded at around 7o'clock in the morning and refers to the past 24 hours. To get the correct amount of precipitation on a given day, the recorded values have therefore been adjusted as follows:

Adjusted amount of precipitation = $\frac{7}{24} snow_{rt} + \frac{17}{24} snow_{rt+1}$

Snow denotes the amount of snow, stated in millimetres, recorded in city r on day t. The new variable is referred to as "estimated snowfall" (abbreviated estsnow). This transformation was applied only to snow. As far as rain is concerned, the amount of rain recorded at 7 o'clock in the morning on day t was shifted backward to day t – 1, because it was assumed that rain falling between midnight and 7 in the morning would not have very much of an impact on traffic. This assumption is reasonable, because only a minor share of all traffic takes place between midnight and 7 in the morning. The new variable is referred to as "estimated rain" (abbreviated estrain). The effects of precipitation on the number of accidents have been modelled according to the following functions:

Function for snow = $-\frac{1}{\sqrt{(estsnow + 0.1)}}$

Function for snowdepth = $-\frac{1}{\sqrt{(snowdepth + 1)}}$

Function for rain = $-\frac{1}{estrain + 0.5}$

As noted above, days were divided into three groups depending on the maximum and minimum temperatures. Days in which the temperature crossed zero are referred to as "crosszero". These days are identified by means of a dummy variable which takes the value of 1 when zero degrees Celcius was crossed. The effects of studded tyres on accidents was captured by means of the following interaction terms:

Interaction with snow = function for snow · ln(percent use of studded tyres + 1)

Interaction with snowdepth = function for snowdepth · ln(percent use of studded tyres + 1)

Interaction with crosszero = dummy for crosszero · ln(percent use of studded tyres + 1)

The functions for snow and snowdepth are the transformed variables defined above. Ln is the natural logarithm. A constant one 1 has been added as a scaling parameter, since the natural logarithm of 1 equals 0. The variable will then assume the value of zero when the percent use of studded tyres is zero.

2.6 Treatment of missing data

Temperature data are missing for Drammen for a few short periods in 2002, many short periods in 2003 and most of the year 2004. Temperature enters the analysis

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

only in the form of a dummy variable that takes the value of 1 if zero degrees Celcius was passed at least once in a day, otherwise zero. Missing data for those parts of the year when temperature is unlikely to cross the freezing point is therefore no problem. It was judged unlikely that the temperature would cross the freezing point in the months of June, July and August. In 2002, data were missing for 14 days in November. There is a fairly high probability that the temperature may cross the zero point in November. Data for the years that had complete data were used to judge the probability of days with temperature crossing zero degrees Celcius. It was found that there was between 5 and 13 days crossing zero in the month of November in Drammen in the years from 2004 to 2008.

In November 2002, precipitation in the form both of rain and snow was recorded nine days. The temperature was assumed to cross zero all these days.

For the years 2003 and 2004, there was too much missing data to replace by means of estimates based on years with complete data. The years 2003 and 2004 were therefore omitted from the multivariate analysis for Drammen. These years were, however, included in the exploratory analysis.

2.7 Approach to accident modelling

The approach taken to accident modelling in this study is based on explicit analytic choices made on the basis of an exploratory data analysis. These choices refer to the following aspects of modelling:

1. The structure of systematic variation in the number of accidents.
2. The choice of model form.
3. The choice of functional form for the relationship between each of the explanatory variables and the dependent variable.

The presence of systematic variation in the number of accidents is indicated by over-dispersion in the distribution of accidents in the sample of study units. The study unit in this study is city-days. If the variance of the number of accidents per city per day exceeds the mean, there is systematic variation in the number of accidents. The next step is to determine the structure of the systematic variation. This was done by comparing how well two theoretical probability distributions for the number of accidents fitted the empirical distribution. These two distributions were the negative binomial distribution and the Poisson lognormal distribution. The latter distribution was included because previous studies show that it fits the distribution of accidents on 1-kilometre sections of national roads in Norway better than the negative binomial distribution (Maher and Mountain 2009).

It was found that the negative binomial distribution describes the empirical distribution of injury accidents very well. None of the theoretical probability distributions described the empirical distribution of insurance reported accidents very well. In view of this, and in order to keep this study as consistent with the previous study (Fridstrøm 2000) as possible, negative binomial regression was adopted.

As far as model form is concerned, the main choices to be made concern (Lord and Mannering 2010, Elvik 2011):

1. Using a single-state model or a dual-state model.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

2. Using a single-level model or a multi-level model.
3. Including only main effects or interaction effects in addition to main effects.

Dual-state models are based on the assumption that there are two modalities for the accident generating process, generating different expected numbers of accidents per unit of time. When dual-state models were first introduced, it was in the form of zero-inflated models (Shankar et al. 1997). A zero-inflated model postulates that there are two modalities for the accident generating process: one in which the expected number of accidents is zero (a perfectly safe state) and one in which the expected number of accidents is more than zero. Zero-inflated models are highly implausible and have been criticised as nonsensical (Lord et al. 2005, 2007). This criticism is supported here. It is regarded as nonsense to pretend that the expected number of accidents could ever be zero. It must always be a positive number, although it may be a very low number.

Another version of a dual-state model has been proposed by Malyshkina and Mannering (2009). This model does not postulate a perfectly safe state, but models the accident generating process as switching randomly between a normal state and a state in which there is a higher expected number of accidents. This model is intended to capture the effects of factors that temporarily increase the risk of accidents, like a spell of bad weather. Again, however, there is no need for a dual-state model to reliably estimate such effects. If the data are analysed at the lowest meaningful level of aggregation, the effects of factors that exert a temporary effect on accidents will be captured.

It is concluded that no convincing reasons can be given for adopting a dual-state model. A single-state model has been estimated.

Multi-level models are applied when data refer to more than one level, such as data using the count of injured road users as dependent variable. Such data will have three levels: (1) the road user level, (2) the vehicle level, and (3) the accident level. In the analyses presented in this report, the number of accidents is the dependent variable. There is therefore no need to apply a multi-level model.

With respect to the use of interaction terms, the fitted model does include interaction terms between weather variables and the use of studded tyres. The reason for using these variables is the same as explained in the report published in 2000: “By this specification, we attempt to avoid or minimise omitted variable bias due to the possible correlation between studded tyre use and any variable exhibiting a clear seasonal pattern of variation. Only variables that also work in interaction with the weather factors are likely to give rise to such bias.” (Fridstrøm 2000, page VI).

2.8 Models fitted

Three models were developed. One model was developed in order to estimate the effects on accidents of changes in the use of studded tyres. This model had 23 independent variables and was, as far as available data permitted, identical to the model fitted by Fridstrøm in 2000 for the same purpose. This model is the most important of the three models that were developed. The same independent variables were used in the model for property-damage accidents as in the model

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

for injury accidents. The model was fitted by means of negative binomial regression employing a log link function and maximum likelihood estimation.

The second model was developed in order to explain variation in traffic speed. Road users adjust speed in response to changing weather and in response to their type of tyre and the condition in which road users believe their tyres are. Those who think that the tyres are worn, tend to adapt their behaviour less than those who think their tyres are in good condition (Fosser and Ingebrigtsen 1991). A linear least squares regression model was adopted to explain speed adaptation among road users. The model explains variation in the mean speed of traffic, not the speed choice made by each driver. However, the choices made by each driver will be reflected in the mean speed of traffic to the extent that all drivers adapt their behaviour the same way. This is a reasonable assumption on urban roads with a high traffic volume, which does not permit drivers to freely choose their speed.

The third model was developed to explain changes in the use of studded tyres. The principal independent variable in this model was the existence of a fee for using studded tyres. Such a fee exists in Oslo, Bergen and Trondheim, but not in Drammen and Stavanger. A linear regression model was fitted with the percentage use of studded tyres as dependent variable.

2.9 Estimating effects on accidents by means of the sample enumeration method

The accident prediction model is a log-linear model in which the predicted number of accidents is obtained by inserting coefficients into an exponential function:

Predicted number of accidents = $e^{\left(\sum_{i=0}^{n} \beta_i x_i\right)}$

Here, e is the exponential function (i.e. the base of the natural logarithms, 2.1828) raised to the power of the sum of coefficients (β_i) multiplied by the respective values of the independent variables (x_i).

By inserting the values cell-by-cell into the exponential function, the predicted number of accidents can be obtained for every day in every city for the data set included in the multivariate analysis (13,269 observations; the full data set is 14,000 observations; the omission of Drammen in 2003 and 2004 reduced this to 13,269 observations).

The effect on accidents of changes in the use of studded tyres was estimated by means of the sample enumeration method. This method was implemented in order to answer the basic question of this evaluation:

What would have happened if the use of studded tyres had not been reduced?

The answer to this question represents the counterfactual condition that any evaluation study needs to establish. In this study, the counterfactual is defined as the use of studded tyres that was observed in the first year of the study, 2002. With a few exceptions, the use of studded tyres in 2002 was the highest level observed in the period covered by the study. The question stated above can thus be reformulated as:

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

What would the number of accidents have been if the use of studded tyres in the years after 2002 had remained unchanged at the level observed in 2002?

To answer this question, the actual use of studded tyres in the years, 2003, 2004, ... , 2009 is replaced by the use in 2002. Thus, in Oslo, the counterfactual and actual use of studded tyres becomes:

Year	Actual use	Counterfactual use
2002	32.0	32.0
2003	28.4	32.0
2004	28.0	32.0
2005	23.8	32.0
2006	19.3	32.0
2007	19.5	32.0
2008	16.2	32.0
2009	16.5	32.0

In other words, the effect of reduced use of studded tyres is estimated by comparing the estimated number of accidents *assuming the observed reduction in the use of studded tyres had not taken place, but all other factors had changed as observed after 2002* to the estimated number of accidents *given the observed changes (in general reduction) in the use of studded tyres.*

To give an example: The estimated number of accidents in Oslo from 2002 to 2009 was 7207.3. By replacing the actual use of studded tyres each year by the use in 2002, the number of accidents was estimated as 7146.3. Thus, if the reduction in the use of studded tyres had not taken place, there would have been slightly fewer accidents than the number that was estimated given the reduction in the use of studded tyres. The difference is 7207.3 − 7146.3 = 61 accidents.

The statistical significance of this change was assessed by applying the following test. The standard error of the difference between the expected values of two Poisson distributions can be approximated as:

Standard error = $\sqrt{N_{act} + N_{counter}} = \sqrt{7207.3 + 7146.3} = 119.8$

In the models fitted, there is residual over-dispersion. The residual variance of a negative binomial regression model is:

Residual variance = $\lambda \cdot (1 + (\mu \cdot \lambda))$

Here, λ is the estimate of the expected number of accidents and μ is the over-dispersion parameter. To obtain an approximately correct estimate of the standard error, the standard error estimated according to the Poisson assumption above is adjusted by means of the over-dispersion parameter:

Adjusted standard error = $119.8 \cdot (1 + (0.075 \cdot 119.8)) = 1196.2$.

The statistical significance of the estimated differences in the number of accidents has been assessed by applying the adjusted standard error.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

3 Results

3.1 Description of the data

3.1.1 Use of studded tyres

The (peak) use of studded tyres from 2002 to 2009 in the five cities included in the study is shown in Table 2.

Table 2: Use of studded tyres in the five Norwegian cities included in the study of the effects on road safety of reduced use of studded tyres from 2002 to 2009.

	Percent of cars using studded tyres in each city – second week of February				
Year	Oslo	Drammen	Stavanger	Bergen	Trondheim
2002	32.0	40.1	28.8	31.1	44.5
2003	28.4	41.3	29.1	32.4	41.1
2004	28.0	33.7	27.8	26.8	39.5
2005	23.8	29.4	29.7	29.9	37.7
2006	19.3	25.3	30.8	27.8	34.9
2007	19.5	26.2	27.6	21.2	30.4
2008	16.2	26.6	33.4	9.9	20.5
2009	16.5	30.5	27.8	14.0	20.4

From 2002 to 2009, there has been a reduction of the percentage of cars using studded tyres in all five cities. The largest reductions are seen in the cities of Oslo, Bergen and Trondheim, where the use of studded tyres has been reduced by about half since 2002. Trondheim is the only city in which there has been a uniform decline. The use of studded tyres has been reduced every year since 2002. In Oslo and Bergen, the trend is a little irregular, with a small rebound to a higher use of studded tyres at the end of the period. In Drammen and Stavanger, there has been a smaller reduction in the use of studded tyres; in Stavanger, the use of studded tyres in 2009 was only marginally lower than in 2002, and there is no clear trend in the years in-between.

Figure 5 shows estimated use of studded tyres in the five cities year-by-year. The figure contains the same information as Table 2, but provides additional detail by showing how changes in the use of studded tyres were estimated at the beginning and end of the season, to permit comparison with the estimates presented in Figure 2.

The effects of weather on the willingness of car owners to change tyres can be discerned by the steps in each of the columns showing use of studded tyres.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

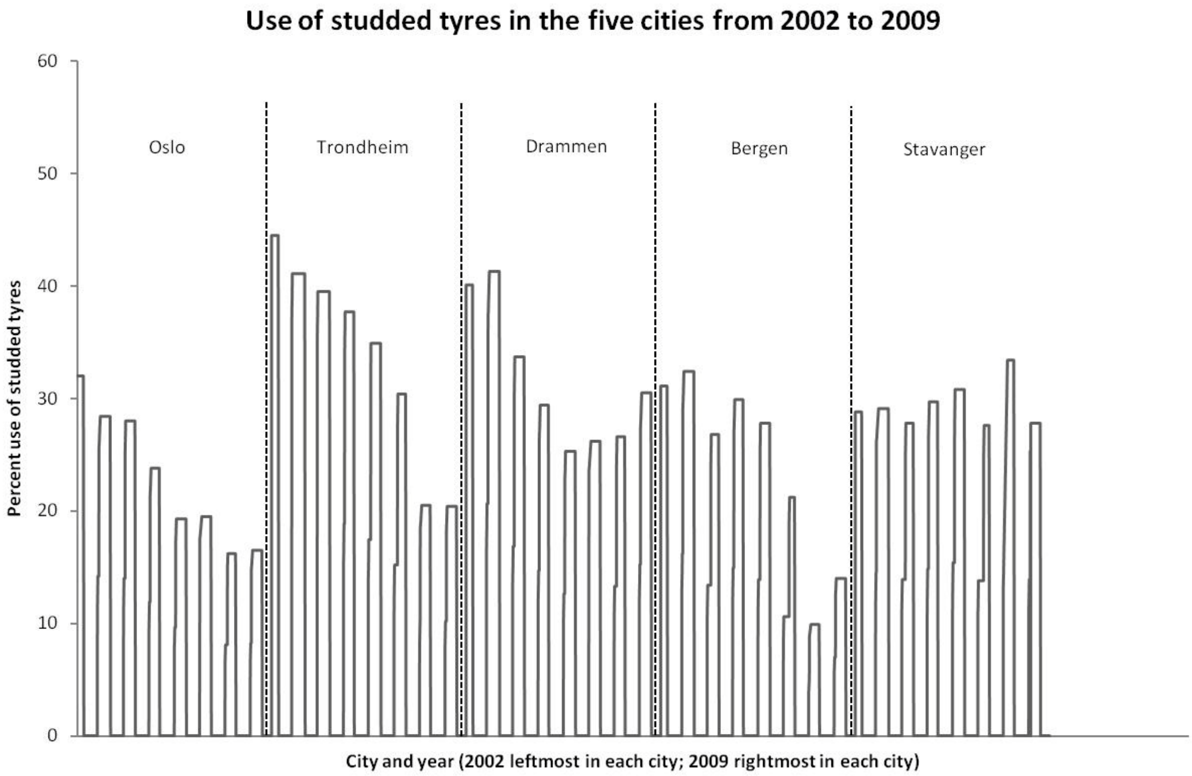


Figure 5: Estimated percentage use of studded tyres in five Norwegian cities from January 1, 2002 to August 31, 2009 – percent of cars using studded tyres

The length of the season for using studded tyres, which varies from year-to-year, can be seen by comparing the widths of the columns. Please note that only part of the 2001-2002 season is included, as the data series started on January 1, 2002, about two months into the season. There is sufficient variation in the use of studded tyres both within and between cities for an analysis of the safety effects of this variation to make sense.

3.1.2 Number of accidents

The number of injury accidents in each city and in total is shown in Table 3. The table is a complete listing of all injury accidents that were recorded during the study period.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 3: Number of police reported injury accidents per city per day in study of effects on accidents of reduced use of studded tyres in Norwegian cities

	City					
Count	Oslo	Drammen	Stavanger	Bergen	Trondheim	Total
0	349	2446	1658	1031	1555	7039
1	583	326	844	996	904	3653
2	576	27	242	471	267	1583
3	502	1	49	195	62	809
4	351		7	76	10	444
5	229			24	2	255
6	113			6		119
7	55			1		56
8	25					25
9	8					8
10	6					6
11	2					2
12	1					1
Total city days	2800	2800	2800	2800	2800	14000
Mean per day	2.578	0.137	0.537	1.068	0.598	0.984
Variance	3.618	0.140	0.557	1.258	0.621	1.962

Both the mean number of accidents and the variance varies considerably between cities. For the full sample, the mean number of injury accidents per day is 0.984 and the variance is 1.962. This indicates that 49.8 % of the variation in the number of accidents per city per day is systematic, 50.2 % is random. In some of the cities, random variation is the dominant contribution to the variation in the number of accidents from day to day. For the full sample, however, both the mean number of accidents and the variance are clearly above the values that Lord (2006) suggest could lead to low mean value bias.

The mean number of insurance reported accidents per city per day was 14.71. The variance was 226.181. Figure 6 shows the number of insurance reported accidents per city per day in groups comprising values that cover one standard deviation. Thus, for example the group 1-14 include all counts between the mean and one standard deviation below the mean. In a similar manner, the group 15-29 includes counts that are between the mean and one standard deviation above the mean. The maximum number of insurance reported accidents in one day was 252.

99 city-days had zero insurance reported accidents. There are 14,000 city-days in total. A majority of them had between 1 and 14 insurance reported accidents. The distribution is skewed and has a long tail of days that had a substantially higher number of accidents than the mean number per city per day. On the average, the number of insurance reported accidents is about 15 times greater than the number of injury accidents.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

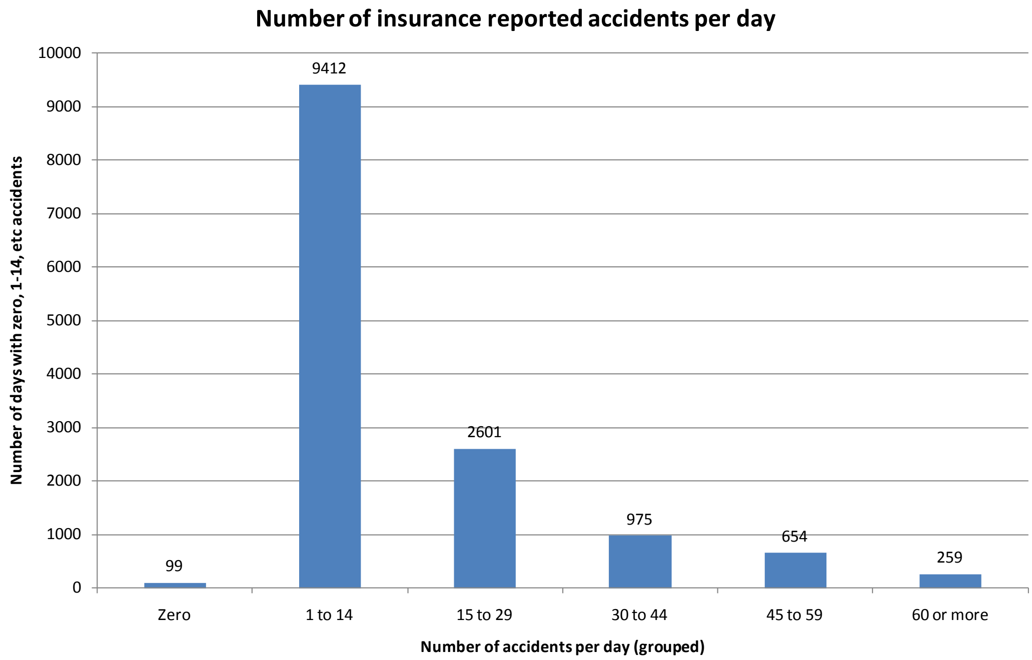


Figure 6: Number of Insurance reported accidents (mostly property-damage accidents) per city per day January 1, 2002 to August 31, 2009 (grouped) in the cities of Oslo, Drammen, Stavanger, Bergen and Trondheim

3.1.3 Traffic volume

Traffic volume is measured in terms of the number of vehicles passing an automatic counting station each day in each city. There are 2,800 observations in each city. As an example of what these data look like, the data for Oslo are shown in Figure 7.

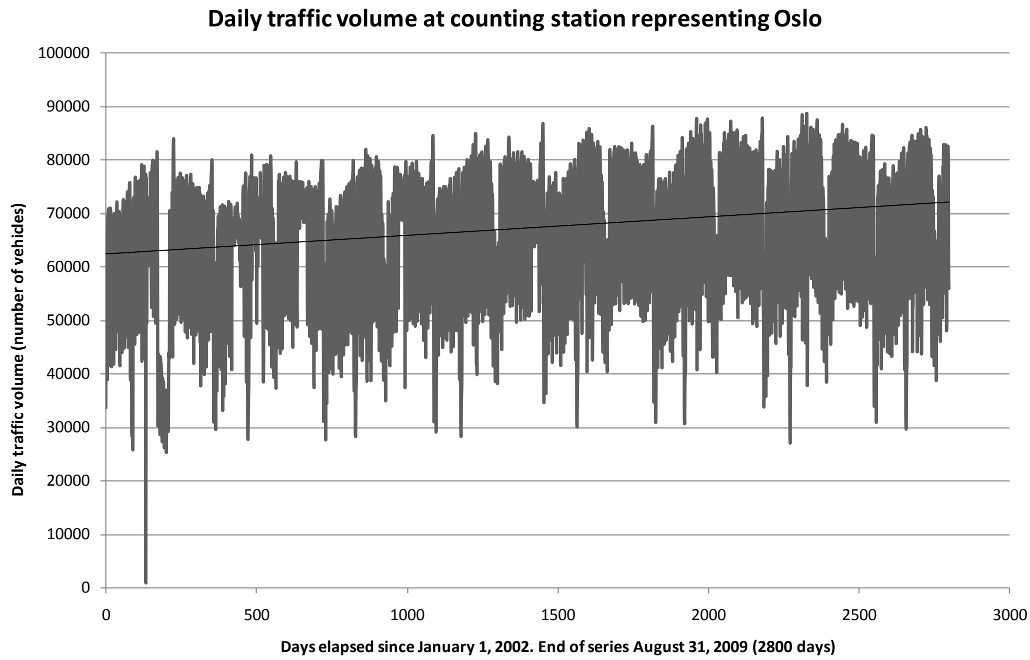


Figure 7: Daily traffic volume in Oslo from 2002 to 2009

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

A trend line has been inserted in the figure, showing that traffic volume has increased from 2002 to 2009.

3.1.4 Temperature

Based on minimum and maximum temperature, each day has been put in one of the following three groups:

1. Days when the temperature was above zero degrees Celcius.
2. Days when the temperature crossed zero degrees Celcius at least once.
3. Days when the temperature was below zero degrees Celcius.

Global warming has attracted considerable attention in recent years, and it is of some interest to see if an effect of global warming can be detected in the data. Such an effect would imply that the number of days in group 1 has increased over time, and the number of days in group 3 has declined over time. Table 4 shows how the number of days in each group has changed from 2002 to 2008. The city of Drammen was not included in 2003 and 2004. The year 2009 is not included in Table 4 (since the study ended on August 31, 2009).

Table 4: Percentage of days above zero, crossing zero and below zero degrees Celcius from 1.1.2002 to31.12. 2008. All cities(Oslo, Drammen, Stavanger, Bergen, Trondheim) combined

	Percentage of days above zero, crossing zero and below zero						
Group	2002	2003	2004	2005	2006	2007	2008
Above zero	69.6	74.2	76.7	74.0	73.9	75.0	75.9
Crossing zero	20.9	20.5	17.0	21.0	18.2	18.4	20.0
Below zero	9.5	5.3	6.3	5.0	7.9	6.6	4.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
N	1825	1460	1464	1825	1825	1825	1830

A tendency can be seen for the share of days above zero to increase over time and the share of days below zero to decline. This is consistent with a trend towards a warmer climate.

3.2 Exploratory analyses

An exploratory analysis has been performed by studying changes from year-to-year in the number of accidents per day and relating these changes to changes in the use of studded tyres. This is a simple bivariate analysis that does not control for any confounding variables, but only serves to check if any clear trends can be seen in the data.

The dependent variable in the analysis is adjusted changes in the mean number of accidents per day when the use of studded tyres is more than zero percent. Changes from one year to another in the mean number of accidents per day when studded tyres were used are divided by the corresponding changes in the mean number of accidents per day when studded tyres were not used. An odds ratio estimator of effect is thus formed:

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Estimate of effect = odds ratio =

$$\frac{\left(\frac{Accidents\ \ per\ day\ when\ studded\ \ tyres\ \ are\ used\ \ in\ city\ \ A\ in\ year\ \ 2}{Accidents\ \ per\ day\ when\ studded\ \ tyres\ \ are\ used\ \ in\ city\ \ A\ in\ year\ \ 1}\right)}{\left(\frac{Accidents\ \ per\ day\ when\ studd\ ed\ tyres\ \ are\ not\ used\ \ in\ city\ \ A\ in\ year\ \ 2}{Accidents\ \ per\ day\ when\ studded\ \ tyres\ \ are\ not\ used\ \ in\ city\ \ A\ in\ year\ \ 1}\right)}$$

As an example, the mean number of accidents per day in Oslo in 2002 on days when the use of studded tyres was more than zero percent was 2.196. This changed to 2.305 in 2003 (more precisely the 2002-2033 winter season). The corresponding number of accidents per day when nobody used studded tyres was 3.276 in 2002 and 2.742 in 2003. The odds ratio estimate thus becomes:

Odds ratio = (2.305/2.196)/(2.742/3.276) = 1.254.

This corresponds to an increase of about 25 % in the number of accidents per day in 2003, adjusted for the changes that took place outside the season for using studded tyres. The use of studded tyres in Oslo was reduced from 32.0 % in 2002 to 28.4 % in 2003, a relative decline of 11 percent (stated as 0.89).

If a reduction in the use of studded tyres is associated with an increase in the number of accidents, one would expect the odds ratio to be above the value of 1 when the use of studded tyres was reduced from year N to year N + 1. On the other hand, an increased use of studded tyres would be expected to be associated with an odds ratio smaller than 1. A total of 35 estimates of the odds ratio and corresponding changes in the use of studded tyres was developed (5 cities times 7 changes from one year to the next). The results for injury accidents are shown in Figure 8.

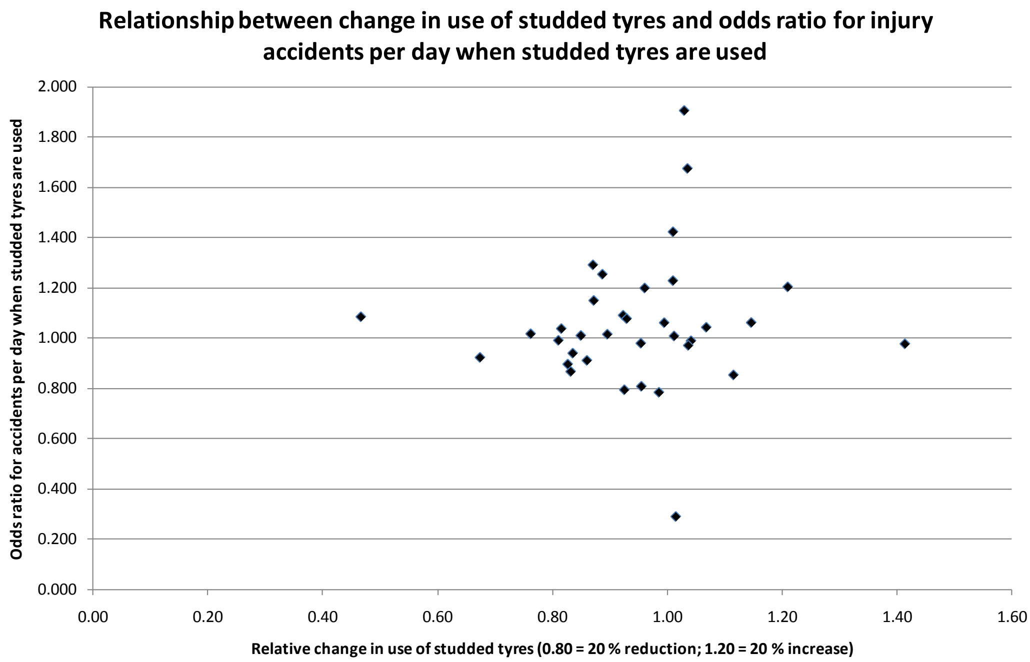


Figure 8: Bivariate association between changes in the use of studded tyres and changes in the number of injury accidents per day. All cities and all years combined (35 data points).

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

The data points in Figure 7 have different statistical weights, depending on the number of accidents they are based on. A weighted regression analysis found no relationship whatever between changes in the use of studded tyres and changes in the mean number of accidents on days when studded tyres are used.

Figure 9 shows the relationship for insurance reported accidents.

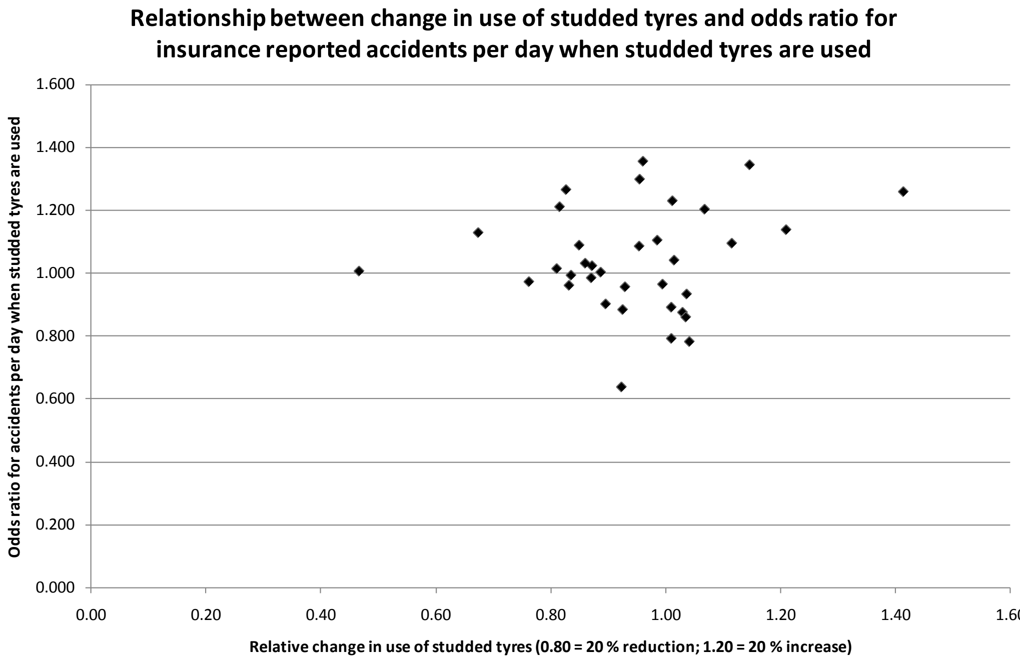


Figure 9: Bivariate association between changes in the use of studded tyres and changes in the number of property damage accidents. All cities and all years combined (35 data points).

A quadratic function was found to best fit the data. This function is not very plausible. It suggests that the number of accidents reaches a minimum when there is no change in the use of studded tyres and increases both when the use of studded tyres increases and when it decreases. It is difficult to imagine an explanation for such a relationship; it is likely that it is spurious.

3.3 Effects on accidents of reduced use of studded tyres

3.3.1 Negative binomial regression model

A negative binomial regression model was fitted by maximum likelihood estimation to determine the effects of factors that influence the number of accidents. The coefficients estimated, their standard errors and their p-values are shown in Table 5. The table also reports the over-dispersion parameter and the Elvik index of goodness of fit. This index shows the share of systematic variation in accident counts that is explained by the model. It takes values between 0 (no systematic variation explained) and 1 (all systematic variation explained).

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 5: Coefficients estimated by negative binomial regression. Dependent variable: injury accidents per city per day

Variable	Coefficient	Standard error	P-value
Constant term	-5.347	0.692	0.000
Snowfall (-1/√(mms as melted + 0.1)	0.023	0.116	0.841
Snowdepth (-1/√(cms + 1)	-0.338	0.366	0.355
Cross zero (temperature crosses freezing point)	-0.044	0.073	0.550
Rainfall (-1/(mms + 0.5)	0.044	0.012	0.000
First snow (dummy = 1 on day of first snow)	0.243	0.169	0.151
Last snow (dummy = 1 on day of last snow)	-0.134	0.209	0.521
Snowfall · ln(percent studded tyres + 1)	0.020	0.036	0.582
Snowdepth · ln(percent studded tyres + 1)	0.034	0.114	0.768
Cross zero · ln(percent studded tyres +1)	0.030	0.025	0.229
Ln(traffic volume)	0.470	0.064	0.000
Dummy for Oslo	1.297	0.036	0.000
Dummy for Drammen	-1.397	0.066	0.000
Dummy for Stavanger	0.416	0.084	0.000
Dummy for Bergen	1.346	0.114	0.000
Dummy for Trondheim (set to zero)	0.000		
Share of daylight (proportion of 24 hours)	-0.294	0.082	0.000
Dummy for Sundays and holidays	-0.290	0.040	0.000
Dummy for Saturdays	-0.214	0.035	0.000
Dummy for Easter	-0.199	0.074	0.007
Dummy for Ascension day	0.082	0.074	0.271
Dummy for Whitsun	0.079	0.100	0.433
Dummy for Christmas	-0.384	0.083	0.000
Year count	-0.019	0.004	0.000
Over-dispersion parameter	0.075	0.011	0.000
Elvik index of goodness of fit	0.919		
Number of observations	13269		

The coefficients for the variables representing traffic volume, cities, daylight and year count are all highly statistically significant. Most of the coefficients for calendar events are also statistically significant. The coefficients representing weather are mostly not statistically significant. The interaction terms intended to capture the effects of studded tyres are not statistically significant.

Most of the variables were defined the same way as in the previous study (Fridstrøm 2000) and the results can therefore be compared directly. The results with respect to the sign and statistical significance of the model coefficients are identical with respect to the following variables: traffic volume, time trend (year count), length of daylight, Sundays and holidays, Christmas, rainfall, snowfall and

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

temperature crossing zero. The signs of the coefficients for the interaction terms representing the use of studded tyres are the same as in the previous study for snow depth and temperature crossing zero, but not for today's snowfall. Broadly speaking, the results are therefore consistent with the previous study.

Table 6 reports the results for insurance reported accidents.

Table 6: Coefficients estimated by negative binomial regression. Dependent variable: insurance reported accidents per city per day

Variable	Coefficient	Standard error	P-value
Constant term (see note in text)	-1.934	0.241	0.000
Snowfall (-1/√(mms as melted + 0.1)	0.241	0.042	0.000
Snowdepth (-1/√(cms + 1)	-0.155	0.133	0.246
Cross zero (temperature crosses freezing point)	0.030	0.028	0.282
Rainfall (-1/(mms + 0.5)	0.064	0.005	0.000
First snow (dummy = 1 on day of first snow)	0.222	0.062	0.000
Last snow (dummy = 1 on day of last snow)	-0.032	0.067	0.635
Snowfall · ln(percent studded tyres + 1)	-0.035	0.013	0.007
Snowdepth · ln(percent studded tyres + 1)	0.125	0.041	0.002
Cross zero · ln(percent studded tyres +1)	-0.001	0.009	0.894
Ln(traffic volume)	0.464	0.022	0.000
Dummy for Oslo	1.244	0.013	0.000
Dummy for Drammen	-0.755	0.015	0.000
Dummy for Stavanger	0.405	0.029	0.000
Dummy for Bergen	1.289	0.040	0.000
Dummy for Trondheim (set to zero)	0.000		
Share of daylight (proportion of 24 hours)	-0.356	0.031	0.000
Dummy for Sundays and holidays	-0.491	0.014	0.000
Dummy for Saturdays	-0.322	0.013	0.000
Dummy for Easter	-0.247	0.025	0.000
Dummy for Ascension day	-0.025	0.031	0.415
Dummy for Whitsun	0.086	0.040	0.032
Dummy for Christmas	-0.376	0.026	0.000
Year count	0.018	0.002	0.000
Over-dispersion parameter	0.067	0.002	0.000
Elvik index of goodness of fit	0.928		
Number of observations	13269		

The results for insurance reported accidents are, for all variables that can be compared, highly consistent with the previous study. Model predictions are unbiased. This can be determined by comparing the predicted number of accidents with the actual number of accidents. Such a comparison is shown in Table 7.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 7: Actual and predicted number of accidents by city. All years (1.1.2002-31.8.2009)

	Police reported injury accidents		Insurance reported accidents	
City	Actual	Predicted	Actual	Predicted
Oslo	7219	7207.3	105585	105114.9
Trondheim	1674	1671.8	26030	26058.3
Drammen	279	278.9	8425	8433.4
Bergen	2990	2986.2	40918	40980.8
Stavanger	1503	1501.0	21396	21375.9

3.3.2 Estimated effect on accidents of changes in use of studded tyres

The sample enumeration method was applied, as explained in Chapter 2, to estimate what the number of accidents would have been if no changes in the use of studded tyres had taken place after 2002, but all other factors, such as traffic volume, weather, etc. had changed the way they actually did after 2002. The results are shown in Figure 9.

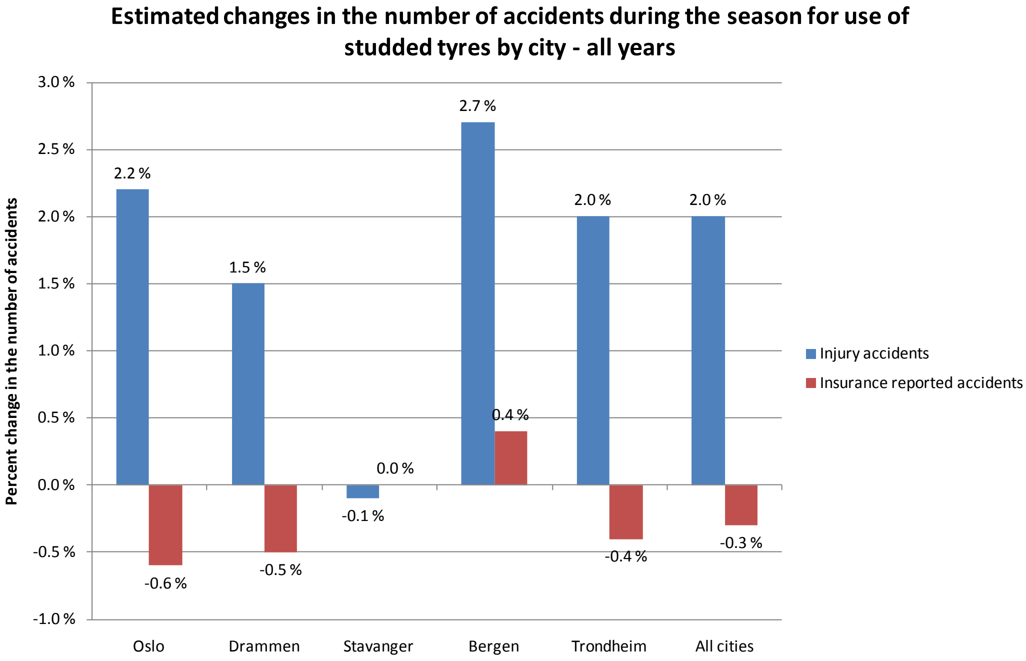


Figure 10: Estimated percentage changes in the number of accidents associated with changes in the use of studded tyres from 2002 to 2009

Reduced use of studded tyres was associated with an increase in the number of injury accidents during the season for use of studded tyres (defined as all days when estimated use of studded tyres was more than 0.0 percent) in all cities except the city of Stavanger. In the city of Stavanger, the mean use of studded tyres in the years 2003-2009 was slightly higher than the use of studded tyres in the year 2002. For all cities combined, changes (mainly reduction) in the use of studded tyres after 2002 is associated with an increase of about 2 percent in the number of injury accidents during the season for use of studded tyres. This change

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

is very far from being statistically significant. Strictly speaking, it cannot be concluded that there has been any real increase in the number of injury accidents. The changes in the number of insurance reported accidents are even smaller than the changes in the number of injury accidents and tend to go in the opposite direction of the changes in the number of injury accidents. The estimated number of insurance reported accidents has increased only in the city of Bergen. Again, the estimated changes are nowhere near statistically significant.

3.3.3 Dose-response pattern in changes in the number of injury accidents

The very small changes in the number of insurance reported accidents will not be analysed further. A more detailed analysis has been performed for injury accidents, in order to assess whether the changes are likely to be real, even if not statistically significant, and attributable mainly to reduced use of studded tyres, not to one or more confounding factors.

If the estimated changes in the number of injury accidents is mainly attributable to changes in the use of studded tyres, one would expect that:

1. When there is a reduction in the use of studded tyres, the number of accidents will increase.
2. When there is an increase in the use of studded tyres, the number of accidents will decrease.
3. The larger the changes in the use of studded tyres, the larger the changes in the number of accidents.
4. If the use of studded tyres is reduced to less than 20 % of vehicles, there may be a larger increase in the number of accidents, as the effect of studded tyres in wearing down snow or ice is then reduced.

To test if such a pattern is found, the changes in the number of injury accidents during the season when studded tyres are used, as estimated by means of the sample enumeration method, were plotted against the change in the use of studded tyres, stated as percentage points of change using 2002 as baseline. Thus, for Oslo, the use of studded tyres in 2002 was 32.0 percent. In 2003, it was 28.4 percent. The percentage points of change was therefore 28.4 – 32.0 = − 3.6. In 2009, the use of studded tyres in Oslo was 16.5 percent, making the percentage points of change − 15.5 (16.5 – 32.0).

A total of 33 data points were generated for the cities included in the study. Five data points indicated an increased use of studded tyres, 28 indicated a reduced use of studded tyres. Six data points – four in Oslo, two in Bergen – referred to less than 20 percent use of studded tyres. The data points are shown in Figure 11.

There is a very clear and systematic pattern. All five data points representing an increased use of studded tyres are associated with a reduction in the number of injury accidents. All data points representing a reduction in the use of studded tyres, except one, are associated with an increase in the number of injury accidents. The largest estimated increase is 9.5 percent, in the city of Bergen in 2008, when the use of studded tyres dropped to 9.9 percent in the city. The data points do not have the same statistical weight. A weighted regression analysis was performed in which each data point was weighted in inverse proportion to its

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

sampling variance. A second degree polynomial best fitted the data points (R-squared 0.833).

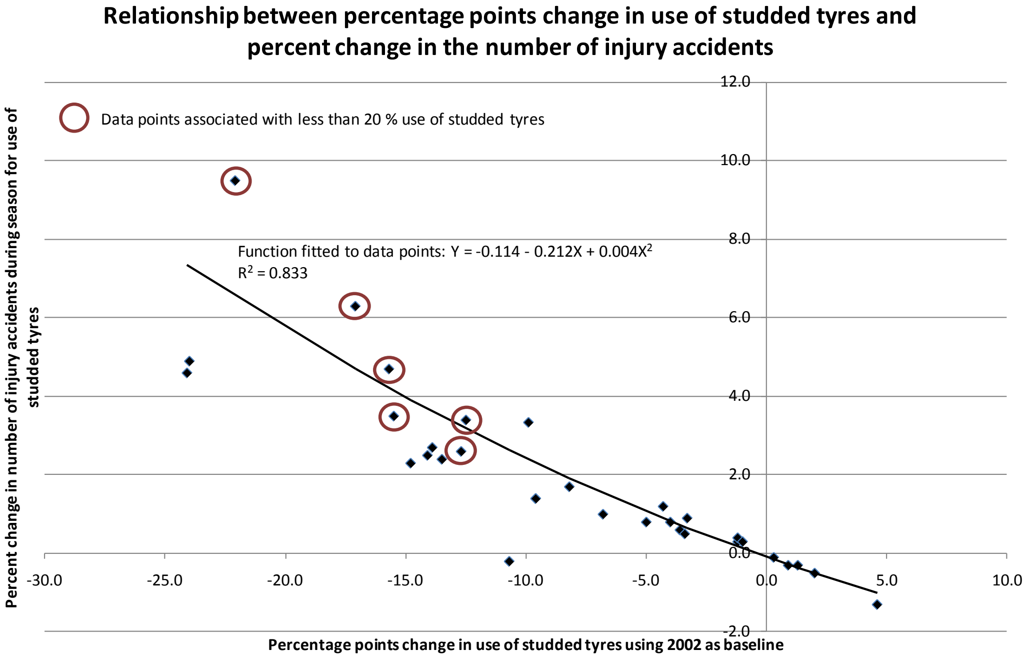


Figure 11: Relationship between changes in the use of studded tyres and changes in the number of injury accidents during the season when studded tyres are used – based on sample enumeration analysis. All cities and all years.

While it is obviously not appropriate to extrapolate the polynomial beyond the range covered by the data, the polynomial is well-behaved within the range of the data and shows only moderate curvature.

The six data points marked by a red square in Figure 11 represent less than 20 percent use of studded tyres. The rightmost of these data points is located at a reduction of 12.5 percentage points in the use of studded tyres. There are twelve data points representing a reduction of 12.5 percentage points or more in the use of studded tyres. Six of these data points refer to reductions resulting in less than 20 percent use of studded tyres, six refer to reductions resulting in a use of studded tyres of more than 20 percent (although two of the data points for Trondheim are very close, at 20.5 and 20.4 percent use of studded tyres).

Four of the six data points referring to less than 20 percent use of studded tyres are located above the function fitted in Figure 11. All of the six data points referring to more than 20 percent use of studded tyres are located below the function. The (simple) mean increase in accidents when the use of studded tyres falls below 20 percent is 5 percent. The (simple) mean increase in accidents when the use of studded tyres stays above 20 percent is 3.2 percent. These estimates are based on data points representing a decline of more than 12.5 percent in the use of studded tyres.

In general, the results display a very systematic pattern that is likely to mainly reflect the effects of changes in the use of studded tyres, controlled for all other variables included in the negative binomial regression model.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

3.3.4 Changes in the distribution of accidents between different types of accident

According to the contract for this research project, potential effects of changes in the use of studded tyres on the distribution of accidents between different types of accident should be studied. Since studded tyres may influence all types of accident, it is difficult to have specific hypotheses concerning the effects to be expected. To see if there have been major changes in the distribution of accidents between different types of accident, the distribution of accidents between different types has been estimated for the years 1993, 2000 and 2007 in each of the five cities included in the study. Unfortunately, data identifying cities are not included in the accident data file for 2008 and 2009. 2007 is therefore the most recent year for which this information is available. Table 8 shows the results.

Accidents during the whole year have been included. In all cities except for Oslo, the number of accidents during the season when the use of studded tyres is permitted is too low to discern any trends over time with respect to the distribution of accidents between different types of accident. In the city of Drammen, even the total count of accidents during one year is so low that random variation has a major influence on the distribution of accidents between different types of accident.

In the city of Oslo, the major change from 1993 to 2007 is that rear-end collisions have increased, but accidents involving crossing or turning vehicles have declined. The growth in rear-end collisions is probably attributable to denser traffic on the major roads in the city. The decline in accidents at junctions (crossing or turning) may in part be the result of conversion of many junctions to roundabouts, which have a lower accident rate than any other type of junction.

The changes in the city of Stavanger are quite similar to those observed in the city of Oslo. It is unlikely that the changes have anything to do with changes in the use of studded tyres. In Oslo, the use of studded tyres was reduced from about 85 % in 1993 to about 35 % in 2000 and further to about 20 % in 2007. In Stavanger, the use of studded tyres was reduced from about 75 % in 1993 to about 40 % in 2000, and 28 % in 2007. Thus, changes over time in the use of studded tyres in the two cities differ considerably (a decline of 65 percentage points in Oslo and 47 percentage points in Stavanger), but the trends with respect to the distribution of accident between types of accidents are very similar.

The distribution of accidents between different types of accident shows an erratic pattern in the city of Drammen, which is not very surprising in view of the fact that the total number of accidents per year is in the range of 50-60. In the cities of Bergen and Trondheim, the net changes from 1993 to 2007 in the distribution of accidents between different types of accident are small. The use of studded tyres has been reduced in both cities, but the decline is greater in the city of Trondheim than in the city of Bergen.

It is concluded that changes in the use of studded tyres are unlikely to have much of an impact on the distribution of accidents between different types of accident, and that the changes observed in the cities between 1993 and 2007 are probably the result mainly of more dense traffic, conversion of junctions to roundabouts and, in the smaller cities, random variation from year to year.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 8: Distribution of injury accidents according to type of accident in 1993, 2000 and 2007

		Percentage distribution of injury accidents		
City	Type of accident	1993	2000	2007
Oslo	Rear-end	30.4	36.2	41.9
	Head-on	6.1	5.4	7.4
	Crossing-turning	24.8	22.5	15.3
	Pedestrian	23.3	25.1	21.0
	Single	7.4	6.5	7.9
	Other	8.0	4.3	6.5
	N	921	1007	811
Drammen	Rear-end	24.2	27.9	7.5
	Head-on	9.7	3.3	49.1
	Crossing-turning	30.6	24.6	13.2
	Pedestrian	22.6	27.9	15.1
	Single	9.7	11.4	9.4
	Other	3.2	4.9	5.7
	N	62	61	53
Stavanger	Rear-end	23.1	29.6	33.1
	Head-on	3.4	12.0	12.3
	Crossing-turning	46.2	35.2	30.0
	Pedestrian	17.1	16.8	15.4
	Single	9.4	4.8	6.9
	Other	0.8	1.6	2.3
	N	117	125	130
Bergen	Rear-end	35.4	23.9	32.9
	Head-on	11.1	13.4	10.8
	Crossing-turning	19.0	28.0	21.0
	Pedestrian	16.4	24.5	17.0
	Single	10.8	8.7	10.2
	Other	7.3	1.5	8.1
	N	342	322	371
Trondheim	Rear-end	24.4	39.1	26.9
	Head-on	14.6	7.3	9.5
	Crossing-turning	33.2	27.5	31.0
	Pedestrian	19.0	15.0	24.8
	Single	4.9	6.8	4.1
	Other	3.9	4.3	3.7
	N	205	233	242

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

3.4 Behavioural adaptation to adverse weather

Road users adapt behaviour to adverse weather. During snow, speed is greatly reduced. To model road user behavioural adaptation, a multiple least squares regression model (ordinary linear additive model) was run with the mean speed of traffic as dependent variable. Figure 12 shows an example of speed data. It shows the daily mean speed of traffic at the Manglerud permanent traffic counting station in Oslo for 2,800 consecutive days starting on January 1, 2002 and ending on August 31, 2009.

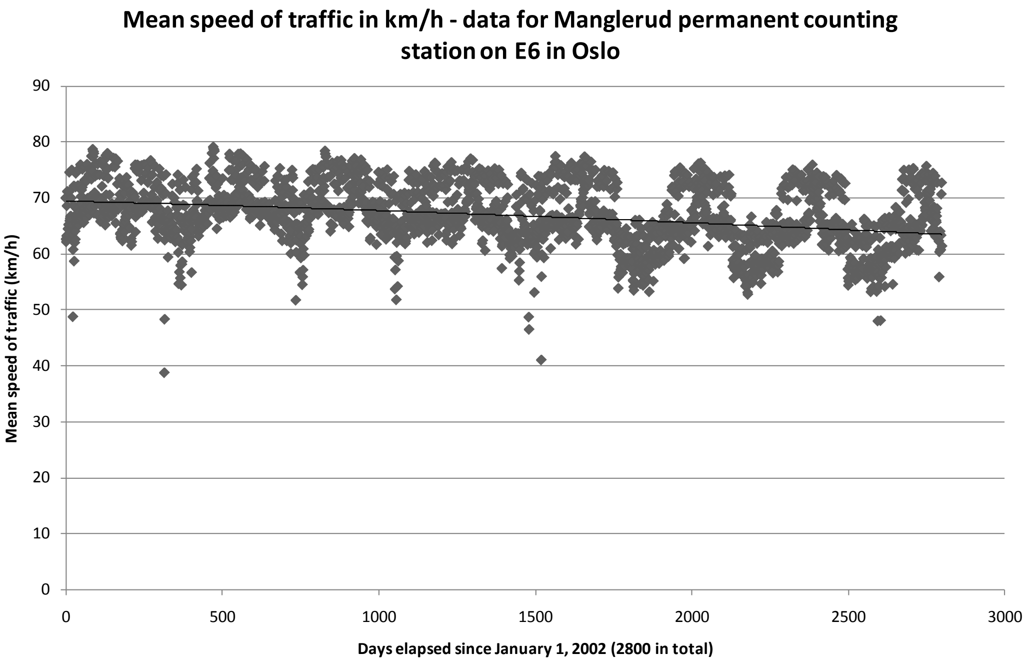


Figure 12: Mean speed of traffic (km/h) at Manglerud traffic counting station in Oslo

A trend line has been fitted, indicating that mean speed is slowly declining over time. This is probably because the site is becoming more and more congested, as indicated by the increasing traffic volume shown for the same site in Figure 6.

Table 9 shows the results of the multiple regression analysis, using the mean speed of traffic as dependent variable. The results are mostly consistent with those of the previous study (Fridstrøm 2000). Like the previous study snowfall, rainfall and snow depth were found to reduce speed. The effect of snow is greater than the effect of rain. Increased traffic volume was associated with lower speed. The effects of the calendar events were broadly consistent with those found before. However, the effect of the percent use of studded tyres was not the same in this study as in the previous study. In this study, the coefficient was negative, suggesting that the higher the share of studded tyres, the lower the speed. The present study found the time trend variable (year count) to be negative, whereas the previous study found that it was positive. Speed is being reduced over time, perhaps because of increasing congestion. The length of daylight has a fairly strong effect on speed: the longer the daylight, the higher the speed.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Table 9: Coefficients estimated by least squares regression. Dependent variable: mean speed of traffic per city per day

Variable	Coefficient	Standard error	P-value
Constant term	48.568	0.142	0.000
Ln (percent studded tyres + 1)	-0.223	0.026	0.000
Today's snowfall (mm)	-0.524	0.117	0.000
Snow depth (√estdepth) (cm)	-0.964	0.151	0.000
Cross zero (dummy)	-0.448	0.161	0.005
Today's rainfall (√estrain) (mm)	-0.237	0.018	0.000
Snowfall · ln(percent studded tyres + 1)	-0.019	0.035	0.584
Snow depth · ln(percent studded tyres + 1)	0.213	0.046	0.000
Cross zero · ln(percent studded tyres +1)	0.209	0.053	0.000
Rainfall · ln (percent studded tyres + 1)	0.067	0.008	0.000
Daily traffic volume (vehicle count)	-0.0000937	0.000	0.000
Dummy for Oslo	22.897	0.191	0.000
Dummy for Drammen	52.360	0.119	0.000
Dummy for Stavanger	9.468	0.063	0.000
Dummy for Bergen	Omitted		
Dummy for Trondheim	38.436	0.135	0.000
Share of daylight (proportion of 24 hours)	4.468	0.176	0.000
Dummy for Sundays and holidays	1.565	0.069	0.000
Dummy for Saturdays	1.229	0.066	0.000
Dummy for Easter	1.395	0.125	0.000
Dummy for Ascension day	0.139	0.167	0.405
Dummy for Whitsun	-0.397	0.215	0.065
Dummy for Christmas	0.631	0.134	0.000
Year count	-0.063	0.009	0.000
Squared correlation coefficient	0.983		
Number of observations	13269		

To illustrate the effects of selected variables on speed, estimates have been developed for the city of Oslo, which is by far the largest of the cities included and accounts for the largest share of accidents. Figure 13 shows the relationship between daily traffic volume and daily mean speed of traffic at the Manglerud counting station in Oslo. The contours of the outer data points have been indicated by the dashed line. It is clearly seen that increased traffic volume is associated with reduced speed.

The extent to which road users adapt their speed to adverse weather is a major importance for road safety. The variables representing weather were, in general, not highly significant in the model predicting injury accidents, but had a somewhat stronger effect on property damage accidents.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

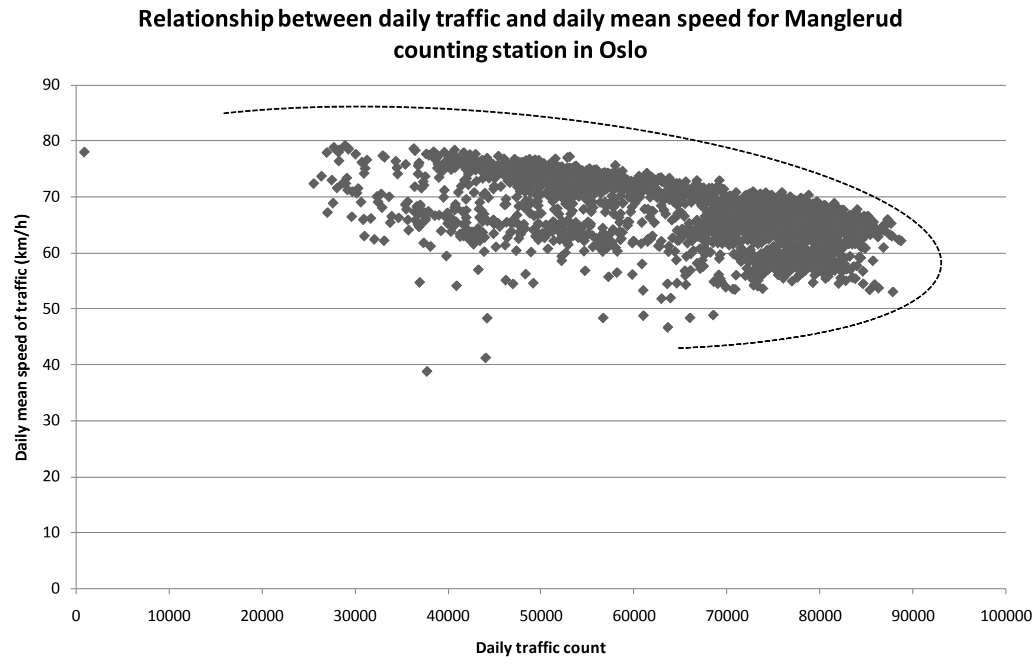


Figure 13: Relationship between traffic volume and speed at Manglerud counting station in Oslo

Figure 14 shows estimated speed in Oslo for different weather conditions and different levels of use of studded tyres. Speed was estimated by applying the coefficients shown in Table 9.

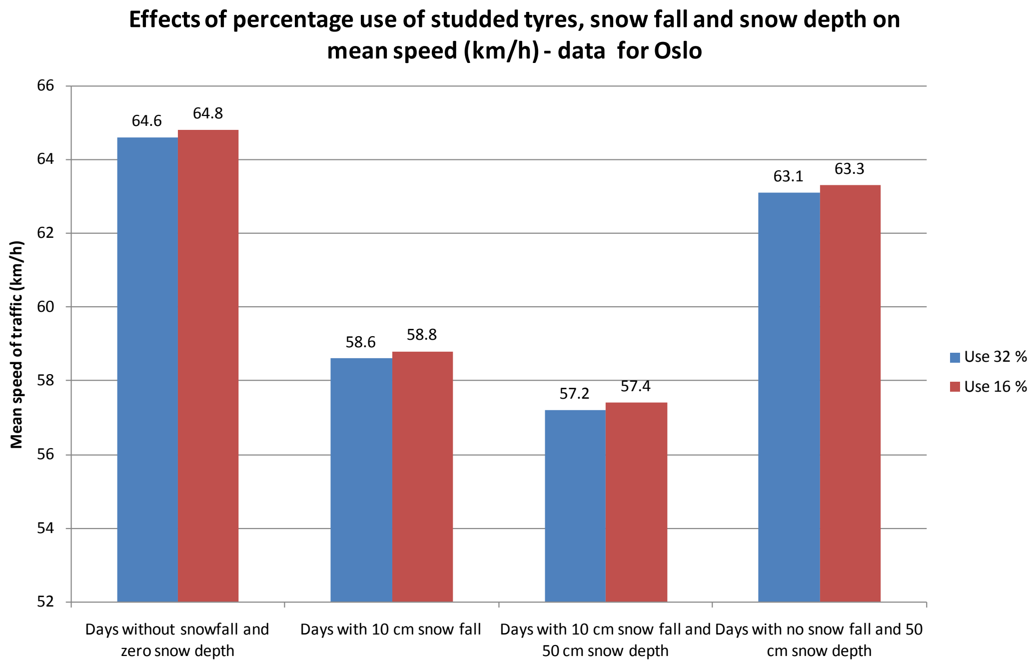


Figure 14: Estimated mean speed of traffic in Oslo depending on weather conditions and use of studded tyres

Two levels have been assumed for the use of studded tyres: 32 % (observed in 2002) and 16.2 % (observed in 2008). It is seen that a reduced use of studded tyres is associated with a slightly higher mean speed. This may seem surprising in view of studies (Rumar et al. 1976, Fosser and Ingebrigtsen 1991) which show that

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

drivers adapt their behaviour to the type of tyres used and tend to drive faster with studded tyres. It is nevertheless not entirely implausible that the mean speed of traffic can increase slightly when fewer cars use studded tyres. The use of studded tyres contributes greatly to the spread of dirty splash water on wet road surfaces. This reduces visibility and makes drivers use windshield wipers and cleaners more often to see better. When fewer cars use studded tyres, these impacts are reduced and visibility may improve, leading to higher speed. It should also not be forgotten that the studies quoted above are both quite old, and the differences between studded tyres and non-studded winter tyres have become smaller over time. The noise produced by studded tyres may reinforce the impression of speed and can make drivers slow down to keep the noise less annoying, at least when driving on bare road surfaces. When the road surface is covered by snow, the noise produced by the studs is not heard.

Figure 13 shows that speed is reduced on days with 10 cm snow fall (10 cm snow corresponds to 10 millimetres when melted). Speed is further reduced if there is already 50 cm of snow on the ground. However, the additional effect of snow depth on speed is considerably smaller than the effect of snow falling. Speed is reduced when there is now on the ground even when snow is not falling. Snow as deep as 50 centimetres will in most cases generate high snow walls along the road, possibly reducing available road width.

3.5 Effects on accidents of daylight

The risk of accident is higher in darkness than in daylight (Johansson et al. 2009). All else equal, one would therefore expect there to be fewer accidents when there is much daylight than when there is little daylight. Daylight is included in the model as the proportion of each day when the sun is above the horizon. This proportion varies enormously, from a low close to 0.20 in Trondheim to a high of more than 0.80. The range from a value of 0.25 (the value in Oslo around Christmas) to about 0.75 (the value in Oslo close to midsummer) represents the addition of twelve hours of daylight. Figure 15 shows the effect of the length of daylight on the number of injury accidents and property damage only accidents.

The addition of twelve hours of daylight is estimated to be associated with about 14 % fewer injury accidents and about 16 % fewer property damage accidents. The effect can also be presented as a sinus curve superimposed on the curve describing the length of daylight throughout the year. The amplitude of this curve will be smaller in Oslo than in Trondheim, because the variation in the length of daylight is greater in Trondheim than in Oslo. However, the effect of daylight is the same in all cities.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

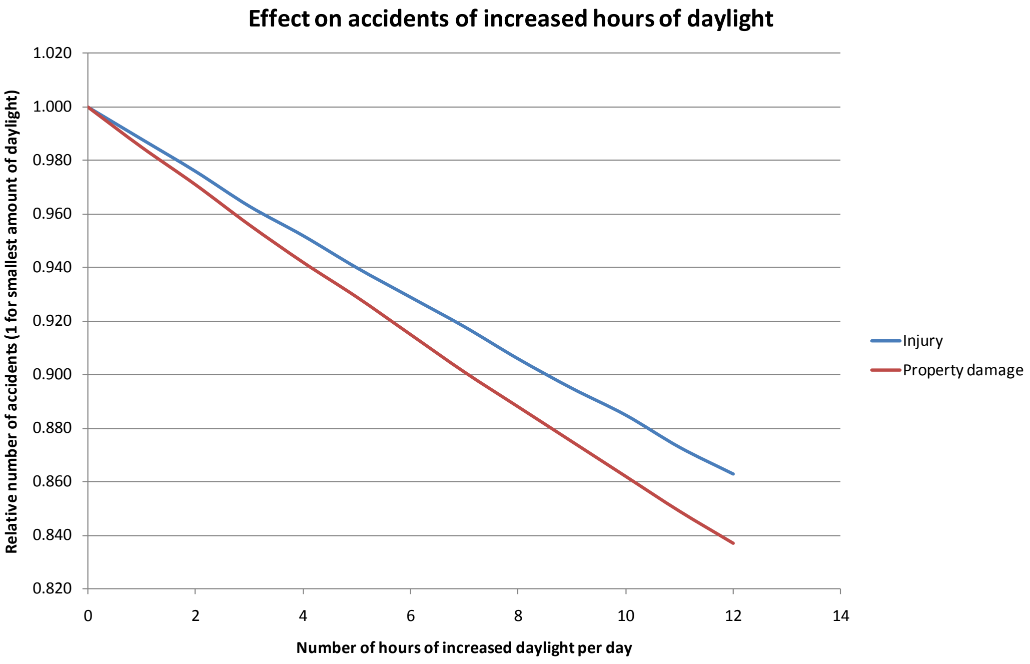


Figure 15: Effects on accidents of length of daylight

3.6 Effects on accidents of weather

Precipitation in the form of snow has an adverse impact on accidents. Snow makes the road slippery and it reduces visibility. Although drivers adapt behaviour to snow by reducing speed, the behavioural adaptation is not sufficient to prevent snow from leading to an increased number of accidents. This shown in Figure 16.

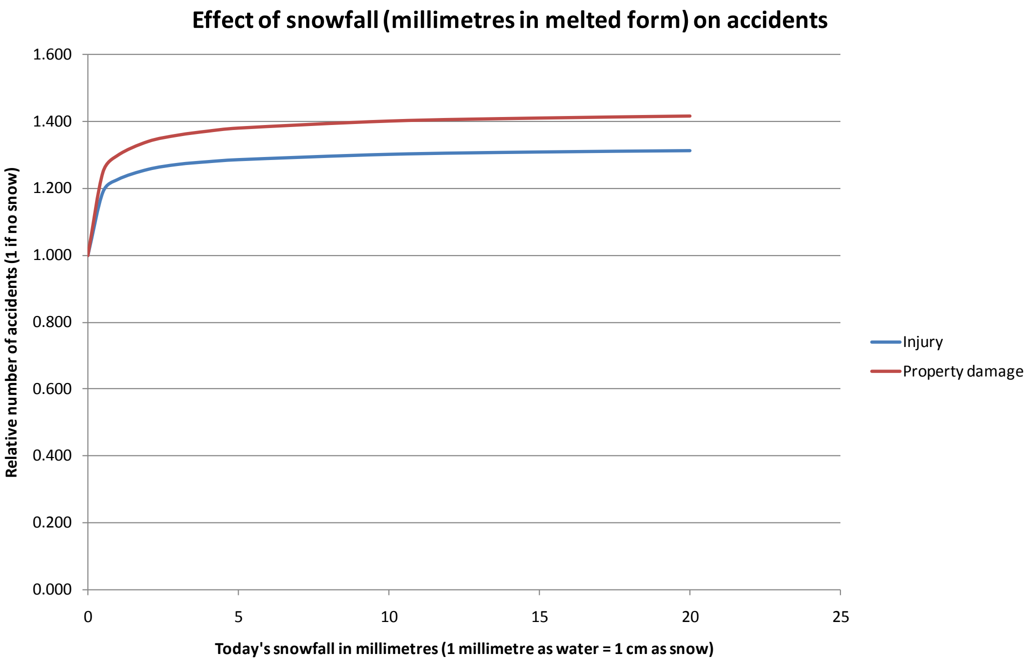


Figure 16: Effects of snow fall on accidents

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Snow increases the number of injury accidents by up to about 30 % and the number of property damage accidents by about 40 %. Rain also contributes to increasing the number of accidents. Precipitation in the form of rain is associated with lower speed, but the behavioural adaptation is not sufficient to prevent the number of accidents from increasing. Figure 17 shows the effects of rain on the number of accidents.

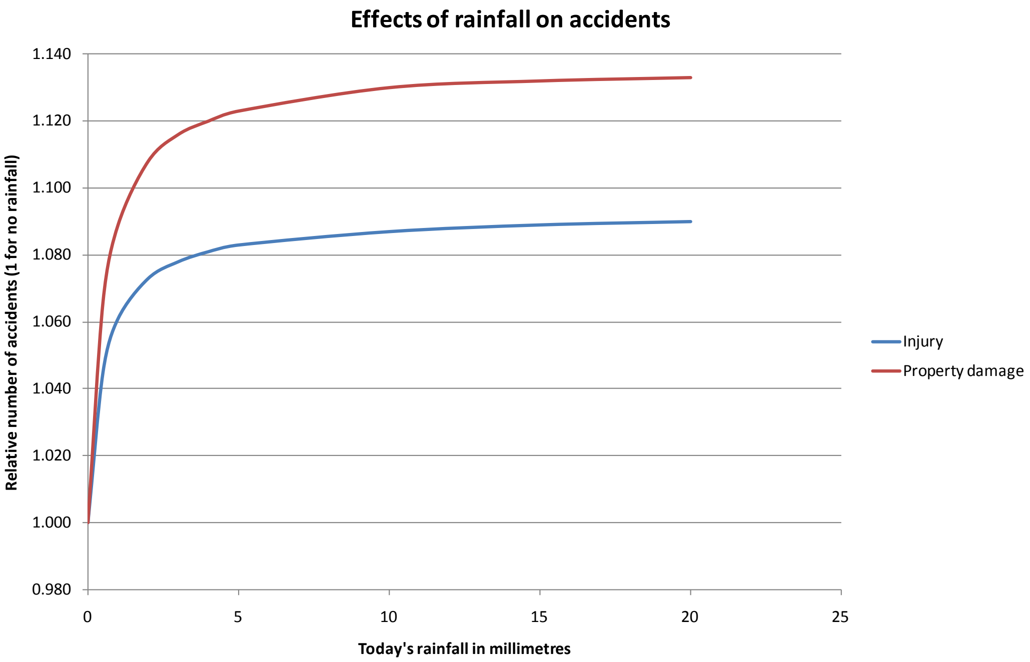


Figure 17: Effects of rainfall on accidents

Rain has a small effect on the number of injury accidents, but is found to have a somewhat larger effect on the number of property damage accidents. The effects of rain are smaller than those of snow (for a given precipitation in millimetres).

The final weather related variable to be considered is snow-depth. The relationship between snow-depth and the number of accidents is shown in Figure 18. The effect of snow-depth is mixed. It is a protective factor with respect to injury accidents, but is associated with an increased number of property damage accidents. Similar findings were reported by Brorsson et al.(1988) and Eisenberg (2004).

All the weather variables interact with the use of studded tyres with respect to their effect on accidents. These interactions will not be further discussed in this report.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

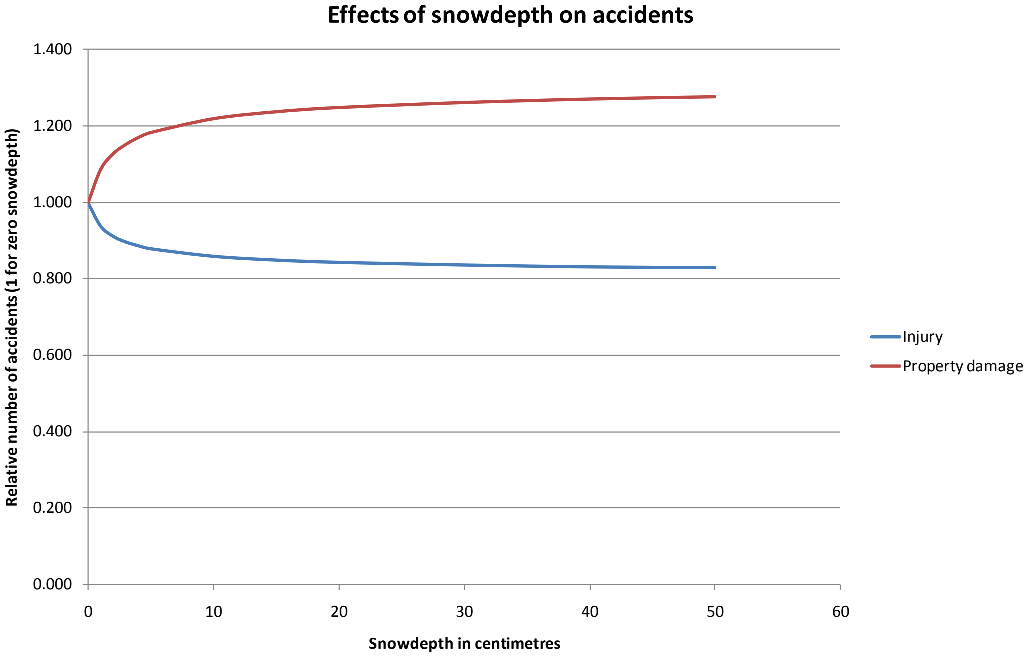


Figure 18: Relationship between snow-depth and the number of accidents

3.7 Effects on accidents of calendar events

Table 10 shows the effects of calendar events on the number of accidents. The number of accidents has been set equal to 1.000 for days that are not associated with any calendar events. The other values are accident modification factors, showing how much higher or lower the number of accidents is on days associated with calendar events.

Table 10: Relative number of accidents associated with calendar events

	Relative number of accidents	
Calendar event	Injury accidents	Property damage accidents
None	1.000	1.000
Sundays and holidays	0.749	0.612
Saturdays	0.808	0.725
Easter	0.820	0.781
Ascension day	1.086	0.975
Whitsun weekend	1.082	1.090
Christmas	0.681	0.686

The effects of the various calendar events are quite similar for injury accidents and property damage accidents. Most calendar events are associated with a reduced number of accidents.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

3.8 Factors influencing the use of studded tyres

A linear regression model was developed in order to estimate the effects of factors influencing the use of studded tyres. The model included year, city dummies, dummy for season of use of studded tyres and dummy for the presence of a tax on the use of studded tyres as independent variables. The percentage of cars using studded tyres was used as dependent variable. Table 11 reports the coefficients estimated.

Table 11: Coefficients estimated in model of factors influencing the use of studded tyres

Variable	Coefficient	Standard error	P-value
Constant term	1647.362	44.803	0.000
Year	-0.822	0.022	0.000
Dummy for Oslo	Omitted		
Dummy for Drammen	2.492	0.169	0.000
Dummy for Stavanger	1.002	0.156	0.000
Dummy for Bergen	-0.440	0.149	0.003
Dummy for Trondheim	5.661	0.150	0.000
Seasonal dummy	26.792	0.122	0.000
Dummy for tax	-4.042	0.175	0.000
R-squared	0.845		

It can be seen that there is a trend for the use of studded tyres to be reduced by about 0.8 percentage points every year. The introduction of a tax on the use of studded tyres reduces their use by about 4 percentage points.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

4 Discussion and conclusions

4.1 Discussion of findings

Trying to evaluate the effects of a road safety measure by means of a multivariate analysis involves a number of challenges. To get correct estimates of the effect of the safety measure, all relevant potentially confounding factors must be controlled for and the effects of all variables included in the model developed must be correctly estimated. Furthermore, the data must be of high quality and as complete as possible.

Has the study presented in this report successfully established a causal relationship between changes in the use of studded tyres and changes in the number of accidents?

To answer this question, it is necessary to consider if there are other plausible explanations of the findings of the study than changes in the use of studded tyres. Although the findings, at least for injury accidents, are consistent with a causal interpretation, there are at least three alternative explanations of study findings. These are:

1. There is an increasingly adverse selection of drivers using studded tyres, i.e. as the group of drivers who use studded tyres becomes smaller, these drivers have a higher accident rate than other drivers. Alternatively, it might be suspected that the accident rate of drivers who have recently ceased using studded tyres will temporarily increase.
2. The effects of studded tyres is mostly external, i.e. studded tyres influence safety mainly be wearing down snow or ice, and this effect has become smaller as the use of studded tyres has declined.
3. There have been changes over time in winter maintenance of roads. More specifically, if maintenance has been reduced, road surface conditions may have worsened, leading to more accidents.

All these hypotheses are based on the assumption that there is no true difference in accident rate between cars using studded tyres and cars using non-studded tyres. It is assumed that whatever difference one might find in the accident rate between these groups of cars are attributable to other factors, such as driver characteristics.

If there actually is no difference in accident rate between cars using studded tyres and cars not using studded tyres, given that the cars are driven the same way, any change in the number of accidents associated with changes in the percentage of cars having studded tyres must be attributable to other factors.

4.2 Adverse selection of drivers

The hypothesis about adverse selection of drivers essentially states that the last drivers to quit using studded tyres are those who need them the most, because

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

they are not highly skilled in driving on roads where studded tyres may confer a safety benefit. Thus one can imagine that when 30 percent of drivers use studded tyres, those who do so have a relative accident rate of about 1.5 when the accident rate for drivers not using studded tyres is set to 1.0. When the use of studded tyres is reduced to 15 percent, the respective accident rates may be 2.4 and 1.0. Simple model estimates show that if the distribution of accident rates in the population of drivers is stable, the fact that some drivers stop using studded tyres will not be associated with changes in the total number of accidents. Drivers maintain their level of risk, but simply move from one group to the other. A change in the number of accidents would only occur if drivers who quit using studded tyres experience an increase in their accident rate. But in that case, the basic assumption of no difference in accident rate between different types of tyres would be wrong, and it would be correct to say that reduced use of studded tyres causes an increase in the number of accidents.

Based on this reasoning, it is concluded that the mere fact that drivers self-select into one group using studded tyres and one group not doing so, will not by itself produce changes over time in the number of accidents unless driver accident rates are affected when drivers change from one group to another. All else equal, driver accident rates can only be affected if one type of tyre is safer than the other – in which case a causal inference is valid – or if road surface conditions get worse as a result of reduced use of studded tyres, influencing the accident rates of all drivers irrespective of the type of tyres they use.

4.3 Studs wearing down snow or ice

The impact of studded tyres in wearing down snow or ice could be weakened if the percentage of cars using studded tyres is reduced. This, however, would not necessarily be a problem if the frequency of heavy snowfall has also been reduced over time. The percentage of days that recorded snowfall (all cities combined) was 8.6 % in 2002, 5.2 % in 2003, 6.1 % in 2004, 5.9 % in 2005, 7.1 % in 2006, 6.3 % in 2007, and 6.2 % in 2008, the last year with complete data. Although the percentage of days with snowfall has fluctuated from year to year, there is no tendency for snowfall to become more frequent.

However, if the impact of studded tyres with respect to wearing down or ice has in fact been weakened as a result of less use of studded tyres, that is not really an alternative explanation of the findings, but more a specification of the causal mechanism by which studded tyres influence safety. Unfortunately, the study does not have data on the actual road surface condition from day to day. It is therefore not possible to verify if slippery road surfaces are more common today than some years ago.

4.4 Winter maintenance of roads

The winter maintenance of roads may have changed over time. The lack of detailed information regarding winter road maintenance is clearly an omitted variable in the study. If, for example, winter road maintenance has been reduced, there is no way of knowing whether the increase in the number of accidents

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

should be attributed to reduced use of studded tyres or a reduced standard of winter maintenance.

To assess whether winter road maintenance may have been reduced, cost figures were extracted from the KOSTRA data base maintained by Statistics Norway. Statistics regarding total operating expenditures on municipal roads and streets were selected. From 2002 to 2009, these expenditures grew by a factor of 2.29 in Oslo, 1.77 in Drammen, 1.70 in Stavanger, 1.69 in Bergen and merely 1.01 in Trondheim. The growth in road maintenance expenditures is well in excess of the general growth in wage expenditures for municipal employees in all cities except for Trondheim. It would thus appear that all cities except for Trondheim were spending more in real terms on the operation and maintenance of municipal roads in 2009 than in 2002. Increasing the level of road maintenance may have partly counteracted the effect on accidents of reduced use of studded tyres, but the data available for this study does not permit this effect to be estimated. However, in all cities that had a lower use of studded tyres during all or most of the years after 2002 than they had in 2002 (i.e. all cities except for Stavanger), the number of injury accidents has increased.

4.5 Conclusions

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

1. The effects on accidents of changes in the use of studded tyres – mainly reduction – in five Norwegian cities between 2002 and 2009 have been evaluated. The evaluation relies on a multivariate analysis employing negative binomial regression.
2. A clear dose-response relationship between changes in the use of studded tyres and changes in the number of injury accidents was found. This pattern suggests that the changes in the number of injury accidents are mainly attributable to changes in the use of studded tyres. The changes vary between a reduction of nearly 1 percent and an increase of nearly 10 percent in the number of injury accidents during the season when the use of studded tyres is permitted. On the average, the number of injury accidents increased by 2 percent during the season for use of studded tyres.
3. Results for insurance reported accidents were less systematic and indicated only very small changes in the number of accidents in all five cities.
4. An important omitted variable in the study is changes in winter road maintenance. Data on municipal expenditures suggest that winter maintenance has been increased in all five cities except for the city of Trondheim. It is not possible to estimate whether this has counteracted the tendency for injury accidents to increase (i.e. whether the increase would have been greater if winter maintenance of roads had not been increased).
5. The number of accidents is greatly influenced by the environmental variables included in the study: the length of daylight, precipitation in the form of snow or rain and the depth of snow covering the ground.
6. Road users adapt to environmental factors by modifying speed. These behavioural adaptations are, however, not sufficient to fully offset the impact of the environmental factors on the risk of accident.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

7. The use of studded tyres is reduced when a tax for using studded tyres is introduced.
8. The study confirms all main findings of a previous study reported in 2000, which this study was intended to replicate.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

5 References

Asano, M., Tanabe, S., Hara, F., Yokoyama, S. 2002. Economic evaluation of banning studded tires because of environmental impact. Transportation Research Record, 1794, 84-93.

Brorsson, B., Ifver, J., Rydgren, H. 1988. Injuries from single-vehicle crashes and snow depth. Accident Analysis and Prevention, 20, 367-377.

Eisenberg, D. 2004. The mixed effects of precipitation on traffic crashes. Accident Analysis and Prevention, 36, 637-647.

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. 2011. Assessing causality in multivariate accident models. Accident Analysis and Prevention, 43, 253-264.

Fosser, S., Ingebrigtsen, S. 1991. Dekkstandardens betydning for person- og varebilføreres fartsvalg på glatt føre. TØI notat 0947. Oslo, Transportøkonomisk institutt.

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

Fridstrøm, L., J. Ifver, S. Ingebrigtsen, R. Kulmala and L. K. Thomsen. 1995. Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. Accident Analysis and Prevention, 27, 1-20.

Johansson, Ö., Wanvik, P. O., Elvik, R. 2009. A new method for assessing the risk of accident associated with darkness. Accident Analysis and Prevention, 41, 809-815.

Krokeborg, J. 1998.Veggrep på vinterveg. Sluttrapport fra Veg-grepsprosjektet. Oslo, Vegdirektoratet.

Lord, D. 2006. Modeling motor vehicle crashes using Poisson-gamma models: Examining the effects of low sample mean values and small sample size on the estimation of the fixed dispersion parameter. Accident Analysis and Prevention, 38, 751-766.

Lord, D., Mannering, F. 2010. The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives. Transportation Research Part A, 44, 291-305.

Lord, D., Washington, S. P., Ivan, J. N. 2005. Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory. Accident Analysis and Prevention, 37, 35-46.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Lord, D., Washington, S. P., Ivan, J. N. 2007. Further notes on the application of zero-inflated models in highway safety. Accident Analysis and Prevention, 39, 53-57.

Maher, M., Mountain, L. 2009. The sensitivity of estimates of regression to the mean. Accident Analysis and Prevention, 41, 861-868.

Malyshkina, N. V., Mannering, F. L., Tarko, A. P. 2009. Markov switching negative binomial models: an application to vehicle accident frequencies. Accident Analysis and Prevention, 41, 217-226.

Malyshkina, N., Mannering, F. 2010. Zero-state Markov switching count-data models: An empirical assessment. Accident Analysis and Prevention, 42, 122-130.

Muskaug, R., Nygaard, L. M., Rosland, P., Johansen, K., Sjøvold, J. 2008. Tilstandsundersøkelser 2008. Rapport TS 2009:02. Oslo, Vegdirektoratet, Veg og trafikkavdelingen, Trafikksikkerhetsseksjonen.

Rumar, K., Berggrund, U., Jernberg, P., Ytterbom, U. 1976. Driver reaction to a technical safety measure – studded tires. Human Factors, 18, 443-454.

Scheibe, R. R. 2002. An overview of studded and studless tire traction and safety. Report WA-RD 551.1 Washington State Transportation Center (TRAC), University of Washington, Seattle, Washington.

Shankar, V., Milton, J., Mannering, F. 1997. Modeling accident frequencies as zero-altered probability processes: an empirical inquiry. Accident Analysis and Prevention, 29, 829-837.

Strandroth, J., Rizzi, M., Olai, M., Lie, A., Tingvall.C. 2011. The effects of studded tires on fatal crashes with passenger cars and the benefits of electronic stability control (ESC) in Swedish winter driving. Manuscript submitted to Accident Analysis and Prevention.

Strong, C., Ye, Z., Shi, X. 2010. Safety effects of winter weather: the state of knowledge and remaining challenges. Transport Reviews, 30, 677-699.

Öberg, G., Möller, S. 2009. Hur påverkas trafiksäkerheten om restriktioner av dubbdäcksanvåandning införs? Kan en förbättrad vintervååghållning medföra att trafiksäkerhetsnivån bibehålls? VTI rapport 648. Linköping, Väg- och Transportforskningsinstitutet.

Copyright © Transportøkonomisk institutt, 2011
Denne publikasjonen er vernet i henhold til Åndsverkloven av 1961

Visiting and postal address:
Institute of Transport Economics
Gaustadalléen 21
NO 0349 Oslo

Telephone: +47 22 57 38 00
Telefax: +47 22 60 92 00
E-mail: toi@toi.no

www.toi.no

Institute of Transport Economics (TØI)
Norwegian Centre for Transport Research

Established in 1964, the Institute of Transport Economics is an interdisciplinary, applied research centre with approximately 70 professionals. Its mission is to develop and disseminate transportation knowledge that has scientific quality and practical application.

A private, non-profit foundation, TØI receives basic funding from the Research Council of Norway. However, the greater part of its revenue is generated through contract research. An important part of its activity is international research cooperation, mostly in the form of projects under the Framework Programmes of the European Commission.

TØI participates in the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) located near the University of Oslo. See www.ciens.no.

TØI covers all modes of transport and virtually all topics in transportation, including road safety, public transport, climate change and the environment, travel behaviour, tourism, land use and urban planning, decision-making processes, freight and travel demand, as well as general transport economics.

Claiming copyright to its products, TØI acts independently of its clients in matters of scientific approach, professional judgment and evaluation. TØI reports are generally downloadable for free at www.toi.no.