International Transport Forum

Why Does Road Safety Improve When Economic Times Are Hard?

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International Traffic Safety Data and Analysis Group

Research Report

OECD

DECADE OF ACTION FOR ROAD SAFETY 2011-2020

Why Does Road Safety Improve When Economic Times Are Hard?

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INTERNATIONAL TRANSPORT FORUM

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Table of contents

List of figures

List of tables

EXECUTIVE SUMMARY

There is clear evidence that when economic growth declines, and particularly when unemployment increases, road safety improves.

This report reviews previous studies that have examined the relationship between economic performance and road safety. Most of the studies use the rate of unemployment as a principal indicator of economic performance and find that when unemployment increases, road safety improves, i.e. there is a reduction in the number of road crash fatalities and injuries. Studies that have investigated the relationship between economic performance and safety for different groups of the population find that the reductions in traffic fatalities during economic downturns tend to be largest among young people.

The research indicates three main mechanisms favourable to road safety during downturns:

- Economic downturns are associated with less growth in traffic or a decline in traffic volumes.
- Economic downturns are associated with a disproportionate reduction in the exposure of high-risk groups in traffic; in particular unemployment tends to be higher among young people than people in other age groups.
- Reductions in disposable income may be associated with more cautious road user behaviour, such as less drinking and driving, lower speed to save fuel, fewer holiday trips.

The financial and economic crises which started in 2007 were accompanied by marked falls in annual numbers of road deaths in most OECD countries.

The financial crisis of 2007-08 and the subsequent severe economic downturn have been accompanied by marked falls in annual numbers of road deaths in most OECD countries – larger falls than countries had become accustomed to before. Most OECD countries have reached their lowest level of road fatalities ever recorded, whether in absolute numbers or in rate per 100 000 inhabitants. In 2012, five countries had a mortality rate below 3.

It is important to understand how much of the accelerated reduction in numbers of deaths during the downturn that began in 2008 was attributable to the changed economic conditions.

In most OECD countries by 2008, road safety policies aiming to reduce death and injury on the roads and the implementation of these policies had become much more systematic than in earlier decades. This makes it more important than in earlier decades to try to understand how much of the accelerated reduction in numbers of deaths during the downturn that began in 2008 was attributable to the changed economic conditions. It is important to understand what the mechanisms for the accelerated reduction were and to what extent the acceleration may be reversed as economic development recovers from the effects of the crisis.

The six studies in the report are accompanied by an overview, which sets out concisely the resulting state of knowledge and its implications for interpretation of recent and current national annual numbers of road deaths in the monitoring and evaluation of past and current road safety policies and their future development.

The economic downturn in 2009-10 may well have contributed to about two-thirds of the decrease in fatalities from 2008.

According to extensive statistical analysis by Rune Elvik of data for 14 OECD countries over the period 1970-2010, the increase in unemployment in those countries during 2009 and 2010 is estimated to have contributed about 4 850 to the reduction of 7 467 (i.e. about two-thirds), that took place in the number of traffic fatalities in those countries during these two years. The remainder of the reduction is broadly consistent with a continuation of a long-term trend that was apparent before the financial crisis.

The recent downturn has had repercussions on the Gross Domestic Product (GDP) and unemployment rate and has influenced the number of road deaths through a reduction in vehicle-kilometres driven, especially by young men and by heavy goods vehicles, a reduction in speeding and in drink-driving, and a reduction in learning to drive by young men.

A number of ways in which changes in economic development may lead to changes in road safety have been identified. These can be summarised in terms of what may happen when GDP per inhabitant falls (or at least rises noticeably more slowly than has been customary) and unemployment rises. Some consequential changes that could improve road safety are:

- Fewer vehicle-kilometres may be travelled.
- Some of the vehicle-kilometres may be driven more safely.
- The proportion driven by young adults may be smaller.

The research indicates that favourable influences like these outweigh others that might worsen road safety, such as:

- Some vehicle-km may be driven less safely.
- Fewer new vehicles may be bought and older ones may remain in use for longer.
- Less may be spent on vehicle maintenance or on safety features in vehicles.
- Less may be invested by governments in road safety engineering.

The reviews make clear the importance of the distinction between the effects of changes in the number of vehicle-kms travelled and those of changes in the risk of deaths per vehicle-km travelled. The former reflect changes in activity leading to changes in amounts of vehicle use, and the latter reflect changes in road user behaviour, in the composition of traffic and in spending on new, safer cars, thus making roads safer.

Policy makers need to take careful account of these results when setting road safety targets and when designing road safety strategies for the future.

While in 2015 it is expected that the worst of the economic crisis is behind us, policy makers need to anticipate the consequences of economic recovery on the volume of traffic and driving behaviour. As shown through the six studies included in this report, the very good performances obtained in most OECD countries since 2008 are not solely the fruit of determined road safety policies. In order to consolidate the good road safety results obtained in the past few years, sound road safety policies need to be intensified, supported by modelling to identify areas where future gains in terms of fatality and serious injury reductions can be made. In particular, efforts will be needed to intensify enforcement in relation to drink driving, speeding and the use of protective equipment (such as seat belts or helmets). In addition, there is a need for further investment in the maintenance of the existing infrastructure and development of (low-cost) safety measures, which could be implemented quickly. Finally, a systematic and regular monitoring and publication of key safety performance indicators (using an early-warning signal) will assist policy makers to intervene if performance declines.

CHAPTER 1. OVERVIEW[1]

Introduction

As long ago as the fluctuations in the price of oil in the early 1970s it was noticed that setbacks in economic growth in many OECD countries were often accompanied by unusual falls in the annual numbers of road deaths in the affected countries. This happened again in recessions or periods of slower economic growth in the early 1980s and the early 1990s and by the turn of the century a number of studies of the phenomenon had been made. It therefore came as no surprise to those concerned with road safety that the financial crisis of 2007-08 was also accompanied by marked falls in annual numbers of road deaths in most OECD countries – larger falls than countries had become accustomed to as a result of road safety policies and other influences.

In most OECD countries by 2008, road safety policies aiming to reduce death and injury on the roads and the implementation of these policies had become much more systematic than in earlier decades. These now call for correspondingly more careful monitoring and interpretation of annual numbers of road deaths and other relevant indices of road safety. This makes it more important than in earlier decades to try to understand how much of the accelerated reduction in numbers of deaths during the recession that began in 2008 was attributable to the changed economic conditions, and if possible what the mechanisms for the accelerated reduction were and to what extent the acceleration may be reversed as economic development recovers from the effects of the crisis.

For this reason, a number of further studies of the phenomenon have been undertaken and six of these are brought together in this report. The focus of these and earlier studies is mainly upon annual numbers of deaths and related death rates rather than on other possible road safety indicators, because numbers of deaths are much more nearly comparable among countries and across the years than other indicators. One of the studies also analysed monthly numbers of deaths.

This synthesis of the six studies tries to set out concisely the resulting state of knowledge and its implications for interpretation of recent and current national annual numbers of road deaths in the monitoring and evaluation of past and current road safety policies and their future development. It does so in terms of the scope of previous work; the relevant quantitative indicators of road safety and economic development; mechanisms by which the indicators of economic development may influence the indicators of road safety; quantitative modelling of these influences and its implications for the interpretation of changes in annual numbers of road deaths; and the scope for further useful related research.

1. Author: Richard Allsop, Centre for Transport Studies, University College London.

Previous research work on the relationship between road safety performance and economic development

Two independent critical reviews by Wijnen and Rietveld and by Elvik provide overviews of studies dating mainly from the mid-1970s to 2011 and the mid-1980s to 2011 respectively. They concentrate upon studies that investigate statistically the relations between national indicators of road safety and economic development across numbers of countries in a single year and over periods of years for individual countries and for groups of countries taken together. These relations are examined within the longer term context, already well-established for many higher income countries, of the annual number of road deaths per million inhabitants in a country first rising with national income in that country when this is rising from a low level, and later falling as national income continues to rise once it has passed a certain level. The studies reviewed have, however, largely assumed linear or log-linear relations between indicators of road safety and economic development over the periods studied.

The studies reviewed consider a number of indicators of each kind in a range of countries over various periods of years and allowing for different combinations of other relevant variables. It is therefore to be expected that the estimates they provide of relations between any one indicator of road safety and any one indicator of economic development differ widely in magnitude and sometimes in sign. But one finding that emerges strongly and clearly is that a substantial majority of the studies indicate that, other things being equal, road safety in a country tends to fare better when economic development in the country is weaker, and to fare less well when economic development is stronger.

Quantitative indicators of road safety and economic development

Over the six studies taken together, four principal indicators of national level of road safety are considered:

- The number of road deaths in each calendar year.
- The number of road deaths at ages 18-24 in each calendar year.
- The number of road deaths per million inhabitants in each year.
- The number of road deaths per billion vehicle-km travelled in each year.

Some of the work discussed considers numbers of fatal accidents rather than numbers of deaths and one of the studies analyses monthly numbers of deaths. The age group 18-24 (17-24 in UK studies) is singled out because of indications that their numbers of road deaths may be particularly strongly associated with economic downturns.

Three principal indicators of national economic development are considered, as estimated for each country and each calendar year:

- The number of unemployed people.
- The unemployment rate – the number of unemployed people as a percentage of the workforce.
- The Gross Domestic Product (GDP) per inhabitant.

To enable analysis covering different countries, GDP can be expressed in a common currency and adjusted for differences in purchasing power between countries.

Outstandingly important among a range of other variables that have been considered in previous work on the relation between these two sets of indicators is the number of vehicle-km travelled each year in each country. This is not an indicator of either kind, but it is an important quantitative element in the mechanisms relating them.

Mechanisms relating road safety to economic development

A number of ways in which changes in economic development may lead to changes in road safety have been identified. These can be summarised in terms of what may happen when GDP per inhabitant falls (or at least rises noticeably more slowly than has been customary) and unemployment rises. Some consequential changes that could improve road safety are:

- fewer vehicle-km may be travelled
- some of the vehicle-km may be driven more safely
- the proportion driven by young adults.

Others that might worsen road safety are:

- some vehicle-km may be driven less safely
- fewer new vehicles may be bought and older ones may remain in use for longer
- less may be spent on vehicle maintenance or on safety features in vehicles
- less may be invested in road safety engineering.

Vehicles being driven more safely may result, for example, from drivers wishing to save fuel or from reduction in drink driving. Vehicles being driven less safely may result, for example, from reduced spending on vehicle maintenance or replacement of less safe older vehicles.

Pointers to mechanisms like these are found in the previous work and in the reviews made of it in this report, but evidence enabling the effects of different mechanisms to be established definitively or to be distinguished or quantified is sparse. What is more susceptible to analysis is the aggregate effect of whichever mix of these and other mechanisms may actually be operating.

To this end, the reviews make clear the importance of the distinction between the effects of changes in the number of vehicle-km travelled and those of changes in the risk of death per vehicle-km travelled. The former reflect changes in activity leading to changes in amounts of vehicle use, and the latter reflect changes in road user behaviour, in the composition of traffic, and in spending on new safer cars and on making roads safer. Changes of these two kinds may either reinforce one another or offset one another in contributing to the aggregate change in road safety. The reviews are supported by analysis by Elvik and by Fletcher, Noble *et al.,* in indicating that changes in the risk of death per vehicle-km travelled may well contribute more than changes in the number of vehicle-km travelled to changes in annual numbers of road deaths during economic downturns.

The reviews also distinguish between previous studies that have analysed the relation between numbers of road casualties and economic development and those that have analysed the relation between risk per vehicle-km and economic development. For studies of both kinds a clear majority indicate that road safety fares better rather than less well when economic development is weaker, but the majority is larger for studies analysing numbers of casualties than for those analysing risk per vehicle-km.

Discussion of mechanisms in the reviews is reinforced, illustrated and augmented by Fletcher, Noble *et al* through a detailed investigation of how a wide range of factors may have contributed to the falls in annual numbers of road deaths in Great Britain between 2007 and 2010. Their largely empirical examination of national data from a number of sources provides strong support for the hypothesis that changes influenced by the recession have had a major role in leading to these falls. In relation to the longer term context, they note that the increase in vehicle-km travelled associated with rising GDP per inhabitant had been more modest since the mid-1990s than before the economic downturn of the early 1990s. Then in 2008-10 motor vehicle-km decreased, and the decrease was particularly marked in heavy goods traffic and in driving by men aged 17-24, the number of whom gaining driving licences also decreased. Distance walked also decreased, while cycling increased, and rail travel continued to increase as it had been doing since the late 1990s. Contributors other than the recession to the decrease in vehicle-km were unusually high fuel prices in 2008 and a step change in the level of enforcement of laws against driving of unlicensed or uninsured vehicles. Vehicle-km travelled by cars up to 5 years old decreased, while those travelled by older cars increased, notwithstanding a car scrappage scheme in 2009 intended to stimulate buying of new cars.

Associated with the decreases in heavy goods traffic and in driving by young men were larger than average falls in deaths in collisions involving heavy goods vehicles or drivers aged 17-24, accounting between them for about half the fall in road deaths between 2007 and 2009. The fall in road deaths was spread over all four quarters of the year but the numbers in the fourth quarter of 2009 and in both the first and the fourth quarters of 2010 were exceptionally reduced, probably by severe winter weather rather than by any effect of the recession. The fall in deaths was spread over all the main types of road: main roads and side roads, both built-up and not built-up, and motorways. Deaths among males fell more than those among females. Deaths fell in all age groups, but the fall was greatest among young adults. The fall in deaths was somewhat greater among those living in localities in the highest quartile of socio-economic deprivation than among the less deprived. In relation to vehicle secondary safety, the proportion of driver casualties who were killed continued the same downward trend after 2007 as previously, indicating that any increase associated with increased driving of older cars and reduced driving of newer ones was somehow offset, perhaps by a combination of accelerated improvement in occupant protection and more careful driving.

Concerning driver behaviour, there were modest but clear reductions in speeding on all the main types of road, results of police breath-tests and coroners' blood analysis of killed drivers and riders indicate some reduction in drink driving after 2007, the numbers of deaths attributed to drink driving were lower, and rear seatbelt wearing by adults increased. These indicate safer vehicle-use, perhaps influenced by the recession. But mobile phone use increased after 2007.

In short, the study by Fletcher, Noble *et al.* identifies likely influences of the recession on the number of road deaths through reduction in vehicle-km driven, especially by young men and by heavy goods vehicles, reduction in speeding and in drink driving, and reduction in learning to drive by young men. Other identified likely contributors to the fall in road deaths were two severe winters and stricter enforcement of some traffic laws. Accelerated improvement in car occupant protection is ruled out as a likely substantial contributor to the unusual size of the fall in deaths. Road safety policy and its implementation remained broadly unchanged from 2007 until halfway through 2010.

Modelling the influence of economic development on road safety

Studies included in this report have concentrated on relations between annual numbers of road deaths and two of the indicators of economic development: GDP per inhabitant and the unemployment rate. Some of the work has disaggregated the numbers of deaths or fatal accidents, notably by distinguishing deaths among, or accidents involving vehicles driven by those aged 18-24 (17-24 for analysis in Great Britain).

Influence of GDP per inhabitant

Bergel-Hayat, Christoforou and Ferriere have revisited for five countries the long term relation between annual number of road deaths and GDP per inhabitant. They noted that by 2008 the familiar downward trend in deaths per year with increasing GDP above a certain level had been evident in all the five countries for at least 12 years, but this trend did not reverse when GDP fell in 2009, as would have been expected if the relation were causal and independent of direction of change in GDP, but instead continued downward in 2009 and the next years of lower GDP.

In one of a range of modelling exercises, Elvik has related annual numbers of road deaths at all ages in the years 1995-2010 to year (to allow for trend over time) and to the logarithms of the GDP per inhabitant and of the unemployment rate. He has done this for each of 14 OECD countries separately using negative binomial regression models. The resulting models comply well with a number of criteria for statistical performance. The relation with unemployment rate is discussed later in this synthesis. The fitted coefficients for year and logarithm of GDP per inhabitant are mixed in magnitude and sign, but when these are combined linearly using two appropriate multipliers, the combination is broadly consistent across countries and is negative. This indicates that over the period 1995-2010 the trend and association with GDP per inhabitant combine to result broadly consistently in an estimated decrease in annual number of deaths, after allowing for any effect of unemployment. The mix in magnitude and sign among the coefficients for year and GDP per inhabitant in the 14 countries results largely from the high correlation between these two variables. In principle, the coefficient for year estimates an annual trend in the number of deaths and the coefficient for logarithm of GDP per inhabitant estimates the elasticity of the number of deaths with respect to GDP per inhabitant, but the correlation prevents the individual coefficients from being interpreted reliably as such. Elvik repeats this analysis for numbers of deaths among those aged 18-24 only, yielding a not dissimilar mix of coefficients for year and logarithm of GDP per inhabitant.

Antoniou, Yannis, Papadimitriou and Lassarre begin by exploring the technical matter of the degree of integration of time series for annual GDP per inhabitant and number of road deaths in 30 European countries. They have then estimated coefficients of the logarithm of GDP per inhabitant for these 30 countries from a linear regression model for the logarithm of annual numbers of deaths without allowance for any effect of unemployment. The estimates of elasticity are mostly positive, ranging from -1.27 to 1.86 with one larger outlier, alongside an estimate of 2.3% decrease per year as an average trend. The possibilities of quadratic trend and quadratic relation with the logarithm of GDP per inhabitant are explored separately. Elvik's corresponding estimates are quoted for the 12 countries common to the two studies. In both authors' models, allowance is made for certain circumstances, notably road safety interventions, in particular countries and particular years that are known to have affected annual numbers of deaths markedly.

Antoniou, Yannis and Papadimitriou have investigated the shorter term relation between annual numbers of deaths and GDP per inhabitant by linear regression of the logarithm of the ratio of the numbers of deaths in each year and its preceding year upon the logarithm of the corresponding ratio of values of GDP per inhabitant. The estimated coefficient of the latter is an estimate of the elasticity of the annual number of deaths with respect to the GDP per inhabitant, and the estimated constant term provides an estimate of the trend per year in the annual number of deaths. The model makes no allowance for the unemployment rate. It is fitted to three groups of European countries - North-western, Eastern and Southern – in such a way as to provide distinct estimates of elasticity with respect to increases and decreases in GDP per inhabitant. For the first two groups of 11 and 9 countries respectively, the elasticity is in each case estimated to be numerically larger for decreases in GDP than for increases, but this difference could have arisen by chance. Common trends for all countries in each group are estimated to be 1.25% downwards for the North-western group and 0.95% downwards for the Eastern group. For the Southern group of just 4 countries the model accounts for very little of the variation in the annual numbers of deaths.

A similar model fitted by the same authors to data for 30 countries but without distinguishing between elasticities with respect to increases and decreases in GDP provides a separate estimate of trend and elasticity for each country. For all but one country the trend is estimated to be downwards, by up to 9% per year, and for all but four countries the estimated elasticity is positive, ranging from -0.31 to 2.56 with one outlier in each direction. Estimates of elasticity from a corresponding analysis by Elvik which does allow for unemployment are quoted for the 12 countries common to the two studies and range from -0.05 to 1.57.

Influence of the unemployment rate

The analysis by Elvik already discussed of numbers of deaths per year in 14 countries in 1995-2010 provides an estimate for each country of the elasticity of the number of deaths with respect to the unemployment rate. For numbers of deaths at all ages, 10 of the 14 estimated elasticities are negative, and two of the positive values are for countries with exceptional combinations of values for the other two coefficients in the model. For numbers of deaths among those aged 18-24 only, nine of the 14 estimated elasticities are negative, and these are on average clearly larger numerically and more significant statistically than for deaths at all ages, and again two of the positive values are for countries with exceptional combinations of values for the other two coefficients in the model. These results point to a tendency for numbers of road deaths to be lower when unemployment is higher, and for this relation to be stronger for deaths among those aged 18-24 than for deaths at all ages. The latter interpretation is consistent with the observation of Fletcher, Noble *et al.,* that numbers of deaths in collisions involving car drivers aged 17-24 fell faster than numbers of other deaths on the roads of Great Britain in the recession after 2007.

Elvik investigates the relation of annual number of road deaths to unemployment rate more deeply by analysing the year-on-year percentage changes in numbers of deaths and percentage point changes in unemployment rate in the same 14 countries for the years 1970-71 to 2009-2010. In interpreting his analysis, it is important to note that a change of one percentage point in the unemployment rate refers to an increase from p% to (p+1)% or a decrease from p% to (p–1)%. For each country and for each pair of successive years he uses statistical models to estimate what percentage change in the number of deaths was associated with the concurrent change in the unemployment rate. For each country, each model yields 40 pairs of values: (x = change in unemployment rate in percentage points, y = associated percentage change in annual number of road deaths). For the country concerned, regressing y on x provides in the slope an estimate of the percentage change in annual number of road deaths per percentage point by which the unemployment rate rises, and in the intercept an estimate of the average annual percentage change in the number of deaths in the absence of any change in the employment rate.

Elvik uses a combination of long term and short term models for this purpose – a negative binomial regression model for numbers of deaths, a linear regression model for changes in numbers of deaths, and a linear regression model for the logarithm of the ratio of numbers of deaths in successive years. This results in three regressions of y on x for each country, and in each case the three regression lines are sufficiently similar for it to be reasonable to take a combination of the three, suitably weighted according to their goodness of fit, as providing a single estimate for each country of the percentage change in annual number of road deaths per percentage point by which the unemployment rate rises. For the 12 European countries among the 14 studied, these estimates range from -3.7% to -0.23%. Similarly, the combination of models provides an estimate of the average annual percentage change in the number of deaths in the absence of any change in the unemployment rate. For the 12 European countries these estimates range from -1.8% to -4.3%. Elvik uses the resulting estimates for all 14 countries to calculate that about two-thirds of the fall of 13% in the total number of road deaths in these countries in 2010 compared with 2008 is associated with rises in unemployment in these countries between those two years.

Bergel-Hayat, Christoforou and Ferriere use a structural time-series model to investigate the relation between monthly numbers of road deaths and the unemployment rate in each month. They estimate that for France in the period 1983-2012, during which there were many fluctuations both upwards and downwards in unemployment, a decrease of 3.1% in the number of deaths was associated with each percentage point increase in the unemployment rate (for example from 10% to 11%) and a similar increase in deaths with each percentage point decrease in unemployment. This estimate is supported by analysis of annual numbers of deaths. They found a broadly similar result for Spain. Elvik's estimate for France was a much smaller decrease of only 0.23%, but he recognises that this is out of line with his corresponding estimates ranging from 0.64% to 3.7% for other European countries, among which his estimate of 3.3% for Denmark is closest to Bergel-Hayat and her colleagues' estimate for France.

Influence of recession upon fatal accidents of different kinds

Forsman, Simonsson, Wiklund and Berg have made a disaggregate comparison of fatal accidents in Sweden in December 2008-March 2009, during the economic recession, with those in the corresponding months of the three preceding years of economic growth. Statistically significant differences were that in these months of 2008-09 the number of fatal accidents was down by nearly 40%, the proportion of these with two or more people killed was down from about 1 in 10 to about 1 in 30, the percentage fall in the number involving just one vehicle and no other road user was about half the percentage fall in other kinds of fatal accident, and the number involving an unlicensed driver was about 40% higher, compared in each case with the preceding three years. Other aspects investigated but for which no statistically significant difference was found were time of day, administration of road, age of killed car drivers, type of vehicle involved, seat belt use, use of alcohol or other drugs, suspicion of speeding and quality of tyres.

Implications for interpreting changes in annual numbers of road deaths

Although the studies reviewed and described in this report do not provide clearly definitive estimates of the relations between road safety and economic development, they do make it clear that there are strong statistical associations between national annual numbers of road deaths and both GDP per inhabitant and unemployment rate in European countries, Japan and the USA. These associations need to be seen in the context of a general downward trend in annual number of road deaths in these countries over recent decades. This downward trend is concurrent with but by no means wholly associated with the upward trend in GDP per inhabitant over most of these decades.

The recent analyses in this report indicate the following advice to those concerned with road safety who wish to interpret changes over the years in annual numbers of road deaths.

- Both short term and long term relations are informative, but they should be clearly distinguished.

- Analysis should take account of the occurrence of step changes or sudden changes in trend in numbers of deaths associated with substantial road safety interventions that take place on known dates.

- Analysis should take into account changes in the unemployment rate, bearing in mind that these changes may well be correlated with changes in the GDP per inhabitant.

- Analysis should take into account changes in GDP per inhabitant in a way that allows for the possibility that the association of annual numbers of deaths with falls in GDP per inhabitant differs in strength from the association with rises in GDP per inhabitant.

- Alongside these two indicators of economic development, analysis should allow for a long term trend in annual numbers of deaths. Analysis should bear in mind that because of the long term upward tendency in GDP per inhabitant and a tendency, other things being equal, for number of deaths per year to rise with GDP per inhabitant, the recent historical downward tendency in number of deaths in higher income countries is the net effect of an upward tendency associated with rising GDP per inhabitant and a stronger downward tendency associated in part with road safety policies. Because of the difference in nature between these two influences, estimates provided by long term statistical models for annual numbers of deaths may not distinguish clearly between trend and association with changes in GDP per inhabitant.

- It may be helpful in distinguishing between trend, the association with GDP per inhabitant and the association with unemployment rate to complement modelling of annual numbers of deaths by modelling also the change in this number between each year and the next. The following is a basic example from a range of possible models:

$$\left(\frac{\text{deaths in year } n}{\text{deaths in year } n-1}\right) \sim e^{\alpha} \left(\frac{\text{GDP/inhabitant in year } n}{\text{GDP/inhabitant in year } n-1}\right)^{\beta} \left(\frac{\text{unemployment rate in year } n}{\text{unemployment rate in year } n-1}\right)^{\gamma}$$

  where $100(e^{\alpha} - 1)$ is the annual percentage trend and β and γ are indicators of elasticity of annual number of deaths with respect to GDP per inhabitant and unemployment rate respectively. To estimate α, β and γ, the model is fitted by regressing the difference between the natural logarithms of the numbers of deaths in year n and year $n - 1$ upon the corresponding differences in logarithms of the GDP per inhabitant and the unemployment rate. This can be done in such a way that the value of β estimated for the minority (so far) of years n in which the GDP/inhabitant is lower than in year $n - 1$ differs from the value of β estimated for the majority of years in which the reverse is the case. In cases where the two estimated values do not differ appreciably, a common value can be estimated.

- Because the analyses also indicate that the relation between the risk of death per vehicle-km travelled and economic development may well contribute strongly to changes in numbers of road deaths, the effects of this relation should also be investigated where suitable data concerning vehicle-km travelled are available.

Some possibilities for further research

The gradual process of recovery from the recession that began in 2008 is providing further data that can be used to test and strengthen the basis for the insights into the relation between road safety and economic development provided by the work described in this report. Only time will tell to what extent data from years to come will exemplify periods of growth or downturn.

In any case there is scope for further clarifying and quantifying the relation between annual numbers of road deaths and the unemployment rate, including gaining greater understanding of the range of elasticity values estimated so far for different European countries and investigating the relation between numbers of young adult road deaths and the young adult employment rate. Understanding and short term forecasting may also be helped by more extensive analysis of monthly or quarterly data, including comparison of resulting elasticity estimates with those from analysis of concurrent annual data.

Findings concerning in particular the relation between numbers of road deaths among young adults and the unemployment rate may have a part to play in addressing the wider challenge of enabling young adults to progress through the stages of initial driver training and then gaining experience as qualified drivers at reduced cost in terms of fatal or serious injury to themselves and to other road users. Comparison of driving by employed and unemployed young adults might enable provision of better advice and information to both groups – as might also be the case for employed and unemployed drivers in other age groups.

For the relation between numbers of road deaths and GDP per inhabitant, further analysis of changes from one year to the next may enable the parts played by association with GDP per inhabitant and by trend over time in the long term trajectories of numbers of road deaths, including possible non-linearity in these relations, to be elucidated. It should be possible to reconcile and integrate the findings from analyses of changes from one year to the next with analyses of annual numbers over long periods of years. Further investigation is also required to provide understanding of the wide range of the elasticity values estimated so far for different European countries – to what extent these reflect real differences between relations in the countries concerned, and to what extent they result from random variation and the resulting approximate nature of the estimation process.

In relation to both of these economic indicators, there is scope for further investigation of the use of combined analysis of data for groups of countries as distinct from separate analysis country by country. In this and other respects, analysis in this area should take account of continuing development of techniques for time-series and regression modelling of annual, quarterly and monthly data for long periods of years, including the possibility of co-integration of relevant time series and non-linearity of the relations.

It should be noted that the analyses discussed here are related wholly to higher income countries. In the global context there is great scope for counterpart analyses for middle and lower income countries, having regard to the challenges they face both in road safety itself and in the availability of data for analysis.

Alongside possibilities for further statistical modelling there is challenging scope for multidisciplinary research, by no means confined to statistical modelling, that could shed light upon the possible mechanisms underlying the strong aggregate relation between road safety and economic development that has been investigated here.

CHAPTER 2. THE IMPACT OF ECONOMIC DEVELOPMENT ON ROAD SAFETY: A LITERATURE REVIEW[1]

This chapter reviews evidence from the literature regarding the relationship between short and medium term economic fluctuations and road safety development. It analyses to what extent this relation impact the number of casualties and crash risk. Finally it reviews the mechanisms behind these relations.

Introduction

Economic development is very likely to have an impact on road safety. In the long run, the increase of a country's economic prosperity may affect the road safety level because of increased motorization, investments in infrastructure and health care, and other long term developments. Also short or medium term economic fluctuations are likely to have an impact on road safety: travel patterns may be influenced by the economic situation, and there may be an impact on driver behaviour and expenditures on safety. One of the first influential papers on short/medium term economic fluctuations and road safety was written by Peltzman (1975). In a time-series analysis in the United States, he found a positive correlation between income and the number of fatalities per vehicle kilometre. His explanation was that people assign a higher value to time in times of economic prosperity, making them driving more "intensively" (faster, more risky). In a cross-section analysis he found a negative correlation between income and the number of fatalities per vehicle kilometre however. He explained this by increased expenditure on safety, for example on safer cars, in economic good times. This example shows that different "mechanisms" may be at work, possibly with opposite impacts, which may explain relations between economic development and road safety.

The main focus of this paper is on the relation between short/medium term economic fluctuations and road safety. Since Peltzman's publication further research into, and discussion about, this relation has taken place, until the mid-1990s mainly in North-America and later also in other parts of the world. This paper reviews the available literature about the relation between economic development and road safety from 1975 until now. The paper particularly addresses three issues:

- What evidence has been found in the literature for a relation between economic development and road safety?

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- To what extent does this relation refer to (changes in) the number of casualties or crashes, and to what extent to crash risk (number of casualties or crashes per unit of distance travelled)?
- Which mechanisms (may) explain these relations?

Reviews of the literature about the relation between economic development and road safety have been carried out previously, covering different time spans. Hakim *et al*. (1991) reviewed 14 studies on macro models aimed at establishing the relation between road safety and explanatory factors like vehicle kilometres travelled, demographic indicators, and economic indicators. The studies in their review were published between 1975 and 1989 and nine studies in this review included economic indicators. Scuffham (1998) reviewed the literature about the relation between economic development and road safety published between 1986 and 1996. This review included 24 studies on modelling the relation between road safety and economic development. Finally, a literature review was carried by Wiklund *et al*. (2011). They included 20 studies published between 1984 and 2011. Only two studies in their review were also included in one of the previous reviews. There is no such overlap between the reviews by Hakim *et al*. (1991) and Scuffham (1998).

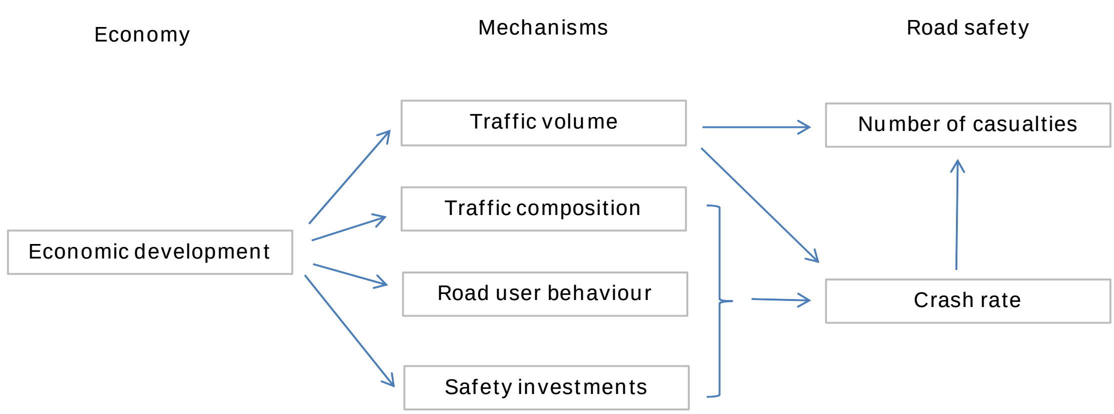
This literature review differs from these previous reviews in three aspects. Firstly, this review covers a longer time period (1975-present), thereby aiming to include the majority of the relevant literature. Secondly, we explicitly distinguish between the relationship of economic development with, on the one hand, the number of casualties or crashes and, on the other hand, with the crash risk. This helps to better understand the relation between economic development and road safety, because these relations may be different as well as the mechanisms that may explain them. Thirdly, we systematically review the mechanisms found or mentioned in this literature that (may) explain these relations.

The paper is structured as follows. Section 2 discusses the conceptual framework that we will use regarding the relation between economic development and road safety. In Section 3 we address the issue of long term versus short term relations between economic development and road safety. Section 4 describes how the literature included in this paper has been selected. In Section 5 a descriptive analysis of the results of the literature and some methodological aspects will be given. Section 6 gives an overview of the mechanisms that are discussed in the literature to explain a relation between economic development and road safety, and the evidences that is found for these mechanisms. In Section 7 we discuss the literature and the policy implications that a relation between economic development and road safety may have. In section 8 conclusions and recommendations will be given.

Conceptual framework

This section presents a conceptual framework for relations between economic development and road safety. We define economic development as the growth or decline of economic activity, as measured by, for example, the volume growth of the Gross Domestic Product (GDP) or the unemployment rate (share of unemployed people in the labour force). There are several possible explanations for a relation between economic development and road safety performance, measured as the number of road casualties (fatalities and/or injuries). Elvik (2014) distinguishes three mechanisms. Firstly, economic development may influence the traffic volume and thereby the exposure to risk and the number of road casualties. Traffic volume may also have a direct impact on crash risk (crash risk is likely to increase less than proportionally with traffic volume increases). Secondly, economic development may influence the traffic composition that may result in a change in the share of "risky kilometres". For example, economic development may have an impact on the share of young drivers in the traffic volume, the distribution of traffic volume among weekends (or weekend-nights) and weekdays, or the share of high-risk transport modes in the traffic volume (e.g. heavy goods vehicles or bicycles). Thirdly, road users may adapt their behaviour in traffic to economic circumstances. For example, in economic good times they may be more often in a hurry and drive faster, or drink more often in restaurants and bars resulting in more drink-driving. A fourth mechanism can be added to this: economic development may have an impact on the investments in safety by governments, road users and companies. For example, in economic recessions road authorities may invest less in safety of infrastructure, and consumers and companies may postpone their purchase of new (and safer) cars or buy cheaper or second hand (and less safe) cars. Regarding the last three mechanisms, economic development affects the crash risk (and thereby the number of casualties), while the first mechanism implies that the number of casualties is affected by the impact of economic development on (only) the traffic volume. Figure 2.1 summarises this schematically. Note that the four mechanisms may not be completely independent. For example, an increase in traffic volume may be accompanied by an increase in new (safer) car sales, or a change in the age distribution of car drivers will also have an impact on road user behaviour. Here we focus on the direct relations between economic development, the mechanisms, and road safety, and so these interactions between the mechanisms are not pictured in Figure 2.1.

Figure 2.1. **Conceptual framework for the relations between the economy and road safety**

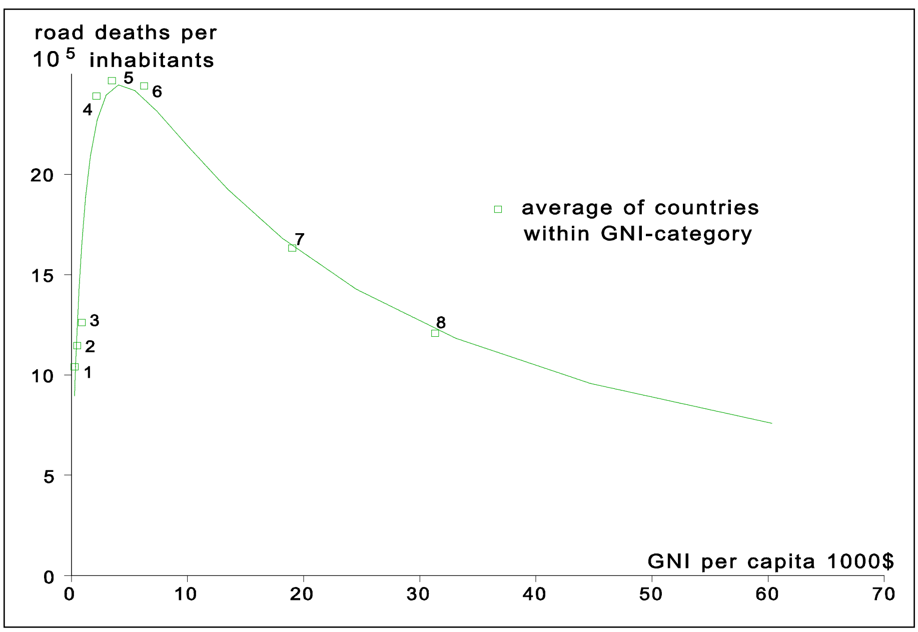


As we will see below, empirical studies into the relation between economic development and road safety do not exactly follow this conceptual framework. Most of the literature focuses on estimating the relation between economic development and the number of casualties and/or crash rate directly, omitting the intermediate mechanisms. In Section 5 we review the results of these studies, where we distinguish between the impact of economic development on the number of casualties and on the crash rate. Following this framework, this provides information about the type of mechanisms (in particular traffic volume versus the other three mechanisms) that may occur. In section 6 the mechanisms that are discussed in the literature are reviewed, which may explain relations between economic development and road safety.

Long-term versus short-term relations

As noted above, there is evidence that the relation between economic development and road safety shows an inverted U-curve. This evidence is based on analyses of the economic performances, measured as GDP or Gross National Income (GNI) per capita, and the mortality rates (number of fatalities per capita) in a large sample of countries. This relationship between economic performance and mortality has been analysed in Beeck *et al*. 2000, Bishai *et al*., 2006, Kopits and Cropper, 2005, Koornstra, 2007 and Law, 2011); they all find an inverted U-curve. As an example, Figure 2.2 shows the results of Koornstra (2007). He categorised a large number of (low, middle and high income) countries into eight groups on the basis of GNI per capita, and found a positive relation between GNI per capita the mortality rate for countries with an GNI up to about USD 5 000 (price level 2000). After this turning point there is a negative relation between GNI per capita and mortality rate. The curve is explained by a two underlying relationships. Firstly, there is a positive relation between GNI per capita and motorization rate (motor vehicles per capita), and thus a positive relation between GNI per capita and mortality rate (all other things being equal). Secondly, there is a negative relation between GNI per capita and crash risk (fatalities per motor vehicle) (all other things being equal), because, for example, a higher national income allows road authorities and road users to spend more money on safety. Up to the turning point the impact of GNI on mobility (exposure) dominates the impact on crash rate, and after the turning point the negative impact of GNI on crash rate dominates the impact on mobility. In other words, in low income countries an increase in GNI per capita is related to more mobility and thus a higher fatality rate, whereas in high income countries this effect is outweighed by a decrease in crash rate because. The other studies mentioned above found similar results.

Figure 2.2. **Relation between economic performance (Gross National Income per capita) and mortality rate**



Source: Koornstra (2007).

There is very little information about the relation between economic performance and the number of injuries per capita. The studies discussed here focus only on fatalities (mortality rate), except Bishai *et al*. (2006). They found that the inverted U-curve does not apply to injuries: the number of injuries continues to increase as GDP per capita increases, so there is no turning point. Further research in this area is recommendable.

The inverted U-curve may be considered as the general long-term development that may occur as the economic performance of a country increases. However, the curve is based on cross-section or panel data for a (large) number of countries, and the long-run relation between GDP (or GNI) and the mortality rate in individual countries may be different. There are countries where the number of fatalities shows an inverted U-curve in the long term (for example, Canada or Spain), but in other countries there is a long-term downward trend since the 1970s (examples are the United Kingdom and Sweden)[2]. Furthermore, the inverted U-curve does not give information about the relationship between economic development and road safety in the short or medium term. Yannis *et al*. (2014) studied the short term relation between GDP growth and mortality rate in 27 European countries in the period 1975-2011, and found a positive relationship: an increase in GDP per capita is related to an increase in the mortality rate. Their findings refer to short term fluctuations in economic performance: periods of high economic growth (upturns) are typically followed by periods of lower or even negative economic growth (downturns or recessions). For example, in the period 1970-2003 there were seven economic cycles on average in a sample of 12 OECD-countries (Cotis and Koppel, 2005). The average duration of an economic downturn and upturn was 1.5 and 3.5 years respectively, although there are substantial differences between countries. In order to understand the relation between economic development and road safety in a country, including these short- or medium-term upturns and downturns, we particularly focus on studies for individual countries in the remainder of this paper.

Selection of literature

As mentioned above, three literature reviews have been carried out previously. Almost all of the studies included in these reviews use econometric models and/or statistical techniques to estimate the relationship between road safety and various explanatory variables, among which in most cases economic development. Some studies particularly focus on the relation between economic factors and road safety developments, while others also focus on other influences. There are also a number of papers that aim to estimate the effect of road safety measures, for example drink driving measures (e.g. Ruhm, 1995; Saffer and Chaloupka, 1989), seat belt legislation (Loeb, 1995) or speed limit reduction (Johanssson, 1996). The models they use often include economic indicators, and thus provide evidence about the relationship between economic development and road safety in addition to the relation with road safety measures.

We used these three reviews as a basis for this literature review. We excluded studies that do not include general indicators for economic development like GDP per capita or unemployment rate, since we are here primarily interested in the relationship between economic development and road safety. The excluded studies sometimes include indicators that may be related indirectly to economic development, like expenditure on roads. These indicators may explain a relationship between economic development and road safety, and in that respect we will take them into account in the discussion. Other studies do not include economic variables, but do include other variables that are assumed to be related to economic development (for example, distance travelled). These studies are not regarded as relevant for this review. Furthermore, some articles, e.g. Newstead *et al*. (1998) and Scuffham (2003), present the results of updated or extended versions of models that have been published previously, covering a longer time period for example. In such cases we only include the most recent publication.

Table 2.1 indicates the studies included in this review and the country and the period for which data have been analysed, showing that 41 studies have been included. More than half (26) of the studies, especially the older studies, is from the US, and the others are from several European countries (8), Australia (4), Canada (1), China (1) and New Zealand (1). The period analysed in time series studies ranges from 6 years (Loeb, 1995) to 53 years (Joksch, 1984). The majority (36 studies) are articles that are published in peer-reviewed journals.

2. This does not necessarily mean that there is no inverted U-curve in these countries. The downward trend may be the right part of this curve, and the turning may have occurred before data became available (around 1970).

Table 2.1. **Studies included in the analysis**

Study	Year of publication	Country	Period
Peltzman	1975	US	1947-1972
Eshler	1977	US	
Hoxie *et al.*	1984	US	1975-1982
Jocksch	1984	US	1930-1982
Partyka	1984	US	1960-1984
Wagenaar	1984	US (Michigan)	1972-1983
Zlatoper	1984	US	1947-1980
Hoxie and Skinner	1985	US	1975-1983
Mercer	1987	Canada (British Columbia)	1978-1984
Evans and Graham	1988	US	1946-1985, 1975-1984
Saffer and Chaloupka	1989	US	1980-1985
Wagenaar and Streff	1989	US	1976-1985
McCarthy and Ziliak	1990	US (Californian cities)	1982-1985
Wagenaar *et al.*	1990	US	1978-1988
Zlatoper	1991	US	1987
Reinfurt *et al.*	1991	US	1960-1986
Leigh and Waldon	1991	US (District of Columbia)	1976-1980
Partyka	1991	US	1960-1989
Pettitt *et al.*	1992	Australia (Victoria)	1981-1991
McCarthy	1993	US (Indiana counties)	1981-1989
Haque	1993	Australia (Victoria)	1966-1990, 1985-1990
Keeler	1994	US	1970, 1980
McCarthy	1994	US (Californian counties)	1981-1989
Ruhm	1995	US	1975-1988
Loeb	1995	US (Texas)	1982-1987
Ruhm	1996	US	1982-1988
Johansson	1996	Sweden (7 counties)	1982-1991
Robertson	1996	US	1975-1991
Wilde and Simonet	1996	Switzerland	1963-1993
Farmer	1997	US	1975-1995
Newstead *et al.*	1998	Australia (Victoria)	1983-1996
Fridstrøm	1999	Norway	1973-1994
Ruhm	2000	US	1972-1991
Scuffham	2003	New Zealand	1970-1994
Tay	2003	Australia (Victoria)	1983-1992
Neumayer	2004	Germany	1990-2000
Van den Bossche *et al.*	2005	Belgium	1990-2001
Hermans *et al.*	2006	Belgium	1974-1999
Garcia-Ferrer *et al.*	2007	Spain	1975-2003
Hu *et al.*	2008	China	1985-2005
Wiklund *et al.*	2011	Sweden	1981-2008

Synthesis and analysis of study results

Methods

Three types of methods are used in the literature to study the relationship between economic development and road safety in a country: time-series analysis, panel studies, and cross-section analysis. In time-series analysis developments over time in a country are studied. There are many types of time-series analysis. Scuffham (1998) for example distinguishes between ARIMA-studies (integrated autoregressive moving average models), econometric time-series studies, and stochastic trend studies.

ARIMA-models are specifically suited to study short-run developments, while the other two types are aimed at longer term relations and often explicitly take into account time trends. For a comprehensive overview and discussion of time-series analyses, see EC (2004). In cross-section analysis data regarding road safety, economic conditions and other relevant variables for a number of states, counties, or provinces are analysed at one moment in time. An advantage of cross-section analysis is the larger variation in the independent variables. Cross-section analysis does not give information about developments over time however, and therefore this type of analysis is less suited to analyse short run relations between variables. It does provide information about long(er) run relations however (Scuffham, 1998). In panel studies cross-section and time-series data are combined allowing to include a larger number of observations in the analysis.

Relation between economic development and road safety

We analysed the results of the included studies into the relation between economic development and road safety, as well as their methodological aspects. Regarding the results of the studies we distinguish between evidence for a relationship of economic factors with the number of casualties (fatalities and/or injuries) or (fatal or injury) crashes on the one hand, and with the crash risk on the other. Table 2.2 shows the percentages of studies that found a significant positive, significant negative or non-significant relationship of economic development with the number of casualties and crash risk. If a study found both positive and negative relations the study has been counted more than once. This is the case if more than one economic variable was included in the model, different methods have been used (both time-series and cross-section) or different datasets have been analysed.

Table 2.2. **Percentage of studies that found a positive, negative, non-significant relation of the number of casualties and crash risk with economic development**

	Number of casualties (n=49)	**Crash risk (n=19)**
Positive	69%	58%
Negative	20%	37%
Non-significant	10%	6%

The majority of the studies (69%) found a positive relation between economic development and the number of casualties: in times of economic growth there are more road casualties, and in times of recession there are less casualties. 20% of the studies found a negative relation, and 10% found relation(s) to be non-significant. Fewer studies estimated the relation of economic development with crash risk. The majority of these studies (58%) found a positive relation, while 37% found a negative relation and 6% a non-significant relation.

As explained above, an impact of economic development on the number of casualties may be solely explained by an impact on traffic volume or (also) by changes in the crash risk. To explore this, Table 2.3 shows whether the relation with crash risk is positive, negative of non-significant, separately for studies that found a positive/negative relation with the number of casualties (if the relation with the number of casualties is non-significant also the relation with the crash risk should be non-significant). Note that this table is restricted to 19 studies that estimated the relation between economic development with both the number of casualties and the crash risk (or from which these relationships could be retrieved, see below).

Table 2.3. **Percentage of studies that found a positive, negative, non-significant relation of crash risk with economic development, if the relation with number of casualties is positive/negative**

	Relation with crash risk if relation with number of casualties is:	
	Positive (n=14)	Negative (n=5)
Positive	71%	0%
Negative	21%	100%
Non-significant	7%	0%

Table 2.3 shows that studies that find a positive relation with the number of casualties in most cases (71%, 10 studies) also find a positive relation with crash risk. This indicates that in economic upturns the increase in distance travelled (if any) is not as strong as the increase in the number of casualties. Vice versa, in economic recessions a decrease in distance travelled is weaker than the decrease in the number of casualties, resulting in a lower crash risk. It is not clear to what extent the relation between economic development is also explained by changes in traffic volume: only three studies provide information about this (two of them showing that the number of casualties is not explained by an impact of the economy on traffic volume). Although the studies often show that the traffic volume is significantly related to the number of road casualties, these studies do not reveal whether the traffic volume is affected by the economy (see discussion below).

In three studies (21%) a positive relation between economic development and the number of casualties is accompanied by a negative relation with crash risk. This means that in economic upturns the number of casualties is higher due to a higher traffic volume, which is partly offset however by a lower crash rate. In only one study the positive relation between economic development and the number of casualties is fully explained by a higher traffic volume. Not surprisingly, all studies showing a negative relation between economic development and the number of casualties also show a negative relation with crash risk. This means that a decrease in number of casualties in economic upturns is explained by a decrease in crash rate, which is not accompanied by a (stronger) decrease in distance travelled (and vice versa).

Indicators for road safety and economic development

The studies that estimate a relation with the number of casualties use various road safety indicators as dependent variables. Most of the studies (34) focus on fatalities by using the number of fatalities or fatal crashes (total number or per capita) as a dependent variable. Other studies (18) also include serious or all injuries (separately or added to the number fatalities). Two studies (McCarthy, 1993; McCarthy, 1994) also include property damage only crashes as dependent variable. As noted above, there are fewer studies that estimated a relation with crash risk. Only a few studies estimate the relation between economic development and crash risk directly by taking a crash risk indicator (number of crashes or casualties per unit of distance travelled) as the dependent variable. Other studies provide evidence about crash risk by analysing whether there is still a significant relation between economic development and the number of casualties if the distance travelled is added to the model as an explanatory variable. This shows whether the relation of economic development and the number of casualties is fully explained by distance travelled, or whether there is also a relation with crash risk. In other studies it is not clear whether there is, besides a relation with the number of casualties or crashes, also a relation with crash risk. This explains why the number of studies that provide evidence about the relation of economic development with crash risk is lower.

Various economic indicators are used as independent variables. The majority of the studies (28) use an unemployment indicator, like unemployment rate or number of unemployed persons. Income indicators, like GDP per capita or disposable income per capita, are used in 15 studies. Some other studies use indicators for consumption or consumer sentiment and industrial production. Inflation and interest rate have also been used in a single study.

Table 2.4 shows the percentages of studies finding a (significantly) positive, negative or non-significant relation, separately for studies that use unemployment, income and other economic variables. It shows that particularly unemployment has been found to correlate positively both with the number of casualties (79% of the studies) and with the crash risk (78%). The relation between income and road safety is relatively more frequently negative (33% for both number of casualties and crash risk), while about half of the studies using an income indicator find a positive relation with the number of casualties and crash risk. Apparently unemployment and income indicators may not be fully regarded as substitutes, and different mechanisms may occur that could explain relations of these indicators with crash risk (discussed below). Another explanation may be that relations between income and number of casualties reflect long(er) term relations. Income measures like GDP per capita normally show a positive trend, and the negative sign may partly refer to a long run relationship between economic growth and the number of road casualties (depending on the type of model that is used, see discussion). Unemployment indicators (particularly unemployment rate) are less likely to show a long term trend and may reflect short and medium term fluctuations more accurately.

Table 2.4. **Percentage of studies that found a positive, negative, non-significant relation of the number of casualties and crash risk with economic development**

	Unemployment		Income		Other	
	Number of casualties (n=28)	Crash risk (n=9)	Number of casualties (n=15)	Crash risk (n=6)	Number of casualties (n=7)	Crash risk (n=4)
Positive	79%	78%	53%	50%	71%	75%
Negative	14%	22%	33%	33%	14%	0%
Non-significant	7%	0%	13%	17%	14%	25%

Comparison time-series, panel and cross-section studies

Most of the studies included are time-series analyses (29) or panel studies (12). Only four studies present a cross-section analysis. Table 2.5 shows the percentage of studies that found a positive, negative or non-significant relation of the number of casualties and crash risk for each method. It shows that the cross-section studies more often find a negative relation between economic development and the number of casualties. Although the number of cross-section analyses is very limited, this could support the idea that in cross-section analyses long-term adaptations in response to changing economic conditions are taken into account, as noted by Peltzman (1975). As mentioned above, in a time-series analysis he found a positive relation between income and crash risk and in a cross-section analysis of US states, using the same dataset, a negative relation. He notices that an initial increase of the number of fatalities in an economic upturn may be offset by increased expenditure on safety, for example on safer cars. This effect may occur in the long term as it takes time before people buy a new car. This long term impact may be taken into account in a cross-section analysis, as the effect on car sales (or other effects) may already have occurred in the states that have a higher income.

Table 2.5. **Percentage of studies that found a positive, negative, non-significant relation of the number of casualties and crash risk with economic development**

	Time-series		Panel		Cross-section	
	Number of casualties (n=29)	Crash risk (n=13)	Number of casualties (n=12)	Crash risk (n=3)	Number of casualties (n=3)	Crash risk (n=1)
Positive	72%	77%	83%	33%	33%	0%
Negative	17%	15%	8%	67%	67%	100%
Non-significant	10%	8%	8%	0%	0%	0%

Mechanisms

As shown by Figure 2.1, economic development can have an impact on road safety by affecting the exposure and/or by affecting crash risk. The relation between economic development and exposure is quite straightforward: in economic downturns people travel less because there is less commuting traffic due to higher unemployment, there are fewer business trips, people spend less money on recreational activities, etc. As shown above, the majority of the studies included in this review have found a positive relation between economic development and road safety, which is not (only) explained by changes in exposure (see Table 3). Relations between economic development and crash rate that have been found in the literature should by definition be explained by other mechanisms than changes in exposure. These mechanisms are more complex, and the question is to what extent they actually occur. In this section we primarily focus on these mechanisms.

We reviewed the mechanisms that are mentioned, discussed or analysed in the literature. Table 2.6 gives an overview3. The table distinguishes between mechanisms that have a (assumed) positive impact on the crash risk (i.e. a higher crash risk in economic upturns) vs. mechanisms with a negative impact on the crash risk. We distinguish between changes in traffic composition, driver behaviour and safety investments (see Figure 2.1). The mechanisms that are related to traffic composition (may) explain a positive relation between economic development and crash risk (i.e. higher crash risk in economic upturns), while mechanisms related to safety investments may explain a negative relation. Mechanisms related to road user behaviour may explain both positive or negative relations, and some mechanisms may have either a positive or a negative impact on the crash risk. For example, some researchers note that an increase in the number of new, and safer, cars sold in economic upturns may result in a lower crash risk. Others note that drivers may be unfamiliar with their new car however, resulting in a higher crash risk.

In Table 2.6 the studies that have studied a mechanism are marked (*, right column), as well as the mechanisms for which evidence has in fact been found in this literature (*, middle column). Only 12 studies analysed one or more mechanisms, and (some) evidence has been found for only three mechanisms. These are particularly related to young drivers and to alcohol consumption and drink-driving. We discuss them here in more detail.

3. The mechanisms are formulated in a way that they are positively related with economic development. For example: in times of economic *growth*, there is *more* risky driving, more alcohol consumption, etc.

Table 2.6. **Mechanisms addressed in the literature to explain relations between economic development and crash risk**

Mechanism (positively related to economic development)		**References**
Positive relation with crash risk (i.e. higher risk)		
Traffic composition	Distance travelled by young drivers*	Partyka (1984)*, Hoxie and Skinner (1985)*, Mercer (1987)*, Saffer and Chaloupka (1989)*, Leigh and Waldon (1991)*, Haque (1993), Ruhm (1995)*, Farmer (1997)*, Wilde and Simonet (1996)*, Tay (2003)
	Distance travelled by heavy good vehicles	Joksch (1984), Haque (1993), Wiklund (2011)*
	Distance travelled on rural roads	Hoxie and Skinner (1985)*
	Distance travelled at (weekend) night	Hoxie and Skinner (1985)*, Wagenaar (1984)
	Recreational trips -> vehicle occupancy rate	Evans and Graham (1988), Haque (1993)
	Distance travelled by older drivers	Tay (2003)
Road user behaviour	Risky driving (caused by a higher value of time, more optimistic mood)	Peltzman (1975), Joksch (1984), Wagenaar (1984), Evans and Graham (1988), Ruhm (1996), Wagenaar and Streff (1989), Wiklund (2011)
	Alcohol consumption, drink driving*	Wagenaar (1984), Evans and Graham (1988), Wagenaar and Streff (1989)*, Leigh and Waldon (1991)*, McCarthy (1993), Haque (1993), Ruhm (1995)*, Ruhm (1996)*, Tay (2003), Wiklund (2011)*
	Number of inexperienced drivers	Joksch (1984)
	Fatigue	Wiklund (2011)*
Safety investments (vehicles)	Number of new/safer cars sold	Joksch (1984), Wagenaar (1984), Wagenaar and Streff (1989)
Negative relation with crash risk (i.e. lower risk)		
Road user behaviour	No unemployment stress	Wagenaar (1984), Evans and Graham (1988), Wagenaar and Streff (1989), Leigh and Waldon (1991), Haque (1993)
	Alcohol consumption, drink driving	Saffer and Chaloupka (1989), Wagenaar and Streff (1989), Leigh and Waldon (1991)*
	Less driving without driver license*	Wiklund (2011)*
Safety investments — Vehicles	Number of new/safer cars sold	Peltzman (1975), Wagenaar (1984), Wagenaar and Streff (1989), Keeler (1994), Tay (2003)
	Quality and condition motor vehicles	Wagenaar (1984), Wagenaar and Streff (1989), Saffer and Chaloupka (1989), Ruhm (2000), Tay (2003)
	Number of second-hand cars sold	Van de Bossche (2005), Hermans *et al*. (2006)
	Quality tires	Wiklund (2011)*
Roads	Investments in (quality of) roads	Evans and Graham (1988), Ruhm (2000), Scuffham and Langley (2002), Tay (2003), Van de Bossche (2005)
Post-crash	Quality of health care	Keeler (1994)

Young drivers

One of the mechanisms that have been studied is that young drivers are more responsive to economic ups and downs, and therefore travel more and buy more cars in economic good times (and vice versa). Leigh and Waldon (1991) show that the travel volume of young male drivers is positively related to the unemployment rate. They compared the results of a model including the share of young drivers in traffic volume with the outcomes of the model if this share is not included as an explanatory variable. If the percentage of young male drivers is added to their model the relation between the unemployment rate and the number of fatalities becomes insignificant, implying that the share of young drivers (partly) explains the relation between unemployment and the number of fatalities.

Mercer (1987) developed a model to examine the correlation of the number of casualties (fatalities and injuries) and crash severity (measured by the share of fatalities in the total number of injuries) with indicators for unemployment, alcohol-related crashes, use of protection devices, driver age and gender as independent variables. His analysis shows that the decrease in the number of injuries in the time period analysed (1978-84) was partly associated with an increase in unemployment, and that the higher unemployment resulted in less young drivers on the road. The lower number of young drivers was in turn related to less drink-driving and more protection device use, reducing the crash risk and severity.

Some other time-series studies separately estimate the correlation between economic development and fatalities among young drivers, in addition to the correlation with all fatalities (Partyka, 1984; Hoxie and Skinner, 1985; Saffer and Chaloupka, 1989; Ruhm, 1995; Wilde and Simonet, 1996; Farmer, 1997). Four of these studies show that economic indicators are stronger related to the number of fatalities among young drivers than to other fatalities, implying that the young drivers are more responsive to economic conditions. Wilde and Simonet (1996) and Farmer (1997) do not find evidence for this, however. Wilde and Simonet (1996) suggest that in economic recessions an decrease in the number of fatalities among young drivers may be offset by an increase in pedestrian fatalities, because young people may travel more by foot (and public transportation) instead of by car.

Alcohol

Three studies in the US investigated the relation between economic development, alcohol consumption, and road safety in the late 1970s and 1980s. In a panel study Ruhm (1995) analysed data on economic situation (income per capita and unemployment), alcohol consumption and road fatalities. He finds a positive relation between economic conditions (especially income) and alcohol consumption, as well as a positive relation between alcohol consumption and fatalities. He shows that an increase in income is related to an increase in the number of fatalities trough more alcohol consumption.

In another panel study Ruhm (1996) analysed the relation between several alcohol policies, like raising the minimum drinking age, and road safety (number of fatalities per capita and per vehicle mile). His model includes income and unemployment as independent variables. The analysis shows that the negative relation he finds between the alcohol policies and both the number of fatalities and the crash risk are weaker if economic variables are included in the model. This may indicate that the economic conditions partly account for changes in alcohol-related crashes. Ruhm (1996) also found a positive relation between economic conditions and the number of fatalities per capita and per vehicle mile, that may strengthen this conclusion.

In a time-series model Wagenaar and Streff (1989) studied the relations between economic indicators (an index for industrial production and an index for consumer sentiment), alcohol consumption and the number of fatal crashes per capita in the US (at night-time, only one vehicle involved). They found a significant correlation between consumer sentiment and alcohol consumption, although the impact is small (1% increase in consumer sentiment was related to 0.1% increase in alcohol consumption). The correlation between the production index and alcohol consumption was not significant. They also found a strong positive significant relation between alcohol consumption and fatal crashes. This could suggest that consumer sentiment affects fatal crashes through alcohol consumption. However, the relation between consumer sentiment and fatal crashes was found to be negative which they could not explain. The authors concluded that their model did not support the hypothesis economic conditions have an effect on fatalities by affecting alcohol consumption.

Leigh and Waldon (1991) tested the hypothesis that economic development is related to alcohol consumption and thereby to road fatalities by comparing the results of a model including alcohol consumption with the outcomes of the model if alcohol consumption is not included as an explanatory variable. Their analysis shows that including alcohol consumption in the model does not alter the (negative, significant) relation between the unemployment rate and the number of fatalities. From this they conclude that two influences cancel out: in economic recessions people on the one hand buy less alcohol because of lower income, and on the other boredom when people are unemployed may increase alcohol consumption. It is not clear however whether these two mechanisms in fact occur: an alternative interpretation, that they do not mention, is that there is no (significant) relation between the unemployment rate and alcohol consumption (and road fatalities) at all.

Finally, Wiklund *et al*. (2012) compared the number of alcohol- or drugs-related fatal crashes between a three-month recession period and the same periods in three previous years with economic growth (see below for more details about this study). They did not find a significant difference between the number of crashes between the recession period and the other periods.

In conclusion, there is mixed evidence about the relation between economic situation, alcohol consumption and road safety. There is evidence that higher income leads to more alcohol consumption, (probably) because people can afford to buy more alcohol. This impact is apparently stronger than the (positive) impact of unemployment on alcohol consumption, induced by more stress or being boring, that is mentioned by some researchers. It is not clear however whether the impact of the economy on alcohol consumption also results in more drink-driving and more alcohol-related crashes. The researchers addressing this issue note that higher income may lead to more drinking in public and more non-business trips, resulting in more drink-driving. Also young people, who may be more involved in alcohol-related crashes, may drive more if income is higher. There is no clear evidence for that however.

Other mechanisms

In a Swedish study Wiklund *et al*. (2012) analysed the relation of economic development with a number of risk factors: fatigue, distance travelled by heavy good vehicles, seat belt use, speeding, driving without driver license, and the quality of tires. For each risk factor they compared the share of fatal crashes where a risk factor was involved (e.g. the number of fatal crashes where a driver was suspected for sleepiness) in a recession period (December 2008-March 2009) with this share in the same periods in the three previous years with economic growth. The only significant difference concerned driving without driver license: in the recession period the share of fatal crashes where a driver involved did not have driver license was significantly higher than in the other periods. The reason may be that some people cannot easily afford driver lessons in times of recession. Wiklund *et al*. (2012) did not find significant differences for the other risk factors.

The other mechanisms in Table 2.6, for which no evidence has been found or which are only mentioned in the literature as plausible explanations for a relation between economic development and road safety, mainly relate to driver behaviour and vehicle safety. Regarding driver behaviour a number of authors note that in economic good times people may be less reluctant to take more risk in traffic. Their value of time may be higher, for example, because more people have a job and/or wages are higher, and this could make them driving faster. On the other hand, the opposite may occur when in times of high unemployment people have more stress or drink (and drive) more. Mechanisms related to vehicle safety concern the car fleet: the average age of the car fleet may go down in economic upturns, and a safety benefit could be expected because in general new cars are safer. Vehicle owners may also spend more money on maintenance of their vehicle. Finally, impacts of economic development on investments in (the quality of) roads and on the quality of health care have been mentioned in the literature. However, all these mechanism are purely hypothetical because they have not been tested.

Discussion

The relation between road safety and economic development

The majority of the studies for individual countries reviewed in this paper show that there is positive relation between economic development and the number of road casualties: the number of road casualties is higher in economic upturns and vice versa. The literature suggests that this is most probably is a causal relation: a variety of possible mechanisms has been discussed in the literature that may explain that economic upturns lead to more road casualties and vice versa. Elvik (2011) discusses the criteria that should be met for causality. A check to what extent the relations that have been found in the literature satisfy these criteria of causality could provide more information about causality, which is beyond the scope of this paper however.

Most studies use economic indicators that are related to unemployment or income. The relation between economic development and road safety seems, to some extent, to depend on the choice of this indicator: studies using income more often find a negative relation with the number of casualties and the crash risk. This may indicate that the mechanisms that should explain the relations are different for unemployment and income. For example, safety investments may be more dependent on income than on unemployment. If in a recession unemployment increases (resulting in less casualties because of a lower traffic volume for example), income may not decrease as sharply because of people may receive unemployment benefits. If income also starts to decrease, safety investments may decrease, offsetting the decrease in casualties. From the literature it is not clear however how economic indicators are related to mechanisms, so we can only speculate about this. Another explanation may be that relations between income and number of casualties reflect long(er) term relations. Income measures like GDP per capita normally show a positive long term trend, and the negative sign may refer to a long run relationship between economic growth and the number of road casualties. Unemployment indicators (particularly unemployment rate) are less likely to show a long term trend and thus reflect short and medium term fluctuations more accurately. We recommend further analysis of the outcomes of different types of models, as some type of models are more suited for estimating short run relations while others are (also) aimed at the long run. This may give more detailed information about the time span of the relations between number of casualties and economic development.

Some studies explicitly discuss the contribution of economic factors to a change in the number of casualties. For example, according to Newstead *et al*. (1998) reduced economic activity, measured by the unemployment rate, contributed 2 to 16% annually to a decreases in the number of serious casualty crashes between 1990 and 1996 in Australia. Few studies report results like these however. Another way to gain information about the extent to which economic development affects road safety (if we assume a causal relation) is to analyse the coefficients estimated in the models. As noted by Elvik (forthcoming) the coefficients often have different interpretations. However, Elvik (forthcoming) analysed the coefficients that can be interpreted as elasticities from a limited number of studies. The elasticity is defined as the percentage change in road safety (in most studies indicated by the number of fatalities) associated with a 1%increase in the unemployment rate. He found elasticities ranging from about -0.3 to 0.3. The majority of the elasticities was found to be negative (in line with our results).

All studies in this review, except a Chinese study, concern high-income countries. It is not clear to what extent the results would also apply to low and medium income countries. In the long run, a positive relation between economic development and the mortality rate may be expected in low income countries on the basis of the inverted U-curve, but there is no evidence about the short/medium term relations. The mechanisms, such as an impact of the economic situation on mobility, may be different in than those in high income countries. We recommended carrying out studies into the (short/medium term) relation between economic development and road safety in low and middle income countries.

The current strong economic recession that is taking place from about 2008 in many countries is accompanied by a decrease in the number of road fatalities, raising the question to what extent these two developments are related. The literature shows that past economic downturns have been related to an increase in road safety performance, giving an argument to assume that this relation may also be present in recent years. Although there are no studies yet that give evidence for a relation between the current recession and the decrease in number of fatalities, such a relation seems plausible.4 The fact that the current recession is stronger than most previous recessions could mean that the impact of the recession (if we assume a causal relation) is stronger than in 'normal' downturns. No studies have been found however that specifically focus on strong economic recessions. Exceptions are studies into the impact of the oil crises in the 1970s (e.g. Tihansky, 1974). These are considered less relevant for explaining recent developments however because the economic situations are very different (especially regarding fuel prices).

Methodological issues

The majority of the studies are time-series analyses or panel studies. An issues regarding (particularly yearly) time-series analysis is that independent variables can be correlated with a time trend. This may imply that the relation of road safety indicators with economic variables may not be separated from the relation with continuous changes such as improving road safety knowledge (and thus better effectiveness of road safety policies) or improvements in post-crash health care (Hakim *et al*., 1991). This may be an issue if income indicators like GDP per capita are used in models, since these indicators usually show a structural growth besides short and medium term fluctuations. However, these fluctuations may imply that a possible correlation with a time trend is not as strong as for other common independent variables like demographic variables. Unemployment indicators, particularly unemployment rate, are less likely to be correlated with a time trend as they reflect short and medium term fluctuations in the economic situation.

Another methodological issue concerns collinearity of independent variables. This occurs when independent variables tend to change simultaneously over time, making it difficult to identify the relationships between the dependent and independent variables. In the models reviewed in this paper this may apply to economic indicators and exposure related indicators (e.g. distance travelled, number of vehicles per capita, fuel sales). Our review shows that this is indeed an issue: in more than half of the

4. Wiklund *et al.* (2012) analysed the first years of this recession by comparing a number of risk factors in this period with previous periods of economic upturns (see above). However, this study focused on mechanisms instead of estimating the relation between economic development and road safety in recent years.

studies it is not clear whether the relation between economic development and road safety is associated with changes in exposure induced by economic fluctuations. This is either because of the problem of collinearity or because an exposure indicator has not been included in the model. In the other studies the relation of road safety with (an) economic indicator(s) has been distinguished from the relation with exposure. This is done for example by running different models that include the dependent variable alone and together, and then comparing their results. This allows drawing conclusions about the relation between economic development and crash rate.

Mechanisms

The studies reviewed in this paper show that the relation between economic development and the number of casualties is not, or not only, explained by changes in traffic volume but also by changes in crash risk. Many mechanisms have been addressed in the literature to explain the relation with crash risk, covering the three types of mechanisms as distinguished in our conceptual framework. Most of these mechanisms concern traffic composition, driver behaviour and consumer expenditures on cars. However, only a limited number of papers actually analysed whether these mechanisms occur, and the literature barely answers the question which mechanisms may explain a relation with crash risk (and the number of casualties). A reason for that is that many papers are not specifically focused on the contribution of economic development to road safety. Their aim is for example to estimate the effects of road safety measures, and they include an economic indicator as a confounding factor. Also other papers provide little empirical evidence about mechanisms however.

One of the most plausible explanations for an impact of the economy on crash risk is that young drivers, who in general have a substantially higher crash risk and a relatively high share in the number of road casualties, are more responsive to economic fluctuations. They may be the first who lose their job in times of economic recession, and the first to get a new job in economic good times. Some evidence has been found for this mechanism that could explain a relation of economic development with the (aggregate) crash risk. Changes in road user behaviour are often mentioned a possible explanation for a relation between economic development and crash risk, but the literature provides little evidence for this. Economic conditions may affect alcohol consumption, especially in bars and restaurants, and thereby the frequency of drink-driving, but the evidence about this is mixed. The idea that people would behave more risky in economic good times is only speculative, because no studies have been found that support this hypothesis.

Surprisingly, the literature pays relatively little attention to the possible impact of economic development on (safety) investments in road infrastructure. In a Norwegian study expenditures on roads were found to be a significant variable to explain road crashes (Fridstrom and Ingebrigtsen, 1991). They did not relate this to economic development however, and no attempts have been made so far to quantify this relation. An explanation for this may be, as noted by Tay (2003), that these investments may be regarded as more or less fixed in the short term and not much affected by short term economic fluctuations. Infrastructure budgets, or least parts of these budgets like maintenance budgets, are likely to be changed depending on the economic situation however. Changes in these budgets may therefore be a relevant mechanism to explain a relation of economic development with crash risk. Another plausible mechanism concerns vehicle sales: new vehicle sales are known be dependent on the economic situation, and new cars are known to be safer. In a Belgian study Hermans *et al*. (2006) found car registrations to be negatively correlated with the number of road casualties, but from this study it is not clear whether economic development affects road safety through car sales. These two mechanisms may explain the negative relations between economic development and crash risk (and possibly the number of casualties) that have been found in some studies.

Further research is needed to gain more insight in the mechanisms that may explain the relation between economic development and road safety. Estimating the correlation between the intermediate variables and the economic variables, in addition to the correlation between intermediate variables and road safety, is needed to get more information about the mechanisms that may explain a relation between economic development and road safety. Examples of such intermediate variables are the number of speeding offences, share of heavy good vehicles in traffic volume, new car sales, expenditures on roads, etc. Some papers include such variables, but do not estimate the correlation with the economic variables. For example, road safety performance is found to be significantly correlated with the frequency of speeding, and economic conditions are taken into account as a confounding factor. In this case, no information is given about the possible impact of economic conditions on the frequency of speeding which in turn can explain road safety fluctuations. Data availability can be a serious obstacle however, and collecting new data, for example regarding traffic composition or road expenditures, might be needed. Naturalistic driving studies may give opportunities to get information about the relation between economic conditions and driving behaviour. For example, do employed people drive faster, are they more frequently distracted, or more vulnerable to sleepiness than unemployed people?

Policy implications

Given the evidence that the number of road casualties is related to economic ups and downs, the question is whether policy makers should anticipate on this impact, and if yes, how they should anticipate. On the one hand, road safety policy makers could say that the state of the economy is an exogenous factor that they cannot influence. On the other hand, the fact is that economic upturns (most probably) result in a higher number of road casualties which could (or should) be a reason to intervene. In order to be able to mitigate the impact of economic upturns, ideally it should be known which mechanisms are accountable for an increase in the number of road casualties, so policy interventions can focus on the group of road users (e.g. young drivers, heavy good vehicles), their behaviour (e.g. drink driving, speeding) or road types (e.g. rural roads) that are affected by the economy. The lack of knowledge about the mechanisms makes it difficult however to specify such road safety policies. Nevertheless, in economic good times governments could invest more in road safety measures that have been proven to be cost-effective to counterbalance the unfavourable impact of the economic growth on road casualties. Governments are also likely to have larger budgets in economic good times, making it easier to do these (extra) investments.

Conclusions and recommendations

This paper addressed three issues:

- What evidence has been found in the literature for a relation between economic development and road safety?
- To what extent does this relation refer to (changes in) the number of casualties or crashes, and to what extent to crash risk (number of casualties or crashes per unit of distance travelled)?
- Which mechanisms (may) explain these relations?

Regarding the first issue, we distinguish between long term and short or medium term relations between economic development and road safety. Concerning the long run, analyses of the economic performance and mortality rates in a large number countries have shown an inverted U-curve: in low-income countries economic growth results in a higher mortality rate because mobility increases; on the other hand the crash rate is found to decrease as income increases, resulting in a decrease of the mortality rate from a certain income level. The main focus of this paper however is on studies in individual countries that (also) provide information about the short and medium term relation between economic development and road safety. This literature provides evidence that there is a positive relation between economic development and the number of road casualties: the majority of the studies show that the number of road casualties is higher in economic upturns and vice versa. Therefore, fluctuations in the state of the economy are a factor that should be taken into account when explaining changes in the number of road casualties, and in evaluations of road safety measures and road safety outlooks. The studies included in this review concern high-income countries, and it is not clear to what extent the results also apply to low and medium income countries. We recommend carrying out studies into the relation between economic development and road safety in these countries.

Concerning the second question, this review shows that the relation between economic development and the number of road casualties is not only explained by changes in the traffic volume (exposure to risk), but also by changes in crash risk. This implies, with respect to the third issue, that the state of the economy should have an impact on the traffic composition, road user behaviour and/or safety investments. Both positive and negative relations between economic fluctuations and crash risk have been found. Changes in traffic composition (e.g. share of young drivers or heavy goods vehicles) could explain higher crash risk in economic upturns, while an increase in safety investments could explain a lower crash rate. However, the literature barely provides evidence about the mechanisms may explain relations between economic development and crash risk. A plausible explanation, for which evidence has been found, is that young drivers who have a higher crash risk, are more responsive to economic fluctuations. A few other possible mechanisms have been studied, particularly regarding the impact of the economic situation on alcohol consumption for which there is some evidence. Other hypotheses that could explain relations between economic development and road safety, for example regarding road user behaviour, are only speculative.

It is recommended to perform more studies into the mechanisms that may explain causal relations between economic development and road safety. These studies could aim at estimating the correlation between economic variables and intermediate variables regarding traffic composition, road user behaviour, and safety investments. Data availability may be a serious obstacle however, and collecting new data might be needed. Possibly such data collection could be incorporated in current studies or data collection initiatives, for example naturalistic driving studies.

A better understanding of the mechanisms that may explain relations between economic development and road safety, based on empirical evidence, will also help to develop policies that can mitigate unfavourable impacts of economic upturns on road safety. The higher number of road casualties in combination with larger budgets could anyway be a reason for governments, companies, and consumers to spend more money on prevention of road casualties in economic good times.

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CHAPTER 3. AN ANALYSIS OF THE RELATIONSHIP BETWEEN ECONOMIC PERFORMANCE AND THE DEVELOPMENT OF ROAD SAFETY[1]

This chapter reviews 20 studies that have examined the relationship between economic performance and road safety. It analyses the relative importance of the mechanisms through which economic fluctuations influence road safety. Finally, it proposes a model to best describe this relationship and to assess the contribution of the economic recession that started in 2008 on the reduction in the number of fatalities.

Background and research problem

The International Transport Forum (ITF) and IRTAD (International Road Traffic Accident Data) have jointly invited researchers to write a paper on the relationship between developments in road safety and economic performance. The background for this invitation is that a remarkable decline in the number of road accident fatalities was observed in many OECD countries in 2010 and 2011. While part of this decline is likely to be the result of road safety policies, it may also be the result of the economic decline that started in 2008 and has affected almost all OECD-countries. The ITF and IRTAD are interested in a better understanding of the relationship between economic performance and road safety.

Terms of reference

According to the terms of reference, the study should address three main topics:

- Inventory and summary of studies on the relationship between safety and economic performance from 1970 to 2012.
- Identification of economic factors influencing road safety performance.
- Development and econometric estimation of a model to describe the relationship between economic and safety performance.

With respect to the first topic, it is noted that there have been many studies of the relationship between economic performance and changes in road safety. The terms of reference call for a review and synthesis of selected studies.

Several economic factors may influence road safety. These include unemployment, freight flows, the level of consumption, etc. These factors may influence both traffic volume and road user behaviour. To uncover these mechanisms, the terms of reference propose an analysis of data from a selection of countries with different economic patterns (highly industrialised countries, emerging economies, etc.).

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The third part of the study is the development and estimation of an accident prediction model designed to uncover the relationship between economic performance and changes in road safety.

It is useful to explain how the terms of reference have been interpreted in the present study and offer some comments to them. The first and third points are, in principle, fairly unproblematic. The second point is, however, more difficult.

The terms of reference suggest that economic development may influence driving behaviour. It is stated that: “The consultant is expected to identify the various mechanisms in place and how different factors affect traffic patterns, driving behaviours and in turn safety performance.” It is added: “As an example: difficult economic conditions may translate into less heavy vehicles on the road, less driving by young people, more careful driving, etc.”

These points of view are reasonable and probably largely correct. Yet, it is not realistic to expect a study to directly uncover the mechanisms that generate a relationship between economic performance and road safety performance. The main reason for this is that data at this level of detail are unlikely to be available. It has, for example, been suggested that driving speed may be influenced by economic changes. However, few countries monitor speed continuously and in a statistically representative way, and it is unlikely that any country will have a time-series of such data going back to, for example, 1970.

Travel behaviour surveys are performed regularly in many countries. The surveys are, however, not annual and do not have a history going back to, for example, 1970. In most cases, it will therefore be unknown – and impossible to find out – whether young people reduce their driving more than other groups in times of economic hardship. It is a reasonable hypothesis, but it cannot be documented directly.

Despite these problems, an attempt has been made in estimating the accident prediction models to indirectly uncover the mechanisms generating a relationship between economic performance and road safety. More is said about this later in the paper.

Research problems

The main research problems addressed in this paper can be stated as follows:

- What is the current state-of-knowledge regarding the relationship between economic performance and road safety as established by previous studies?
- To what extent have the mechanisms that generate a relationship between economic performance and road safety been uncovered?
- What is the relationship between economic performance and road safety in selected OECD-countries, assessed for the period 1970-2010?

Study objectives

Corresponding to the main research questions, the main objectives of the study can be stated as follows:

- To summarise current knowledge regarding the relationship between economic performance and road safety, preferably by means of a formal research synthesis (meta-analysis) stating the main points of knowledge in quantitative terms.

- To develop a causal model of the relationship between economic performance and road safety, serving as the basis for estimating the relationship by means of multivariate statistical techniques.
- To estimate the current relationship between economic performance and road safety in a sample of OECD countries.

Review of previous studies

This section presents a review of previous studies of the relationship between economic performance and road safety.

Study retrieval and coding

Studies were retrieved by examining the list of references in a comprehensive literature survey reported by the Swedish Road- and Transport Research Institute (VTI) in 2011 (Wiklund *et al*. 2011). This literature review was regarded as likely to be quite complete. Relevant studies were retrieved. For each study, further studies were identified from the list of references. The studies that were identified were of two types:

- Studies of the relationship between the level of economic development in a country and its level of road safety.
- Studies of the relationship between fluctuations of the business cycle and road safety within a single country or part of a country.

While the first type of studies does address the relationship between economic development and road safety, these studies do not include an estimation of the effects of changes in the business cycle. Several studies relying on international data sets have been reported (Beeck *et al*. 2000, Kopits and Cropper 2005, Bishai *et al*. 2006, Law *et al*. 2011). The findings of the studies are very consistent. They show that when a country becomes richer and experiences rapid motorisation, the number of traffic fatalities tends to grow. Beyond a certain level of income, however, the number of traffic fatalities starts to decline. Broadly speaking, this has been the trend in most OECD-countries after about 1970. These studies will not be further discussed in this report.

Studies of the second type are more relevant for this report. These studies evaluate statistically the relationship between one or more indicators of economic performance and one or more variables intended to describe road safety. A total of 22 studies have been reviewed. Table 1 lists these studies as well as some details for each study. Two studies (Evans and Graham 1988, Haque 1993) analysed more than one sample and are therefore listed twice. The studies span the period from 1984 to 2014.

Studies have been reported for 27 EU-countries as well as Australia, Canada, New Zealand, Norway, Switzerland and the United States. The largest number of studies has been reported in the United States. Most studies rely on time series data, i.e. data for a single geographical area varying in time only. Some studies rely on panel data, i.e. data for many geographical areas varying both in space and time.

Sample sizes differ greatly, from 23 observations to 5016. Most studies are based on data ending before the year 2000, but the most recent studies included the year 2008, when the world-wide financial crisis started. Different statistical techniques have been used to analyse data. Time-series analysis, of which there are many versions, and regression analyses are the two most commonly applied statistical techniques.

Synthesis of study findings

The studies listed in Table 1 all contain one or more estimates of the relationship between economic performance and road safety. In nearly all studies, estimates are stated in the form of coefficients estimated in time-series analysis or multiple regression analysis.

Table 3.1. **Studies of the relationship between economic performance and road safety. Studies listed chronologically**

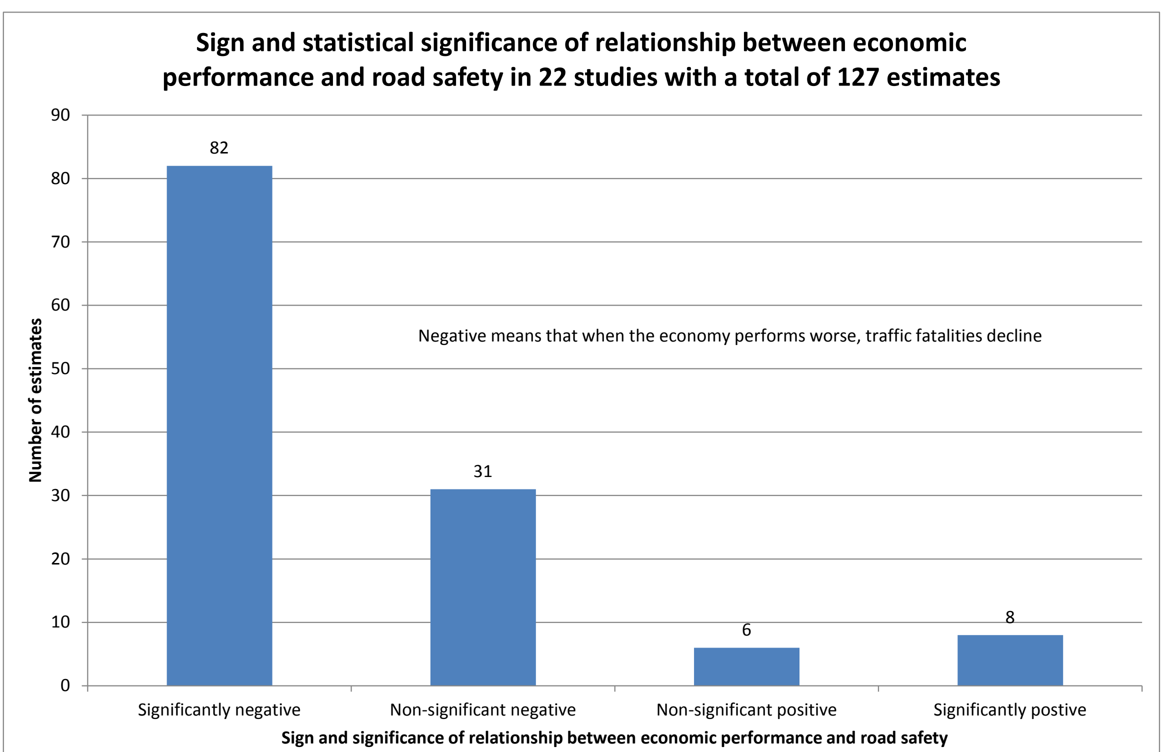
Authors	Year	Country or state	Unit of observation	Type of data	Sample size	Period covered	Method of analysis
Wagenaar	1984	Michigan (USA)	Month	Time series	132	1972-1982	ARIMA time series analysis
Mercer	1987	British Columbia (Canada)	Month	Time series	84	1978-1984	Correlation analysis
Evans and Graham	1988	United States	Year	Time series	40	1946-1985	Regression analysis of time series
Evans and Graham	1988	United States	State-by-year	Panel data	500	1975-1984	Regression analysis of panel data
Leigh and Waldon	1991	United States	State-by-year	Panel data	255	1976-1980	Regression analysis of time series
Partyka	1991	United States	Year	Time series	30	1960-1989	Regression analysis of time series
Reinfurt *et al*.	1991	United States	Year	Time series	23	1960-1982	ARIMA time series analysis
Haque	1993	Victoria (Australia)	Year	Time series	25	1966-1990	Regression analysis of time series
Haque	1993	Victoria (Australia)	Month	Time series	72	1985-1990	Regression analysis of time series
Wilde and Simonet	1996	Switzerland	Year	Time series	31	1963-1993	ARIMA time series analysis
Farmer	1997	United States	Month	Time series	249	1975-1995	Regression analysis of time series
Newstead *et al*.	1998	Victoria (Australia)	Month	Time series	168	1983-1996	Negative binomial regression
Fridstrøm	1999	Norway	County-by-month	Panel data	5016	1973-1994	Negative binomial regression
Ruhm	2000	United States	State-by-year	Panel data	1020	1972-1991	Regression analysis of panel data
Scuffham and Langley	2002	New Zealand	Quarter	Time series	100	1970-1994	State-space time series analysis
Scuffham	2003	New Zealand	Quarter	Time series	100	1970-1994	State-space time series analysis
Tay	2003	Victoria (Australia)	Month	Time series	120	1983-1992	Negative binomial regression
Neumayer	2004	Germany	State-by-year	Panel data	281	1990-2000	Regression analysis of time series
Van den Bossche *et al*.	2005	Belgium	Month	Time series	132	1990-2001	ARIMA time series analysis
Hermans *et al*.	2006	Belgium	Month	Time series	312	1974-1999	State-space time series analysis
Garcia-Ferrer *et al*.	2007	Spain	Month	Time series	348	1975-2003	State-space time series analysis
Kweon	2011	Virginia (USA)	Year	Time series	33	1976-2008	Regression analysis of time-series
Wiklund *et al*.	2011	Sweden	Year	Time series	28	1981-2008	Regression analysis of time series
Yannis *et al*	2014	EU-countries (27)	Country-by-year	Panel data	999	1975-2011	Mixed linear time series model

By far the most common indicator of economic performance is the level of unemployment. This is stated either as the number of unemployed workers or the rate of unemployment in percentage of the labour force. It is not possible to formally synthesise the findings of all studies. Both the indicators of economic performance and the coefficients intended to capture the effects of economic performance differ between studies. It is, however, possible to examine if the direction and statistical significance of the relationship between economic performance and road safety is the same in all studies. There is a negative relationship between economic performance and road safety if a deterioration of economic performance (e.g. higher unemployment) is associated with an improvement of road safety (e.g. a reduction in the number of fatalities). To test if there is such a relationship, the coefficients estimated in the studies listed in Table 1 were sorted in four groups:

- Coefficients indicating a statistically significant (5 % level of significance) negative relationship between economic performance and road safety
- Coefficients indicating a statistically non-significant negative relationship between economic performance and road safety
- Coefficients indicating a statistically non-significant positive relationship between economic performance and road safety
- Coefficients indicating a statistically significant positive relationship between economic performance and road safety

The studies contained a total of 127 coefficients that were classified into these groups. Figure 3.1 shows the number of coefficients in each group.

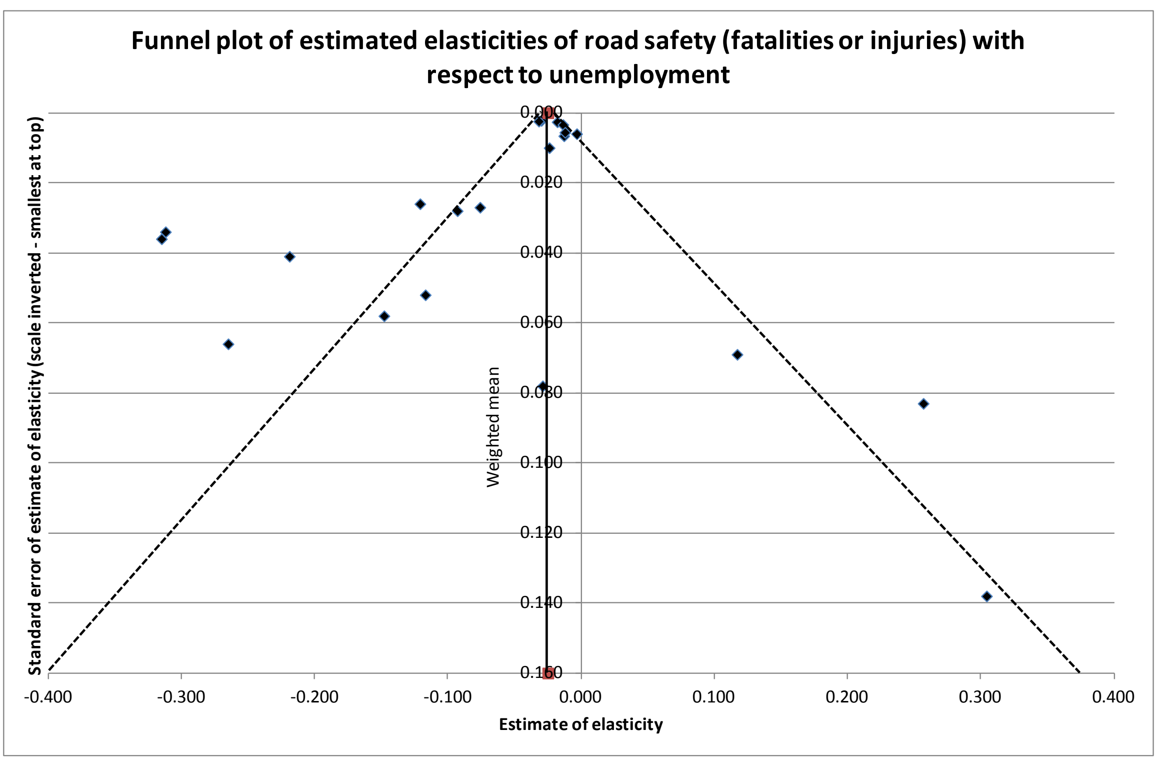
Figure 3.1. **Sign and statistical significance of relationship between economic performance and road safety**



A total of 113 coefficients (89 %) indicate a negative relationship between economic performance and road safety. 82 of these coefficients were statistically significant at the 5 % level. Thus, the preponderance of evidence from previous studies suggests that there is a negative relationship between economic performance and road safety. In particular, when unemployment increases, the number of accidents or accident victims goes down.

The coefficients estimated in the 22 studies have different interpretations. However, some of the studies have produced coefficients that can be formally synthesised. More specifically, in all studies that used the natural logarithm of the rate of unemployment as an indicator of economic performance, the coefficient for this variable can be interpreted as an elasticity, i.e. the coefficient shows the percentage change in road safety (in most studies indicated by the number of fatalities) associated with a 1%increase in the rate of unemployment (the rate of unemployment is usually stated as the percentage of the labour force out of work). Coefficients representing elasticities were extracted from the studies of Evans and Graham (1988; 3 estimates), Newstead *et al*. (1998; 4 estimates), Fridstrøm (1999; 1 estimate), Ruhm (2000; 4 estimates), Tay (2003; 4 estimates), Neumayer (2004; 2 estimates), Van den Bossche *et al*. (2005; 2 estimates) and Hermans *et al*. (2006; 1 estimate). In total, 21 estimates of the elasticity of road safety with respect to unemployment were extracted from these studies. Figure 3.2 shows a funnel plot of the estimates and a weighted mean value.

Figure 3.2. **Funnel plot of estimates of the elasticity of road safety with respect to the rate of unemployment**



The values of the elasticities are plotted along the horizontal axis. The vertical scale shows the standard errors associated with the estimated elasticities. The scale for the vertical axis has been inverted, so that the smallest standard errors are at the top. Contours indicating a funnel turned upside down are shown by the dashed lines. The weighted mean elasticity (fixed-effects model) is shown by the line connecting the red dots. The weighted mean elasticity was estimated at -0.025.

A fixed-effects model of meta-analysis relies on the assumption that the between-study variation in estimates of the elasticity is random only. However, some of the data points in Figure 3.2 are located outside the contours of the funnel. This indicates that there is systematic variation in estimates of the elasticity between studies. A test for homogeneity was performed in order to determine if estimates of the elasticity vary systematically. The test confirmed that there is systematic variation in estimates of the elasticity. A random-effects meta-analysis was therefore performed. The weighted mean estimate of the elasticity according to the random-effects analysis was -0.060.

A potential source of bias in meta-analysis is publication bias. Publication bias refers to a tendency not to publish results that are not statistically significant or that are unexpected or violate theoretical expectations. The trim-and-fill method (Duval and Tweedie 2000A, 2000B, Duval 2005) was applied in order to test for publication bias. The method was applied to the fixed-effects estimates. The analysis indicated the presence of a slight publication bias and generated three new data points. The addition of these data points did not influence the summary estimate of the elasticity very much. The results of the analysis can be summarised as follows:

Model	**Summary estimate of elasticity**	**Standard error**
Fixed-effects	-0.025	0.001
Random-effects	-0.060	0.024
Fixed-effects, trim-and-fill	-0.024	0.001

The summary estimate of the elasticity is negative and statistically significant in all models of analysis. Based on the review of previous studies, it is therefore concluded that there are stronger reasons to believe that a deterioration of economic performance is associated with an improvement of road safety than to believe the opposite.

The mechanisms underlying the relationship between economic performance and road safety

Variables included in previous studies

Table 3.2 gives an overview of the variables that have been included in previous studies of the relationship between economic performance and road safety. The variables have been classified in three groups:

- Dependent variables, which measure road safety and changes over time in road safety
- Indicators of economic performance, which are the independent variables of principal interest in the studies
- Other variables, which are confounding variables that could influence either road safety, economic performance or the relationship between economic performance and road safety.

The number of people killed in road accidents is the most common dependent variable. A few studies include injury accidents or injured road users in addition to fatalities. There are also a few studies that have more than one dependent variable, such as accidents at different levels of severity.

The rate of unemployment in per cent is the most frequently used indicator of economic performance, followed by the number of unemployed people. Most studies use only one indicator of economic performance, but in recent studies it is increasingly common to use more than one indicator of economic performance.

Studies differ greatly with respect to how many other variables they have included in addition to variables describing economic performance and road safety. Again, a tendency can be seen for more recent studies to include more variables than older studies. Studies that included particularly many variables were reported by Leigh and Waldon (1991), Fridstrøm (1999), Ruhm (2000), Scuffham and Langley (2002), Scuffham (2003), van den Bossche *et al*. (2005) Hermans *et al*. (2006) and Kweon (2011).

Most studies do not discuss the choice of variables to be included at great depth; nor do most studies model explicitly the relationship between the variables that were included. Nevertheless, some studies discuss these aspects, and some of these discussions will be reviewed in the next section.

The study presented in the next chapter of this report is based on international data. It therefore uses the number of road accident fatalities as the principal dependent variable. Differences in the definition of reportable accidents, and in the actual levels of reporting (Elvik and Mysen 1999, Page 2000), make data on injury accidents incomparable between countries.

Few of the previous studies have attempted to measure the mechanism by which economic performance influences road safety. Several studies have, however, discussed this mechanism, or mechanisms. A review of these discussions can give guidance with respect to how best to formulate a model for an international study of the relationship between economic performance and road safety.

Table 3.2. **Variables included in previous studies**

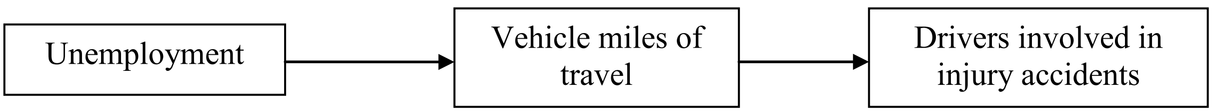
Authors	**Year**	**Dependent variable**	**Indicators of economic performance**	**Other variables included in analysis**
Wagenaar	1984	Drivers involved in injury accidents	Rate of unemployment (percent)	Vehicle kilometres of travel
Mercer	1987	Casualties per million vehicle km; percentage fatal casualties	Rate of unemployment (percent)	Percentage of alcohol-related accidents; percentage use of restraints (in accident); age of accident-involved drivers; share of males among accident involved drivers
Evans and Graham	1988	Fatalities in motor vehicle accidents	Rate of unemployment (percent)	Vehicle kilometres of travel
Evans and Graham	1988	Fatalities in motor vehicle accidents	Rate of unemployment (percent)	Vehicle kilometres of travel; state dummies; year dummies
Leigh and Waldon	1991	Fatalities in motor vehicle accidents	Rate of unemployment (percent)	Number of people above age 15; urban kilometres of travel; rural kilometres of travel; percentage of drivers who are males younger than 24; average speed of traffic, standard deviation of speed; motor fuel consumption; alcohol consumption; number of motor vehicle inspections; minimum legal drinking age; new cars as percentage of all cars; helmet law (yes or no)
Partyka	1991	Fatalities in motor vehicle accidents	Number of unemployed (thousands)	Number of persons not in labour force (thousands)
Reinfurt *et al*.	1991	Fatalities in motor vehicle accidents	Number of unemployed	Number of employed; number of people not in labour force
Haque	1993	Road accident fatalities	Number of unemployed	Amount of motor fuel sales; indicators for road safety initiatives; trend term
Wilde and Simonet	1996	Road accident fatalities	Index of industrial production; percentage level of employment; number of people employed	Year (time-series analysis)
Farmer	1997	Fatalities in motor vehicle accidents	Number of unemployed	Number of employed; number of people not in labour force; vehicle kilometres of travel; new car sales; dummies for month
Newstead *et al*.	1998	Serious injury accidents	Rate of unemployment (percent)	Number of random breath tests; alcohol sales; tickets for speeding; alcohol campaign publicity; trend term
Fridstrøm	1999	Injury accidents	Rate of unemployment (percent)	Nearly 50 other variables were included (not listed here)
Ruhm	2000	Fatalities in motor vehicle accidents	Rate of unemployment (percent)	Personal income;% of population below 5 years of age;% of population above 65 years of age; high school dropouts; share with college education; share of college graduates;% of population who are black;% of population who are Hispanic

Table 3.2 **(cont/d). Variables included in previous studies**

Authors	**Year**	**Dependent variable**	**Indicators of economic performance**	**Other variables included in analysis**
Scuffham and Langley	2002	Number of fatal accidents	Rate of unemployment (percent)	Vehicle kilometres of travel; registered vehicles; population; real Gross Domestic Product per capita; percentage motorcycles; percentage young males 15-24 years; beer consumption per capita; rural speed limit; dummy for 1973 oil crisis; dummy for 1979 oil crisis; dummy for 1984 seat belt law
Scuffham	2003	Number of fatal accidents	Rate of unemployment (percent)	Vehicle kilometres of travel; registered vehicles; population; real Gross Domestic Product per capita; percentage motorcycles; percentage young males 15-24 years; beer consumption per capita; rural speed limit; dummy for 1973 oil crisis; dummy for 1979 oil crisis; dummy for 1984 seat belt law
Tay	2003	Serious injury accidents	Rate of unemployment (percent)	Dummies for month; trend term; alcohol sales; random breath tests; volume of alcohol advertisements; production index
Neumayer	2004	Road accident fatalities	Rate of unemployment (percent)	Real income per capita;% of population below 5 years of age;% of population above 65 years of age;% of foreigners in the population; Gini-index of inequality; gender
Van den Bossche *et al*.	2005	Number of accidents and number of victims – two classes by severity	Number of unemployed; number of car registrations; percentage of second-hand car registrations	Traffic counts; seat belt law; speed limit law; blood alcohol limit law; zebra crossing law; percentage of days with precipitation; percentage of days with frost; percentage of days with snow; percentage of days with thunder; percentage of days with sun
Hermans *et al*.	2006	Number of accidents and number of victims – two classes by severity	Number of unemployed; number of car registrations; percentage of second-hand car registrations; inflation in percent	Traffic counts; seat belt law; speed limit law; blood alcohol limit law; zebra crossing law; precipitation in mm; sunlight hours; percentage of days with precipitation; percentage of days with frost; percentage of days with snow; percentage of days with thunder; percentage of days with sun
Garcia-Ferrer *et al*.	2007	Number of accidents; number of injured; number of fatalities	Index of industrial production; motor fuel consumption	Number of new vehicles; calendar events (Easter, etc.)
Kweon	2011	Number of accidents or victims; seven categories (by severity)	Rate of unemployment (percent)	Beer consumption per capita; manufacturing capacity utilisation index; consumer price index; number of licensed drivers; number of employed persons; motor fuel price; production of motor fuel; gross value-weighted industrial production; per capita income; industrial production index; number of persons in labour force; population, producer price index; sales; number of vehicles; vehicle miles of travel
Wiklund *et al*.	2011	Road accident fatalities	Number of unemployed; Gross Domestic Product	Vehicle kilometres by trucks; vehicle kilometres by young drivers; remaining vehicle kilometres driven
Yannis *et al*.	2014	Road accident fatalities	Gross Domestic Product per capita	Country; year; population

Mechanisms discussed in previous studies

An early study that discussed a mechanism by which economic performance can influence road safety was the study reported by Wagenaar (1984). Wagenaar states that he included a measure of motor vehicle miles travelled, in order to "assess its potentially intervening effect between unemployment and crash involvement". This suggests that his model of the relationship between unemployment and road safety was as shown below:



In other words, Wagenaar conjectured that increased unemployment would reduce vehicle kilometres of travel. This would in turn influence, most likely reduce, the number of drivers involved in injury accidents.

The analysis did not support the hypothesis that vehicle miles of travel was an intervening variable between unemployment and the number of accidents. It did find, however, that the effect of unemployment differed over time. There was a decline in the number of accidents during the same year as unemployment increased, followed by an increase in the second year. When the effect found in the same year and the following year were added, there was a net negative effect, i.e. an increase in unemployment in year T was associated with a net reduction of the number of accidents in years T and T + 1.

Evans and Graham (1988) found that unemployment had a greater effect on the number of fatalities among young drivers than among drivers aged 25 years or more. Their study did not uncover the mechanism underlying this pattern, but recent statistics from many OECD-countries shows that the rate of unemployment tends to be considerably higher among young people than among other age groups of the labour force. This might lead to a reduction of work-related trips, which would be expected to reduce the number of accidents involving young people. Farmer (1997) replicated the finding of Evans and Graham.

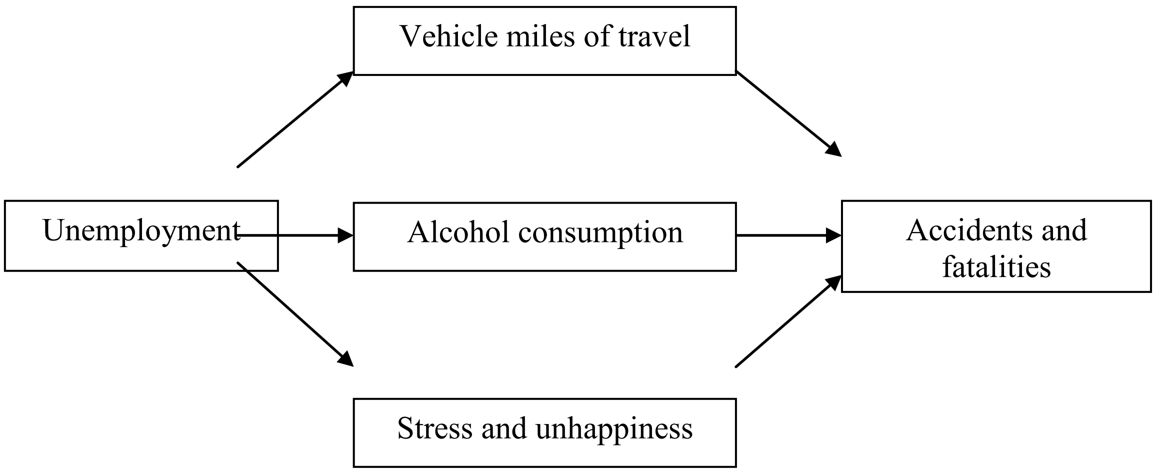
Leigh and Waldon (1991) discuss at length mechanisms that may generate a relationship between economic performance and road safety. They summarise this discussion in the following terms:

"Using econometric models of the data, (panel data for the 50 states and the District of Columbia 1976-1980) we present evidence for two of the three hypothesized effects of unemployment. We conclude that, if the number of miles driven is held constant, worsening unemployment leads to higher fatality rates, most likely due to stress effects. But because more unemployment means less driving, increases in unemployment, on balance, are associated with decreases in fatalities."

The three hypotheses Leigh and Waldon formulated about the effects of unemployment were:

- Increased unemployment is associated with a reduced amount of driving.
- Increased unemployment may influence alcohol consumption, but the direction of the influence is indeterminate.
- Increased unemployment may increase aggregate levels of stress and unhappiness; this would in turn be expected to increase the number of accidents.

These hypotheses can be modelled in terms of a causal diagram:



Leigh and Waldon estimated six models that differed in terms of the variables that were included. By comparing these models, they were able to determine if the causal mechanisms supported their hypotheses. The first model included unemployment only, which had a negative coefficient (i.e. higher unemployment is associated with fewer fatalities). In the second model, several variables were added, including the mean speed of traffic, which had a positive coefficient. If one thinks that a downturn of the economy may lead to lower speeds, it does not make sense to include speed in a model. By doing so, one would in effect control for an effect which should not be controlled for, because it is endogenous. One would, in other words, estimate the effect of unemployment on the number of fatalities, when speed is held constant (statistically). In the models including speed, its coefficient was positive, suggesting that, controlling for the other variables included, increased speed was associated with an increased number of fatalities.

When variables representing vehicle miles of travel were included in the model, the sign of the coefficient for unemployment changed from negative to positive. Leigh and Waldon interpret this finding in the following terms:

"The hypothesis that unemployment can lead to anxiety and poor driving, holding constant the amount of driving and percentage of young male drivers, is supported."

However, their paper provides no data showing that drivers actually are more anxious during economic downturns than they are in good times. Besides, no evidence is presented to support the idea that driver anxiety is detrimental to driver performance and safety. Thus, their interpretation is speculative only. This does not necessarily mean that it is wrong. It illustrates a problem frequently encountered in econometric models of road safety, namely that certain causal mechanisms based on road user behavioural adaptation are proposed, but that these mechanisms are not directly observable. Their existence is inferred from the structure of a model and model coefficients. Although such inferences may appear to be plausible, there is no evidence directly supporting them.

As far as the model of Leigh and Waldon is a concerned, one can easily imagine data that would be relevant to their anxiety hypothesis and that could have been collected to shed further light on it. There are statistics on, for example, the consumption of tranquilizers and other drugs taken to relieve anxiety or depression. There are surveys of self-reported health state and changes in it over time. If these, or similar statistics, were found to be related to the rate of unemployment in the way predicted by the anxiety hypothesis of Leigh and Waldon, it would make their findings more plausible. The anxiety hypothesis, as presented by Leigh and Waldon, is nothing more than a speculation, unsupported by any relevant data.

Detailed data regarding road user behaviour and the behavioural adaptation to changes in the business cycle or other factors that may influence road user behaviour are, in general, not available. Some countries have monitored the use of seat belts for some years, but very few countries have a long time series of comparable data covering belt wearing in all seating positions of cars. Even such basic factors as the mean speed of traffic and the level of drinking and driving are not systematically recorded. Data concerning drinking and driving, in particular, are very poor and unreliable (Assum and Sørensen, 2010). This creates a problem for econometric studies designed to uncover the mechanisms that generate a relationship between economic performance and road safety. Unless these mechanisms can be described by means of relevant data, their existence has to be inferred from the model. Can this be done in a scientifically more valid manner than the empty speculations offered by Leigh and Waldon?

Fridstrøm (1999, 2012) discusses a fruitful approach which he gives the name of the "casualty subset test". The test is based on the idea that when it is known that a certain factor has an effect only in one group of road users, or for a specific type of accident, one would expect the coefficients estimated in an econometric model to imply a larger effect of the factor concerned within the group it primarily affects than outside this group. As an example, a road safety campaign targeted at young people, in particular passengers in cars, such as the Norwegian "Speak out!" campaign, would be expected to have an effect within the target group, but not outside it: i.e. one would not expect such a campaign to have an effect among, for example, older drivers (Elvik, 2000). By the same token, if unemployment affects young people more than other age groups, one would expect to find larger reductions in the number of fatalities among young people than in other age groups when unemployment increases.

The casualty subset test has indeed been applied in some of the studies reviewed in this report, although these studies did not use that name for it. To give an example, the hypothesis that alcohol consumption may decline during recessions or be shifted from public bars and restaurants to the home, influencing the amount of drinking and driving, has been successfully tested in two Australian studies relying on a classification of hours of the day into "high alcohol hours" and "low alcohol hours". In fact, there are official definitions of these terms in Australia. The classification is presumably based on accident studies showing that alcohol is more prevalent among drivers and other accident victims on certain days of the week and certain hours of the day than at other times. Although a classification into "high" and "low" alcohol hours will obviously not be perfect (there will be non-alcohol-related accidents in high-alcohol hours and vice versa), it is likely that it will be sufficiently reliable to apply the casualty subset test.

In the first of the two Australian studies (Newstead *et al* 1998) coefficients showing the elasticity of serious injury accidents with respect to unemployment (i.e. coefficients showing the percentage change in accidents associated with a 1%increase in unemployment) were estimated for high-alcohol hours and low-alcohol hours for the city of Melbourne and the rest of the state of Victoria, which is mainly rural. Tay (2003) replicated the analysis, using data for different years. The findings are summarised below:

Study	Location	Hours	Coefficient
Newstead *et al* .	Melbourne	High-alcohol	-0.315
	Rural Victoria	High-alcohol	-0.029
	Melbourne	Low-alcohol	-0.219
	Rural Victoria	Low-alcohol	-0.148
Tay	All Victoria	High-alcohol	-0.312
	All Victoria	Low-alcohol	-0.117

These results display a systematic pattern which is broadly consistent with the casualty subset test. The main findings were reproduced in two studies that were based on data for different years. This suggests that the result is not due to chance or confounding, but indicates the presence of a causal relationship, in which an important causal mechanism operating is the amount of drinking and driving. It is, however, clearly not the only mechanism by which unemployment influences accidents, since negative coefficients were found even during low-alcohol hours.

Causal modelling and criteria of causality

As a basis for the econometric modelling presented in the next chapter of the report, a model of relevant variables was developed. Figure 3.3 shows this model. It gives a simplified description of the relationships of principal interest.

There are two indicators of economic performance: (1) The Gross Domestic Product per capita, (2) The rate of unemployment in per cent of the labour force. These are the two main independent variables of interest in the study. Both indicators of economic performance change over time and take on different values in different countries. To account for these differences, time (year) and country, (a dummy variable for each country) are included in the model. Year and country should be interpreted as scaling variables not as causal variables.

The arrows in Figure 3.3 indicate that the variables are believed to be statistically related to each other. Not all statistical relationships indicated in Figure 3.3 are causal. Those that are believed to be causal are commented below.

Economic performance is thought to influence road safety by means of (at least) three causal mechanisms:

- Economic performance may influence road user behaviour.
- Economic performance may influence the composition of traffic, in particular the share of traffic made up by young people.
- Economic performance may influence traffic volume, i.e. vehicle kilometres of travel.

In principle, all three mechanisms are observable. In practice, however, the first of the three is rarely observable in breadth or detail. To the extent road user behaviour is monitored at all, monitoring is incomplete and may not include very many years of observation. The share of young people in traffic can be estimated on the basis of household travel surveys that are performed regularly in many countries. These surveys are, however, rarely performed annually and are not likely to be available before, say, about 1990 in many countries.

Traffic volume, in terms of vehicle kilometres of travel, is estimated annually in many countries. This variable is therefore to a great extent observable in OECD-countries, although not all countries have equally long time-series of estimates.

Rather than attempting to collect more complete data on the causal mechanisms, modelling has been based on the casualty subset test or a similar logic. In particular, modelling is based on the following assumptions:

- Changes in road user behaviour associated with economic performance will mainly influence the fatality rate per billion kilometres of travel. More specifically, if economic downturns are associated with more cautious behaviour (less speeding, less drinking and driving, etc.) there will be a sharper decline in fatality rate during economic downturns than in other periods.
- Changes in the participation of young people in traffic will, all else equal, manifest itself in a reduction of their share of fatalities. Thus, if economic downturns affect young people to a greater extent than other age groups, the share of young people among traffic fatalities will decline during economic downturns.
- A separate model will be developed to test if vehicle-kilometres of driving are related to economic performance. In the main model, vehicle-kilometres of driving is treated as an endogenous variable and is not controlled for (i.e. not entered as a predictor variable in the model) when modelling the effects of economic performance.

Table 3.3 lists criteria of causality that have been developed for multivariate accident models of the sort developed in this report (Elvik 2011A). The application of these criteria to assess whether there is a causal relationship between economic performance and road safety is as follows:

Figure 3.3. **Model of the influence of economic performance on road safety**

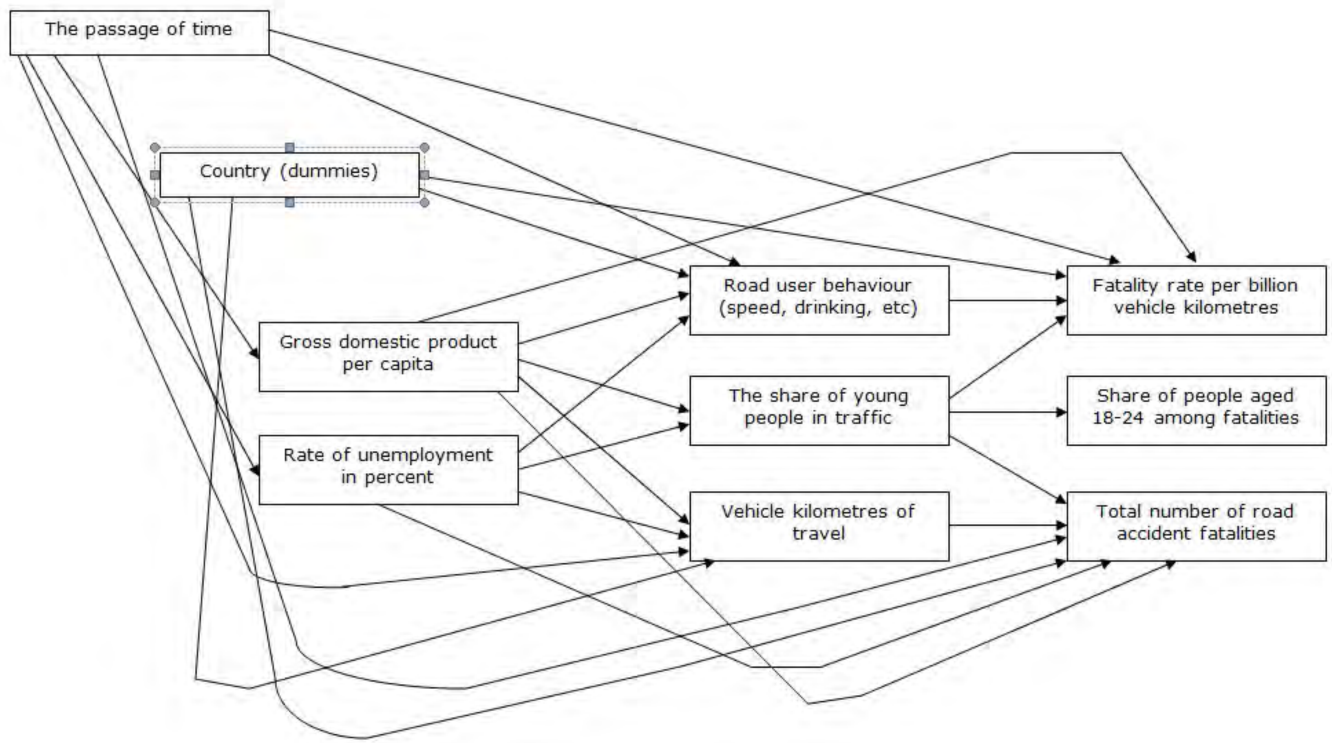


Table 3.3. **Criteria of causality**

Criterion of causality	Theoretical definition	Operational definition
1. Statistical association	There should be a statistical association between cause and effect	A statistically significant change in variables measuring safety associated with the causal variable
2. Strength of association	A strong association is more likely to be causal than a weak association	Causal effect stated in terms of effect size compared to effect sizes for other variables present in the data
3. Consistency of association	A consistent association is more likely to be causal than an inconsistent association	The consistency in direction and size of effect attributed to indicators of economic performance across subsets of the data or different model specifications, assessed by means of a consistency score
4. Clear causal direction	It should be clear which of two variables is the cause and which is the effect	The temporal order between variables; a priori considerations; reversal of effect when causal factors change direction
5. Control for confounders	The association between cause and effect should exist when confounding variables are controlled for	The identification of potentially confounding variables; existence of an effect attributed to treatment after potentially confounding variables have been controlled for; completeness of the control for confounding variables
6. Causal mechanism	The mechanism generating an effect should be identified and measured	Changes in amount of travel, composition of travel and road user behaviour associated with changes in economic performance
7. Theoretical explanation	A plausible theoretical explanation of the findings of a study should be given	Findings should not contradict well established economic theory or results found in most previous studies
8. Dose-response pattern	Large changes in causal variables should have larger effects than small changes	Major fluctuations in economic performance should be associated with larger changes in safety than minor fluctuations in economic performance
9. Specificity of effect (casualty subset test)	Effects of a cause operating only in a certain clearly defined group should only be found within that group	Economic fluctuations may have larger effects on young people than on other age groups

Source: Adapted from Elvik (2011A).

1. Statistical relationship: The variables indicating economic performance, in particular unemployment should have a statistically significant relationship with dependent variables used in the analyses. This will be assessed in terms of the statistical significance of estimated coefficients.

2. Strength of association: The coefficients for the variables indicating economic performance should not be statistically insignificant more often than other variables included in the models.

3. Consistency of association: The coefficients for the variables indicating economic performance should have the same sign and indicate effects of the same magnitude in all model specifications. Estimated effects should be stable over time.

4. Direction of causality: When economic performance changes direction, there should be concomitant changes in the dependent variables. As an example: if the number of fatalities declines when unemployment increases, it should increase, or decline at a slower rate, when unemployment falls.

5. Control for confounders: A statistically significant relationship between economic performance and road safety should be found in models that control for all potentially confounding variables that can be included in a model.

6. Causal mechanism: The pattern of model coefficients should be consistent with hypotheses based on the causal mechanisms specified in Figure 3.3.

7. Theoretical explanation: The main findings of the analysis should be consistent with comparable previous studies, reviewed in this report.

8. Dose-response pattern: There should be a dose-response pattern, in the sense that major changes in economic performance should be associated with greater changes in road safety than smaller changes in economic performance.

9. Specificity of effect: A specificity of effect should be found for young people and for fatality rate. This means that economic downturns are expected to have larger effect on road accident fatalities involving young people (18-24) and be associated with a reduction of fatality rate (above long-term trend).

The interpretation of the criteria of causality will be further discussed with the results of the models developed.

Modelling the relationship between economic performance and road safety

Data requirements

To estimate a model, or a set of models, including the relationships specified in Figure 3.3, data are needed about the following variables (listed from right to left by reference to Figure 3.3):

- the total number of road accident fatalities, by country and year
- the number of road accident fatalities involving young people (defined as 18-24 years old), by country and year
- the number of vehicle kilometres driven, by country and year
- the rate of unemployment in per cent, by country and year

- gross Domestic Product per capita in internationally comparable values, by country and year.

Countries are identified by dummy variables. Year is listed as 1970, 1971, etc.

In keeping with the terms of reference for this study, the aim was to include as many countries as possible for the period 1970-2010, which is the most recent year for which final data have been entered into most OECD databases.

The IRTAD database and databases containing economic indicators were accessed and relevant data downloaded. A data set comprising 14 countries was created for analysis.

Data collection and editing

A database was compiled from the IRTAD database and other databases kept by the OECD containing economic data. The database contains information on relevant variables for the period 1970-2010 for the following countries: Austria, Belgium, Denmark, Finland, France, Great Britain, Ireland, Japan, Norway, Sweden, Switzerland, and the United States of America.

In addition, complete data were found for the years 1980-2010 for the following countries: Germany (unified) and the Netherlands.

The database contains 554 observations. In a few cases, data contained apparent anomalies or were missing. In these data, corrections and interpolations were made. More specifically, the following corrections were made to the data:

- Vehicle-kilometres of travel in Austria appeared abnormally high from 1987 to 1999, compared to figures before 1987 and after 1999. The number of vehicle-kilometres was therefore re-estimated for the years 1987-1999.

- Vehicle-kilometres of travel in Finland from 1970 to 1975 were missing from IRTAD. Estimates for the missing years were developed by using national statistics published in Finland.

- Vehicle-kilometres of travel in Japan for the years 1970-1986 appeared to be unreasonably low compared to data for the years after 1987. Data for the years 1970-1986 were re-estimated.

- Data on vehicle-kilometres travel were missing for the Netherlands for the years 2004-2007. Data for these years were interpolated by assuming that annual changes in vehicle-kilometres of travel were parallel to annual changes in Gross Domestic Product per capita.

- The rate of unemployment in Austria in 1970 was estimated by using domestic sources of data.

- The rate of unemployment in France in 1970 was estimated by using international statistics not published by the OECD.

- The rate of unemployment in Switzerland from 1970 to 1974 was set equal to 0.1%. National statistics indicate a rate of 0.01% for these years, but it is judged as dubious if such a remarkably low rate could be correct.

The Appendix to the report gives an overview and a more detailed description of the changes and additions that were made to the data. It shows both the original and edited data.

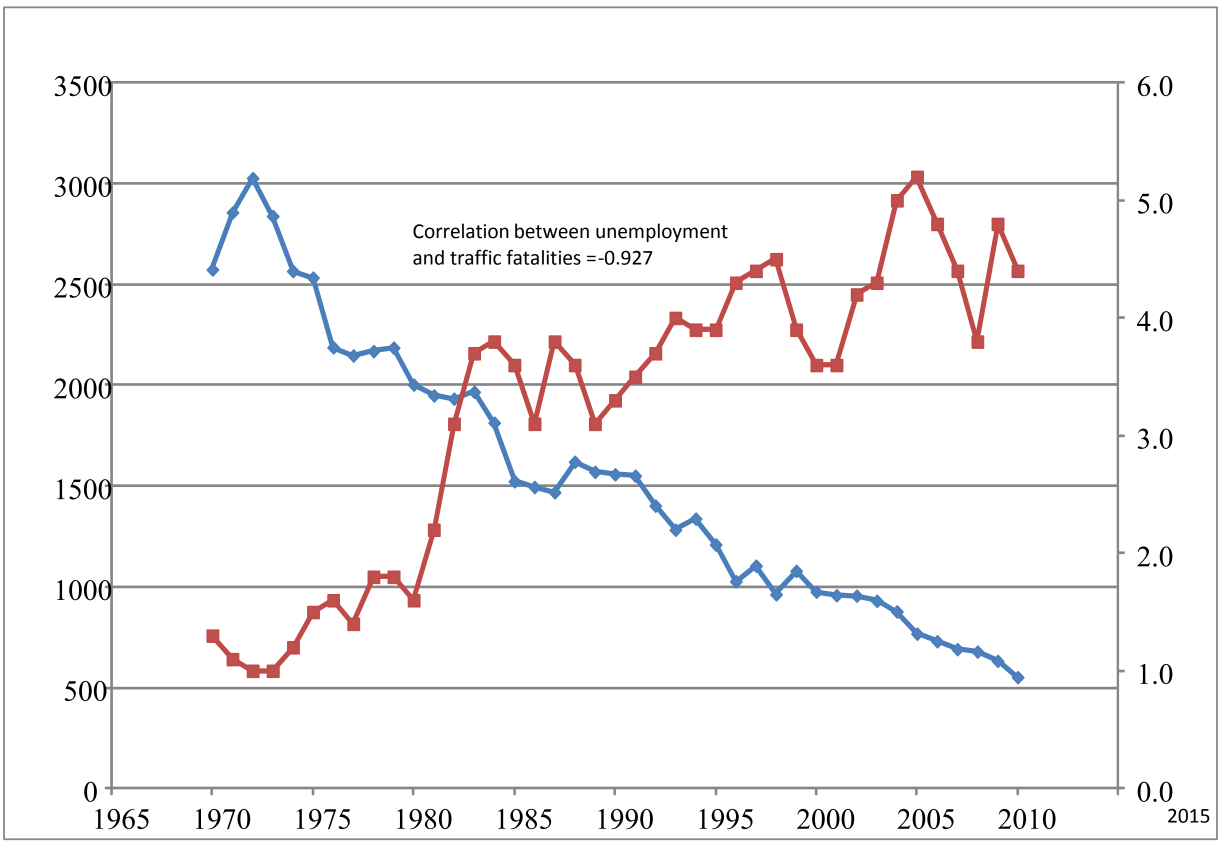
Exploratory description of relationships

Before developing models to analyse the data, it is instructive to give an exploratory description of the data for each country regarding the development of road accident fatalities and unemployment in the period covered by the study.

Austria

Figure 3.4 shows the annual number of traffic fatalities and the annual rate of unemployment in Austria from 1970 to 2010.

Figure 3.4. **Traffic fatalities and unemployment in Austria 1970-2010**

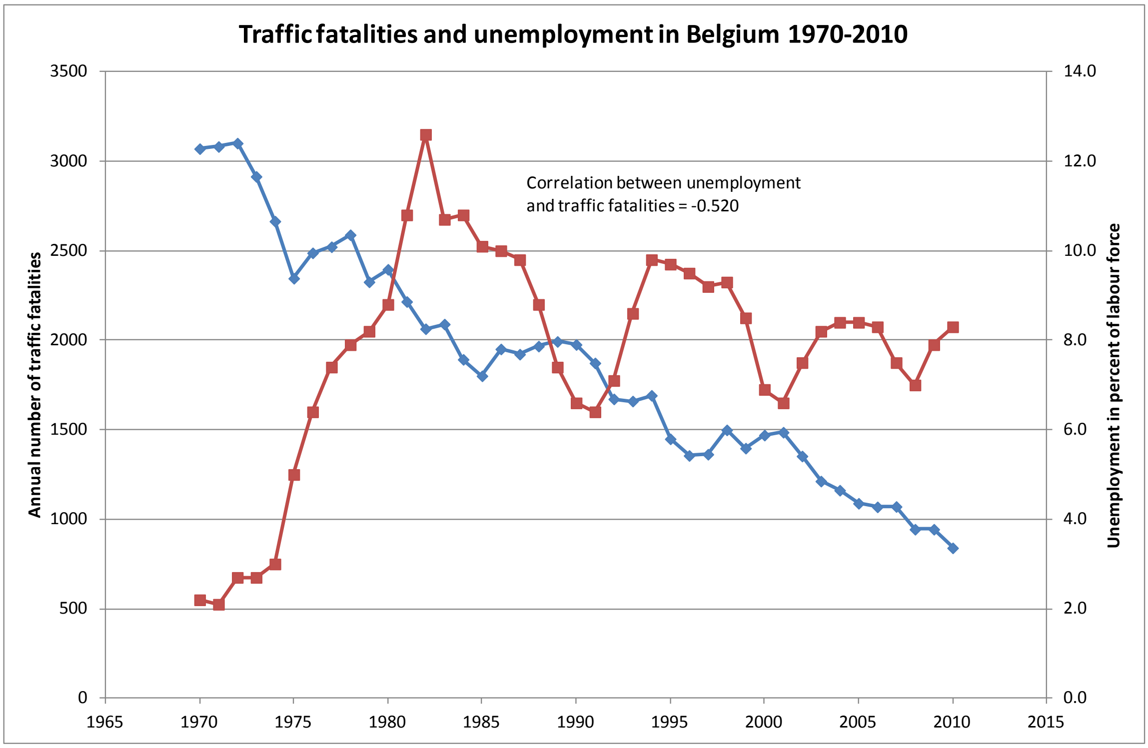


The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a very strong negative correlation between the variables. Traffic fatalities declined in 31 years, increased in nine years. Unemployment increased in 21 years, declined in 15 years and remained unchanged for four years. There has been a very steady decline in traffic fatalities after the year 2000, but comparatively large fluctuations in unemployment during the same period.

Belgium

Figure 3.5 shows the annual number of traffic fatalities and the annual rate of unemployment in Belgium from 1970 to 2010.

Figure 3.5. **Traffic fatalities and unemployment in Belgium 1970-2010**



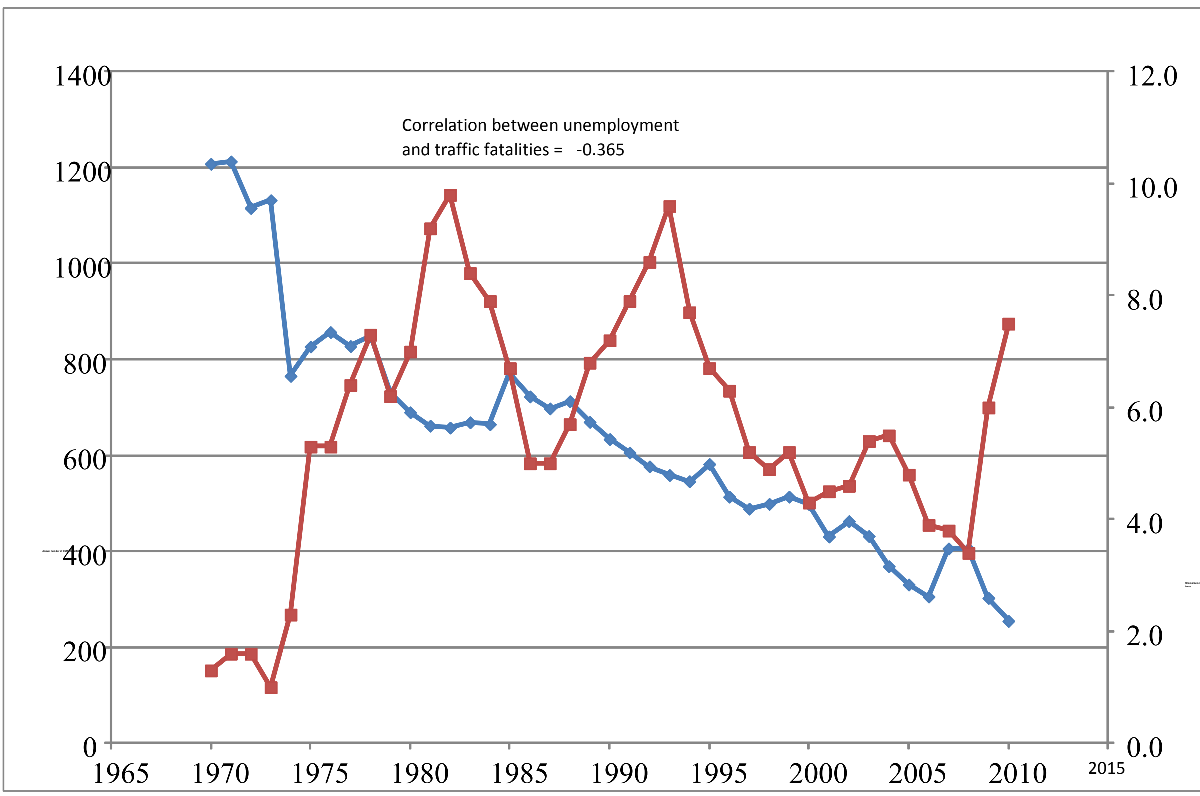
The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a moderately strong negative correlation between the variables. Unemployment increased very sharply during the 1970s, but has since fluctuated considerably, though with a long-term tendency towards decline. Traffic fatalities declined in 25 years, increased in 15 years. Unemployment increased in 20 years, declined in 18 years and remained unchanged for two years.

Denmark

Figure 3.6 shows the annual number of traffic fatalities and the annual rate of unemployment in Denmark from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a moderate negative correlation between the variables. Unemployment increased sharply until 1982, but has since fluctuated, with a slight long-term tendency towards decline. Traffic fatalities declined in 26 years, increased in 13 years and remained unchanged in one year. Unemployment increased in 21 years, declined in 16 years and remained unchanged for three years.

Figure 3.6. **Traffic fatalities and unemployment in Denmark 1970-2010**

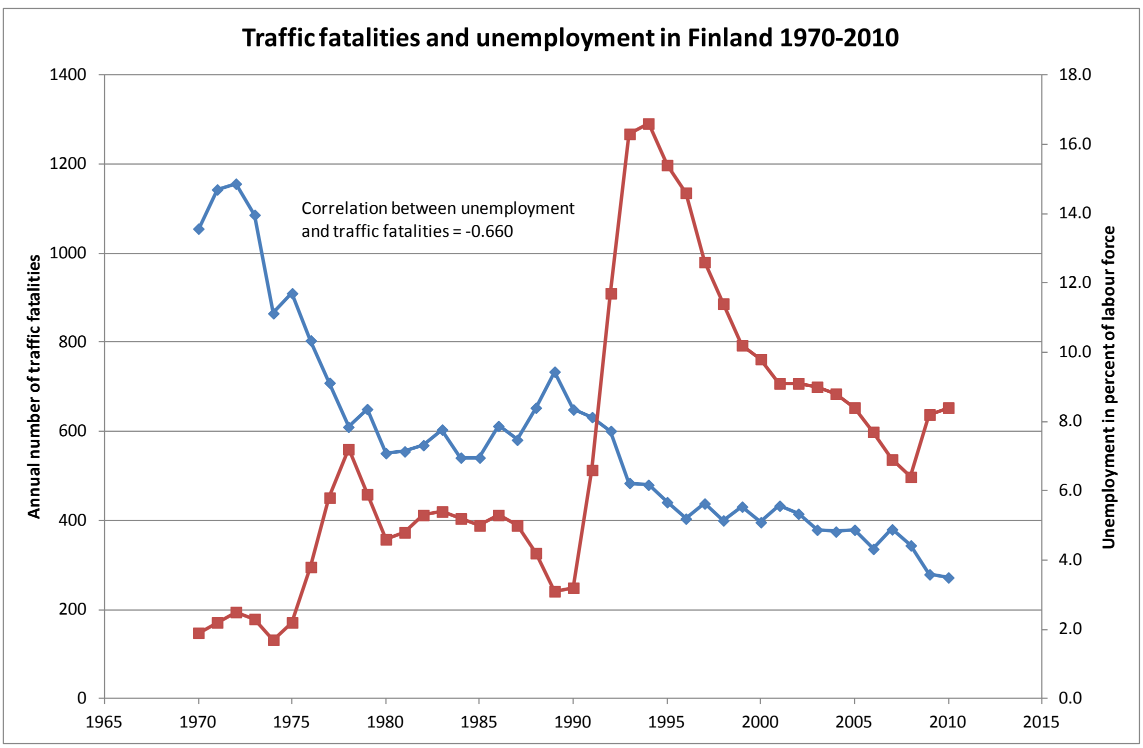


Finland

Figure 3.7 shows the annual number of traffic fatalities and the annual rate of unemployment in Finland from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a fairly strong negative correlation between the variables. Unemployment increased sharply in the early 1990s, but has since declined substantially, but not down to the low level of the start of the period. Traffic fatalities declined in 24 years, increased in 15 years and remained unchanged in one year. Unemployment increased in 17 years, declined in 22 years and remained unchanged for one year.

Figure 3.7. **Traffic fatalities and unemployment in Finland 1970-2010**

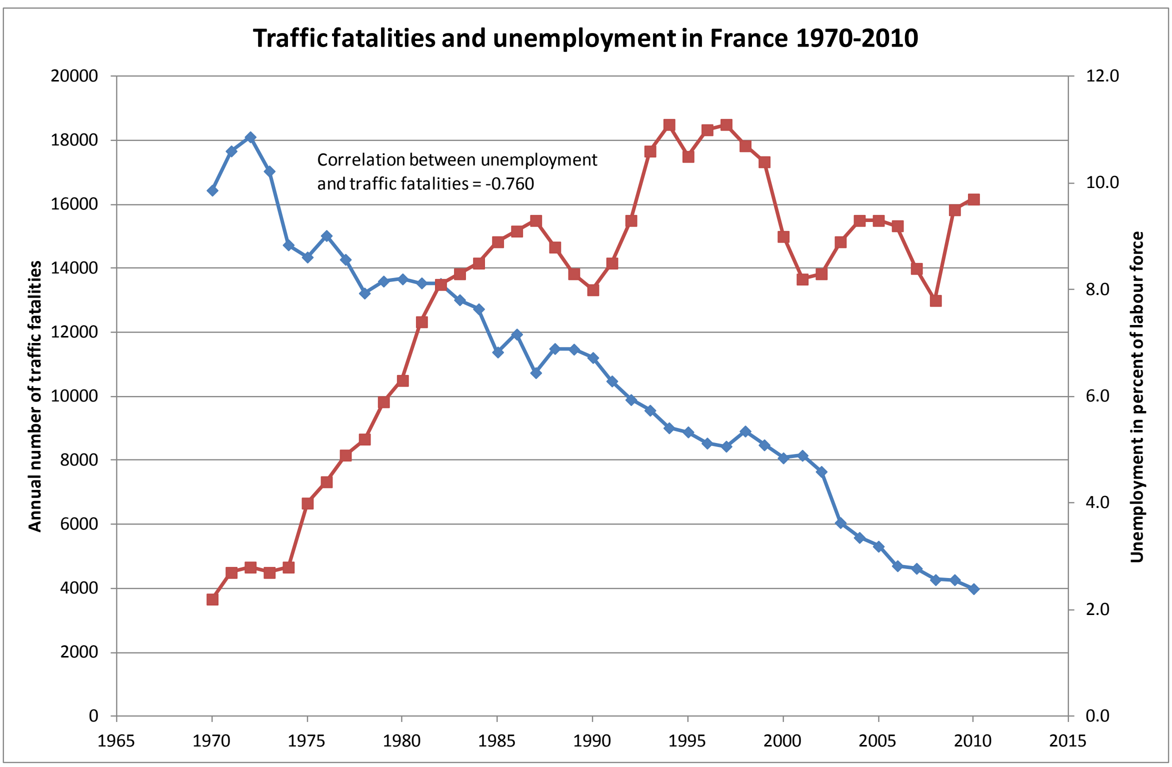


France

Figure 3.8 shows the annual number of traffic fatalities and the annual rate of unemployment in France from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a strong negative correlation between unemployment and traffic fatalities. Unemployment increased almost without interruption from the start of the period until 1994. Traffic fatalities have declined fairly consistently. There was a reduction in fatalities in 31 years, an increase in 9 years. Unemployment increased in 27 years, declined in 12 years and remained unchanged for one year.

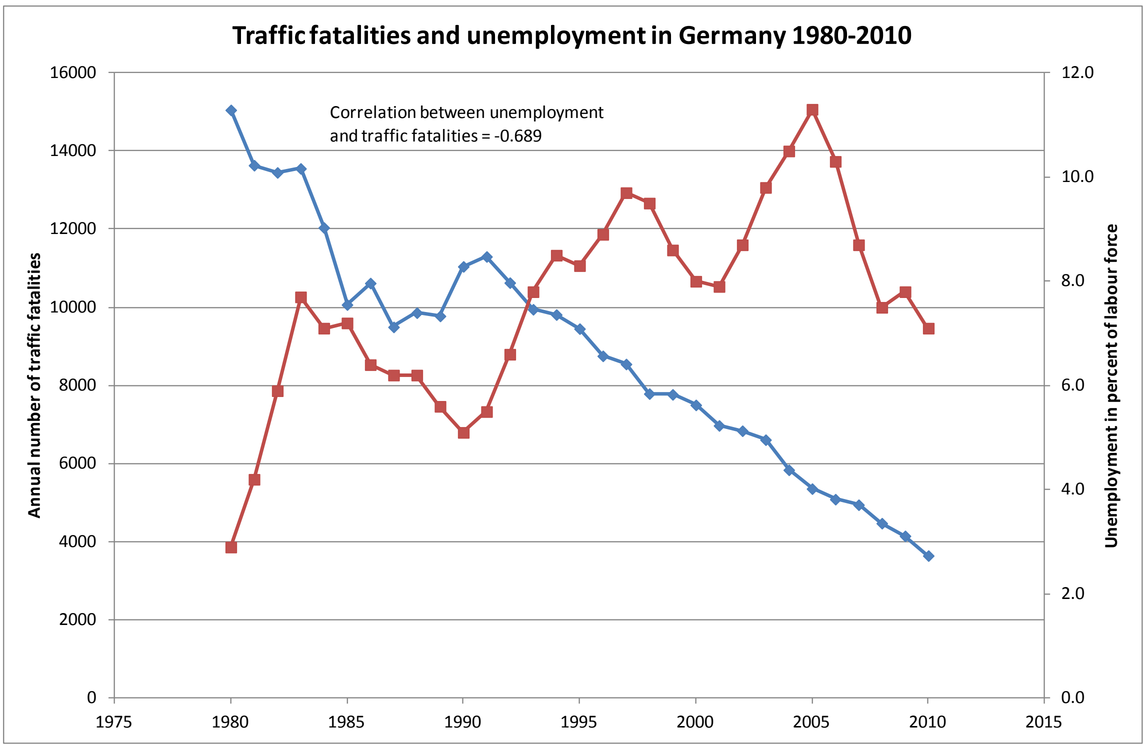
Figure 3.8. **Traffic fatalities and unemployment in France 1970-2010**



Germany

Figure 3.9 shows the annual number of traffic fatalities and the annual rate of unemployment in Germany from 1980 to 2010. The figure applies to the re-united Germany, with data reconstructed back to 1980.

Figure 3.9. **Traffic fatalities and unemployment in Germany 1980-2010**



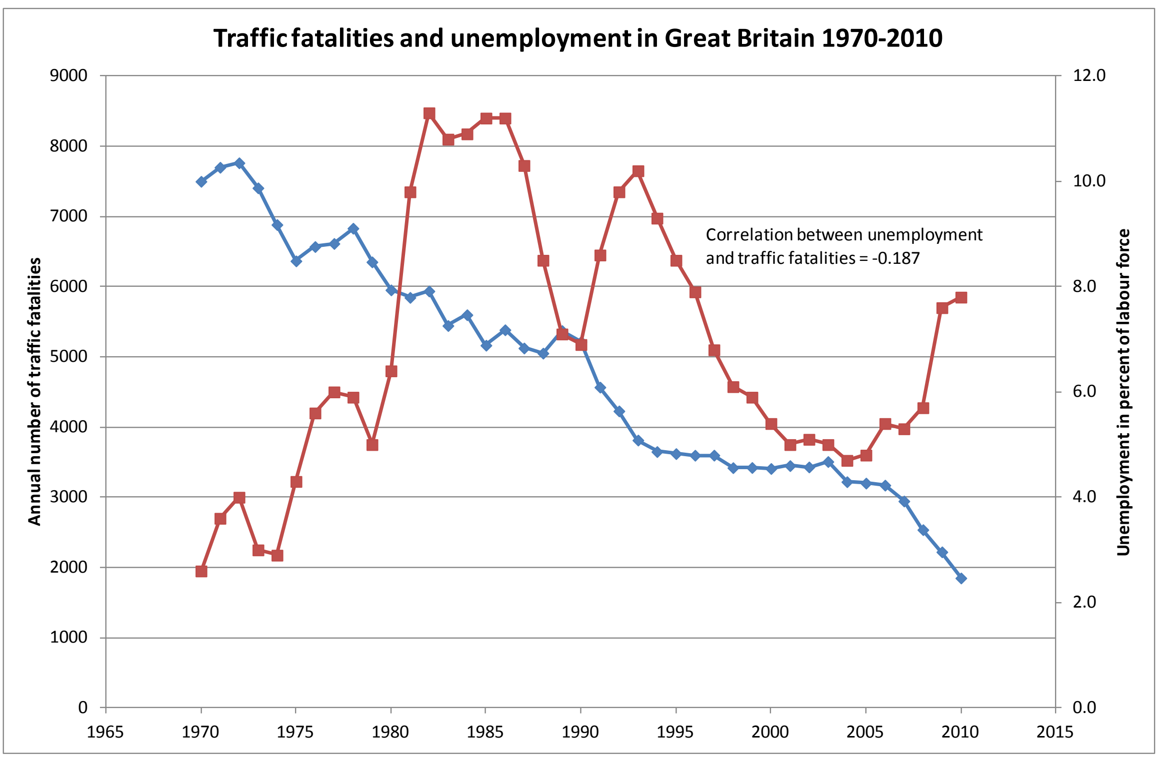
The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a fairly strong negative correlation between unemployment and traffic fatalities. Unemployment increased in the early 1980s, then declined, but has mostly been increasing after 1990. Traffic fatalities have declined fairly consistently. There was a temporary increase at the time of German re-unification. There was reduction in fatalities in 25 years, an increase in five years. Unemployment increased in 15 years, declined in 14 years and remained unchanged for one year.

Great Britain

Figure 3.10 shows the annual number of traffic fatalities and the annual rate of unemployment in Great Britain from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a rather weak negative correlation between unemployment and traffic fatalities. Unemployment increased until 1982, and has since had a tendency to decline, although not regularly. Traffic fatalities have declined fairly consistently. There was a reduction in fatalities in 27 years, an increase in 13 years. Unemployment increased in 19 years, declined in 20 years and remained unchanged for one year.

Figure 3.10. **Traffic fatalities and unemployment in Great Britain 1970-2010**

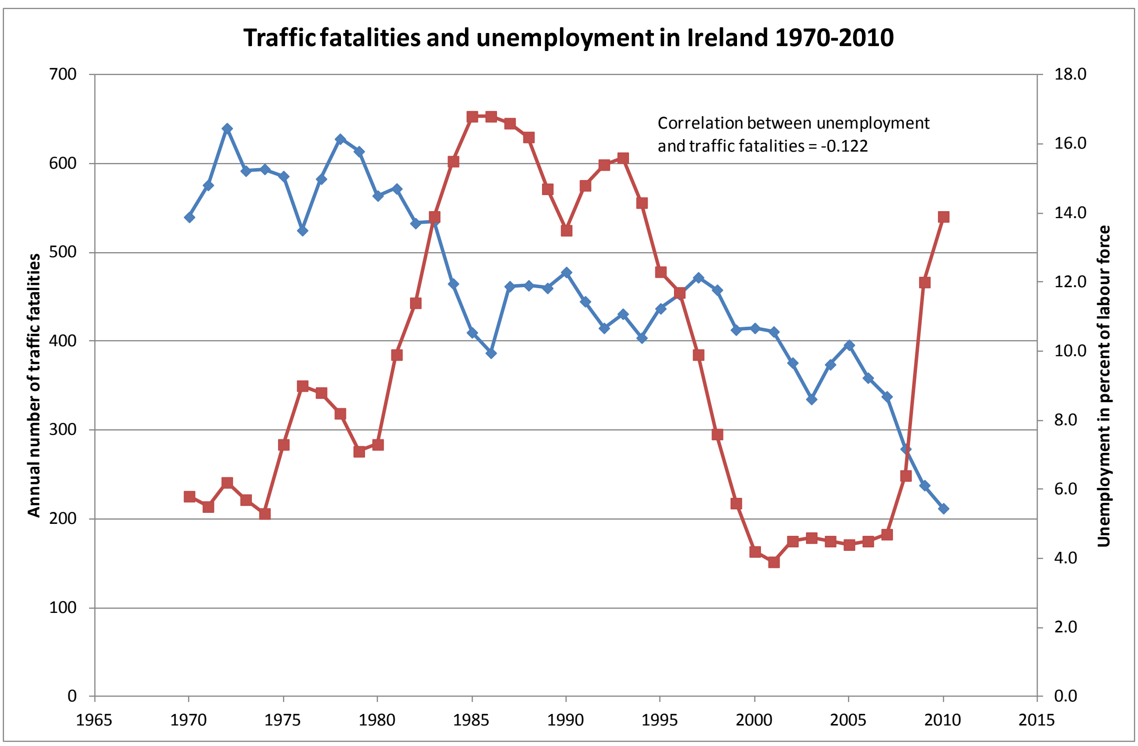


Ireland

Figure 3.11 shows the annual number of traffic fatalities and the annual rate of unemployment in Ireland from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a weak negative correlation between unemployment and traffic fatalities. Unemployment increased until 1985, then declined sharply until 2007 after which it again increased rapidly. Traffic fatalities have declined but not steadily. There was a reduction in fatalities in 23 years, an increase in 17 years. Unemployment increased in 19 years, declined in 20 years and remained unchanged for one year.

Figure 3.11. **Traffic fatalities and unemployment in Ireland 1970-2010**

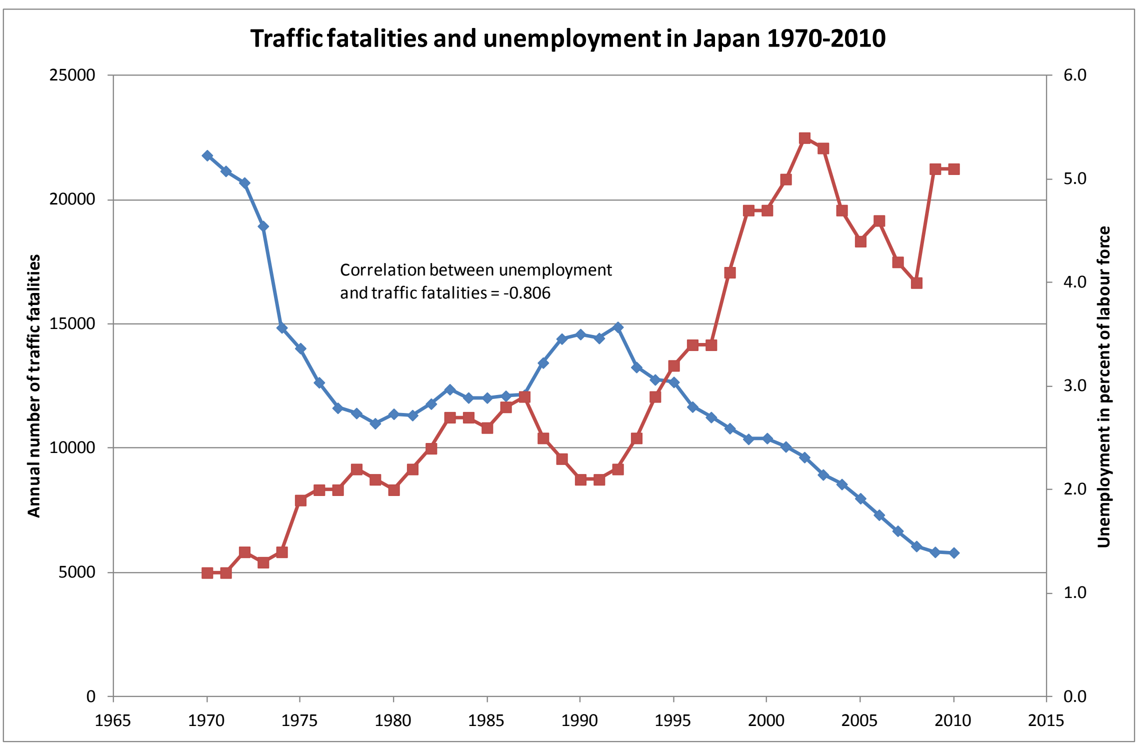


Japan

Figure 3.12 shows the annual number of traffic fatalities and the annual rate of unemployment in Japan from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a strong negative correlation between unemployment and traffic fatalities. Unemployment mostly increased until 2005, after which it briefly declined before again increasing rapidly. Traffic fatalities have declined but not steadily. There was a reduction in fatalities in the 1970s, but then an increase. In recent years there has been a steady decline in traffic fatalities. Traffic fatalities declined in 30 years, increased in ten years. Unemployment increased in 21 years, declined in twelve years and remained unchanged over seven years.

Figure 3.12. **Traffic fatalities and unemployment in Japan 1970-2010**



The Netherlands

Figure 3.13 shows the annual number of traffic fatalities and the annual rate of unemployment in the Netherlands from 1980 to 2010.

Figure 3.13. **Traffic fatalities and unemployment in the Netherlands 1980-2010**

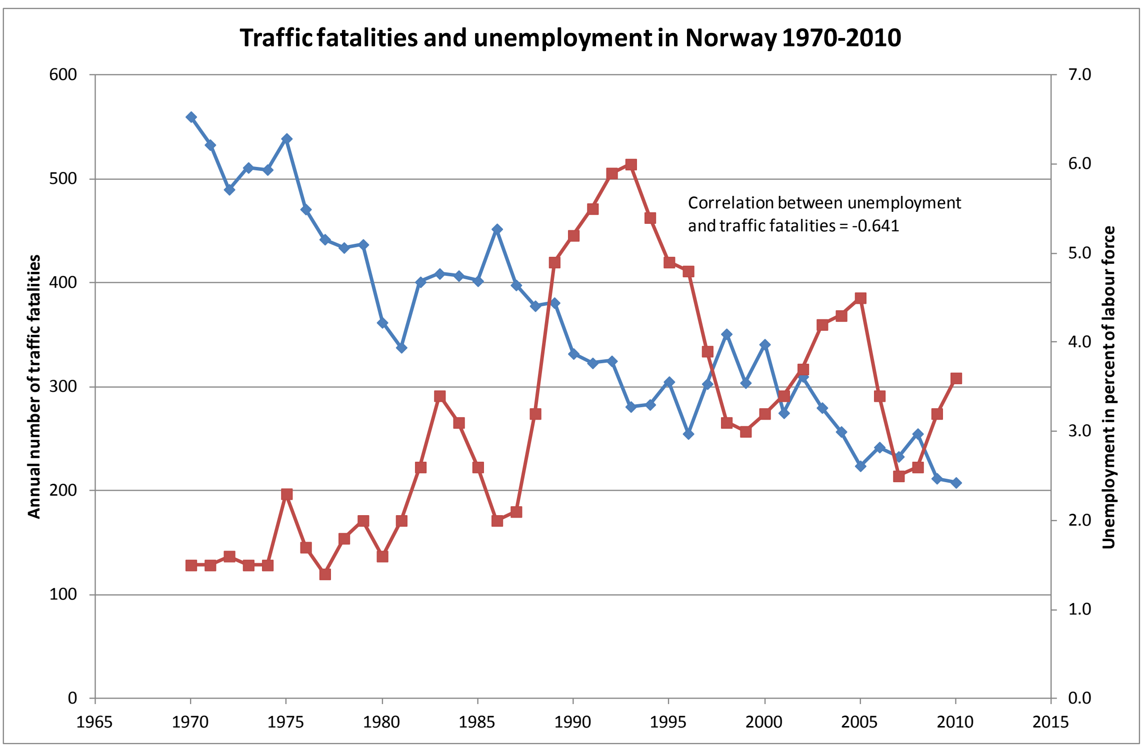
The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a fairly strong positive correlation between unemployment and traffic fatalities. This is the first case of a positive correlation encountered so far in the presentation of the countries included in the study. Both unemployment and traffic fatalities show a tendency to decline over time. Traffic fatalities declined in 23 years, increased in seven years. Unemployment increased in 12 years, declined in 17 years and remained unchanged for one year.

Norway

Figure 3.14 shows the annual number of traffic fatalities and the annual rate of unemployment in Norway from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a moderate negative correlation between unemployment and traffic fatalities. Unemployment increased sharply in the early 1990s, but has since been reduced. Traffic fatalities have declined, but the trend is rather irregular. Traffic fatalities declined in 24 years, increased in 16 years. Unemployment increased in 23 years, declined in 15 years and remained unchanged for two years.

Figure 3.14. **Traffic fatalities and unemployment in Norway 1970-2010**

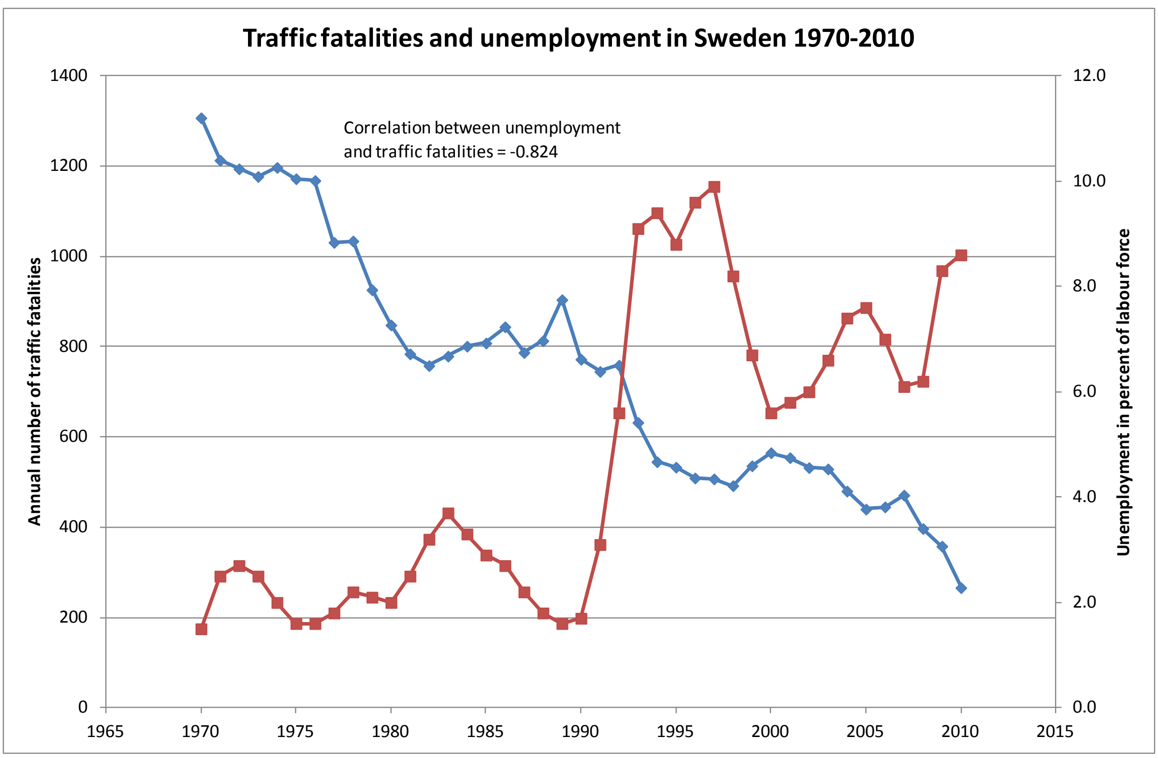


Sweden

Figure 3.15 shows the annual number of traffic fatalities and the annual rate of unemployment in Sweden from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a strong negative correlation between unemployment and traffic fatalities. Unemployment increased sharply in the early 1990s, but has since been reduced, although not down to the level before 1990. Traffic fatalities have declined, but the trend is a little irregular. Traffic fatalities declined in 27 years, increased in 13 years. Unemployment increased in 22 years, declined in 17 years and remained unchanged for one year.

Figure 3.15. **Traffic fatalities and unemployment in Sweden, 1970-2010**

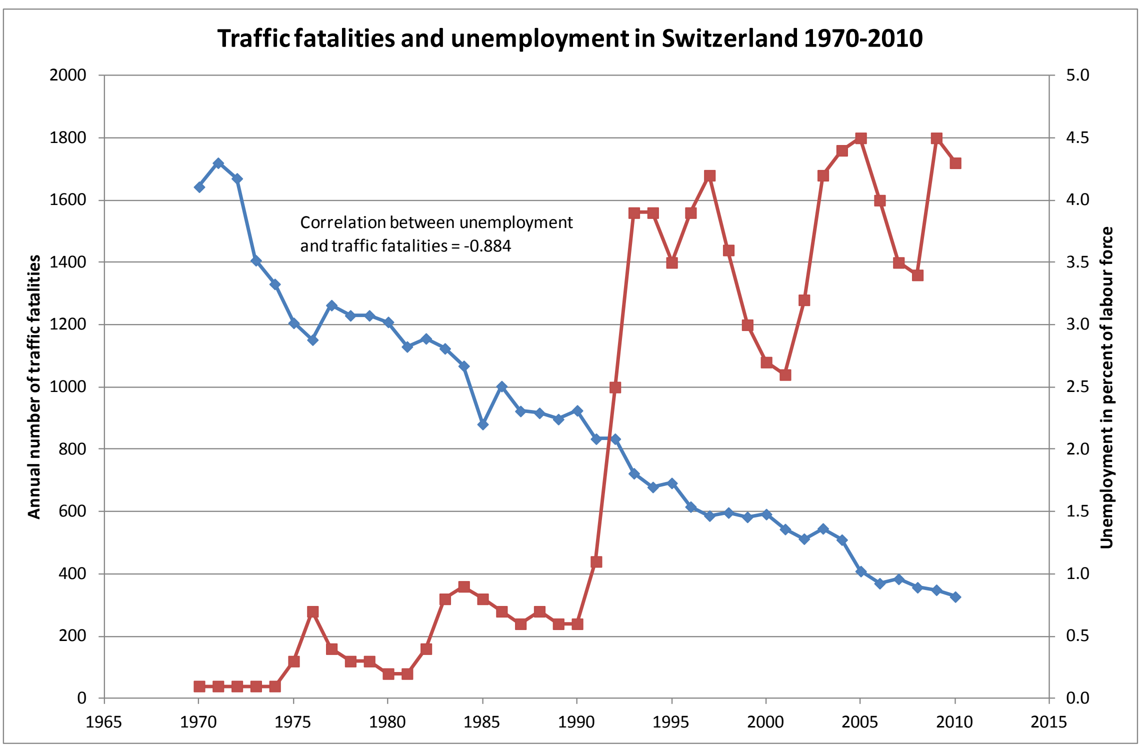


Switzerland

Figure 3.16 shows the annual number of traffic fatalities and the annual rate of unemployment in Switzerland from 1970 to 2010.

The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a very strong negative correlation between unemployment and traffic fatalities. Unemployment increased sharply in the early 1990s, and has remained high since then. Compared to other countries, the rate of unemployment in Switzerland is still low, at less than 5%. Traffic fatalities have declined fairly steadily. Traffic fatalities declined in 28 years, increased in 10 years and remained unchanged in two years. Unemployment increased in 16 years, declined in 16 years and remained unchanged over eight years.

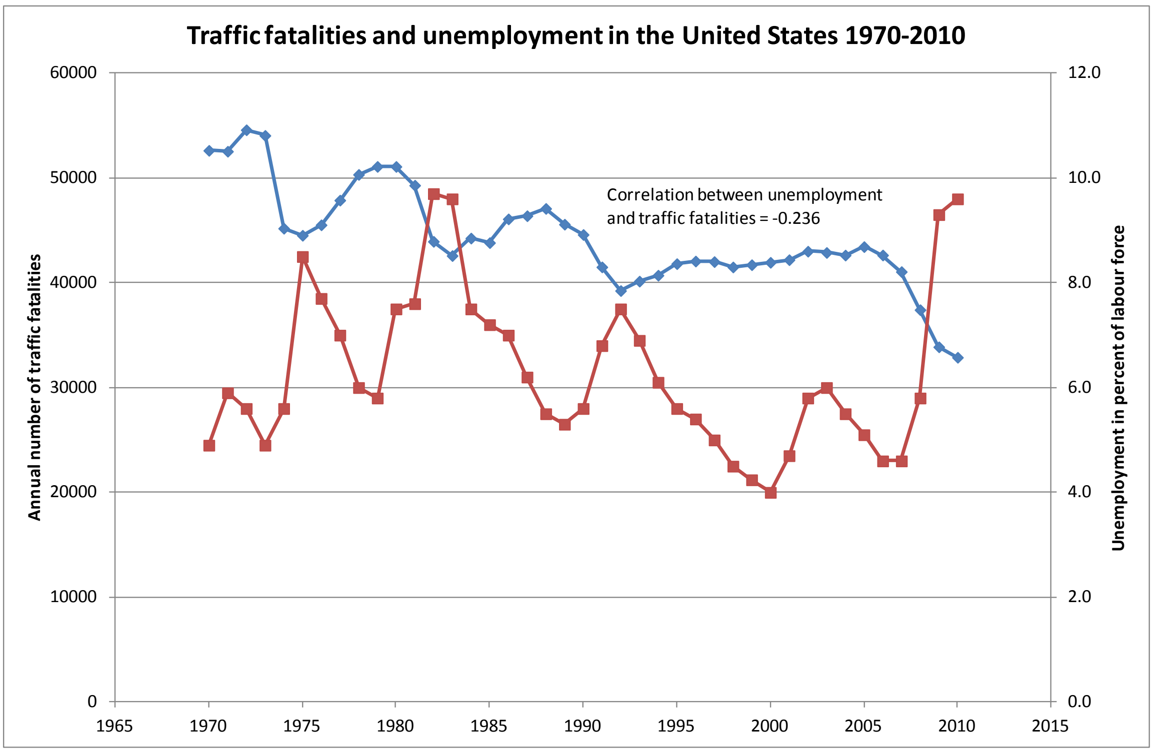
Figure 3.16. **Traffic fatalities and unemployment in Switzerland 1970-2010**



United States

Figure 3.17 shows the annual number of traffic fatalities and the annual rate of unemployment in the United States from 1970 to 2010.

Figure 3.17. **Traffic fatalities and unemployment in the United States 1970-2010**



The blue curve with scale on the left shows traffic fatalities. The red curve with scale on the right shows unemployment. There is a weak negative correlation between unemployment and traffic fatalities. Unemployment has fluctuated up and down with no clear long-term trend. Traffic fatalities have declined, but there was no decline between 1992 and 2007 – the longest period with no decline in traffic fatalities seen in any of the countries included in the study. Traffic fatalities declined in 22 years, increased in 18 years. Unemployment increased in 15 years, declined in 24 years and remained unchanged for one year.

Some preliminary observations

Data are available for 41 years for twelve countries and 31 years for two countries. When changes from year to year are studied, the number of years is reduced by 1, since 1971 (or 1981) is the first year that can be compared to the previous year. Thus, a total of 540 changes from year to year are included in the figures presented above. Although there is clear tendency for traffic fatalities to decline during the period 1970-2010, there are also many years when the number of fatalities increased. For all countries, there were 366 years of decline, 170 years of increase and four years of no change in the number of fatalities. As far as unemployment is concerned, there were 268 years of increase, 238 years of decline and 34 years with no change in unemployment. Thus, both traffic fatalities and unemployment vary in both directions (up and down) sufficiently often to detect a statistical relationship between them.

When changes in unemployment and traffic fatalities are cross tabulated, there are more observations in the cells combining an increase in unemployment and a reduction of traffic fatalities and in the cells combining a reduction of unemployment and an increase in traffic fatalities than would be expected if the variables were not related. The Chi-square is 23.26 with four degrees of freedom. The P-value is 0.0001123, indicating a statistically highly significant relationship. This is a simple bivariate relationship only, but it is very strong and unlikely to disappear when the data are analysed by means of multivariate techniques.

Methodological considerations in model choice and development

Previous studies have, roughly speaking, employed two statistical techniques for analysing data:

- Time series analysis.
- Regression analysis.

The data employed in this study are panel data, i.e. they vary both in time and space. In principle, therefore, both techniques of analysis are relevant. Previous studies relying on panel data have used regression techniques; most often count data techniques, such as negative binomial regression. Some early studies applied regression techniques to time-series data.

Applying ordinary least-squares regression techniques to time-series data entails a risk that effects of factors that vary systematically over time will not always be correctly estimated (Commandeur and Koopman, 2007). This will result in auto-correlated residual terms. In case there is significant residual autocorrelation, the model has not successfully estimated the effects of factors that vary systematically over time. There is, in other words, systematic residual variation over time.

On the other hand, regression models of time series data may be successful. Figure 3.18 shows actual and fitted values for traffic fatalities in Norway from 1979 to 2003 (Elvik 2005). The fitted values are based on a Poisson regression model with parameters for trend, various variables representing traffic volume, belt wearing, sale of new cars, vehicle kilometres on motorways and traffic tickets per vehicle kilometre.

The fitted values track the actual values closely. Autocorrelation of the residuals at lag 1 was estimated at -0.1286, which is far from statistically significant. This shows that Poisson regression, and by extension, negative binomial regression can successfully model time-series data. However, when such techniques are applied to time-series data, it is essential to examine the residuals, in particular with respect to the presence of autocorrelation.

There are two main versions of cross-sectional models for analysis:

- Ordinary least squares regression (OLS) models.
- Count data models.

OLS models are best suited for continuous dependent variables. OLS models can be fitted to data where the dependent variable takes on both positive and negative values. Count data models are best suited for data that are counts and can only take on positive integer values. Count data models include Poisson regression and negative binomial regression (Washington, Karlaftis and Mannering, 2011). The analyses performed in this report have used both ordinary least squares regression and negative binomial regression.

It is generally not recommended to use ordinary least squares regression models when analysing accident data. When such models are applied to accident data, there is a risk of heteroskedasticity in the residual terms of the model. This means that the residuals are not independent of model predictions, but tend to increase as predicted values increase. Thus, a model prediction of, say, 1000 may be less accurate (have a larger residual term) than a model prediction of 100. Accident data are by nature heteroskedastic. In a Poisson distribution, the variance equals the mean.

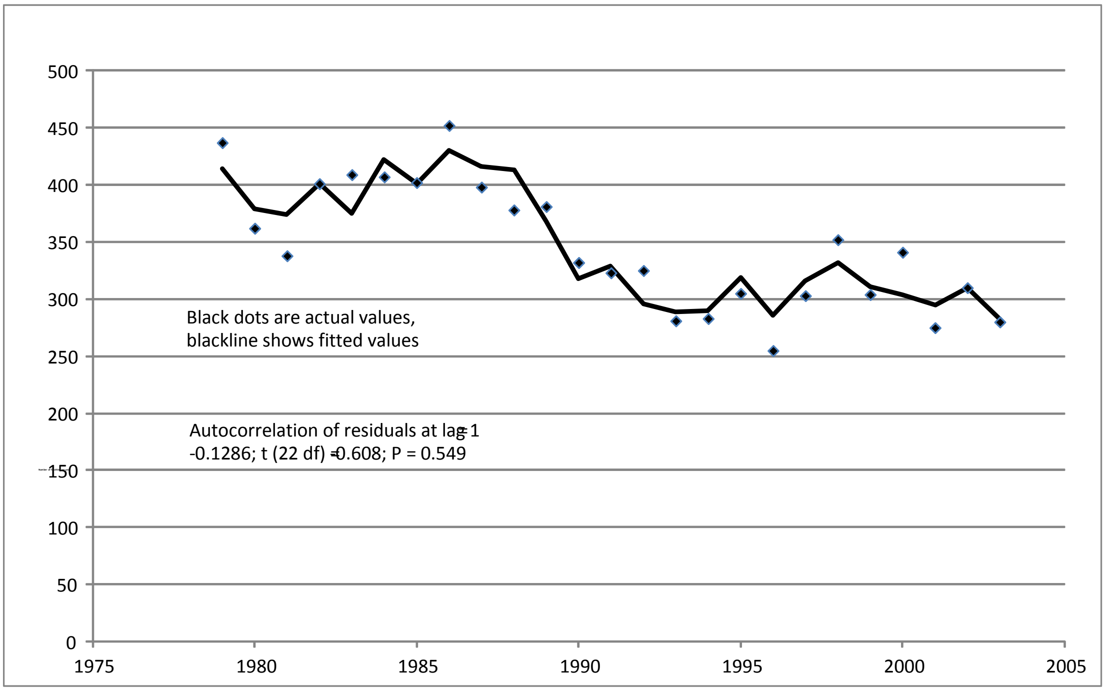
The problem of heteroskedastic residual terms may be reduced by adopting variance-stabilising transformations of the variables. A recent paper by Yannis *et al* (2014) applied such a transformation by converting all variables to natural logarithms. A similar model has been applied in this report.

A problem in developing models based on annual data is the presence of a strong trend over time in these data and a very high correlation between the independent variables. As an example, the correlations between year and GDP per capita in the fourteen countries included in the study were between 0.947 and 0.996. In other words, GDP per capita was almost perfectly correlated with time. An example of the correlation is shown in Figure 3.19. Figure 3.19 refers to Norway. The picture in other countries is very similar to that in Norway.

Correlations between time (year) and vehicle kilometres of travel were also very high, ranging between 0.957 and 0.995. Finally, the correlations between GDP per capita and vehicle kilometres of travel ranged between 0.959 and 0.996. Unemployment is, in general, not very strongly correlated with either time or GDP per capita.

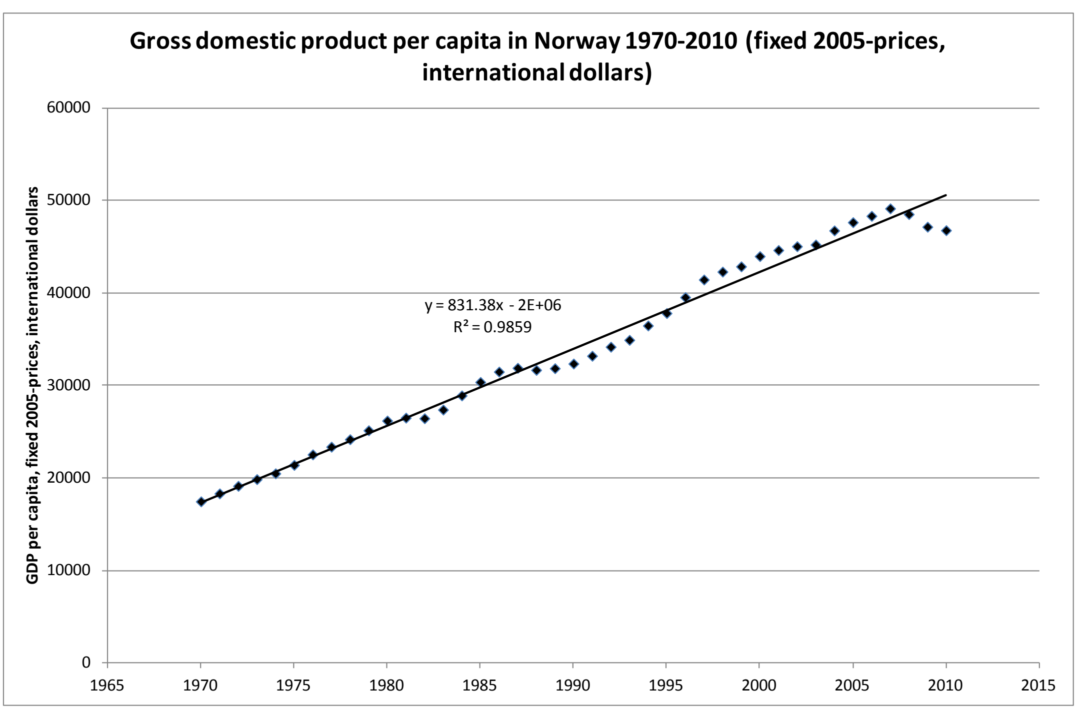
Since there may be problems associated both with count data models and ordinary least squares models, it was decided to develop three main types of models and compare their predictions. This can be viewed as a form of model triangulation (Yeasmin and Rahman, 2012). The idea is that if different models produce nearly identical predictions of effects, these effects are unlikely to be mere artefacts of the models, but more likely to show real relationships.

Figure 3.18. **Actual and fitted values for traffic fatalities in Norway 1979-2003**



Source: Elvik (2005).

Figure 3.19. **Correlation between time (year) and GDP per capita in Norway 1970-2010**



Three main types of model

Three main types of model were developed:

- Negative binomial regression models based on annual data. These models were developed both for the period 1970-2010 and the period 1995-2010.
- Linear regression models based on annual changes in the variables. These models were developed for the period 1970-2010.
- Mixed linear models base on the logarithms of annual changes in the variables. These models were developed for the period 1970-2010.

The negative binomial regression models developed in this study had the following form:

$$\text{Number of traffic fatalities} = e^{(\alpha+\beta_1 \ln(GDP\ per\ capita)+\ \beta_2 \ln(unemployment\ rate)+\beta_3 year)}$$

In this model, e denotes the base of natural logarithms (2.71828) and α and β are coefficients that are estimated by the maximum likelihood technique. Gross Domestic Product and rate of unemployment are entered as natural logarithms. The coefficients for these variables can then be interpreted as elasticities, i.e. they show the percentage change in the number of traffic fatalities when GDP or unemployment increase by 1 percent.

The linear regression model was based on annual differences and had the following form:

$$\Delta \text{ Number of traffic fatalities} = \alpha + \beta_1\text{Year} + \beta_2\Delta\text{GDP per capita} + \beta_3\Delta\text{Unemployment rate}$$

The letter Δ denotes change from one year to the next. All changes were stated in natural units; no conversions of the variables were made. Thus, for the United States, the number of fatalities changed from 52,627 in 1970 to 52,542 in 1971. This was a reduction of 85, stated as -85 in the models developed. Gross Domestic Product per capita increased from 20,544 dollars in 1970 to 20,988 dollars in 1971, stated in the model as 444. Finally, unemployment increased from 4.9%in 1970 to 5.9 per cent in 1971, stated in the model as 1.0.

The mixed linear models had the following form:

$$\text{Ln}(\text{Fat}_{t+1}) - \ln(\text{Fat}_t) = \alpha + \beta_1\text{Year} + \beta_2[\ln(\text{GDP}_{t+1}) - \ln(\text{GDP}_t)] + \beta_3[\ln(\text{Unemployment}_{t+1}) - \ln(\text{Unemployment}_t)]$$

In this model, ln denotes the natural logarithm. For each variable, the natural logarithm was taken in year t and in year t+1 for all years included in the analysis (1971 was the first year that could be compared to the previous year). Then the differences between the logarithms were taken. These transformations stabilised variance and thus reduced the likelihood of heteroskedastic residuals.

Overview of models and variables included

The following group models have been developed:

- **Model group 1**: Estimated vehicle kilometres of travel as dependent variable. Models were developed for all countries and for each country separately.

- **Model group 2**: Fatality count as dependent variable. Year and country were used as independent variables.

- **Model group 3**: Fatality count as dependent variable. Year, country, Gross Domestic Product per capita and rate of unemployment as independent variables. Models were developed for all countries and for each country separately.

- **Model group 4**: Fatality count as dependent variable. Data for 1995-2010 only. Year, country, Gross Domestic Product per capita and rate of unemployment as independent variables. Models were only developed for each country separately.

- **Model group 5**: Young road user fatality count as dependent variable. Data for 1995-2010 only. Year, country, Gross Domestic Product per capita and rate of unemployment as independent variables. Models were only developed for each country separately.

- **Model group 6**: Annual change in fatality count as dependent variable. Year, annual change in Gross Domestic Product per capita and annual change in unemployment as independent variables. Models were developed for the period 1971-2010, but only for each country separately.

- **Model group 7**: Annual change in fatalities involving young road users as dependent variable. Year, annual change in Gross Domestic Product per capita and annual change in unemployment as independent variables. Models were developed for the period 1995-2010, but only for each country separately.

- **Model group 8**: Logarithm of annual change in the number of fatalities as dependent variable. Year, logarithm of annual change in GDP per capita and logarithm of annual change in rate of unemployment were used as independent variables. Models were developed for the period 1971-2010, but only for each country separately.

In all models year was entered with its actual values (1970, 1971, ... , 2010). In models fitted to panel data, countries were identified with dummy variables. Gross Domestic Product per capita is stated in fixed 2005 international dollars. This means that Gross Domestic Product per capita has been adjusted according to purchasing power parities in order to become comparable between countries. Purchasing power parities adjust for the fact that 10 000 dollars may not buy the same basket of goods in, e.g. Norway as in the United States, because prices differ between the two countries. Unemployment is stated as the percentage of the labour force that is out of work. Annual mean values are used.

Models in group 1 were developed in order to test if vehicle kilometres of travel are influenced by economic fluctuations. If statistically significant relationships are found between the variables representing economic performance and vehicle kilometres of travel, the latter will be treated as an endogenous variable and not included as an independent variable in the models using fatality count as dependent variable. Models in group 1 should be interpreted mainly as auxiliary models and will therefore not be discussed in the same detail as the models using fatalities as dependent variable.

Model 2 was developed in order to assess how well fatality counts can be described without entering any economic variables in the model. This model serves as the basis for a comparison with model 3, which includes the variables describing economic performance. By comparing the two models, one may assess the additional contribution economic performance makes to explaining variation in the number of road accident fatalities.

Models 4 and 5 were limited to the years 1995-2010, which is the period for which complete data are available on fatalities involving young people. These data are, unfortunately, not available for the entire period covered by the study (1970-2010).

All models in groups 1-5 are potentially affected by multi-collinearity (see more below). Both Gross Domestic Product per capita and the count of fatalities are characterised by strong trends over time. This generates very high correlations between year and Gross Domestic Product per capita, in particular. One way of (strongly) reducing these correlations is to base the analysis on differences, i.e. changes from one year to the next. Models in groups 6 and 7 were developed mainly to assess whether the findings from models 3, 4 and 5 were reproduced when modelling was based on differences rather than annual values.

As noted before, a potential problem of models in groups 6 and 7 is heteroskedastic residuals. Models in group 8 employed transformed variables in order to reduce this problem. The use of annual differences, transformed to natural logarithms also greatly reduces the correlations between the independent variables.

Assessing model quality

In order to assess the quality of the models, the following criteria have been applied:

- Overall goodness-of-fit: The general goodness-of-fit of the models has been assessed in terms of the percentage of systematic variation in fatality counts explained by the model. This is measured by means of the Elvik-index (Fridstrøm *et al*., 1995, Elvik *et al*., 2013); see details below.

- Unbiasedness of model predictions: Models should not systematically predict too many or too few fatalities; see details below.

- Normality of residuals: Standardised residuals have been estimated and their distribution compared to a normal distribution (Washington, Karlaftis and Mannering 2011); see details below.

- Homoscedasticity of residuals: Standardised residuals have been compared across model-predicted values of the dependent variable in order to assess if residual variance is independent of the predicted values. This criterion is relevant for models based on OLS regression, not for models based on negative binomial regression.

- Autocorrelation of residuals: Residuals should not have serial correlation, as that indicates the potential presence of omitted variable bias; see details below.

The Elvik-index of goodness-of-fit is based on the over-dispersion parameter in negative binomial regression. The over-dispersion parameter is defined as follows:

$$\mathrm{Var}(x) = \lambda \cdot (1 + \mu\lambda) \qquad (1)$$

In equation 1, λ denotes the model-predicted number of fatalities or the mean number of fatalities in raw data; μ denotes the over-dispersion parameter. Solving equation 1 with respect to the over-dispersion parameter gives**:**

$$\mu = \frac{\frac{Var(x)}{\lambda} - 1}{\lambda} \qquad (2)$$

If the mean (λ) and variance (Var(x)) of the raw data (i.e. the empirical distribution of the count of fatalities per country per year) are known, the over-dispersion parameter of the crude data can be estimated by applying equation 2. Denoting the over-dispersion parameter of the raw data as μ_{crude} and the over-dispersion parameter of the fitted model as μ_{model} the Elvik index is defined as follows:

$$\text{Elvik-index of goodness-of-fit} = 1 - \frac{\mu_{model}}{\mu_{crude}} \qquad (3)$$

It takes on values between 0 and 1 and shows the share of systematic variation in fatality counts explained by the model.

Unbiasedness refers to how close the total predicted number of fatalities is to the actual number of fatalities. A simple indicator of this is:

$$\text{Index of bias} = \frac{Sum\ of\ predicted\ fatalities}{Sum\ of\ actual\ fatalities} \qquad (4)$$

This index takes on the value of 1 in the absence of bias. It is less than 1 if the model under-predicts, more than 1 if the model over-predicts.

Normality of residuals is assessed in terms of the distribution of standardised residuals. The standardised residuals are defined as follows:

$$\text{Standardised residual (Z)} = \frac{X_i - \lambda_i}{\sigma_i} \qquad (5)$$

In equation 5, X_i denotes a count of fatalities; λ_i denote the model-predicted number of fatalities for the same country and year; σ_i is the standard error of the model prediction. The standard error of the model prediction is the square root of its variance. The variance of each model prediction is:

$$\text{Variance of model prediction} = \lambda \cdot (1 + \mu\lambda) \qquad (6)$$

Thus, as an example, for Austria in 1970 model 3 based on panel data predicted 2747 fatalities. The count of fatalities in 1970 in Austria was 2574. The over-dispersion parameter of the model was 0.006. The variance of the model prediction is: 2747 [1 + (2747 · 0.006)] = 48023.1. The standard error is the square root of the variance = 219.1. The residual was 2574 – 2747 = -173. The standardised residual was -173/219.1 = -0.789. Standardised residuals should conform to a normal distribution. This means that the Z-scores of equation 5 should distribute as follows:

Less than minus 2:	2.3%
Between minus 2 and minus 1:	13.6%
Between minus 1 and 0:	34.1%
Between 0 and plus 1:	34.1%
Between plus 1 and plus 2:	13.6%
Larger than plus 2:	2.3%

The conformity of the actual distribution of standardised residuals to the normal distribution has been assessed by means of a Chi-square test with 5 degrees of freedom.

Homoscedasticity of residuals can be assessed by plotting standardised residuals against model-predicted values. There should then not be any correlation between the residuals and the model-predicted values.

As far as autocorrelation of residuals are concerned, the value of the autocorrelation coefficient at lag 1 has been used as indicator. It was judged that a lag of 1 year was sufficient and that any impacts of economic fluctuations would manifest themselves within one year.

Fitted models and their interpretation

This section presents the fitted models and comments on their quality. Models are presented in the same order as they were described in section 5.5.

Model group 1: Vehicle kilometres of travel

Several models were developed in order to determine if vehicle kilometres of travel are influenced by economic performance. Four models were fitted to the panel data. All these models produced nonsensical results, for example negative values for kilometres of travel in some years and for some countries. It was therefore decided to develop models for each country separately.

Fitting models for each country was problematic because of the very high correlations between the variables involved in the analyses. It was decided to fit one set of models including year, GDP per capita and unemployment as independent variables and one set of models using year and unemployment as independent variables. Vehicle kilometres of travel were used as dependent variable in both sets of models. A total of 28 models were fitted, two for each country, using ordinary least squares linear regression.

The findings were somewhat inconsistent. The coefficient for unemployment was negative and statistically significant at the 5%level in 11 models, negative but not statistically significant at the 5%level in 7 models, positive but not statistically significant at the 5%level in 6 models and positive and statistically significant at the 5%level in 4 models.

Based on these results, the following preliminary conclusions are drawn:

- There is no strong relationship between economic fluctuations, in particular the level of unemployment, and vehicle kilometres of travel.

- The relationship between the level of unemployment and vehicle kilometres of travel is more likely to be negative than positive (18 out of 28 coefficients were negative).

- Vehicle kilometres of travel will not be included as an independent variable in the models using fatality count as dependent variable, mainly because it is very highly correlated with other independent variables, in particular time (year), but also because it could be partly endogenous (i.e. influenced by economic fluctuations and thus be one of the mechanisms by which these fluctuations influence road safety).

- Vehicle-kilometres of travel have tended to grow at a rather stable rate in most countries. There was a decline in only 61 out of 540 years for which changes from the previous year could be observed.

Model 2: Total fatalities without indicators for economic performance

Table 3.4 shows model coefficients for model 2, the negative binomial regression model without the variables indicating economic performance. The model contains main effects for year and country, in addition to interaction effects between these variables. The interaction terms were added because the long term trends have been different in the different countries. Thus, the United States has had a rather weak declining trend in the number of road accident fatalities, whereas, for example, the Netherlands has had a stronger declining trend.

Table 3.4. **Coefficients for model 2**
Dependent variable: Total number of road accident fatalities

Parameter	Best estimate	Standard error	P-value
Constant term	25.469	2.6498	0.000
Year	-0.007	0.0013	0.000
Austria	57.412	3.8484	0.000
Belgium	38.949	3.8245	0.000
Denmark	39.644	3.9205	0.000
Finland	38.888	3.9053	0.000
France	50.593	3.8344	0.000
Germany	61.947	4.9688	0.000
Great Britain	40.825	3.7929	0.000
Ireland	15.889	3.9875	0.000
Netherlands	27.400	3.8067	0.000
Norway	45.859	5.0662	0.000
Sweden	22.991	4.0142	0.000
United States	Omitted		
Year * Austria	-0.031	0.0019	0.000
Year * Belgium	-0.021	0.0019	0.000
Year * Denmark	-0.022	0.0020	0.000
Year * Finland	-0.022	0.0019	0.000

Table 3.4 **(continued). Coefficients for model 2**
Dependent variable: Total number of road accident fatalities

Parameter	Best estimate	Standard error	P-value
Year * France	-0.026	0.0019	0.000
Year * Germany	-0.032	0.0025	0.000
Year * Great Britain	-0.022	0.0019	0.000
Year * Ireland	-0.010	0.0020	0.000
Year * Japan	-0.014	0.0019	0.000
Year * Netherlands	-0.025	0.0025	0.000
Year * Norway	-0.014	0.0020	0.000
Year * Sweden	-0.023	0.0020	0.000
Year * Switzerland	-0.031	0.0020	0.000
Year * United States	Omitted		
Over-dispersion parameter	0.010	0.0004	0.000
Elvik index	0.997		

The model presented in Table 3.4 has an over-dispersion parameter of 0.010. This is very low and indicates that the model explains most of the systematic variation in the number of fatalities. The Elvik-index goodness-of-fit has the value of 0.997, which indicates that the model explains nearly all systematic variation in the number of fatalities.

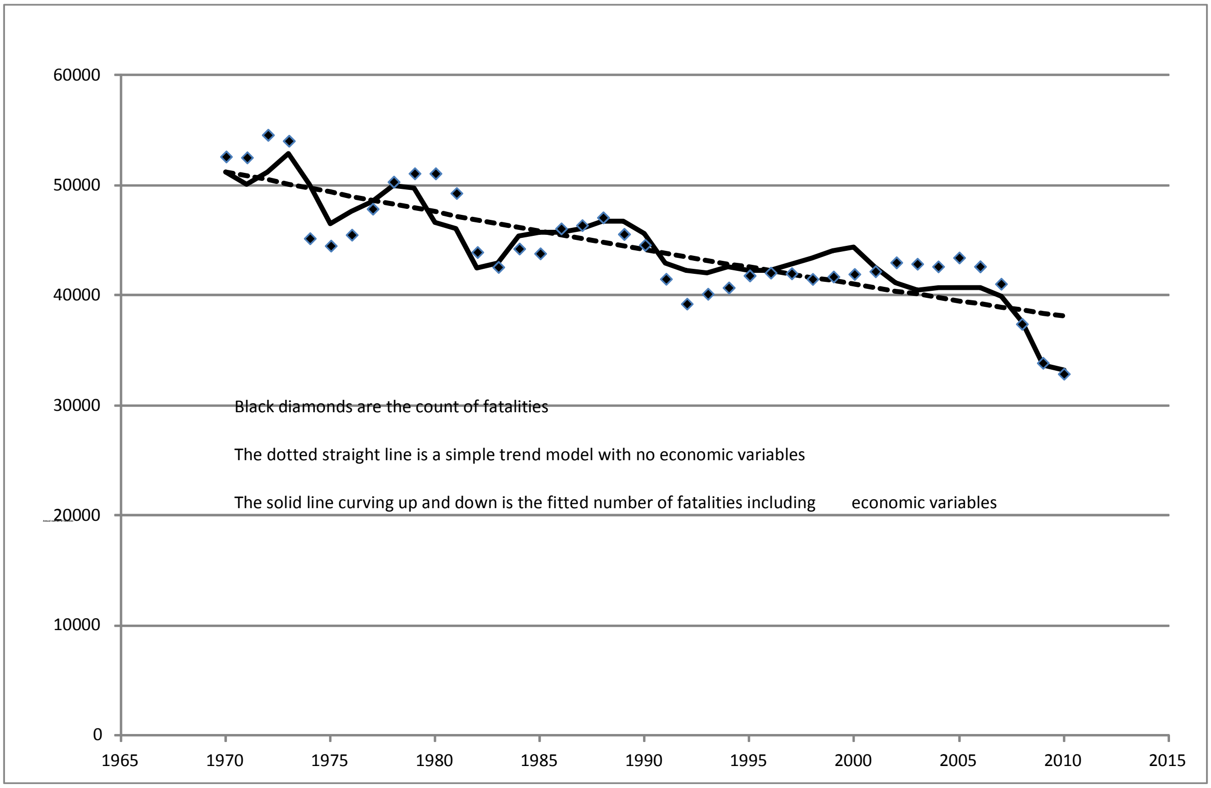
Despite this high value of the goodness-of-fit, it is clear that the model can be improved. The model in Table 3.4 is essentially a simple trend model only. It does not capture any of the fluctuations around the long term trend that may be attributable to variation in economic performance over time.

Model group 3: Total fatalities including variables describing economic performance

Model 3 includes year, country, Gross Domestic Product (GDP) per capita (fixed 2005 prices, international dollars), rate of unemployment and interaction terms between country and year, country and GDP and country and unemployment. GDP per capita and unemployment were entered as natural logarithms. A total of 59 parameters were estimated. Rather than discussing these parameters in detail, the overall goodness of the model will be discussed.

Even a cursory examination of model predictions for each country suggests that inclusion of the variables describing economic performance has improved the model considerably. As an illustration, Figure 3.20 presents the actual and predicted number of traffic fatalities in the United States from 1970 to 2010.

Figure 3.20. **Actual and modelled number of traffic fatalities in the United States 1970-2010**



It is seen that inclusion of the economic variables in the model clearly improves its performance. Despite this, the residuals display a clear autocorrelation. From a time-series perspective, the model can therefore be further improved. The model is unbiased, however, in the sense that the total model-predicted number of fatalities for the entire period is virtually identical to the actual number of fatalities. The model does therefore not systematically predict a too high or too low number of fatalities. The overall goodness-of-fit of the model is assessed in terms of the over-dispersion parameter and the Elvik-index derived from it. The over-dispersion parameter is 0.006. The Elvik-index is 0.999, indicating that the model explains virtually all systematic variation in the data (99.9 percent).

Standardised residuals were estimated by estimating the standard error of each model-predicted number of fatalities, applying the over-dispersion parameter of the model (0.006). The standardised residuals deviate from a normal distribution, which they ideally speaking out to conform to. (Chi-square = 12.624; df = 5; P =0.027).

The presence of autocorrelation in model residuals was tested by computing lag 1 autocorrelations in the residual terms for each country. All these autocorrelations were statistically significant at the 5% level. This indicates that there is systematic variation over time not captured by the model. Autocorrelations varied between 0.385 and 0.892 and were all highly significant.

On the whole, therefore, the model is not regarded as satisfactory. It performs acceptably with respect to absence of bias and overall goodness-of-fit. It does not perform well with respect to normality of standardised residuals and residual autocorrelation. To attempt to improve the model, it was decided to fit separate models for each country.

A major problem in developing models for each country is that the independent variables are very highly correlated, as discussed in the presentation of models in group 1, explaining the development of vehicle kilometres of travel. Another disadvantage of developing models country-by-country is that sample size is reduced from 554 to 41 or 31 (in Germany and the Netherlands). This reduces the power to estimate statistically significant results.

There are at least three approaches that can be taken to the problem of co-linearity among independent variables:

- Forming a single variable as a linear combination of the variables that are highly correlated. This approach is not feasible in this study. The variables of principal interest are GDP per capita and unemployment. These variables, although highly correlated, tend to move in opposite directions: A rapid growth in GDP per capita tends to be associated with a reduction of unemployment, and vice versa. It is therefore desirable to keep them as separate variables in order to model their different developments over time. Besides, combining GDP per capita and unemployment into a single variable makes no sense from either a theoretical or empirical perspective. In fact, a combined variable would be totally unintelligible and un-interpretable.

- Omit one of the variables that are highly correlated. In this study, this would mean to omit either year, GDP per capita or rate of unemployment. Year cannot be omitted, as all countries have experienced a very clear trend over time for the number of fatalities to decline. Year must be included to adequately model this trend. It is also impossible to omit the rate of unemployment, as it is clearly the most sensitive and meaningful indicator of business cycle fluctuations. This leaves GDP per capita, which could be omitted because it is highly correlated with year in all countries. However, the coefficient for year would then become biased, which might lead to auto-correlated residual terms during periods of rapid economic growth. The model coefficient for year would most likely be negative; during years when fatalities declined more slowly than the long-term trend, there would be a string of positive residuals. The most obvious example of this is the long period with no decline in the number of fatalities in the United States between 1992 and 2007, but there have been similar, although less extreme, examples of strings of years with an increasing number of fatalities (or no decline) in other countries too.

- Do nothing; simply include all highly correlated variables in a model. Fridstrøm (2012) advocates this solution: "It makes no sense at all to require that collinearity be avoided. That said, it is a sad fact that when several relevant variables are collinear, it is hard to estimate their respective partial effects. The estimates will be imprecise. But this will be reflected in the estimated standard errors, the t-tests, the p-values, and so on. The regression program will tell us all there is to say about this. The problem is only as big as your reported standard errors." In a similar vein, Washington, Karlaftis and Mannering (2011) point out that even highly correlated variables may not necessarily cause estimation problems.

In this report, the option of keeping all independent variables has been chosen. However, to test whether the results of the fitted models make sense, the following approach has been taken.

- Predicted values have been estimated. If the predicted values display the expected pattern, i.e. a stronger decline in the predicted number of fatalities when unemployment is high than when it is low, this is interpreted as an indication that the model has adequately captured the relationship between economic performance and changes in road safety.

- The models were re-estimated, omitting GDP per capita, which is very highly correlated with year. Predicted values were estimated, and if these did not differ materially from those obtained in the model including all independent variables, this was taken as an indication that collinearity did not greatly influence model predictions.

- Model predictions from the negative binomial regression models were compared to model prediction based on the ordinary least squares model and the model based on the logarithmic transformations of annual changes. If the predictions did not differ greatly, the convergence was interpreted as an indication that the relationships estimated are real and not merely artefacts of the models.

Model group 3: Country-by-country models for the period 1970-2010

Models have been developed on a country-by-country basis. Model performance for the country-by-country models is reported in Table 5.

Models produce unbiased predictions of the number of fatalities. Any deviations found are very small, in the order of 0.1 percent. Overall goodness-of-fit is very high. The models explain a high percentage of the systematic variation in the number of fatalities in all countries. Standardised residuals do not deviate significantly from normality in most countries. However, standardised residuals are not normally distributed in France and Switzerland and are close to deviating from normality in Ireland.

Autocorrelations of residuals at lag 1 are highly significant in all countries except for Denmark. This is clearly not satisfactory. On the other hand, these autocorrelations do not necessarily imply that coefficient estimates are biased, only that the standard errors of the coefficients are underestimated (Fridstrøm *et al*. 1995). Thus, despite the fact that the models have significant autocorrelations in the residual terms, model predictions based on these models will be compared to model predictions based on the ordinary least squares model based on annual differences and the model based on the natural logarithm transformation of annual differences estimated in subsequent sections of the report.

Model predictions for the negative binomial regression models, which are most affected by co-linearity, did not improve when GDP per capita was omitted. On the contrary, models omitting GDP per capita fitted the data worse than models including this variable in all countries except France and Norway.

Table 3.5. **Measures of model performance for models fitted to data for total fatalities for each country for the period 1970-2010**

	Unbiasedness of predictions	Overall goodness-of-fit		Normality of residuals		Autocorrelation of residuals (lag 1)	
Country	Ratio predicted/actual	Dispersion parameter	Elvik-index	Chi-square	P-value	Correlation coefficient	P-value
Austria	1.000	0.005	0.976	3.46	0.629	0.403	0.008
Belgium	1.001	0.003	0.971	2.18	0.824	0.502	0.001
Denmark	1.000	0.006	0.955	5.77	0.329	0.278	0.075
Finland	0.999	0.014	0.907	2.04	0.844	0.563	0.000
France	1.000	0.006	0.957	12.87	0.025	0.558	0.000
Germany	1.000	0.006	0.944	7.04	0.218	0.564	0.000
Great Britain	1.001	0.002	0.979	0.51	0.992	0.429	0.005
Ireland	1.000	0.006	0.882	10.43	0.064	0.463	0.002
Japan	0.999	0.022	0.776	1.36	0.929	0.787	0.000
Netherlands	1.000	0.004	0.954	5.06	0.409	0.484	0.001
Norway	1.000	0.005	0.923	4.19	0.522	0.377	0.014
Sweden	1.000	0.004	0.969	1.65	0.895	0.617	0.000
Switzerland	1.001	0.006	0.971	12.75	0.026	0.494	0.001
USA	1.000	0.002	0.836	2.54	0.770	0.656	0.000

Models 4 and 5: Country-by-country models for the period 1995-2010

Starting in 1995, the IRTAD database contains complete data for all countries regarding the age of road accident fatalities. A more complete analysis is therefore possible for the period 1995-2010. Models were again developed country-by-country. In model 4, the total number of road accident fatalities is used as dependent variable. Statistics regarding the performance of the full models are given in Table 3.6.

There was evidence of changes in the long-term trend in some countries. For Finland, a dummy for the year 2009 was included in order to capture the large decline in fatalities that year. A dummy for the year 2003 was included for France. For Great Britain, a dummy was defined for the years 2007-2010, all of which has larger declines in fatalities than previous years. Similar dummies for the years 2006-2010 were applied for Ireland and the United States.

It is once more seen that model predictions are unbiased. Overall model fit is very good, with models often explaining close to 100% of the systematic variation in the number of road accident fatalities. There is no evidence of non-normality in the distribution of standardised residuals. The largest improvement of the models refers to autocorrelation of the residuals. While there remains a statistically significant (5%level) autocorrelation of residuals at lag 1 in Finland, France and the United States, autocorrelation does not appear to be a problem in the models for the other countries.

The models developed for the period 1995-2010 are therefore treated as satisfactory, if not perfect. Models developed for young accident victims refer to road accident fatalities (all groups of road users) aged between 18 and 24 years. Table 7 presents performance indicators for the models developed for young road users.

Table 3.6. **Measures of model performance for models fitted to data for total fatalities for each country for the period 1995-2010**

	Unbiasedness of predictions	Overall goodness-of-fit		Normality of residuals		Autocorrelation of residuals (lag 1)	
Country	Ratio predicted/actual	Dispersion parameter	Elvik-index	Chi-square	P-value	Correlation coefficient	P-value
Austria	1.000	0.003	0.942	1.16	0.949	-0.077	0.735
Belgium	1.000	0.001	0.959	3.90	0.564	-0.066	0.772
Denmark	1.000	0.004	0.905	1.84	0.871	0.083	0.715
Finland	1.000	0.000	0.999	5.93	0.313	-0.462	0.043
France	1.000	0.006	0.926	2.99	0.702	0.550	0.016
Germany	1.001	0.001	0.983	2.21	0.819	0.415	0.069
Great Britain	1.000	0.000	0.990	5.09	0.405	-0.097	0.670
Ireland	1.000	0.002	0.951	3.95	0.557	0.411	0.072
Japan	1.000	0.001	0.989	5.10	0.404	0.114	0.618
Netherlands	1.000	0.002	0.962	2.48	0.800	0.291	0.202
Norway	1.000	0.003	0.855	1.16	0.949	-0.148	0.516
Sweden	1.000	0.001	0.974	4.13	0.531	-0.156	0.495
Switzerland	1.000	0.001	0.982	3.36	0.645	-0.038	0.869
USA	1.000	0.001	0.887	4.13	0.531	0.562	0.014

Model predictions of the number of fatalities are unbiased. Models fit the data excellently, possibly with a small exception for Finland, although even the model for Finland explains about 60% of the systematic variation in the number of fatalities. Standardised residual are normally distributed in all models. Finally, a statistically significant (5% level) auto-correlation of residuals is found only in three out of fourteen countries (Austria, France, and Germany). Although autocorrelations have not been entirely eliminated, they have been reduced to such an extent that they no longer justify a wholesale rejection of the models on methodological grounds. In the subsequent stages of analysis, one should, however, pay particular attention to whether the results for countries where autocorrelations remain make as much sense as the results for the other countries.

It is therefore concluded that the models developed for the period 1995-2010 have a sufficiently good quality to justify a substantive interpretation of model findings.

Model coefficients are provided in Table 8. Based on the review of previous studies in Chapter 2, on general knowledge regarding variation in unemployment rate by age, and on knowledge about the long-term trends in the number of fatalities in the countries included in the study, the coefficients are expected to show the following pattern:

- The coefficient for year is negative. This applies both when the total number of fatalities and fatalities among young people are used as dependent variable.

- The coefficient for unemployment is negative. The coefficient should be more negative when fatalities among young people are used as dependent variable than when the total number of fatalities are used as dependent variable (a coefficient of -0.50 is more negative than a coefficient of -0.20).

- The sign of the coefficient for GDP per capita is indeterminate. It could be positive, as economic growth is associated with traffic growth, which, ceteris paribus, is expected to increase the number of fatalities. It could also be negative, as previous studies have shown that the number of fatalities tends to decline as countries get richer; besides richer countries may have more effective road safety policies than less rich countries.

Table 3.7. **Measures of model performance for models fitted to data for youth fatalities for each country for the period 1995-2010**

	Unbiasedness of predictions	Overall goodness-of-fit		Normality of residuals		Autocorrelation of residuals (lag 1)	
Country	Ratio predicted/actual	Dispersion parameter	Elvik-index	Chi-square	P-value	Correlation coefficient	P-value
Austria	1.001	0.002	0.966	4.13	0.531	-0.496	0.030
Belgium	1.000	0.001	0.974	1.80	0.876	-0.046	0.839
Denmark	1.000	0.000	0.999	1.89	0.864	-0.331	0.146
Finland	1.000	0.006	0.600	2.57	0.766	-0.326	0.154
France	1.000	0.004	0.947	4.92	0.426	0.448	0.050
Germany	1.000	0.003	0.973	5.19	0.393	0.594	0.009
Great Britain	1.000	0.001	0.934	2.90	0.715	0.386	0.090
Ireland	1.001	0.000	0.999	1.89	0.864	0.235	0.304
Japan	1.000	0.000	0.998	3.27	0.658	-0.301	0.188
Netherlands	1.000	0.006	0.922	4.92	0.426	-0.436	0.056
Norway	0.998	0.009	0.750	2.57	0.766	-0.115	0.616
Sweden	0.999	0.000	0.999	3.68	0.596	0.008	0.972
Switzerland	0.999	0.002	0.979	3.90	0.564	0.044	0.848
USA	1.000	0.002	0.832	2.99	0.702	0.412	0.071

The coefficients presented in Table 8 are consistent with these expectations in all countries except for Germany, Great Britain, Japan and the United States. In Finland, the coefficient for unemployment is negative for total fatalities and positive for fatalities involving young people. There is a minor exception in France as well, since the coefficient for young people fatalities is slightly less negative than the coefficient for the total number of fatalities (-0.278 vs -0.322). This small exception is, however, not interpreted as an anomalous result.

The unexpected sign of the coefficients for Germany, Great Britain, Japan and the United States does not mean that the models for these countries predict erroneously. All four countries experienced a decline in the number of traffic fatalities during the period covered by the models. The models describe this decline quite well and indicate a stronger decline in recent years, after the financial crisis started in

2008 than in earlier years. Thus, model predictions are reasonably correct even if the specific values of some of the coefficients are implausible.

Models 6 and 7: Annual changes in economic variables and traffic fatalities

In addition to the negative binomial regression models based on annual data, models based on annual changes have been developed. These models have been fitted to data for the years 1971-2010. 1971 is the first year for which changes from the year before can be observed.

Table 3.8. **Model coefficients, standard errors and P-values**

		Total number of fatalities as dependent variable			Young people fatalities as dependent variable		
Country	**Variable**	**Coefficient**	**Standard error**	**P-value**	**Coefficient**	**Standard error**	**P-value**
Austria	Year	-0.067	0.0097	0.000	-0.077	0.0212	0.000
	GDP per capita	1.268	0.4939	0.010	1.244	1.0690	0.244
	Unemployment	-0.011	0.1049	0.917	-0.210	0.2251	0.350
Belgium	Year	-0.060	0.0073	0.000	-0.079	0.0162	0.000
	GDP per capita	1.346	0.5113	0.008	2.281	1.1252	0.043
	Unemployment	-0.399	0.1071	0.000	-0.468	0.2288	0.041
Denmark	Year	-0.028	0.0100	0.005	-0.024	0.0229	0.301
	GDP per capita	-1.753	0.9507	0.065	-3.288	2.1630	0.129
	Unemployment	-0.510	0.1425	0.000	-0.550	0.3259	0.091
Finland	Year	-0.056	0.0143	0.000	-0.078	0.0357	0.030
	GDP per capita	0.679	1.0674	0.525	4.018	2.7023	0.137
	Unemployment	-0.294	0.3963	0.458	0.817	1.0156	0.421
France	Year	-0.074	0.0112	0.000	-0.089	0.0054	0.000
	GDP per capita	0.706	1.1582	0.542	2.075	0.5166	0.000
	Unemployment	-0.322	0.3237	0.320	-0.278	0.1406	0.048
Germany	Year	-0.073	0.0078	0.000	-0.097	0.0076	0.000
	GDP per capita	1.104	0.6006	0.066	2.055	0.5747	0.000
	Unemployment	0.152	0.0807	0.060	0.133	0.0750	0.075
Great Britain	Year	-0.102	0.0106	0.000	-0.134	0.0186	0.000
	GDP per capita	3.609	0.5386	0.000	5.951	0.9289	0.000
	Unemployment	0.231	0.1100	0.036	0.646	0.1872	0.001
Ireland	Year	-0.073	0.0322	0.022	0.038	0.0612	0.532
	GDP per capita	0.695	0.8847	0.432	-2.175	1.6822	0.196
	Unemployment	-0.046	0.1859	0.805	-0.662	0.3549	0.062
Japan	Year	-0.070	0.0040	0.000	-0.124	0.0068	0.000
	GDP per capita	1.282	0.4181	0.002	1.310	0.6787	0.053
	Unemployment	0.387	0.0613	0.000	0.281	0.0884	0.001

Table 3.8. (continued) **Model coefficients, standard errors and P-values**

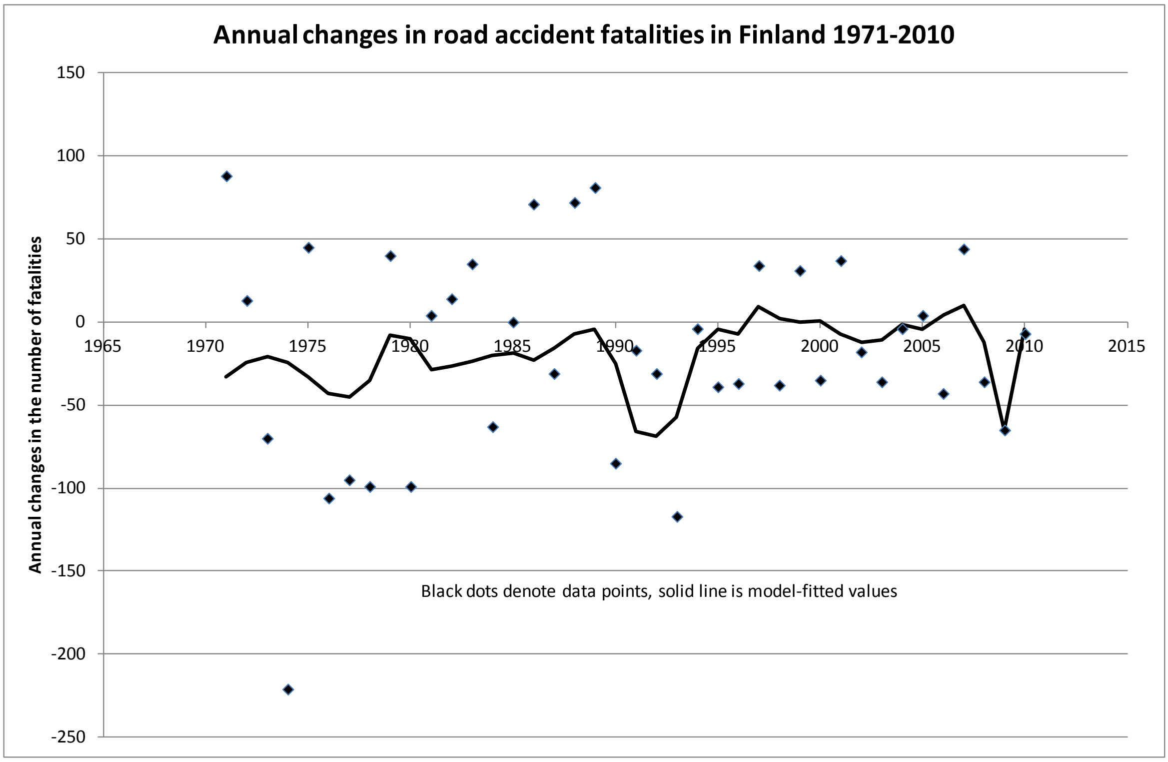
		Total number of fatalities as dependent variable			Young people fatalities as dependent variable		
Country	**Variable**	**Coefficient**	**Standard error**	**P-value**	**Coefficient**	**Standard error**	**P-value**
Netherlands	Year	-0.077	0.0105	0.000	-0.041	0.0239	0.083
	GDP per capita	1.268	0.6498	0.051	-1.225	1.4819	0.408
	Unemployment	-0.051	0.0643	0.428	-0.327	0.1467	0.026
Norway	Year	-0.045	0.0093	0.000	-0.021	0.0205	0.295
	GDP per capita	0.918	0.6043	0.129	-1.140	1.3414	0.395
	Unemployment	-0.285	0.0972	0.003	-0.459	0.2213	0.038
Sweden	Year	-0.067	0.0136	0.000	-0.043	0.0317	0.176
	GDP per capita	1.409	0.5898	0.017	0.742	1.3677	0.587
	Unemployment	-0.377	0.1041	0.000	-0.882	0.2398	0.000
Switzerland	Year	0.006	0.0162	0.727	0.104	0.0384	0.007
	GDP per capita	-4.089	1.2583	0.001	-13.068	3.0187	0.000
	Unemployment	-0.384	0.1113	0.001	-0.590	0.2645	0.026
United States	Year	-0.084	0.0219	0.000	-0.151	0.0375	0.000
	GDP per capita	3.860	0.9681	0.000	7.253	1.6585	0.000
	Unemployment	0.306	0.1377	0.026	0.646	0.2357	0.006

Annual changes can be both positive and negative. The majority of annual changes in the number of traffic fatalities have been negative, as there is a long-term trend for fatalities to decline. Most annual changes in GDP per capita have been positive. Annual changes in unemployment have been both positive and negative.

Annual changes in the number of traffic fatalities were used as dependent variable. Since this variable assumes both negative and positive values, ordinary least squares linear regression was used in the analysis. The independent variables included year, annual changes in GDP per capita and annual changes in unemployment.

Model coefficients estimated for different countries are not directly comparable, as they are influenced by the size of the country. Results for different countries are therefore compared in terms of standardised regression coefficients. A standardised regression coefficient shows how many standard deviations a dependent variable changes when an independent variable increases by one standard deviation. If an increase in unemployment is associated with a reduction in the number of traffic fatalities, the coefficient for unemployment should be negative. Figure 3.21 shows an example of model estimates.

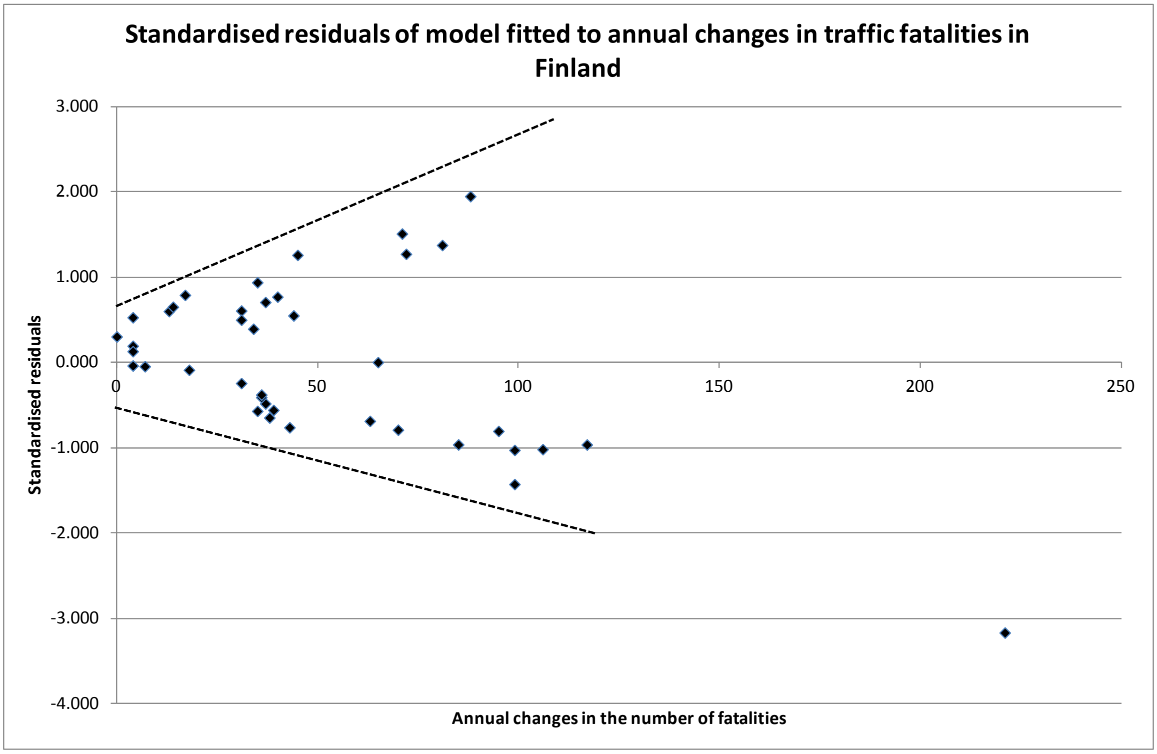
Figure 3.21. **Model of annual changes in traffic fatalities in Finland 1971-2010**



The black dots are data points. The solid line is model estimates. It is seen that the data are quite widely dispersed around model estimates. Nevertheless, the model does to some extent capture the fluctuations in the annual changes in the number of fatalities. The problems of high correlations among the independent variables have been eliminated in the models based on annual changes. In general, however, the models based on annual changes do not fit the data as well as the negative binomial regression models. There is a fairly large element of randomness in the annual changes in the number of traffic fatalities and in small countries few of the annual changes are statistically significant.

The problems of auto-correlated residuals that was found in some of the negative binomial regression models is virtually absent in the models based on annual changes. However, the models based on annual changes tend to have heteroskedastic residual terms. An example showing this is given in Figure 3.22. It shows the standardised residuals of the model fitted for Finland as a function of the size of the annual change in the number of fatalities. The data point located to the right in the figure is clearly an outlier and is located more than three standard deviations from the model estimate.

Figure 3.22. **Standardised residuals of model fitted to annual changes in traffic fatalities in Finland 1971-2010**



The models have been accepted as meaningful despite the heteroskedastic residual terms. Table 9 presents standardised model coefficients for the models fitted to the lagged data. The table presents results of the analyses made for the years 1971-2010 and 1996-2010. Analyses for the latter period include data on traffic fatalities involving young people.

Table 3.9. **Standardised regression coefficients for analyses of annual changes, T-values and P-values**

		All fatalities 1971-2010			All fatalities 1996-2010			Young (18-24) fatalities 1996-2010		
Country	**Variable**	**Coefficient**	**T-value**	**P-value**	**Coefficient**	**T-value**	**P-value**	**Coefficient**	**T-value**	**P-value**
Austria	Year	0.000	-0.003	0.998	-0.251	-0.776	0.454	-0.111	-0.348	0.734
	Change in GDP per capita	0.007	0.036	0.972	-0.525	-1.270	0.230	-0.243	-0.597	0.562
	Change in unemployment	-0.093	-0.461	0.648	-0.607	-1.569	0.145	-0.595	-1.565	0.146
Belgium	Year	0.042	0.243	0.809	-0.254	-0.843	0.417	0.087	0.286	0.780
	Change in GDP per capita	0.107	0.586	0.561	-0.246	-0.681	0.510	0.395	1.084	0.302
	Change in unemployment	-0.217	-1.162	0.253	-0.427	-1.249	0.237	-0.082	-0.238	0.816
Denmark	Year	0.174	1.022	0.313	0.230	0.715	0.489	0.399	1.227	0.245
	Change in GDP per capita	0.332	1.326	0.193	0.121	0.276	0.787	-0.012	-0.026	0.980
	Change in unemployment	0.078	0.313	0.756	-0.398	-0.890	0.393	-0.431	-0.953	0.361
Finland	Year	0.099	0.615	0.542	0.302	0.916	0.379	-0.254	-0.627	0.543
	Change in GDP per capita	0.166	0.750	0.458	0.071	0.172	0.866	0.208	0.412	0.688
	Change in unemployment	-0.158	-0.709	0.483	-0.697	-1.399	0.190	0.283	0.463	0.653
France	Year	-0.063	-0.288	0.775	-0.143	-0.421	0.682	-0.032	-0.094	0.927
	Change in GDP per capita	0.025	0.093	0.927	-0.229	-0.493	0.631	-0.040	-0.086	0.933
	Change in unemployment	-0.071	-0.274	0.786	-0.329	-0.787	0.448	-0.303	-0.732	0.479
Germany	Year	0.117	0.551	0.586	-0.062	-0.190	0.853	-0.106	-0.352	0.732
	Change in GDP per capita	0.219	0.938	0.357	-0.209	-0.571	0.579	-0.066	-0.193	0.850
	Change in unemployment	0.026	0.103	0.919	-0.359	-0.917	0.379	-0.503	-1.375	0.197
Great Britain	Year	-0.049	-0.320	0.751	-0.963	.4.141	0.002	-0.656	-2.140	0.056
	Change in GDP per capita	0.499	2.400	0.022	1.010	3.760	0.003	1.105	3.119	0.010
	Change in unemployment	0.181	0.860	0.395	1.128	3.275	0.007	1.051	2.315	0.041

Table 3.9. **(continued) Standardised regression coefficients for analyses of annual changes, T-values and P-values**

		All fatalities 1971-2010			All fatalities 1996-2010			Young (18-24) fatalities 1996-2010		
Country	**Variable**	**Coefficient**	**T-value**	**P-value**	**Coefficient**	**T-value**	**P-value**	**Coefficient**	**T-value**	**P-value**
Ireland	Year	-0.222	-1.417	0.165	-0.146	-0.322	0.753	-0.141	-0.281	0.784
	Change in GDP per capita	0.151	0.580	0.565	0.608	0.827	0.426	-0.299	-0.365	0.722
	Change in unemployment	-0.199	-0.771	0.446	0.277	0.402	0.696	-0.372	-0.485	0.637
Japan	Year	0.361	2.404	0.021	0.316	1.070	0.308	0.609	2.532	0.028
	Change in GDP per capita	0.711	3.468	0.001	0.290	0.686	0.507	-0.023	-0.068	0.947
	Change in unemployment	0.371	1.876	0.069	0.440	1.026	0.327	-0.152	-0.434	0.672
Netherlands	Year	0.040	0.211	0.834	-0.139	-0.422	0.681	-0.114	-0.339	0.741
	Change in GDP per capita	-0.009	-0.041	0.967	-0.259	-0.672	0.516	-0.316	-0.806	0.437
	Change in unemployment	-0.309	-1.413	0.170	-0.334	-0.838	0.420	-0.241	-0.593	0.565
Norway	Year	0.078	0.438	0.664	-0.089	-0.223	0.827	-0.018	-0.043	0.967
	Change in GDP per capita	0.077	0.370	0.713	-0.174	-0.392	0.703	-0.237	-0.500	0.627
	Change in unemployment	-0.031	-0.153	0.880	-0.514	-1.639	0.129	-0.374	-1.118	0.287
Sweden	Year	0.077	0.488	0.628	-0.381	-1.666	0.124	-0.132	-0.516	0.616
	Change in GDP per capita	0.018	0.085	0.933	-0.270	-0.972	0.352	-0.208	-0.671	0.516
	Change in unemployment	-0.367	-1.743	0.090	-0.607	-2.120	0.058	-0.652	-2.037	0.066
Switzerland	Year	0.135	0.816	0.420	0.096	0.318	0.756	-0.006	-0.026	0.979
	Change in GDP per capita	0.057	0.279	0.782	-0.158	-0.314	0.759	-0.746	-1.874	0.088
	Change in unemployment	-0.103	-0.504	0.617	-0.162	-0.320	0.755	-0.168	-0.420	0.682
United States	Year	-0.010	-0.081	0.936	-0.205	-0.901	0.387	-0.134	-0.507	0.622
	Change in GDP per capita	0.684	2.473	0.018	1.170	1.925	0.081	1.091	1.549	0.150
	Change in unemployment	0.058	0.210	0.835	0.550	0.994	0.342	0.476	0.742	0.473

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The main pattern of the results can be summarised as follows:

- Most of the coefficients are not statistically significant at the 5%level of significance.
- The coefficients for change in unemployment are negative for nine countries, positive for five countries in the analyses of annual changes from 1971 to 2010.
- The coefficients for change in unemployment with respect to total fatalities are negative for ten countries, positive for four countries in the analyses referring to the period 1996-2010.
- The coefficients for change in unemployment became more negative during 1996-2010 than during 1971-2010 in Austria, Belgium, Finland, France, the Netherlands, Norway, Sweden and Switzerland – indicating that economic fluctuations had greater effects in the most recent 15 years than in the previous 40 years.
- The coefficients for unemployment were positive in all analyses for Great Britain, Japan and the United States. Nevertheless, the models predicted a reduction of traffic fatalities in these countries in 2009 and 2010, as was observed in practice.

Model 8: Annual changes in logarithms of economic indicators and traffic fatalities

These models were inspired by the recent paper by Yannis *et al*. (2014), and were fitted separately for each country relying on data for the period from 1970 to 2010. Table 10 gives an overview of model performance. Standardised residuals are presented in Figures in the Appendix to the report.

Model predictions are in most cases slightly biased. This is probably caused by the logarithmic transformation of the variables. Since logarithms are non-linear, and all analyses were based on logarithms, transforming back to natural units by means of model coefficients will not always reproduce natural numbers that are exactly correct. However, the inaccuracies are very small and the model performs very well in other respects.

The model in most cases explains more than 80% of the systematic variation in the number of fatalities. Residuals were in all cases normally distributed. There was, except for Japan and Norway, no statistically significant autocorrelation in the residuals. In this respect, the model performs a lot better than the negative binomial regression model for the period from 1970 to 2010 (see Table 5).

The diagrams showing standardised residuals in the Appendix do not indicate heteroskedasticity. Although the trend lines fitted in the diagrams are not always strictly horizontal, as they ideally speaking ought to be, the slopes are small and far from statistically significant.

On the whole, therefore, the model based on logarithms of annual changes (except for year, which was entered in original form) is regarded as the most successful of the three main models that have been fitted. It is not affected by any of the problems that were found for the other two main models. Its only blemish, although it is small, is that model predictions were in most cases slightly biased.

Table 3.10. **Measures of model performance for models fitted to logarithms of annual changes in economic indicators and traffic fatalities for the period 1970-2010**

Country	Unbiasedness of predictions	Overall goodness-of-fit		Normality of residuals		Autocorrelation of residuals (lag 1)	
	Ratio predicted/actual	Dispersion parameter	Elvik-index	Chi-square	P-value	Correlation coefficient	P-value
Austria	1.000	0.008	0.957	2.65	0.754	-0.169	0.266
Belgium	0.989	0.003	0.970	1.78	0.879	-0.162	0.289
Denmark	0.992	0.009	0.920	5.34	0.376	-0.147	0.335
Finland	0.995	0.030	0.799	6.27	0.281	-0.248	0.104
France	0.992	0.006	0.956	2.83	0.726	-0.051	0.739
Germany	1.020	0.012	0.891	2.40	0.791	-0.099	0.571
Great Britain	1.013	0.004	0.960	4.21	0.520	-0.053	0.730
Ireland	0.993	0.004	0.874	4.48	0.483	0.000	0.999
Japan	1.022	0.035	0.623	1.67	0.893	0.356	0.019
Netherlands	1.022	0.012	0.841	1.39	0.925	-0.190	0.274
Norway	1.005	0.006	0.870	5.68	0.339	-0.372	0.015
Sweden	1.036	0.017	0.854	5.85	0.321	-0.044	0.771
Switzerland	1.010	0.005	0.964	5.24	0.387	-0.228	0.134
USA	1.002	0.025	0.785	2.35	0.799	0.146	0.338

The main interest of this study is to estimate the statistical relationship between indicators of economic performance and changes in the number of road accident fatalities and to assess whether this relationship can be interpreted as causal. Rather than discuss model coefficients in detail, the three main models for the period 1970-2010 have been applied to estimate the relationship between changes in the rate of unemployment and changes in the number of traffic fatalities. The next section of the report presents these estimates and discusses if a synthesis of them is possible and meaningful.

Model triangulation and synthesis

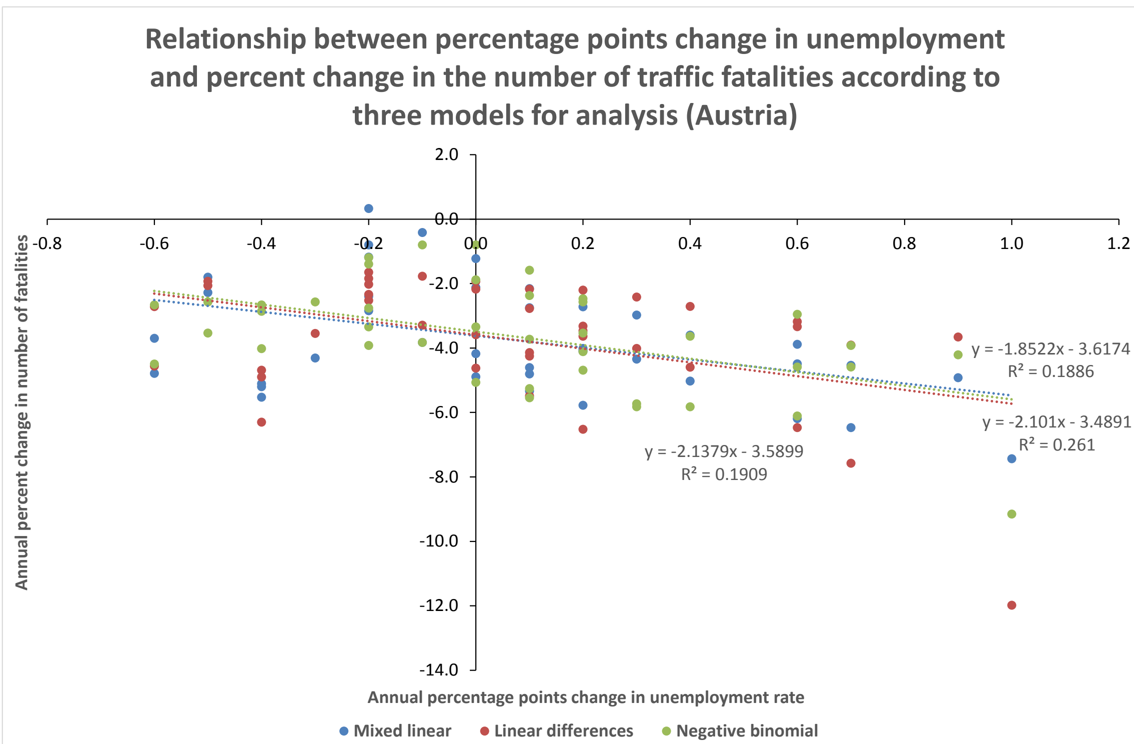
It is obviously very important to develop models that make sense and satisfy criteria of model quality. However, as noted before, even a model that only satisfies, say, 3 or 4 out of 5 criteria of model quality may produce meaningful results. It was therefore decided to compare model predictions. This may be viewed as a form of triangulation. The rationale behind triangulation is that one can be more confident about a result if different methods produce the same result. It is then less likely that the result is simply an artefact of a particular method or model.

To put it in different words: if different models produce the same, or nearly the same result, the convergence of results suggests that the models have been able to uncover the same underlying relationship. The relationship of principal interest in this study is the relationship between unemployment and traffic fatalities.

Austria

Consider Figure 3.23. It shows for Austria the model-estimated relationship between percentage points of change in the rate of unemployment and per cent change in the number of traffic fatalities. Thus, if unemployment increases from 2%to 3 percent, that is an increase of 1 percentage point. The changes in traffic fatalities associated with the changes in the rate of unemployment were estimated by means of three models and are expressed as per cent change. In Figure 3.23, the green data points are based on the negative binomial regression model. The red data points are based on the linear regression model of annual changes. The blue data points are based on the mixed linear model, i.e. the model based on a logarithmic transformation of the annual changes in the economic indicators and the number of traffic fatalities. As can be seen, the three models did not produce identical estimates – the red, green and blue data points are not always located on top of each other or even close to each other.

Figure 3.23. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - Austria**



Curves have been fitted to the data points. These curves are located very close to each other and show almost identical relationships between changes in unemployment and changes in the number of traffic fatalities, although the curves are based on different models. Thus, the curves summarising the relationship between changes in unemployment and changes in the number of traffic fatalities converge despite the fact that they are based on different models that do not predict identical values for any given year.

In the case of Austria, therefore, it would seem that it does not matter which model is used to determine the relationship between unemployment and traffic fatalities. The three curves in Figure 3.23 all cross the ordinate at a value of about -3.5. This corresponds to the mean annual percentage decline in the number of traffic fatalities in Austria from 1970 to 2010. The slope of the curves shows the contribution that fluctuations in unemployment make to the annual decline. It is seen that for Austria, this contribution is rather small, since the curves have a rather small slope.

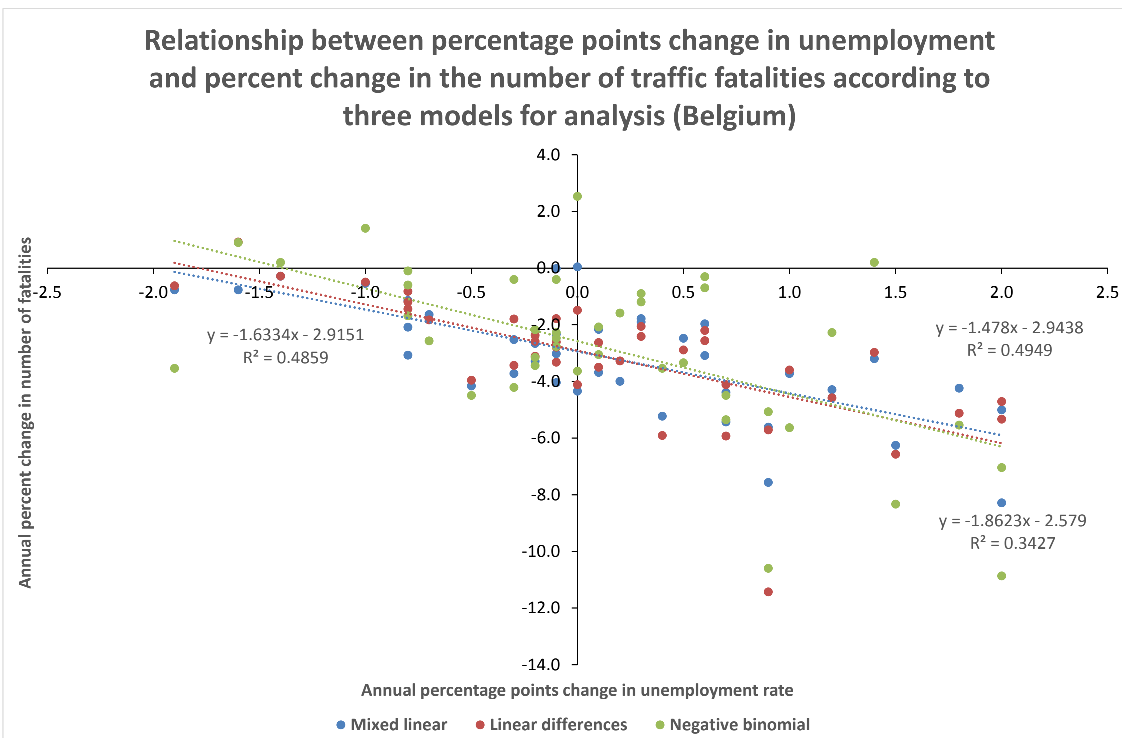
The three curves in Figure 3.23 are so close that it makes sense to combine them into a single curve. This can be done by developing a weighted combined curve, using the inverse value of the residual variance of each curve as statistical weight. Thus, for a curve that has an R-squared value of 0.1909, the statistical weight becomes 1/0.8091 = 1.24. For the other curves in Figure 3.23, the corresponding statistical weights are 1.35 and 1.23. The weighted mean coefficients become -2.0327 for the slope coefficient and -3.5631 for the constant term.

The analysis will proceed country by country.

Belgium

Figure 3.24 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Belgium.

Figure 3.24. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - Belgium**



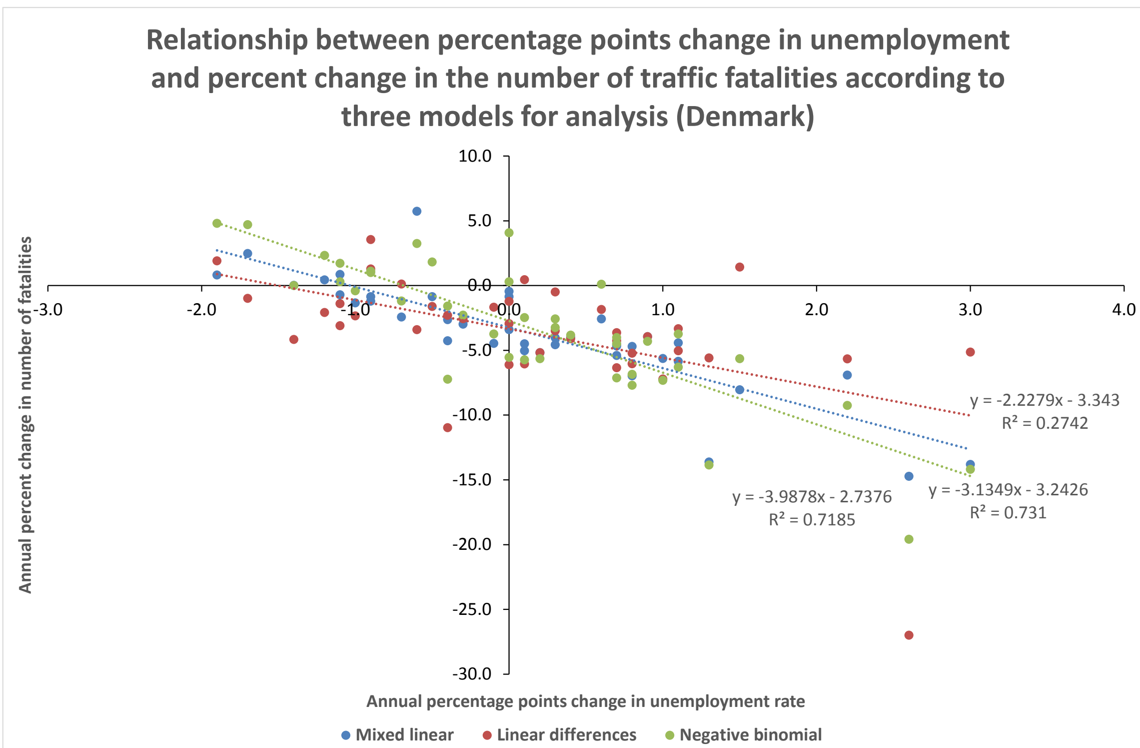
The three curves, based on the three main models developed, are again located very close to each other. The coefficients for the synthetic function (a weighted mean function of the three functions plotted in Figure 3.24) are -1.6409 for the slope and -2.8316 for the constant term.

Denmark

Figure 3.25 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Denmark. The curves were developed by means of the three main models of analysis.

The curves are once again located reasonably close to each other. The flattest curve (red) fits the data considerable less well than the other two curves and will therefore carry little weight in the combined function. The combined function has a slope of -3.3408 and a constant term of -3.0511. Traffic fatalities appear to be more sensitive to changes in unemployment in Denmark than in Austria and Belgium.

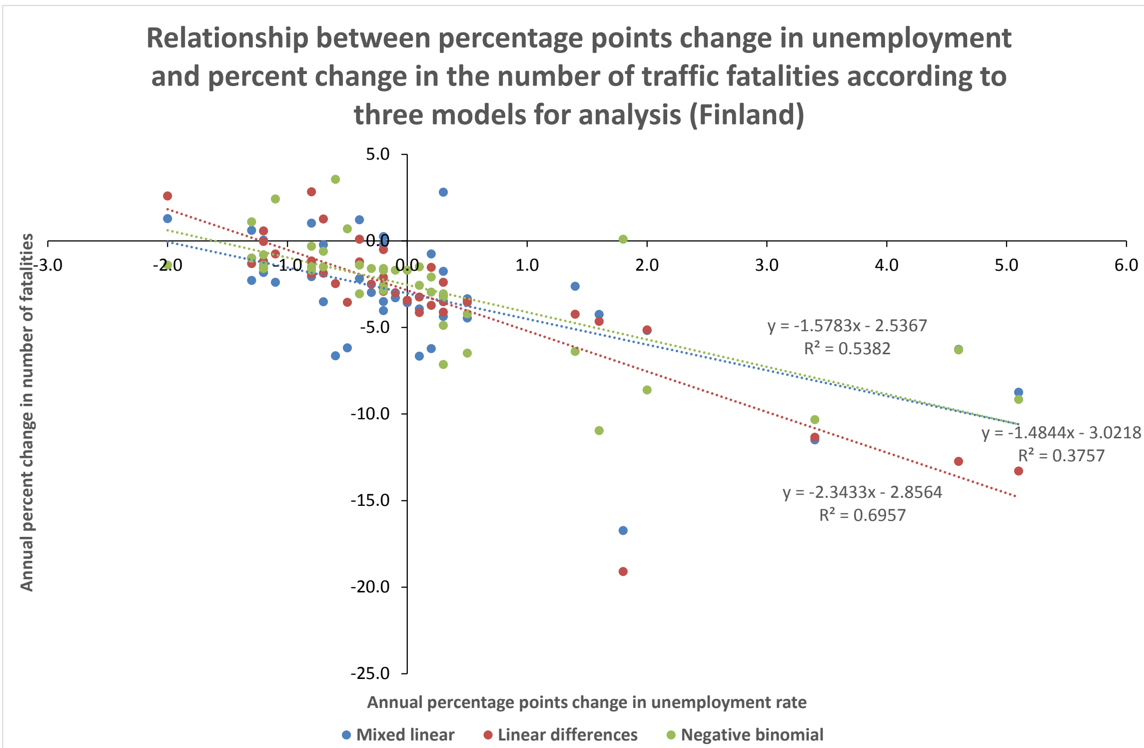
Figure 3.25. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - Denmark**



Finland

Figure 3.26 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Finland. The three curves are similar, but the red curve has a somewhat steeper slope than the other two curves. It is nevertheless regarded as meaningful to combine the curves. The combined curve has a slope of -1.9134 and a constant term of -2.7958

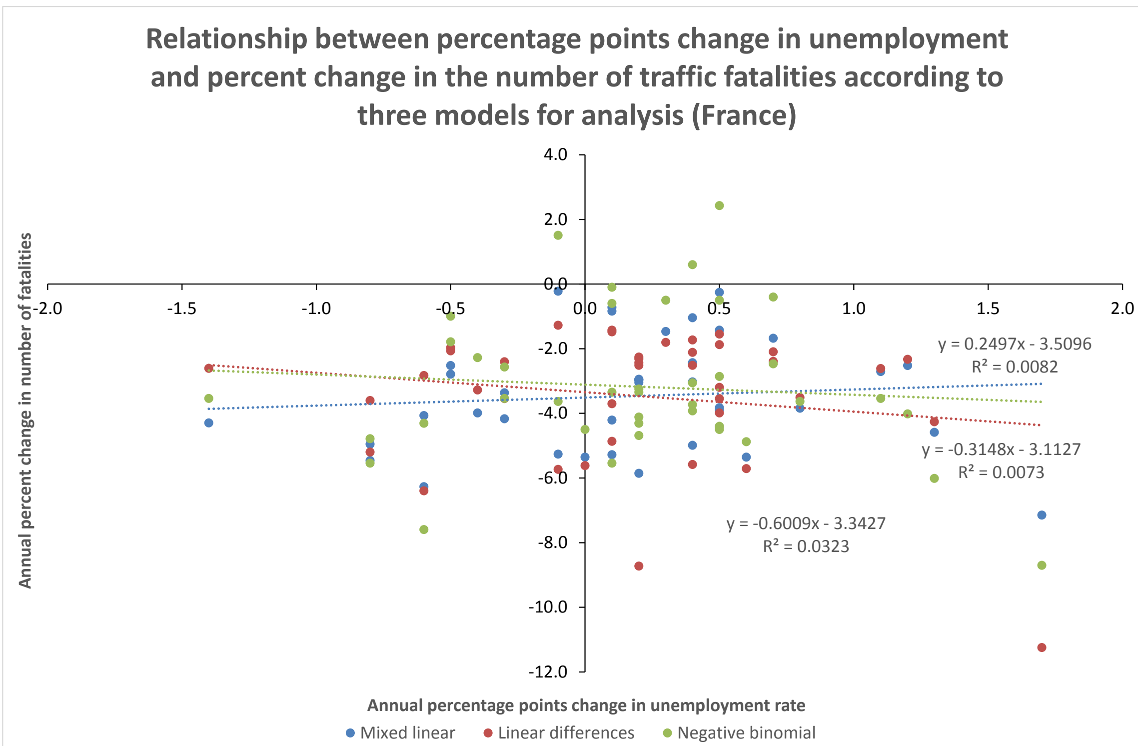
Figure 3.26. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - Finland**



France

Figure 3.27 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in France.

Figure 3.27. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - France**



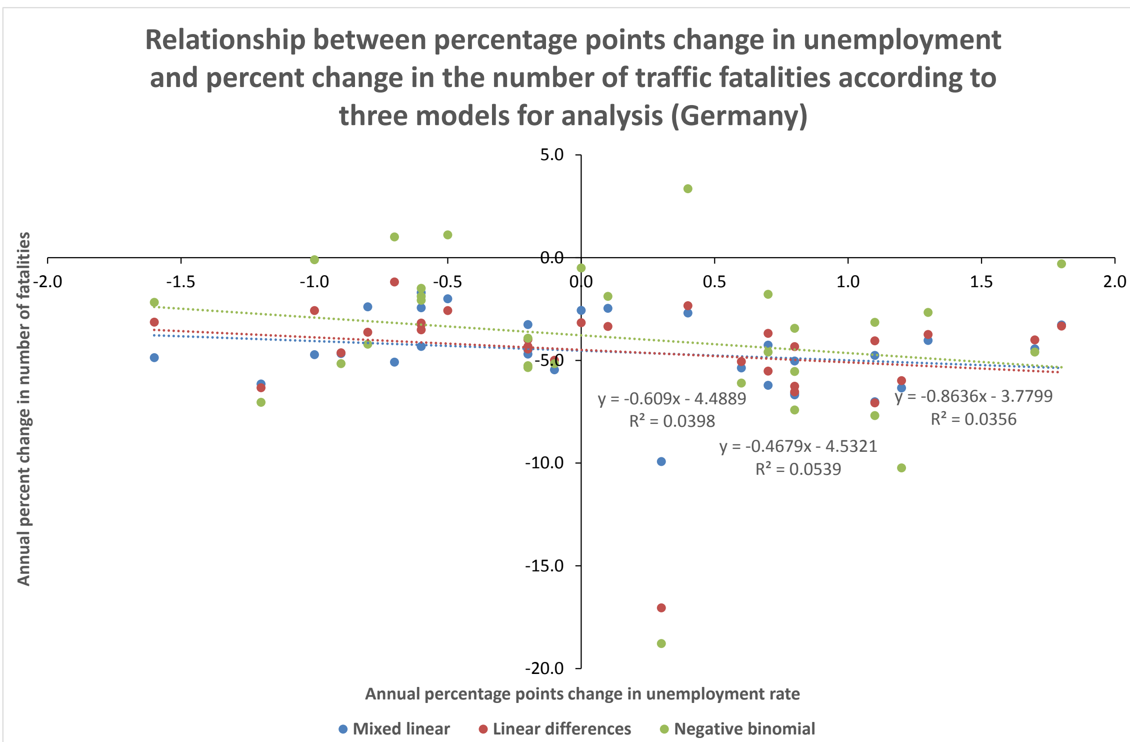
The curves are located close together and are all almost horizontal. The data are widely dispersed around each curve. The curves essentially show that there is no relationship between changes in unemployment and changes in the number of traffic fatalities in France. This sets the country apart from the other countries discussed so far. A synthetic curve has a slope of -0.2251 and a constant term of -3.3219.

Germany

Figure 3.28 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Germany.

The curves for Germany are quite similar to those for France, suggesting only a weak relationship between the level of unemployment and road safety performance. The curves are located close together; a synthesis of them therefore makes sense.

Figure 3.28. **Estimated relationship between change in unemployment and change in the number of traffic fatalities - Germany**

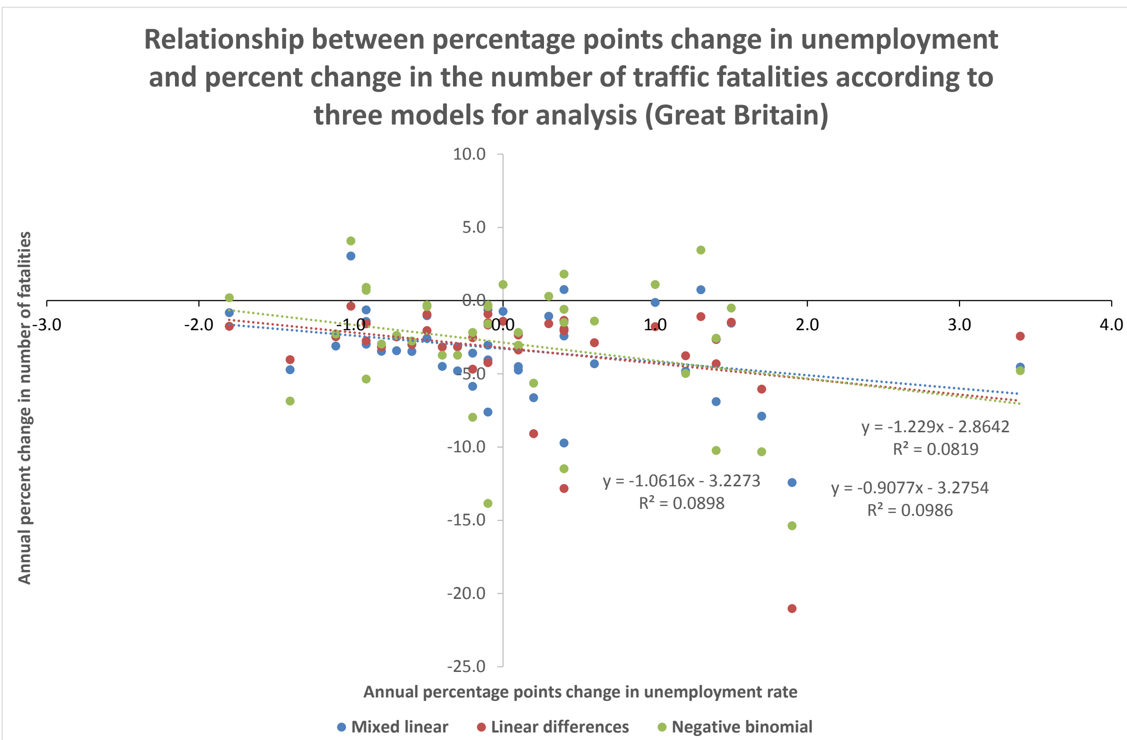


The synthesised coefficients for Germany are -0.6426 for the slope and -4.2690 for the constant term.

Great Britain

Figure 3.29 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Great Britain. The curves are located very close together, although none of them fit the data points very well. Like in France and Germany, there is a weak negative relationship between unemployment and road safety performance. The combined slope is -1.0651 and the combined constant term -3.1235.

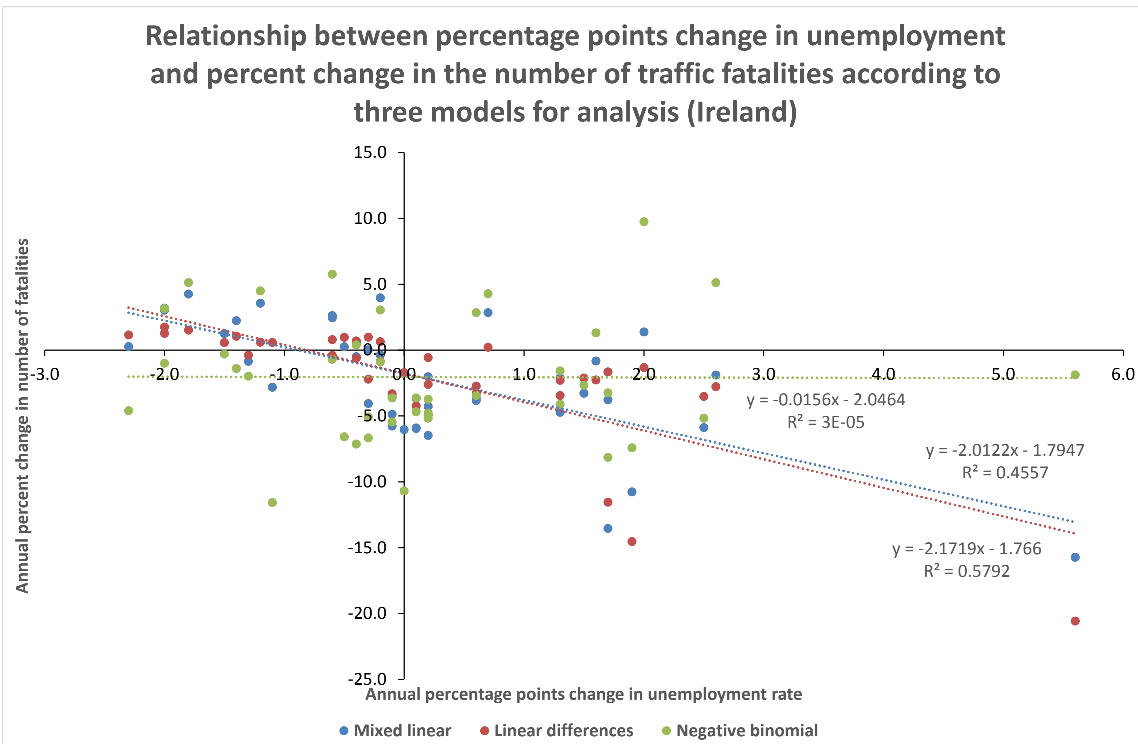
Figure 3.29. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Great Britain**



Ireland

Figure 3.30 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Ireland.

Figure 3.30. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Ireland**

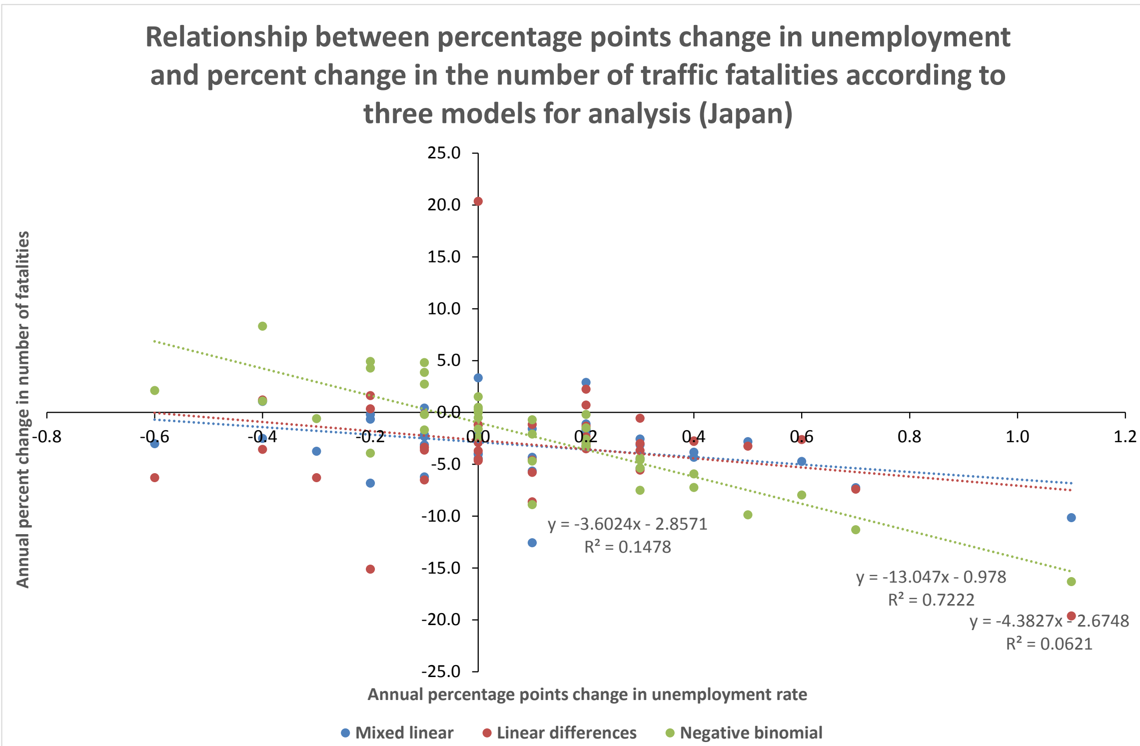


Two of the curves are located very close together, the third curve is almost horizontal and located away from the other two. Whereas the two curves that are close to each other both fit the data reasonably well, the third curve does not fit the data at all. In this case, therefore, only two of the curves were combined, as the third did not contain useful information. The combined slope was -2.1023 and the combined constant term was -1.7785.

Japan

Figure 3.31 shows the relationship between changes in unemployment and changes in traffic fatalities in Japan.

Figure 3.31. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Japan**

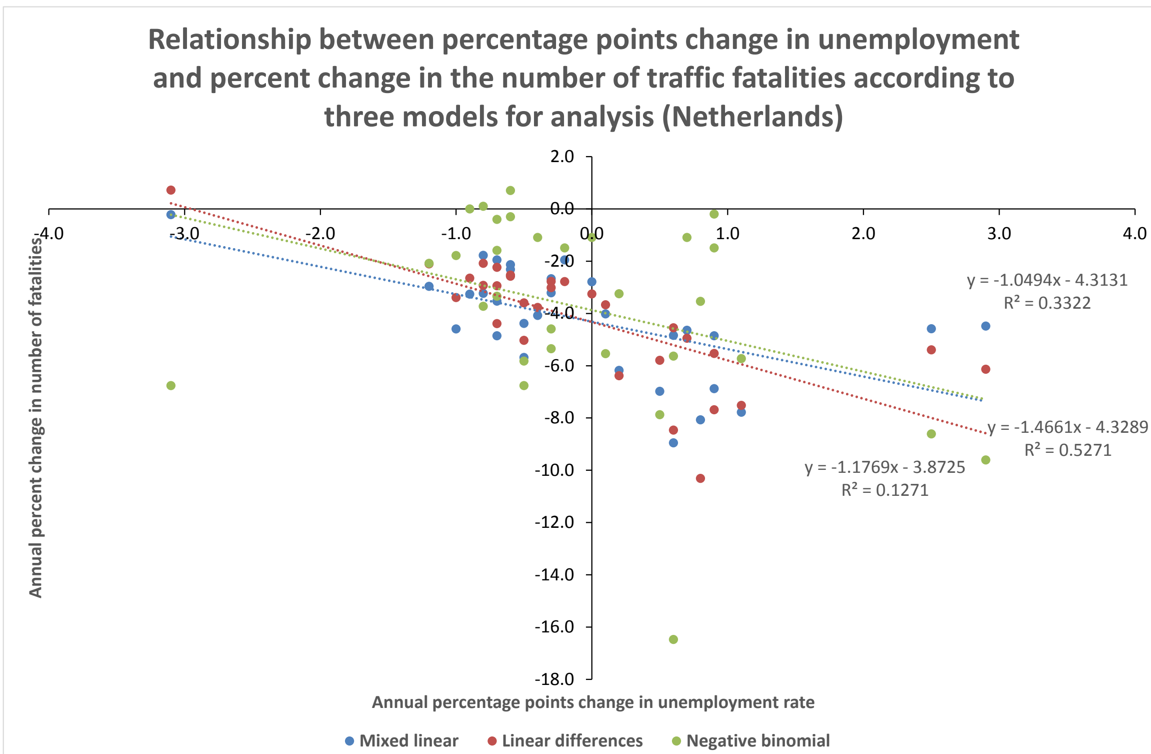


Two of the curves for Japan are very close; the third has a somewhat steeper slope than the other two. The steepest curve also fits the data a lot better than the other two curves and will therefore contribute the most to a synthesised curve. The synthesised curve has a slope of -9.5671 – by far the steepest observed in any country – and a constant term of -1.6654.

The Netherlands

Figure 3.32 shows the relationship between changes in unemployment and changes in the number of traffic fatalities for the Netherlands. The three curves align nicely and are located close to each other. The combined curve has a slope of -1.2653 and a constant term of -4.2140.

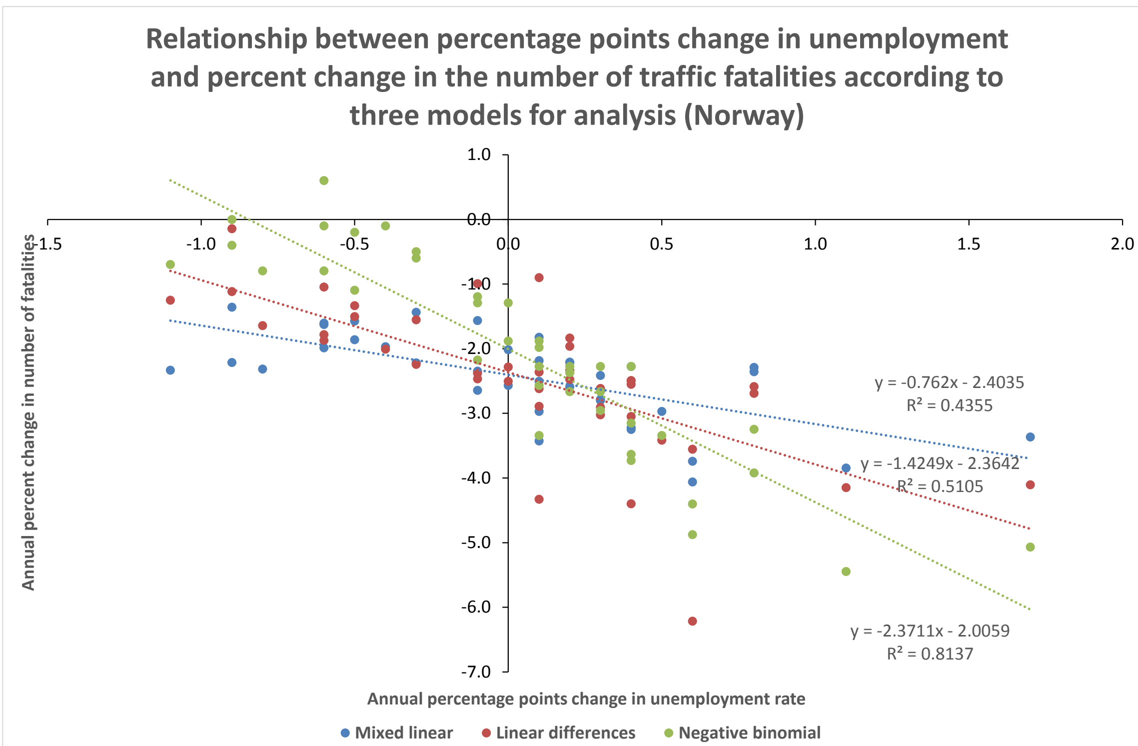
Figure 3.32. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Netherlands**



Norway

Figure 3.33 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Norway.

Figure 3.33. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Norway**



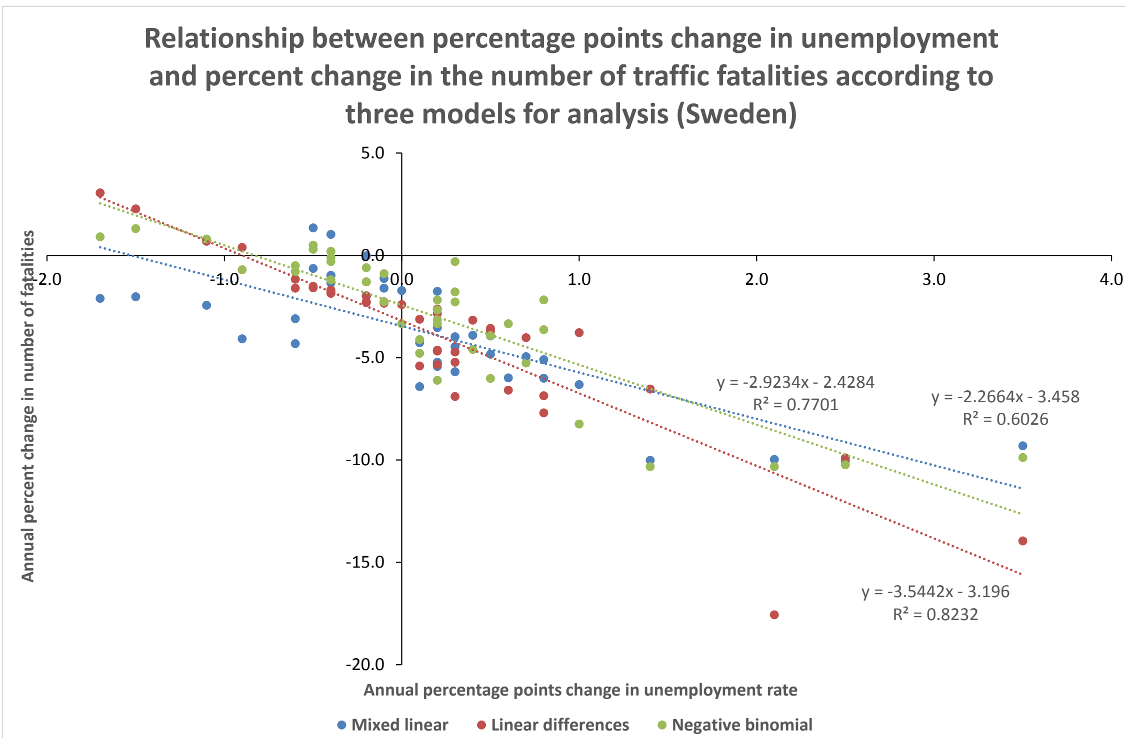
The curves agree with respect to the direction of the relationship, but do diverge somewhat. The green curve best fits the data and will therefore carry the greatest weight in a synthesised curve. The synthesised curve has a slope of -1.8501 and a constant term of -2.1623.

Sweden

Figure 3.34 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Sweden.

The curves for Sweden are close to each other and fit the data reasonably well. The combined function has a slope of -3.7018 and a constant term of -2.9186.

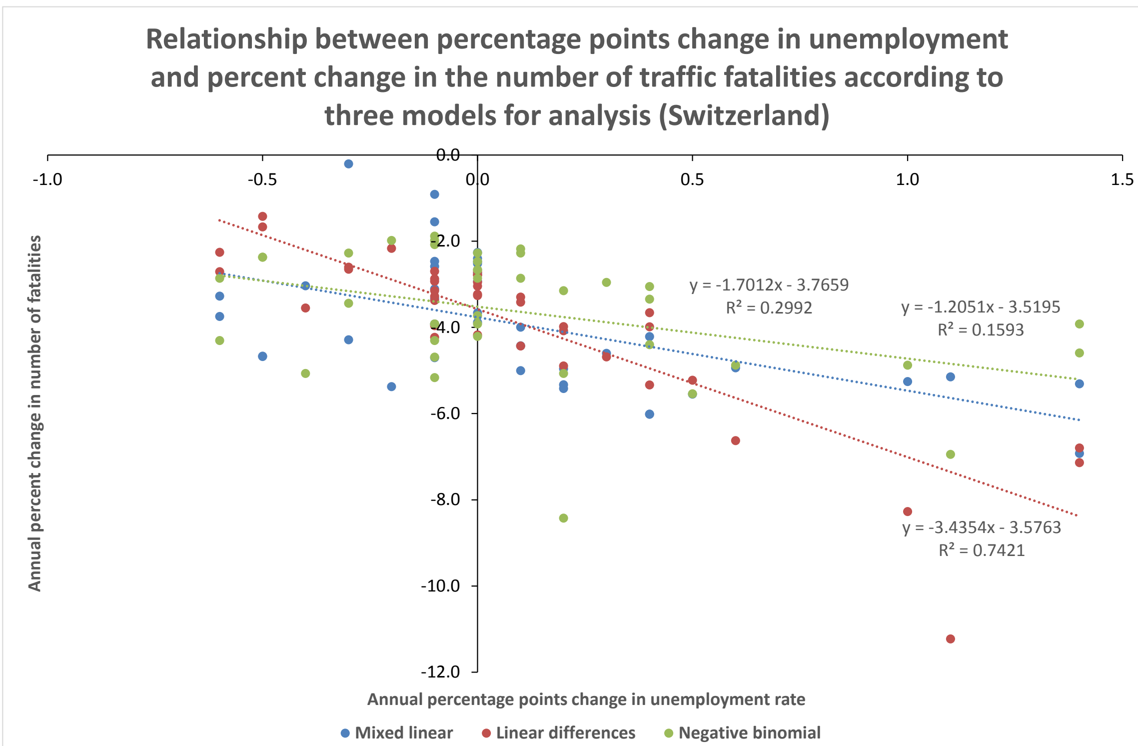
Figure 3.34. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Sweden**



Switzerland

Figure 3.35 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in Switzerland. The curves differ with respect to slope, but all indicate a negative relationship. The consolidated curve has a slope of -2.6458 and a constant term of -3.6076.

Figure 3.35. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – Switzerland**

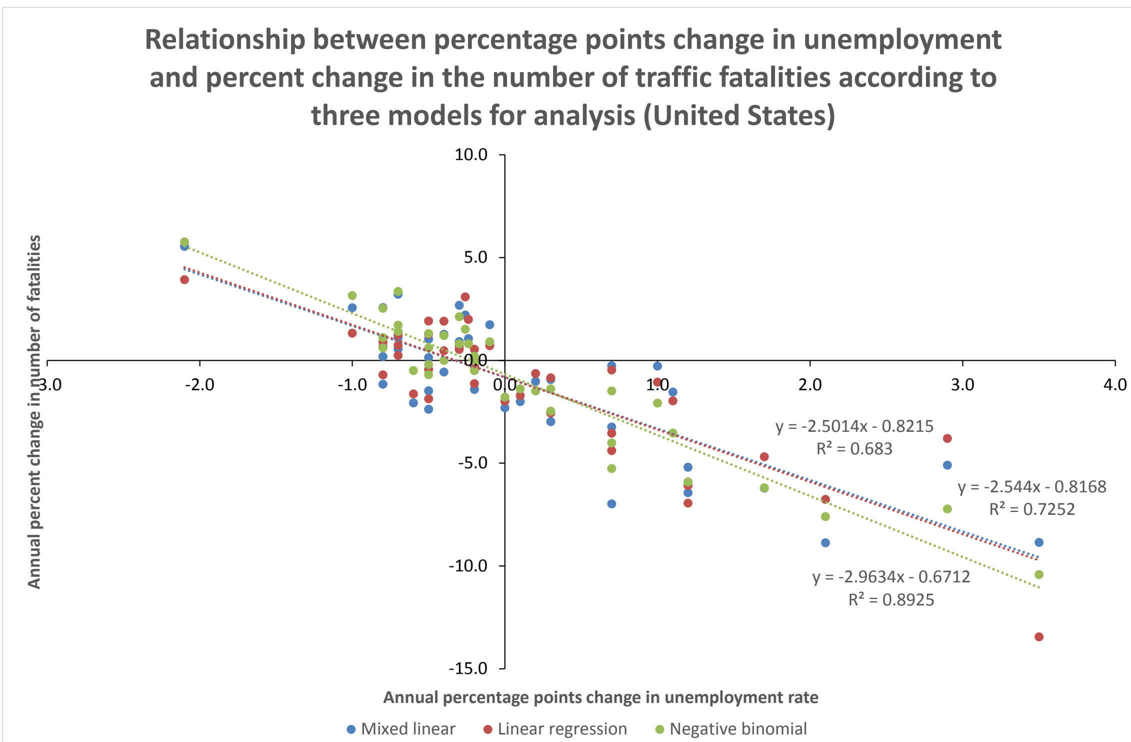


United States

Figure 3.36 shows the relationship between changes in unemployment and changes in the number of traffic fatalities in the United States.

The curves are very close and all fit the data quite well. The combined curve has a slope of -2.7780 and a constant term of -0.7336.

Figure 3.36. **Estimated relationship between change in unemployment and change in the number of traffic fatalities – The United States**



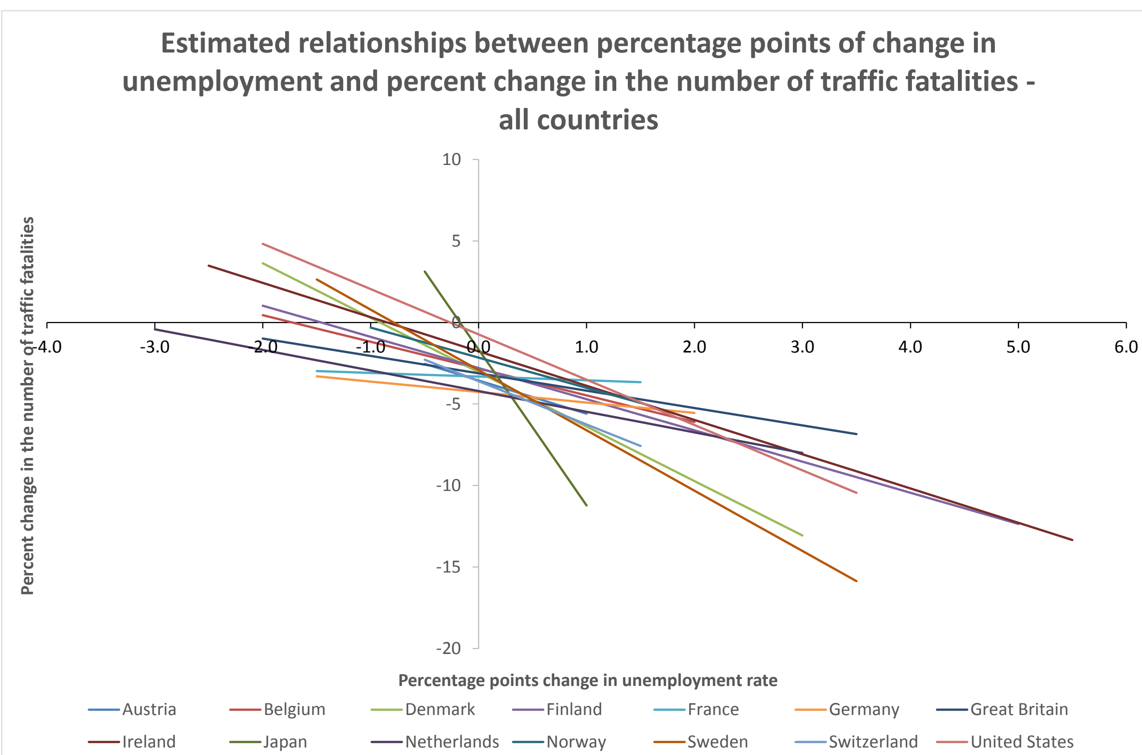
Summary of results for all countries

Figure 3.37 brings together the results for all countries. While it may be difficult to locate a specific country in the swarm of lines, the figure gives a good impression of the direction and size of the effect of unemployment on traffic fatalities. The direction of the relationship is perfectly consistent, but the strength of it varies considerably between countries.

The estimated relationships can be applied to compute the contribution that increased unemployment has made to the decline in traffic fatalities from 2008 to 2010 in the countries that are included in this study.

For all countries, the number of traffic fatalities declined from 59117 in 2008 to 51650 in 2010, a reduction of 7467 or almost 13 percent. By applying the model coefficients derived for each country in the sections above, it is estimated that a reduction of 4847 fatalities, nearly 65% of the total reduction, can be attributed to the increase in unemployment from 2008 to 2010.

Figure 3.37. **Summary of relationship between unemployment and traffic fatalities for 14 countries**



Mechanisms by which economic fluctuations influence road safety

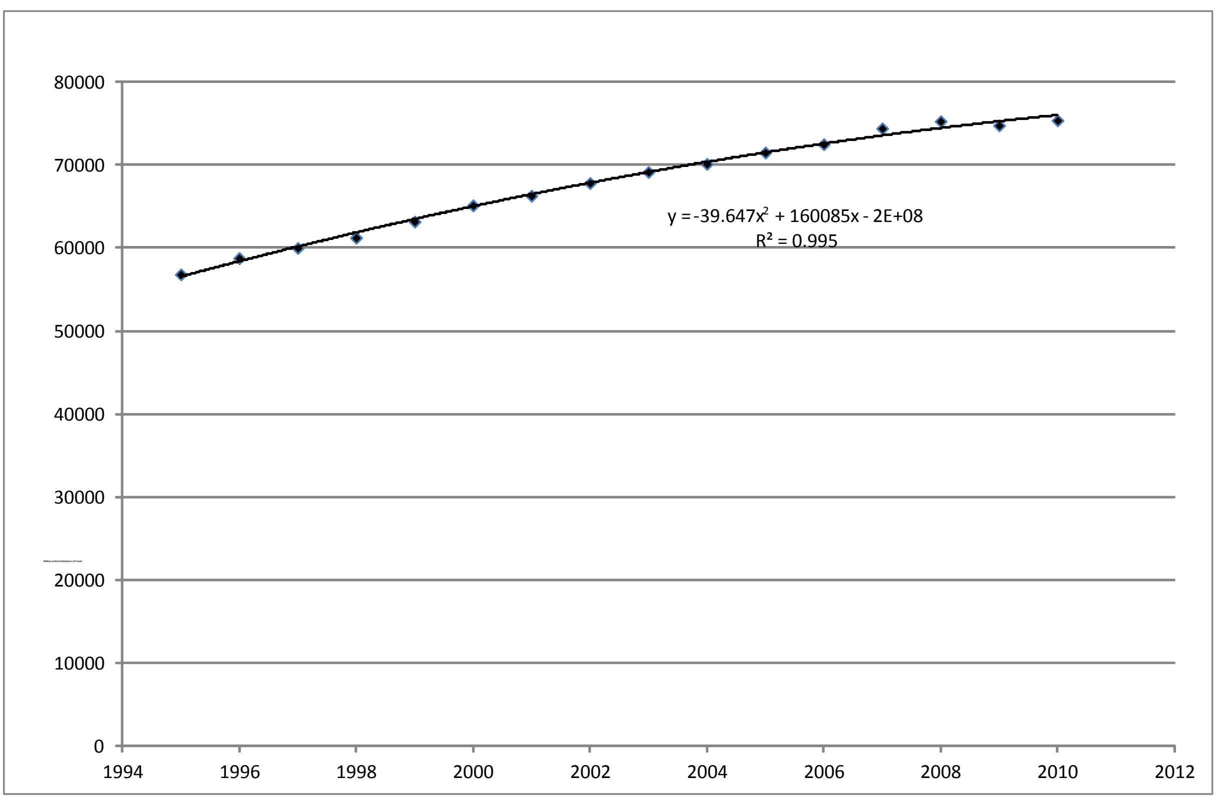
Three main mechanisms that can generate a relationship between unemployment and the number of traffic fatalities were discussed earlier in this report:

- An economic downturn may reduce traffic volume. All else equal, the number of fatalities is strongly influenced by traffic volume.
- An economic downturn may influence the composition of traffic. More specifically, high-risk groups such as young people may be more strongly influenced than the rest of the population.
- An economic downturn may influence road user behaviour, in particular by reducing high-risk behaviour like speeding or drinking and driving.

It is not possible to identify the contributions of these mechanisms very precisely. An attempt has, however, been made to identify the mechanisms and their relative contributions.

As far as traffic volume is concerned, trend lines have been fitted to data about vehicle kilometres of travel in each country. Figure 3.38 shows an example for Austria.

Figure 3.38. **Vehicle kilometres of travel in Austria, 1995-2010**



Whatever trend line best fitted the data was preferred. As can be seen from Figure 3.38, the trend line fits the data points very closely. However, the data points for 2009 and 2010 are located below the trend line. In these years, therefore, traffic did not grow at the rate suggested by the trend line.

The effects of the recent financial crisis became most evident in the years 2009 and 2010 in most countries. These two years have therefore been selected for estimating the contributions of the three mechanisms to the sharp decline in traffic fatalities seen in most countries in these years.

Thus, using Austria as an example, there were 679 traffic fatalities in 2008, 633 in 2009 and 552 in 2010. The decline from 2008 to 2010 was therefore 679 minus 552 = 127 fatalities. The contributions to this decline from four factors have been identified:

- A decline in, or reduced growth, of vehicle kilometres of travel.
- A decline in the share of young people contributing to traffic fatalities.
- An abnormally large reduction of accident rate, possibly as a result of more cautious road user behaviour.
- Any other factor contributing to change in the number of fatalities.

The three first factors are the mechanisms through which economic fluctuations influence road safety. The contributions of these factors have been determined so that their sum is equal to the estimated contribution of increased unemployment to the decline in traffic fatalities from 2008 to 2010. This means that the contribution from other factors is, in practice, treated as a residual term. The procedure will be illustrated for Austria.

The contribution of changes in traffic volume to changes in the number of fatalities has been estimated by using the trend line fitted in Figure 3.38 as an estimate of the "counterfactual" changes in traffic volume, i.e. the trend line shows what traffic volume would have been if the financial crisis had not occurred. The predicted traffic volume for Austria in 2009 and 2010 using the trend line is 75,562 million vehicle kilometres of travel in 2009 and 76,305 million vehicle kilometres of travel in 2010. The actual values for these years were 74,779 and 75,383 million vehicle kilometres, respectively. Thus, in both years, slightly fewer vehicle kilometres of travel were performed than would otherwise have been expected.

When the observed fatality rate in 2009 is multiplied by the actual number of kilometres driven, one gets the recorded number of fatalities as result. When the observed fatality rate in 2009 is multiplied by the slightly higher number of kilometres driven as estimated by the trend line in Figure 3.27, one gets a slightly higher number of fatalities. The difference between these two numbers is an estimate of the decline in the number of fatalities in 2009 attributable to the fact that fewer kilometres were driven than would otherwise have been expected. The same procedure was applied for 2010. Adding for the two years 2009 and 2010 gives an estimated reduction of the number of fatalities of 14.

The contribution to the total decline in the number of fatalities in Austria from the decline among young people can be estimated directly. The decline in the number of fatalities not involving young people in Austria from 2008 to 2010 was from 545 to 450. If an identical percentage reduction had occurred among young people, 111 fatalities would have been expected in 2010. The actual number was 102. Thus, the net excess reduction of fatalities involving young road users was 9. Note that the excess reduction of fatalities involving young people may be negative (when these fatalities declined less than fatalities among in other age groups).

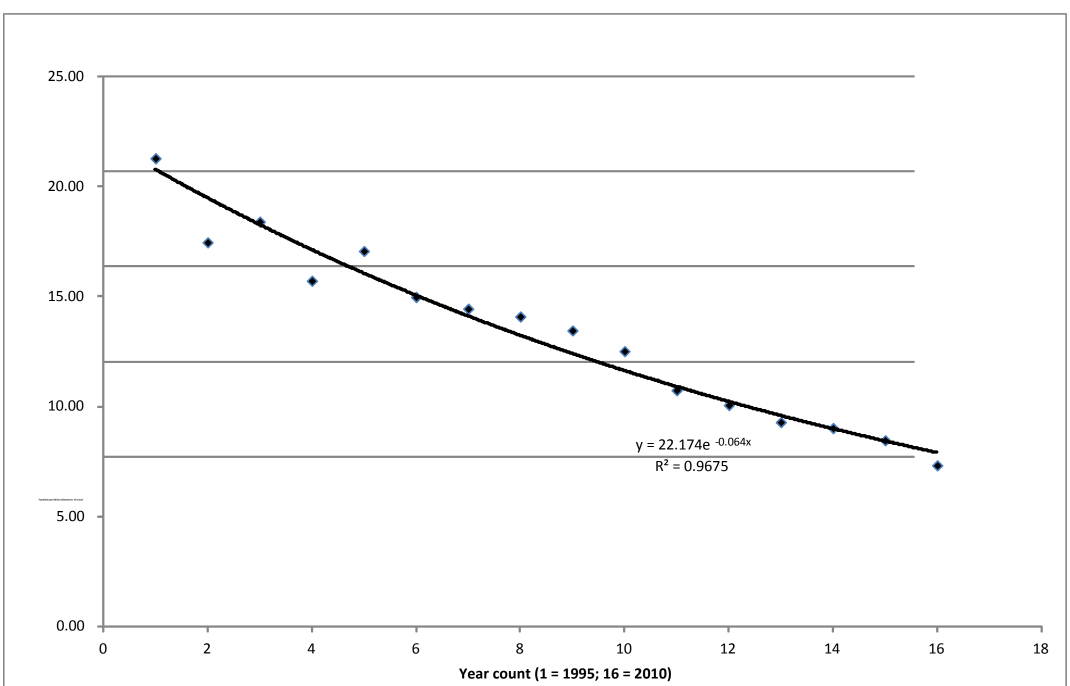
The contribution from lower accident rate was by fitting a trend line to data on fatality rate (fatalities per billion kilometres of travel). Figure 3.39 shows a trend line fitted to data on fatality rate from 1995 to 2010 in Austria. Fatality rate is the number of fatalities per billion vehicle kilometres of travel.

While any best-fitting trend line was chosen with respect to vehicle kilometres of travel, only exponential trend lines have been fitted to fatality rate. Reasons for preferring exponential trend lines are discussed by Duffey and Saull (2003), Evans (2003) and Elvik (2010). In the case of Austria, Figure 3.39 shows that the exponential trend line fitted the data excellently.

The changes in behaviour that have been proposed as an explanation of the decline in traffic fatalities during economic recessions are mostly not directly observable. However, it is suggested that if road user behaviour becomes more cautious, this will manifest itself in a larger reduction of the fatality rate than the reduction one would otherwise have expected to see. Fatality rates have exhibited a long-term decline in all motorised countries for as long as reliable statistics can be produced. There have, however, been fluctuations in the rate of decline. As shown in Figure 3.39, fatality rate in Austria in 2010 was clearly below the long-term trend. This means that the number of fatalities that year was lower than it would have been if fatality rate had been identical to the long-term trend.

The contribution from reduced fatality rate to the reduction of the number of traffic fatalities in Austria in 2009 and 2010 was estimated by comparing the number of fatalities predicted by applying the trend line in Figure 3.39 to the actual number of fatalities. The number of fatalities expected to occur in 2010 without the greater decline in fatality rate is estimated by applying the fitted value of fatality rate according to the trend line. This results in a higher estimated number of fatalities than observed in 2010. The decline in traffic fatalities in Austria from 2008 to 2010 attributable to a reduction of fatality rate below the historical trend was estimated to 50.

Figure 3.39. **Fatality rate in Austria 1995-2010**



Thus, we have the following estimated contributions:

- Slower growth in traffic volume: 14
- Larger reduction among young people: 9
- Fatality rate below historical trend: 50

The sum of these contributions is 73. Model estimates suggest a total contribution for Austria of nine fewer fatalities. Re-estimating, slower growth in traffic volume is assigned a contribution of 2, a larger reduction among young people a contribution of 1 and a lower fatality rate a contribution of 6.

For all fourteen countries included in this study, the estimated contributions to the reduction of the number of fatalities from 2008 to 2010 were estimated to:

- Lower traffic volume or less growth in traffic than historical trends: 179
- Fewer fatalities involving young people (indicator of traffic composition): 487
- Reduced fatality rate below historical trends: 4 181
- Other factors: 2 620

The total reduction in the number of fatalities is 7 467. More than half of this reduction can be attributed to a reduction of fatality rate below historical trends. The contributions from the other mechanisms are comparatively small.

Interpretation of model findings

There are two main interpretations of the findings of any piece of research:

- Methodological interpretations, which argue that the results of research are erroneous or cannot be trusted because of weaknesses in data or analytic methods. A methodological interpretation will reject the results of research as biased or nonsensical.

- Substantive interpretations, which argue that the findings of research show causal relationships of general validity.

It is clearly desirable to reject methodological interpretations and support substantive interpretations. The most relevant methodological interpretation of the research presented in this report is that the models estimated are flawed and therefore cannot show causal relationships. Some researchers even argue that no multivariate statistical model can ever reveal causal relationships (Hauer, 2010), whereas others think that such models can reveal causal relationships when certain conditions are fulfilled (Elvik, 2011A).

It is sometimes argued that, strictly speaking, causality – at least as far social phenomena are concerned – can only be revealed in randomized controlled trials. Even carefully designed experiments can go wrong. Therefore, it is sometimes impossible to detect causal relationships even in experimental studies. It is, however, entirely too restrictive and pessimistic to claim that causality can only be demonstrated in experimental studies. It is easy to give examples of causal relationships that have been found in non-experimental research. Even very simple and non-planned studies can sometimes reveal causal relationships. An instructive example was reported in the local newspaper where I live in the summer of 2008.

It had been observed that water was rising in a creek. Since the creek crossed a road (in a pipeline), there was some concern about this, as flooding might damage the road. It was found that beavers had built a dam in the creek. The beavers were caught, moved to a different creek and the dam removed. Water returned to normal level.

Few people would doubt the validity of the following causal inferences in this case: Flooding in the creek was caused by beavers building a dam in it. Removing the beavers and the dam caused water to return to normal level.

The reason why most people would accept these causal statements is that it was very clear why water was rising in the creek. We understand how it happened – the mechanism producing it. Water can rise in a creek for a number of different reasons. But once we find the reason, we do not doubt the causality of the relationship. To control for confounding factors is no longer relevant, because there are no confounding factors once the mechanism has been understood. The mechanism provides a complete description of the causal process. Yet, what we had in this case – in terms of study design – was a simple before-and-after study without any comparison group (creek without beavers). Such a study would rarely be accepted as showing a causal relationship in the field of road safety.

The relationship between smoking and lung cancer is perhaps the best known and most widely discussed example of a causal relationship revealed by observational studies. Today, few people doubt that regular smoking contributes to lung cancer. It may not be the only contributing factor. It may not always lead to lung cancer – not all smokers get the disease and some people who never smoked do. The relationship between smoking and lung cancer is, in other words, statistical. Not all statistical relationships are causal, but the relationship between smoking and lung cancer is very likely to be causal.

Road safety research, in particular multivariate modelling, reveals statistical relationships, some of which are causal and some of which are not. Assessing the causality of a relationship involves reviewing arguments for and against a causal interpretation and determining the strength of those arguments. This is not an exact science and can never become that. People may therefore legitimately disagree about the causality of statistical relationships. The following sections review arguments for and against interpreting the findings of this study as showing causal relationships.

Methodological arguments

The methodological arguments, i.e. the arguments against a causal interpretation of the results of the study are based on the list of confounding factors in multivariate accident modelling proposed by Elvik (2011A):

- small sample and/or low mean value bias
- bias due to aggregation, averaging or incompleteness in data
- presence of outlying data points
- inappropriate choice of dependent variable
- treating endogenous variables as exogenous
- wrong functional form for effects of independent variables

- co-linearity among independent variables
- omitted variable bias
- misspecification of structure of systematic variation and residual terms
- mixing levels of accident severity
- inappropriate model form.

These points will be dealt with in turn. Lord (2006) proposes a minimum sample size for accident modelling based on the product of the mean value of the sample and sample size. In a sample where the mean number of accidents per unit of observation is 0.25, minimum sample size should be 4 000. In a sample where the mean number of accidents is 5, minimum sample size is 200. The product of the various combinations of mean value and sample size are always equal to 1 000.

All models developed in this study exceeded the minimum sample size requirement by a large margin (1). An argument based on small sample size of low mean value is therefore not regarded as a relevant objection to this study.

The point regarding aggregation, averaging, and incompleteness of data (2) is not relevant for the present study. IRTAD did not contain complete data on the age distribution of traffic fatalities before 1995. This was an important reason for developing separate models for different age groups.

Outlying data points (3) can influence regression models of the relationship between a pair of variables. There is no evidence that outlying data points have influenced the analyses. The presence of outlying data points on the dependent variable (i.e. abnormally high or low values for the number of fatalities) would manifest itself in large standardised residuals. However, the number of extreme residual terms, above or below two standard deviations, is less than expected in a normal distribution. Thus, if anything, there are fewer outlying data points than one would expect by chance.

The dependent variable (4) is the total number of fatalities or the number of fatalities among people aged from 18 to 24. These are both count variables and are the appropriate choice of dependent variable for count data models. In the analyses using annual changes, the dependent variable was the annual change in the number of fatalities. In the majority of cases, this was a negative number as there is a long-term trend towards fewer fatalities in all countries included in the study. Count data models cannot be used for data containing negative numbers. Therefore, ordinary least-squares linear regression was used in the models relying on data about annual changes. In the mixed linear models, the dependent variable was the difference between two logarithms. This is a continuous variable that can take on both positive and negative values. The mixed linear models were therefore fitted by means of ordinary least squares regression.

Endogeneity is not a problem in the present study (5). The typical form of an endogeneity problem in multivariate accident models is that a variable which is influenced by the number of accidents is used as an independent variable in a model. The models developed in this report do not contain any variables that can reasonably be regarded as being influenced by the number of road accident fatalities. There are four independent variables in the study: year, GDP per capita, vehicle-kilometres of travel and unemployment. None of these are influenced by the dependent variables, the number of traffic fatalities. The vehicle-kilometres of travel variable is influenced by the economic variables and is one of the mechanisms through which economic fluctuations influence the number of fatalities. It was therefore not included in the models as an independent variable.

As far as the functional form relating independent variables to the dependent variables is concerned (6), year was entered simply as a count variable increasing in constant steps of 1. For the economic variable of principal interest, the rate of unemployment, four different functional forms were tested in exploratory analyses:

- Rate of unemployment stated as a percent.
- The natural logarithm of the rate of unemployment.
- The square root of the rate of unemployment.
- The rate of unemployment squared.

If no transformation is applied, the rate of unemployment can be entered as, for example, 4, 6, 8, 10 and 12. The natural logarithm of these numbers is 1.39, 1.79, 2.08, 2.30 and 2.48. The square root of the numbers is 2, 2.44, 2.83, 3.16 and 3.46. The squares of the numbers are 16, 36, 64, 100 and 144. The square transformation was found to perform poorest of the four functional forms. There were small differences between the natural logarithm transformation and the square root transformation. Both these transformations are consistent with a declining marginal effect of an additional percentage point increase in unemployment. The untransformed rate of unemployment was found to perform worse than the log and square root transformations, but not as bad as the square transformation. The log transformation was preferred, because of the ease of interpretation of the coefficients as elasticities. The log transformation was also applied to GDP per capita.

Co-linearity among the independent variables (7) is clearly a concern in this study, in particular in the negative binomial regression models. It was a less serious problem in the other two main models that were developed. Thus, in the overall best-performing model, the mixed linear model based on differences between natural logarithms, the correlations between the independent variables never exceeded a value of -0.868, which, although high, is not high enough to represent co-linearity. The correlations among the independent variables in the mixed linear models were more typically smaller than 0.3.

There are obviously very many variables influencing the number of traffic fatalities that have not been included in this study. In principle, therefore, omitted variable bias cannot be ruled out (8). It is important to understand that the omission of a potentially relevant variable will not necessarily cause bias. Bias will only arise if the omitted variable is correlated both with one of the independent variables included in the model and the dependent variable. The coefficient estimated for the variable included in the model will then in part capture the effect of the omitted variable in addition to its own effect.

It can almost always be argued that no model is complete and that some variable has been omitted. It is, however, not really convincing to use this argument without taking the further steps of: (1) Stating which variables ought to have been included in the study, and (2) Making a plausible case that (a) data about these variables could have been obtained, and (b) inclusion of the variables in the model would have made a difference for the results. Unless the omitted variable argument is put in this form, it is in effect vacuous, i.e. it has no meaningful content.

Most of the models developed in this paper explain more than 90% of the systematic variation in the number of fatalities. While this fact alone does not imply that including an omitted variable could not improve the models, it at least suggests that any such variable would have to have a strong influence on the number of fatalities to really improve model fit.

Negative binomial regression models have been applied in this study (9). There are many versions of negative binomial regression. There are also many other assumptions that can be made regarding the distribution of fatalities: Poisson, Poisson-lognormal, negative-binomial Lindley, etc., etc. A standard negative binomial regression model was regarded as fully adequate for this analysis. No attempt was made to develop models based on other statistical distributions. An advantage of negative binomial regression is that it is easy to determine the size of residual variation and make sure an over-fitted model is not developed. An over-fitted model is a model that explains part of the random variation in fatalities in addition to the systematic variation. The linear and mixed-linear models were also checked with respect to the potential for over-fitting. These models were not found to be over-fitted. Time-series analysis is an alternative to negative binomial regression, but it is not clear how to avoid an over-fitted model when using time-series analysis.

Mixing levels of accident severity is not an issue in this study (10), as only fatalities are studied. As far as model form is concerned (11), the main choices are between:

- single-state and dual-state models
- fixed parameter versus random parameter models
- models containing both additive and multiplicative terms versus models containing only one type of term
- models containing only main effects versus models containing interaction effects in addition to main effects.

Dual state models are applied when the accident generating process is believed to have two modalities that differ with respect to the expected number of accidents. On could, as an example, think that adverse weather is associated with a higher expected number of accidents. In this study, there is no argument for using a dual state model. A single-state model makes perfect sense.

The parameters estimated in the models developed in this study are fixed. Random parameters are applied when there is so called unobserved heterogeneity in the data, i.e. systematic variation whose source cannot be identified or included in the model (Washington, Karlaftis and Mannering 2011). This systematic variation is then captured by allowing model parameters to vary between units of observation. A distribution needs to be specified for the random parameters. The models developed in this study explain almost all systematic variation in the number of fatalities and there is no need to adopt random parameter models to account for unobserved heterogeneity.

Models containing both additive and multiplicative terms have been proposed by Hauer (2004). The idea is to better model the difference in effects on safety between risk factors that are continuous and risk factors that are located at specific points along a road. This problem is not relevant for the present study and models with additive and multiplicative terms have therefore not been considered.

The initial models based on the panel data set for 14 countries included interaction terms. However, in the analyses that were made country-by-country, there was no need to include interaction terms.

When the three main models developed were compared, they were, with minor exceptions, found to produce remarkably similar predictions. Since the models are very different, and not affected by the same sources of error, this convergence may be interpreted as an indication that the models are robust and capture the same underlying phenomenon. In other words, the relationship between unemployment and traffic fatalities was found to be almost the same in all models and cannot therefore be dismissed as an artefact of any particular model. If the relationship is indeed an artefact, it would then have to be an artefact of all the three main models that were fitted. Moreover, that artefact would have to produce identical bias in all models. This argument is indeed hypothetical and a straightforward interpretation of the convergent model findings as showing the same underlying true relationship is altogether more plausible.

Substantive arguments

The assessment of the causality of study findings will be based on the operational criteria of causality discussed by Elvik (2011A). These criteria are:

1. There should be a statistical association between cause and effect.
2. A strong statistical association is more likely to be causal than a weak statistical association.
3. A consistent association is more likely to be causal than an inconsistent association.
4. It should be possible to determine causal direction.
5. The association between cause and effect should not disappear when confounding factors are controlled for.
6. A causal mechanism producing the association between cause and effect should be identified.
7. There should be a plausible theoretical explanation for the relationship between cause and effect.
8. There should be a dose-response pattern in the relationship between cause and effect: the larger the dose, the larger the response.
9. If the cause only operates in a certain group, effects should be found only in that group and not outside it.

The extent to which the study satisfies these criteria is discussed below. The rate of unemployment is treated as the causal variable of main interest. The number of fatalities is the effect variable of main interest.

There is a statistical association between the rate of unemployment and the number of traffic fatalities (1). The association is negative. It is also highly consistent between the three main types of models developed. It is therefore concluded that a negative statistical relationship between unemployment and traffic fatalities has been found.

The strength of the statistical association between unemployment and traffic fatalities (2) can be assessed by comparing the statistical significance of the coefficients for unemployment with the statistical significance of the coefficients representing other variables included in the models. The coefficients for year (the trend term) are statistically significant at the 5% level in 21 out of 28 cases, compared to 16 out of 28 cases for unemployment. The coefficient for GDP per capita was statistically significant at the 5% level in 13 out of 28 cases. It is concluded that the time trend is the strongest effect present in the models, followed by unemployment, whereas GDP per capita has the weakest effect on traffic fatalities.

In the models based on annual changes, the standardised coefficients can be compared with respect to their magnitude (absolute value). A total of 42 coefficients were estimated for unemployment: 25 of these coefficients were larger than the other standardised coefficients. This indicates that in most cases, it was changes in unemployment that had the largest influence on changes in the number of fatalities.

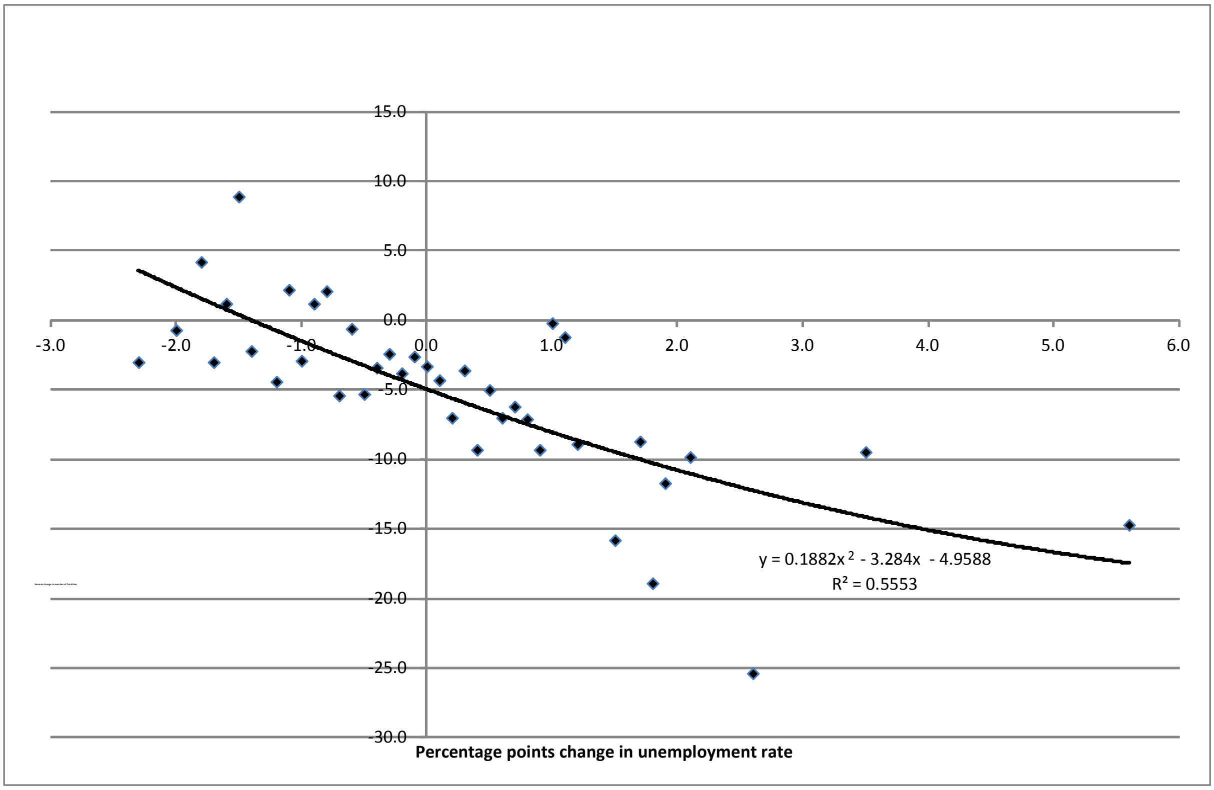
Finally, in the mixed linear models, the beta coefficient for unemployment was the largest of the coefficients estimated in four cases, the second largest in four cases and the smallest in six cases. This shows that unemployment, on the average, has at least as large effects on the dependent variable as the other independent variables included in the models.

The consistency of the association (3) between unemployment and traffic fatalities can be assessed in a number of ways. It was decided to compare the estimated relationship based on the three main types of models and the results were found to be remarkably consistent, both between models and when different countries were compared.

As far as determining causal direction is concerned (4), it can be assessed by inspecting whether effects change direction when the causal factor changes direction. In Figure 3.40, there are 20 data points representing an increase in unemployment. The number of fatalities declined in all these case. There is one data point with no change in unemployment. A decline in traffic fatalities was associated with this data point. Finally there are 19 data points representing a reduction in unemployment. Traffic fatalities increased in six cases and declined in 13 cases. On the whole, it is much more plausible to conclude that the causal direction goes from unemployment to traffic fatalities than the other way around. On the other hand, it is clear that the changes shown in Figure 3.40 are not caused by changes in unemployment only. In the period 1995-2010 there has, independent of changes in unemployment, been a strong declining trend in the number of traffic fatalities in most countries, which means that a decline in the number of fatalities has been observed in many of the years when unemployment dropped and the economy improved.

The models developed in this study control for (5) country, year and GDP per capita when estimating the effect of unemployment on traffic fatalities. Considering the fact that the final models were based on only 40 or 41 data points for each country, this is a fairly good control for potentially confounding factors. As a general rule, the number of observations should be at least ten times the number of variables. This means that if there are 40 observations, at most four independent variables can be used.

Figure 3.40. **Relationship between percentage points change in unemployment and per cent change in the number of traffic fatalities – synthesised data**



Three causal mechanisms have been discussed (6). One of these – changes in road user behaviour – is difficult to observe and data regarding such behaviour are notoriously incomplete. However, changes in fatality rate have been interpreted as an indicator of changes in road user behaviour, although fatality rate is obviously influenced by many other factors. There is, however, little doubt that road user behaviour is one of the most important factors influencing fatality rate. Thus, Elvik (2011B) has estimated that the number of traffic fatalities can be reduced by at least 50% if 15 traffic violations, including speeding, drinking and driving and not wearing seat belts, were eliminated.

The theoretical basis (7) for believing that road safety is related to economic performance has not been discussed at depth in this report, but is the topic of a report to the ITF by Wijnen and Rietveld (2013). It is well known that the volume of travel is closely related to wealth; hence when the growth in income stagnates, one may expect traffic growth to also stagnate. Trips to and from work are directly related to the number of people employed; thus, when there is high unemployment, the number of work-related trips will be reduced. It also seems reasonable to think that people become more risk averse in times of economic uncertainty. To the extent that risk aversion leads to more cautious road user behaviour, this will benefit road safety. Thus the main findings of the study presented in this report are theoretically plausible.

The findings of the study are consistent with a dose-response pattern (8) in the relationship between the rate of unemployment and changes in the number of traffic fatalities. There is, however, considerable scatter of the data points around the dose-response curve.

Finally, as far as selective effects are concerned (9), there is evidence that increasing unemployment has a larger effect on the number traffic fatalities involving young people than on traffic fatalities in other age groups.

It is therefore concluded that there are stronger reasons for believing that there is a causal relationship between changes in unemployment and changes in the number of traffic fatalities than for believing that no such causal relationship exists. It must be added, though, that the relationship is still imperfectly known and that its precise nature is surrounded by great uncertainty.

Conclusions

Three main research problems were formulated for this study:

1. What is the current state-of-knowledge regarding the relationship between economic performance and road safety as established by previous studies?

2. To what extent have the mechanisms that generate a relationship between economic performance and road safety been uncovered?

3. What is the relationship between economic performance and road safety in selected OECD-countries, assessed for the period 1970-2010?

The following answers can be given to these questions. There is evidence from previous studies of a negative relationship between economic performance and road safety. When economic performance gets worse and specifically when unemployment increases, road safety is improved. According to previous studies, the elasticity of the number of road accident fatalities with respect to unemployment is around -0.025 to -0.060. This means that when unemployment increases by 1 percent, the number of traffic fatalities goes down by between 0.025 and 0.060 percent. This may seem like a small effect, but it should be remembered that unemployment has increased considerably more than 1% in many motorised countries during the recent economic recession. As an example, unemployment in the United States increased from 5.8% in 2008 to 9.3% in 2009, an increase of 60 percent. Such an increase in unemployment would, according to previous studies, be expected to be associated with a reduction of between 1.5 and 3.9% of the number of traffic fatalities.

The mechanisms generating a relationship between economic performance -- in particular the rate of unemployment -- and road safety are imperfectly known. Three mechanisms are proposed:

1. Economic recessions are associated with less growth in traffic or a decline in traffic volume.

2. Economic recessions are associated with a disproportionate reduction in the exposure of high-risk groups in traffic; in particular unemployment tends to be higher among young people than people in other age groups.

3. Economic recessions may be associated with more cautious road user behaviour, such as less drinking and driving, lower speed, fewer holiday trips on unfamiliar roads, etc.

These mechanisms are not fully observable. An attempt has nevertheless been made in this report to identify their relative importance. It was found that a reduction of traffic volume contributes very little to the reduction of the number of traffic fatalities associated with economic recessions. The major contributor is a reduction of fatality rate, which to some extent may be the result of changes in road user behaviour.

Based on data collected from IRTAD and other databases made available by the OECD, an attempt was made to develop models describing the relationship between economic performance and road safety in fourteen OECD countries during the period 1970-2010. Three main types of models were developed. While two of these models were not fully satisfactory in all respects, the third type of model (mixed linear model) satisfied all criteria of model quality. Model predictions were found to converge to a remarkable degree.

According to the models, economic recession during 2009 and 2010 has contributed to a reduction of the number of traffic fatalities by about 4,850 during these two years in the fourteen countries included in the study: Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Ireland, Japan, Netherlands, Norway, Sweden, Switzerland, and the United States

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APPENDIX

Original and new estimates of vehicle kilometres of driving in Austria

Estimates are shown below. New estimates are shown in bold italics.

Year	Revised estimate (million)	Original estimate (million)
1970	23559	23559
1971	25421	25421
1972	27734	27734
1973	28982	28982
1974	28837	28837
1975	30366	30366
1976	31307	31307
1977	32779	32779
1978	34188	34188
1979	35282	35282
1980	35600	35600
1981	35600	35600
1982	36419	36419
1983	37730	37730
1984	39051	39051
1985	39871	39871
1986	42622	42622
1987	***43176***	49441
1988	***43545***	49863
1989	***46592***	53353
1990	***48762***	55837
1991	***50238***	57528
1992	***52515***	60135
1993	***53529***	61296
1994	***55730***	63816
1995	***56834***	65081
1996	***58792***	67323
1997	***60012***	68720
1998	***61257***	70146
1999	***63201***	72371
2000	65141	65141
2001	66308	66308
2002	67845	67845
2003	69167	69167
2004	70148	70148
2005	71511	71511
2006	72512	72512
2007	74417	74417
2008	75292	75292
2009	74779	74779
2010	75383	75383

Original and new estimates of vehicle kilometres of driving in Finland

Estimates are shown below. New estimates are shown in bold italics.

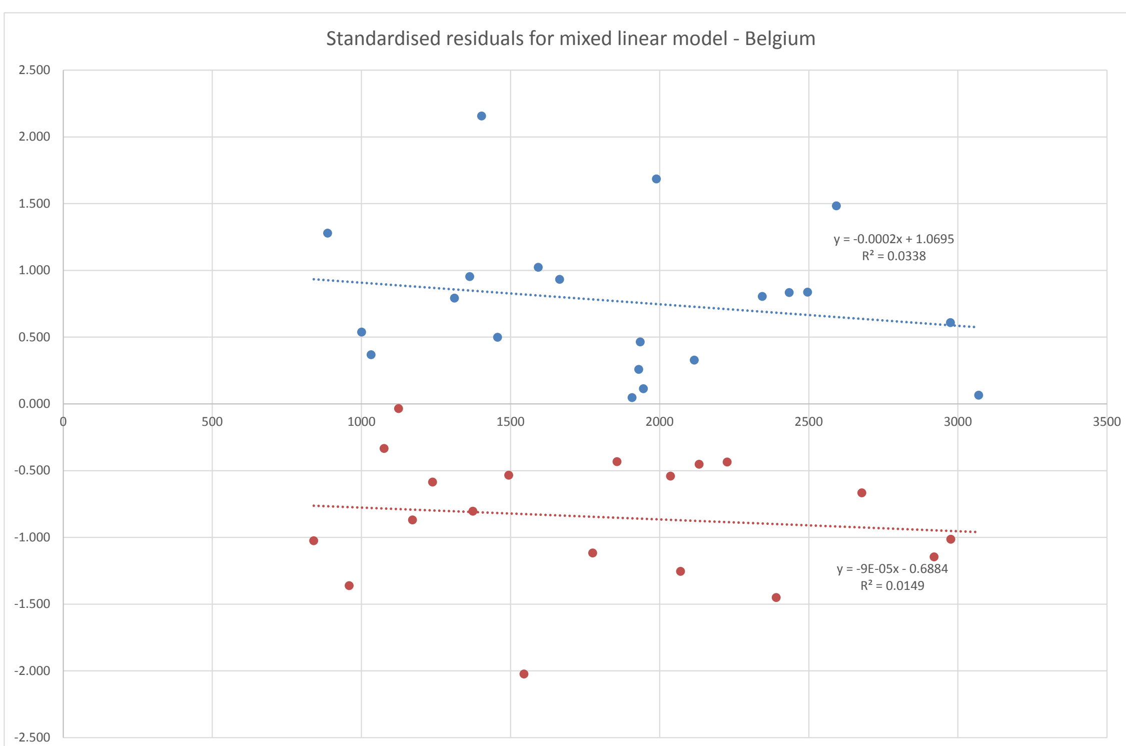
Year	Revised estimate (million)	Original estimate (million)
1970	***17752***	10380
1971	***18586***	10870
1972	***20926***	11870
1973	***22579***	12810
1974	***22195***	12600
1975	***24370***	13840
1976	25090	25090
1977	25390	25390
1978	25920	25920
1979	26420	26420
1980	26760	26760
1981	27270	27270
1982	28200	28200
1983	29080	29080
1984	29940	29940
1985	31150	31150
1986	32530	32530
1987	34250	34250
1988	36510	36510
1989	38710	38710
1990	39750	39750
1991	39170	39170
1992	42350	42350
1993	41950	41950
1994	41750	41750
1995	42170	42170
1996	42520	42520
1997	43530	43530
1998	44800	44800
1999	46010	46010
2000	46710	46710
2001	47650	47650
2002	48750	48750
2003	49790	49790
2004	50890	50890
2005	51675	51675
2006	52150	52150
2007	53250	53250
2008	52980	52980
2009	53350	53350
2010	53815	53815

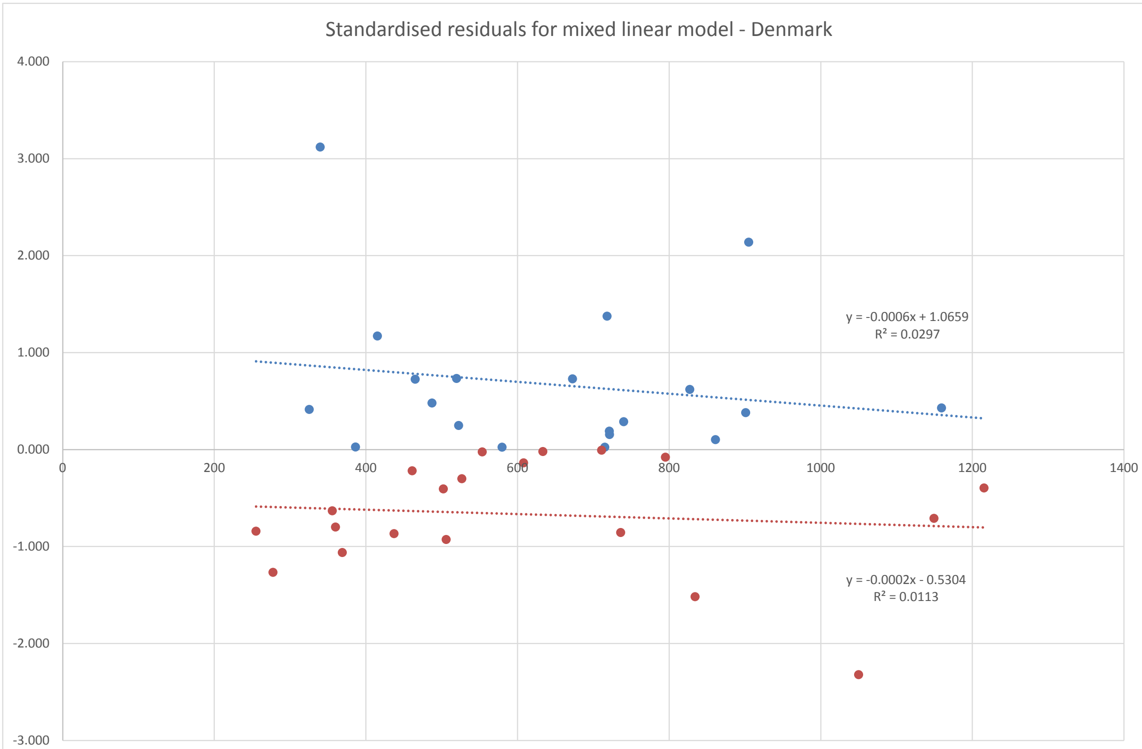
Original and new estimates of vehicle kilometres of driving in Japan

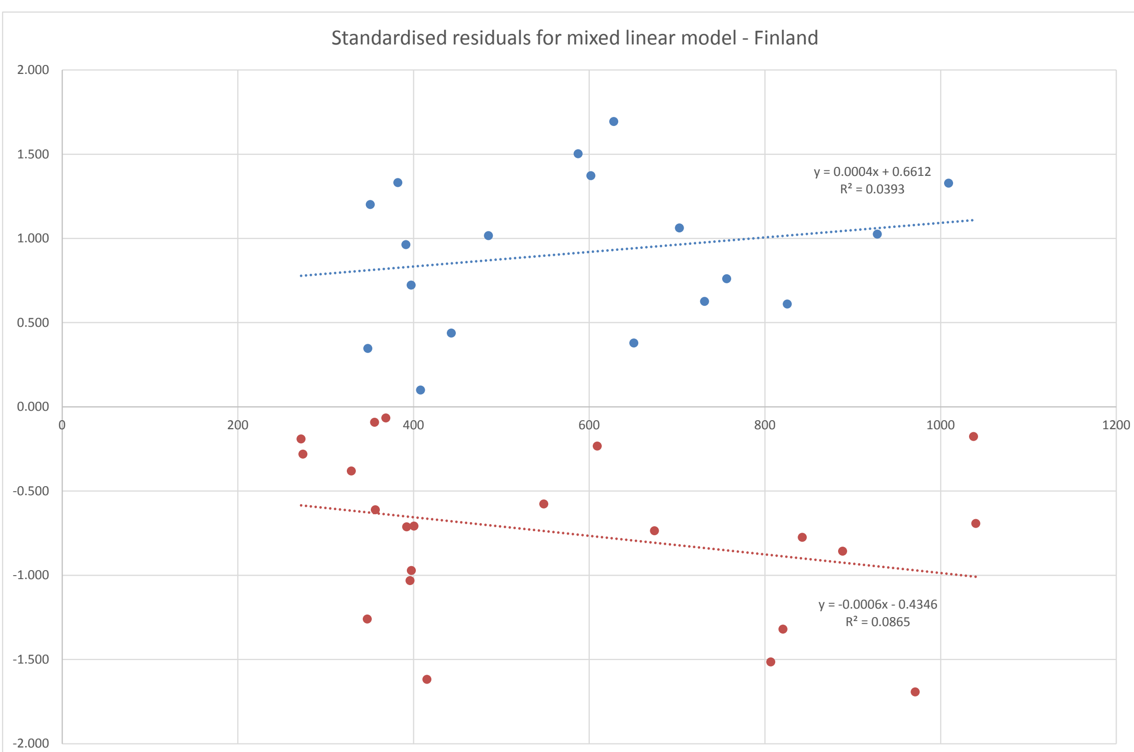
Estimates are shown below. New estimates are shown in bold italics

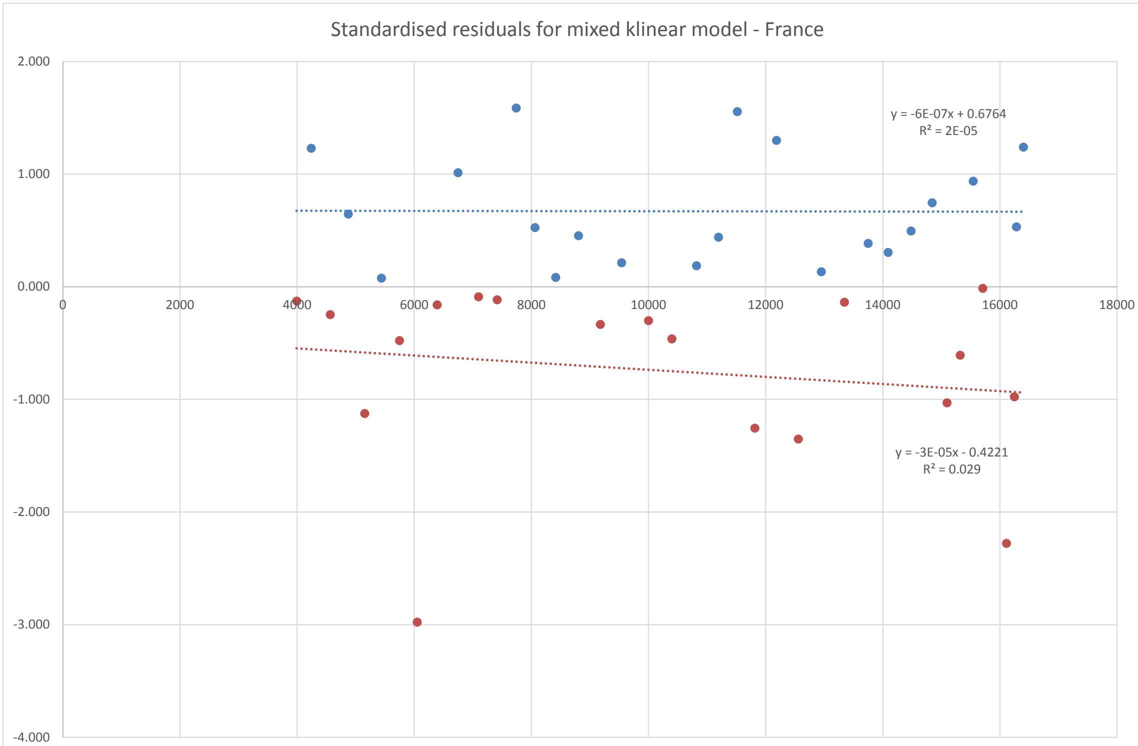
Year	Revised estimate (million)	Original estimate (million)
1970	***271100***	226017
1971	***292045***	243479
1972	***311373***	259593
1973	***331285***	276194
1974	***319639***	266485
1975	***343461***	286345
1976	***371472***	309698
1977	***410609***	342326
1978	***433321***	361261
1979	***458137***	381951
1980	***466665***	389052
1981	***473379***	394658
1982	***483506***	403101
1983	***490495***	408928
1984	***498670***	415743
1985	***513902***	428442
1986	***529700***	441613
1987	548834	548834
1988	575585	575585
1989	600217	600217
1990	628581	628581
1991	657305	657305
1992	678211	678211
1993	683753	683753
1994	694336	694336
1995	720283	720283
1996	737763	737763
1997	744379	744379
1998	746054	746054
1999	765056	765056
2000	775723	775723
2001	790820	790820
2002	790829	790829
2003	793378	793378
2004	781711	781711
2005	768879	768879
2006	762613	762613
2007	763629	763629
2008	746869	746869
2009	746008	746008
2010	***780000***	746008

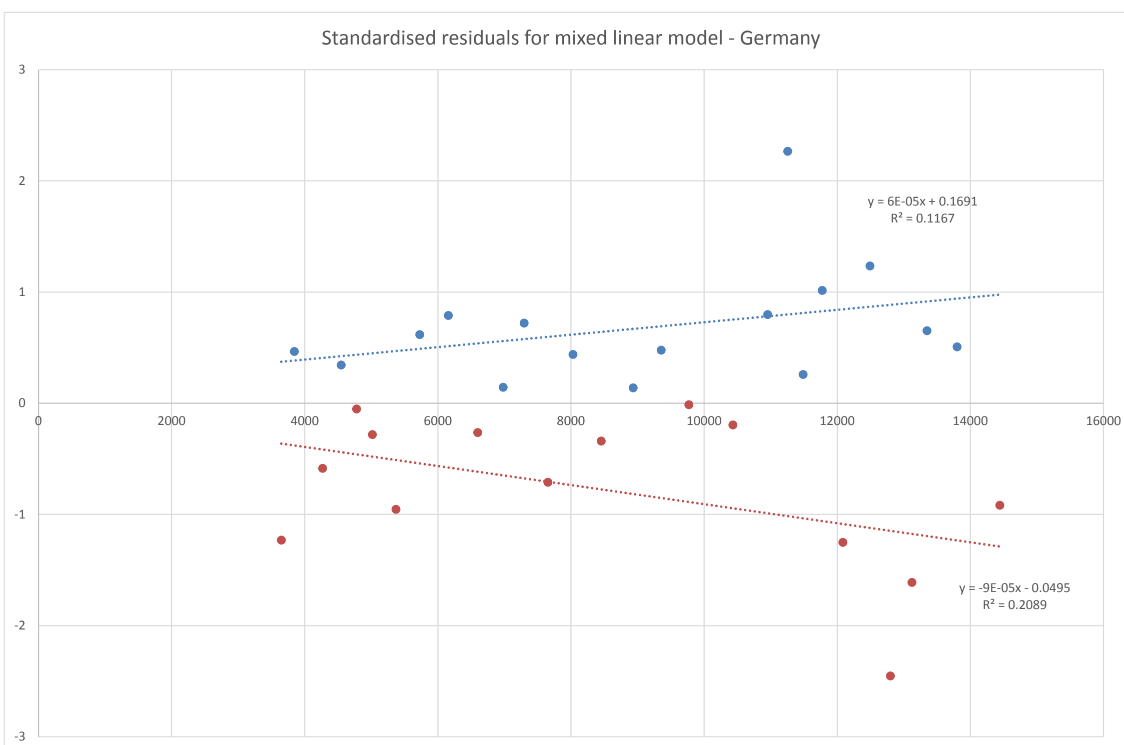

Standardised residuals for mixed linear model - Austria
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
0
500
1000
1500
2000
2500
3000
y = 0.0001x + 0.5398
R² = 0.0155
y = -5E-05x - 0.7761
R² = 0.0032

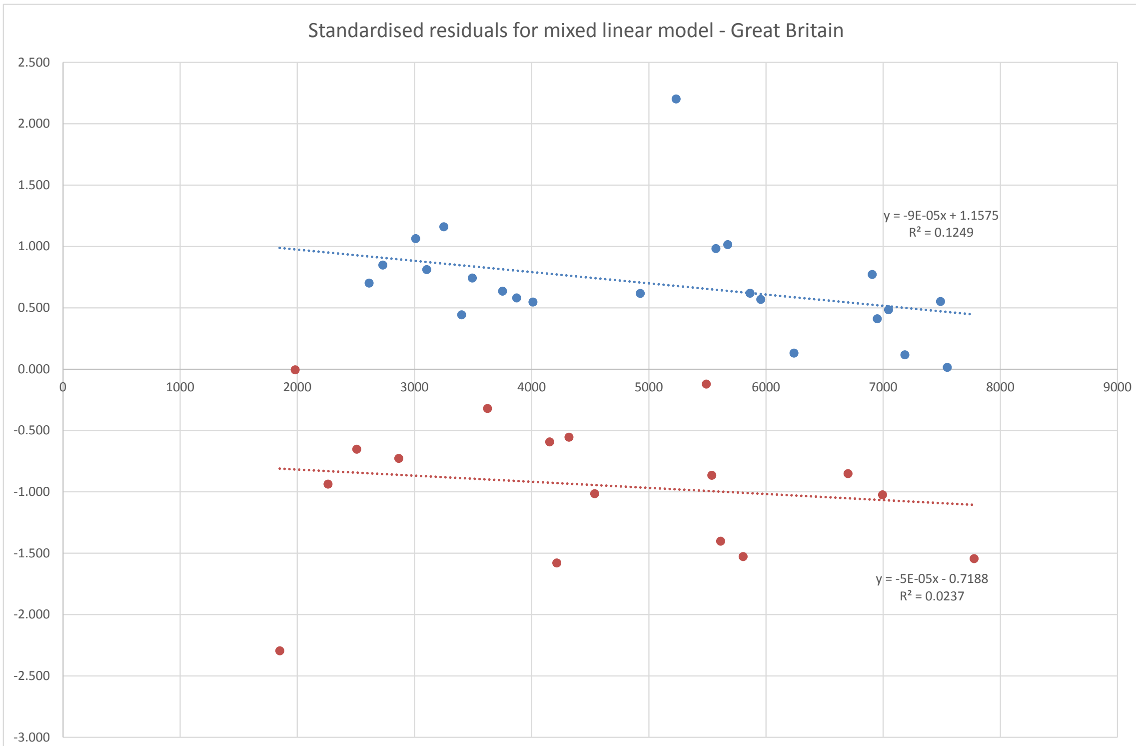

Standardised residuals for mixed linear model - Belgium
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
0
500
1000
1500
2000
2500
3000
3500
y = -0.0002x + 1.0695
R² = 0.0338
y = -9E-05x - 0.6884
R² = 0.0149

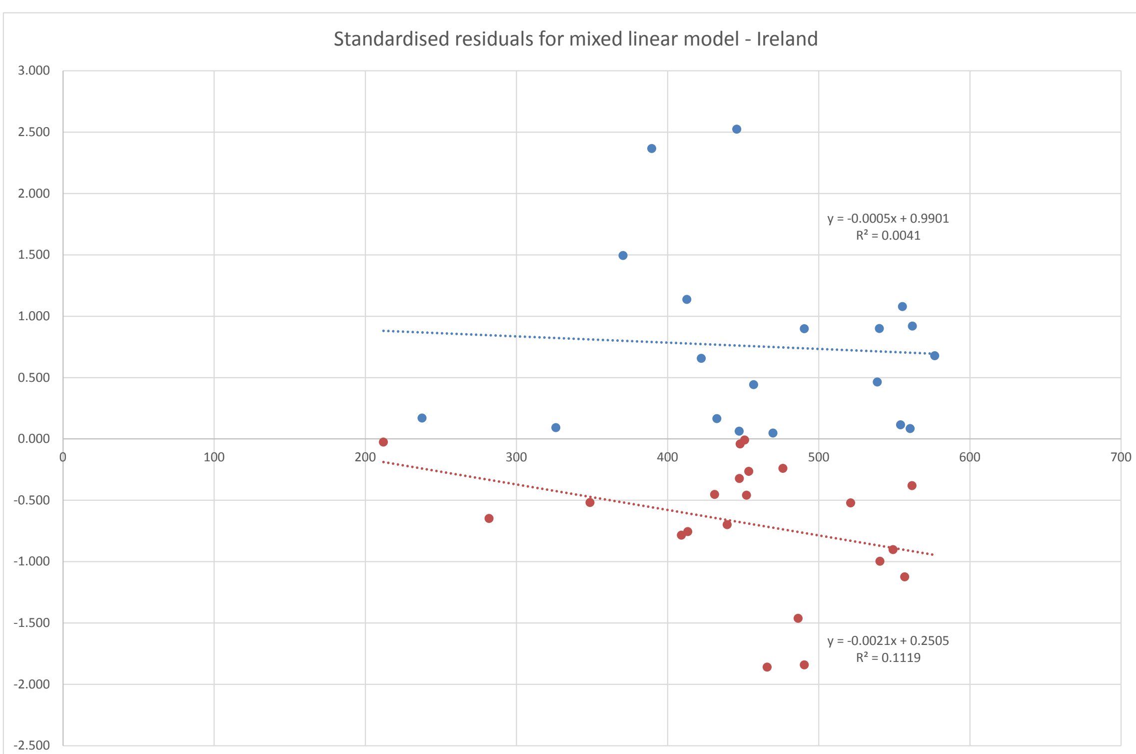

Standardised residuals for mixed linear model - Denmark
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
200
400
600
800
1000
1200
1400
y = -0.0006x + 1.0659
R² = 0.0297
y = -0.0002x - 0.5304
R² = 0.0113

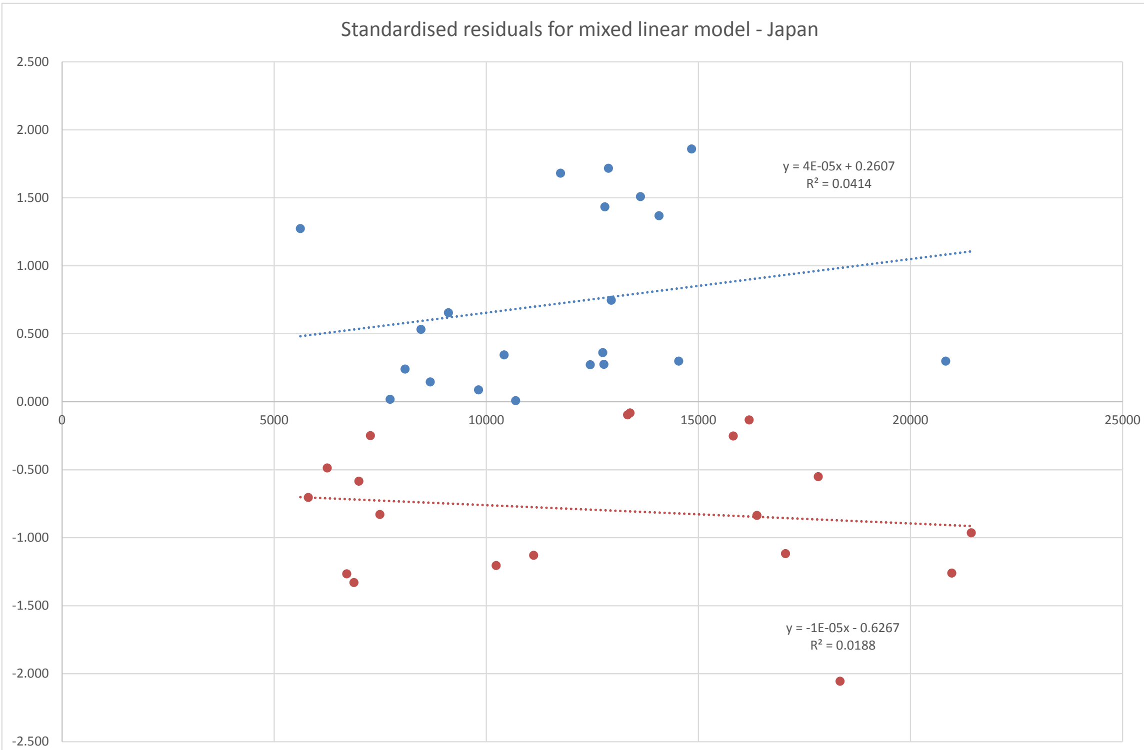

Standardised residuals for mixed linear model - Finland
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
0
200
400
600
800
1000
1200
y = 0.0004x + 0.6612
R² = 0.0393
y = -0.0006x - 0.4346
R² = 0.0865

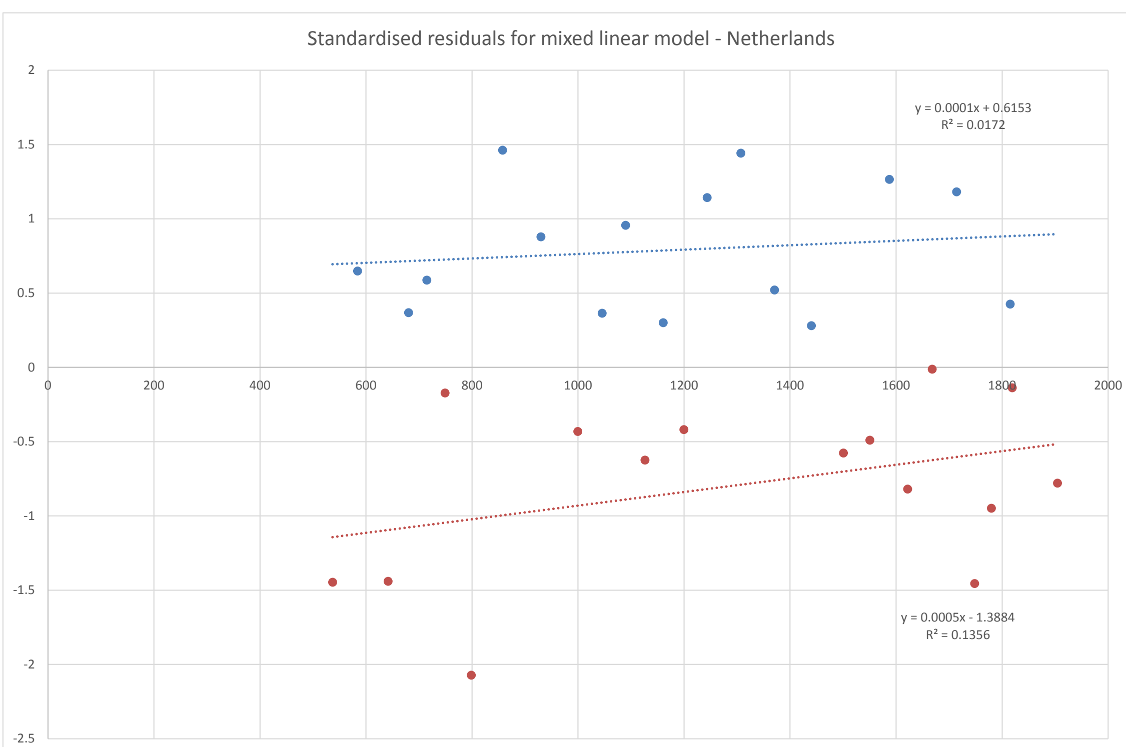

Standardised residuals for mixed klinear model - France
y = -6E-07x + 0.6764
R² = 2E-05
y = -3E-05x - 0.4221
R² = 0.029
2.000
1.000
0.000
-1.000
-2.000
-3.000
-4.000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000

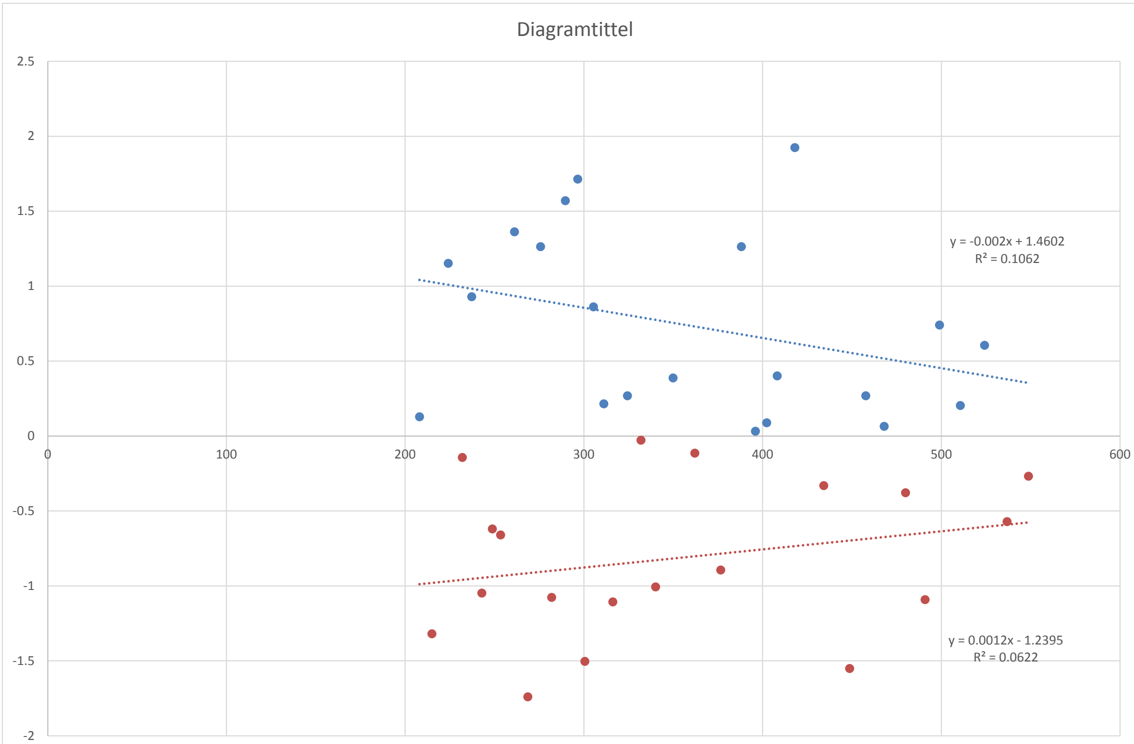

Standardised residuals for mixed linear model - Germany
y = 6E-05x + 0.1691
R² = 0.1167
y = -9E-05x - 0.0495
R² = 0.2089
3
2
1
0
-1
-2
-3
0
2000
4000
6000
8000
10000
12000
14000
16000

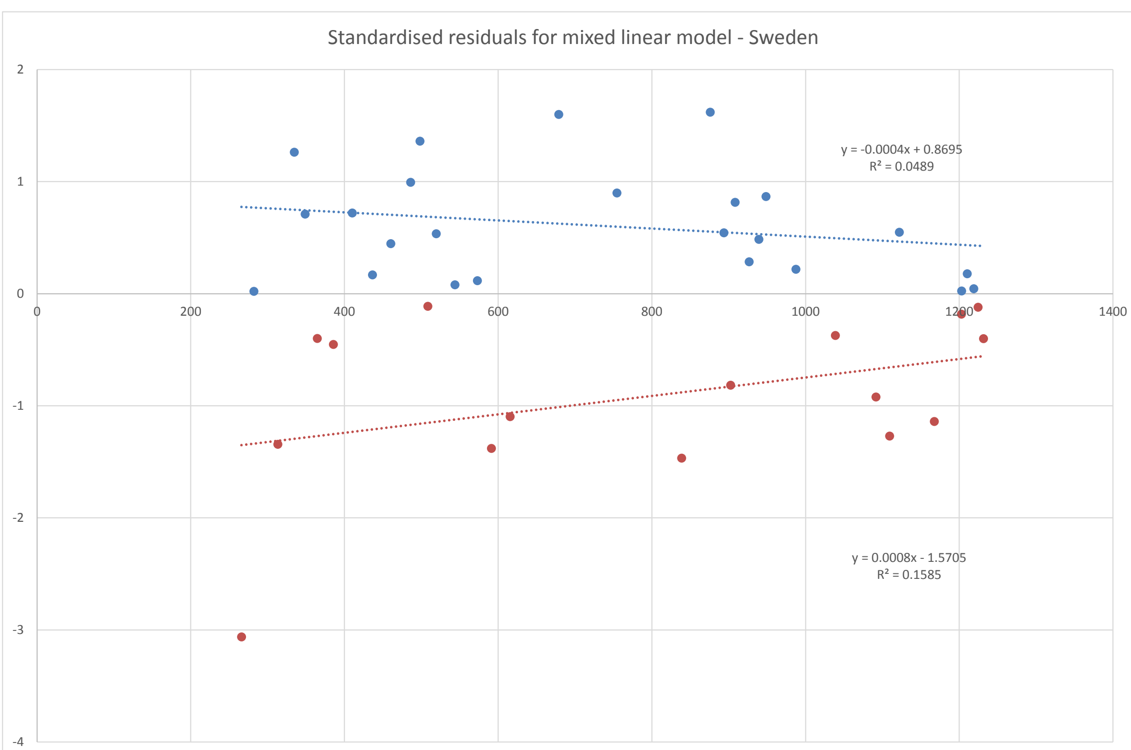

Standardised residuals for mixed linear model - Great Britain
y = -9E-05x + 1.1575
R² = 0.1249
y = -5E-05x - 0.7188
R² = 0.0237

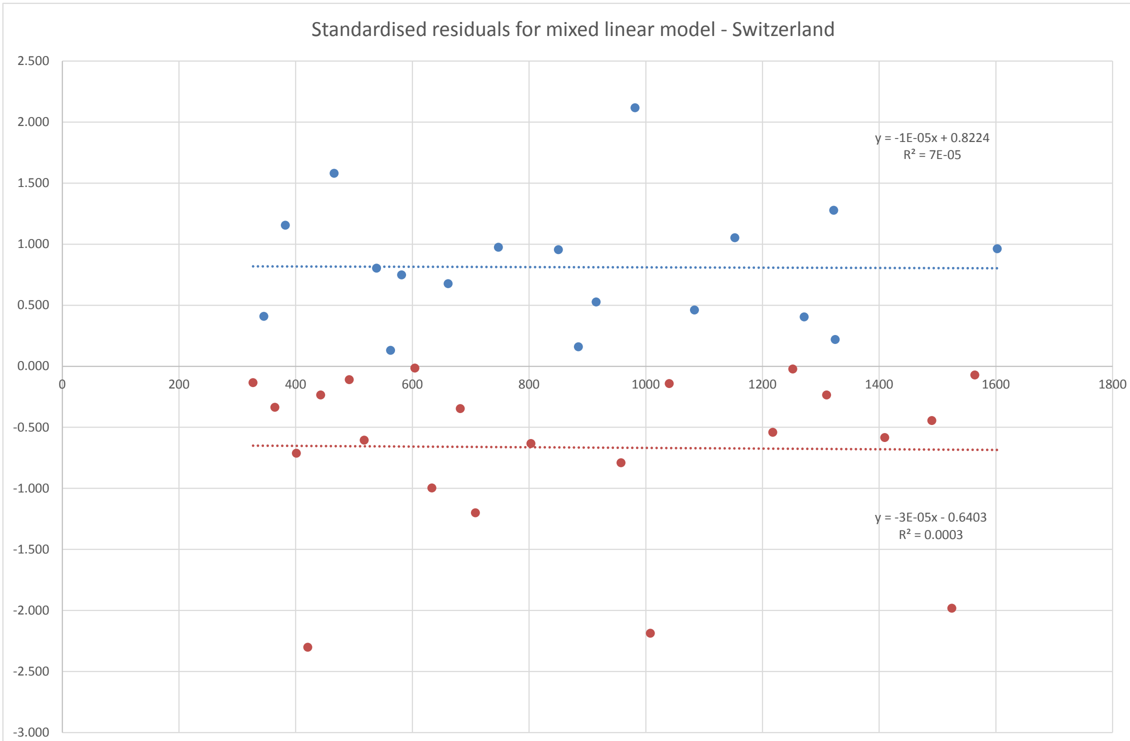

Standardised residuals for mixed linear model - Ireland
y = -0.0005x + 0.9901
R² = 0.0041
y = -0.0021x + 0.2505
R² = 0.1119

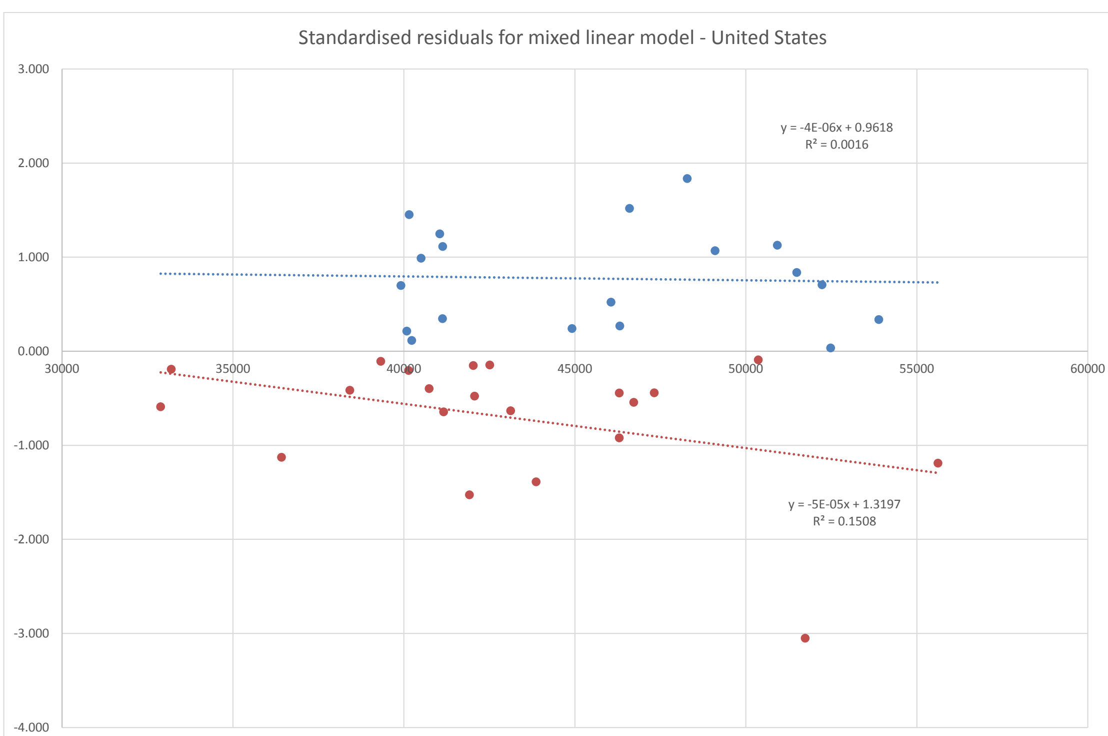

Standardised residuals for mixed linear model - Japan
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
0
5000
10000
15000
20000
25000
y = 4E-05x + 0.2607
R² = 0.0414
y = -1E-05x - 0.6267
R² = 0.0188


Standardised residuals for mixed linear model - Netherlands
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
y = 0.0001x + 0.6153
R² = 0.0172
y = 0.0005x - 1.3884
R² = 0.1356


Diagramtittel
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
100
200
300
400
500
600
y = -0.002x + 1.4602
R² = 0.1062
y = 0.0012x - 1.2395
R² = 0.0622


Standardised residuals for mixed linear model - Sweden
2
1
0
-1
-2
-3
-4
0
200
400
600
800
1000
1200
1400
y = -0.0004x + 0.8695
R² = 0.0489
y = 0.0008x - 1.5705
R² = 0.1585


Standardised residuals for mixed linear model - Switzerland
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
-3.000
0
200
400
600
800
1000
1200
1400
1600
1800
y = -1E-05x + 0.8224
R² = 7E-05
y = -3E-05x - 0.6403
R² = 0.0003


Standardised residuals for mixed linear model - United States
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
-4.000
30000
35000
40000
45000
50000
55000
60000
y = -4E-06x + 0.9618
R² = 0.0016
y = -5E-05x + 1.3197
R² = 0.1508

CHAPTER 4. IMPROVING FATALITIES FORECASTING IN TIMES OF RECESSION IN EUROPE[1]

Modelling road safety is a complex task, which needs to consider both the quantifiable impact of specific parameters, as well as the underlying trends that cannot always be measured or observed. One of the key relationships in road safety links fatalities with risk and exposure, where exposure reflects the amount of travel, which in turn translates to how much travellers are exposed to risk. It is reasonable to expect that – for the same level of risk – when there is a higher amount of travel, fatalities may increase, solely due to the increased exposure. Similarly, of course, when exposure is reduced (e.g. due to a slowdown of the economy), fatalities may decrease, solely on account of this phenomenon, and not due to some underlying road safety improvement. In general the two economic variables – GDP and the unemployment rate – are selected to analyse the statistical relationships with some indicators of road accident fatality risk.

The objective of this research is to provide an overview of the relevant literature on the topic and outline some recent developments in macro-panel analysis that have resulted in on-going research that has the potential to improve our ability to forecast traffic fatality trends, especially under turbulent financial situations. For this analysis, time series of the number of fatalities and GDP in 30 countries for a period of 38 years are used. This process starts by estimating short-term models (as captured by analysis of panel data) and long-term models (as captured by long-term time-series models, which model each country separately). Based on these developments, directions for the combination of short-term and long-term models, utilising state-of-the-art modelling and analysis techniques such as the error-correction representation, are outlined

Introduction

Modelling road safety is a complex task, which needs to consider both the quantifiable impact of specific parameters, as well as the underlying trends that cannot always be measured or observed. One of the key relationships in road safety links fatalities with risk and exposure, where exposure reflects the amount of travel, which in turn translates to how much travellers are exposed to risk. It is reasonable to expect that – for the same level of risk – when there is a higher amount of travel, fatalities may increase, solely due to the increased exposure. Similarly, of course, when exposure is reduced, fatalities may decrease, solely on account of this phenomenon, and not due to some underlying road safety improvement. Examples of such analyses exist in the literature. One of the oldest studies relates to the impact of the petrol crisis and the reduction of the speed limit in the US in the early 70s, which led to a reduction in the number of crashes and traffic fatalities in the US (Tihansky, 1974). Several studies attempted to model the impact of the economic recession that was experienced in the early 80s (Wagenaar, 1984; Hedlund *et al*., 1984; Reinfurt *et al*., 1991). Kweon (2011) found that annual changes

1. Authors: Constantinos Antoniou, George Yannis, Eleonora Papadimitriou, National Technical University of Athens; Sylvain Lassarre, GRETTIA-IFSTTAR, France.

in the unemployment rate and consumer price index (CPI) correlated strongly with the annual trends of the number of crashes and traffic fatalities in the US.

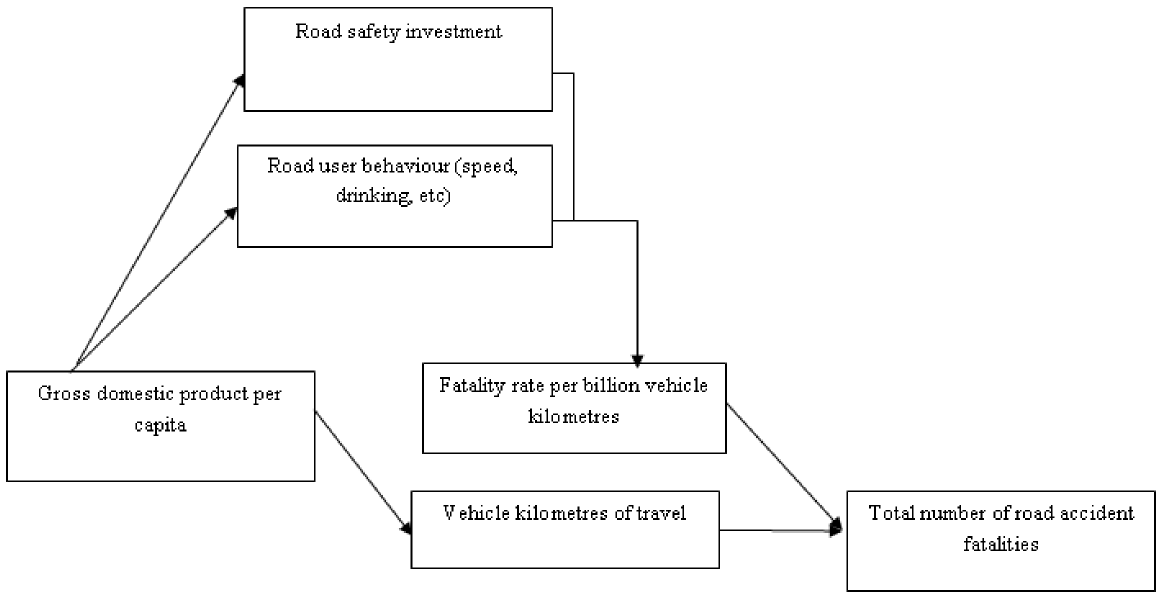
Exposure can vary due to a large number of underlying factors; in the current economic situation, lower Gross Domestic Product (GDP) and rising unemployment are such contributing factors. Antoniou and Yannis (2013) provide a discussion of using different proxy measures to the economic situation (such as the number of vehicles in circulation or fuel consumption), when actual exposure measurements are not available. Kopits and Cropper (2005) develop models to examine the relationship between traffic fatality risk and per-capita income and use it to forecast traffic fatalities for multiple regions. Söderlund and Zwi (1995), after adjusting for motor vehicle numbers, find that the poorest countries show the highest road traffic-related mortality rates. Bishai *et al*. (2006) observe that traffic fatalities increase with GDP per capita in lower-income countries and decrease with GDP per capita in wealthy countries, and explore this finding using fixed effects regression. This is an alarming finding, as it implies that as lower-income countries become richer, traffic fatalities are expected to increase (and indeed the WHO predicts that the current number of 1.3 million global road fatalities per year, may rise to 1.9 million by 2020 (WHO, 2011).

The objective of this research is to provide an overview of relevant literature on the topic and outline some recent developments in macro-panel analysis that have resulted in on-going research that has the potential to improve our ability to forecast traffic fatality trends, especially under turbulent financial situations. This process starts by estimating short-term models (as captured by analysis of panel data; see e.g., Yannis *et al*., 2014) and long-term models (as captured by long-term time-series models, which model each country separately; see e.g. Antoniou *et al*., in press). Based on these developments, directions for the combination of short-term and long-term models, utilising state-of-the-art modelling and analysis techniques such as the error-correction representation, are outlined.

Background

In general, the two economic variables – GDP and unemployment rate – are selected to analyse the statistical relationships with some indicators of road accident fatality risk. The nature of these time series are different: GDP follows a random walk with drift, with two components that are a deterministic trend, usually increasing linearly and a sum of stochastic shocks coming from a random walk; the unemployment rate follows just a random walk. The dependency of these two economic variables is not straightforward. GDP is privileged in the analysis because of its direct influence on the number of kilometres driven, which is a measure of the exposure to the risk of accident directly proportional to the number of fatalities. Figure 4.1 outlines some of the general mechanisms through which economic conditions may be linked to road safety. In particular, changes in the available resources can result in changes in the levels of road safety investment, but also in the behaviour of users, leading them to reduce their speed or change their drinking habits. Both of these changes affect the traffic risk. Furthermore, economic changes have direct effects on the amount of traffic (exposure) and both terms (risk and exposure) result in changes in the total number of road crashes and associated fatalities.

Figure 4.1. **Schematic of the connection between the economy and road safety**



Such influences are rather immediate, as seen in Table 1, which provides an overview of the number of fatalities and GDP per capita during the crisis for selected European countries. Several interesting observations can be made from these data, even before developing models. For several countries, for which the economy recovers after 2009, an increase in fatalities can be observed (either the same year or one year later); these countries include Belgium, Germany, Italy, Finland, Sweden and the UK. On the other hand, in some countries (such as Greece, Ireland, Spain and Portugal), both GDP and fatalities are still dropping in 2011. It is noted that there are a few exceptions (such as Austria, the Netherlands, Hungary and the Czech Republic) where GDP recovers but fatalities continue decreasing. Monitoring of future developments in these countries (growth and safety measures) will provide further insight into the exact processes underway.

Table 4.1. **Overview of number of fatalities and GDP per capita during the crisis for selected European countries**

	Fatalities					GDP per capita				
	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
Belgium	1071	944	942	840	843	38.27	38.61	37.51	38.29	39.14
Czech Republic	1221	1076	901	802	769	13.80	14.15	13.58	13.91	14.29
Germany	4949	4477	4152	3648	4006	35.83	36.30	34.53	35.89	37.01
Estonia	196	132	100	79	101	12.48	11.92	10.33	10.58	11.31
Ireland	338	280	238	212	188	50.80	47.94	43.70	42.84	41.98
Greece	1612	1553	1456	1281	1100	24.79	25.01	24.46	23.34	22.16
Spain	3823	3100	2714	2478	2298	26.92	26.74	25.53	25.38	25.41
France	4620	4275	4273	3992	3969	35.11	34.88	33.73	34.05	34.42
Italy	5131	4725	4237	3934	3941	30.95	30.31	28.55	28.78	28.86
Lithuania	740	499	370	300	299	8.61	8.88	7.60	7.72	8.15
Hungary	1232	996	822	739	639	11.15	11.26	10.52	10.66	10.97
Netherlands	709	677	644	640	550	41.92	42.55	40.69	41.20	41.71
Austria	691	679	633	552	521	39.70	40.54	38.94	39.69	40.62
Poland	5583	5437	4572	3907	4164	8.95	9.41	9.57	9.94	10.36
Portugal	974	885	840	845	782	18.72	18.66	18.14	18.34	17.97
Finland	380	344	279	272	290	41.69	42.05	38.55	39.92	41.44
Sweden	471	397	358	266	311	44.22	43.87	41.47	43.70	45.55
United Kingdom	3059	2645	2222	1905	1998	39.29	39.02	36.90	37.15	37.32

Source: Yannis *et al.*, 2014.

Methodological approaches

Table 2 provides a systematic classification of analysis approaches for different types of data. When a single country is considered and a sufficiently long time series is available, then univariate time series models can be used (Commandeur *et al.*, 2013). Different types of functional forms can be specified, e.g. autoregressive regression with linear trend, ARIMAX, structural model (bivariate). When a large number of countries is available (e.g. 30), but only a small number of time observations are available, then cross-sectional and micro-panel analysis can be performed using (Poisson or negative binomial) regression, possibly with autoregressive terms. Finally, when there are data that span multiple countries and offer a sufficient number of time observations, then macro-panel analysis with regression considering co-integration of the time-series can be performed.

Table 4.2. **Analysis methods**

Country N	**Time T**	
	Small (1 to 5)	**Large (30)**
Small (1)		Univariate time series model: autoregressive regression with linear trend, ARIMAX, structural model (bivariate)
Large (30)	Cross-sectional and micro panel analysis with (Poisson or NB) regression (+autoregression)	Macro-panel analysis with regression (cointegration)

In the methodological framework presented, two statistical techniques are used to analyse the panel data of European countries:

- A macro-panel regression of the first difference of the logarithm of the number of fatalities by the first difference of the logarithm of GDP. This corresponds to a short-term analysis of the relationship between the annual changes in safety and economy or to a growth rate model.

$$\log FAT_{it} - \log FAT_{it-1} = \alpha_i + \beta_{0i}(\log GDP_{it} - \log GDP_{it-1}) + \nu_{it}$$

- A macro-panel regression of the logarithm of the number of fatalities by the logarithm of GDP. This corresponds to a long-term analysis of the relationship between safety and economy or to a static model.

$$\log FAT_{it} = \alpha_i + \beta_{0i} \log GDP_{it} + \nu_{it}$$

These two models are special cases of a general dynamic model, called the autoregressive distributed lag model, with restrictions on the model parameters ($\beta_{i1} = \beta_{i2} = 0$ for static, $\beta_{i1} = -\beta_{i0}$, $\beta_{i2} = 1$ for differentiated model).

$$\log FAT_{it} = \alpha_i + \beta_{i0} \log GDP_{it} + \beta_{i1} \log GDP_{it-1} + \beta_{i2} \log FAT_{it-1} + \nu_{it}$$

The main interest in macro-panel analysis is to obtain more robust estimates of the effects of economic variables on the number of fatalities by aggregating or grouping the regressions undertaken, which can give more reliable predictions than from one country alone. Furthermore, there is also a gain in parsimony and precision of the grouping models for a set of countries used to predict the number of fatalities, compared to the compilation of individual and independent models country per country.

Macro-panel analysis allows two kinds of estimate of the short- and long-term elasticities. Either we suppose that they are homogeneous among the countries, and the pooled estimate is recommended, or they are heterogeneous and the mean-group estimate based on individual country regressions is recommended. Most of the models are fixed-effect models on the intercepts rather than random-effect models, because there are large differences in terms of risk level between the European countries.

Exploratory analysis

Nature of the time series

We have at our disposal for this analysis 30 time series of the number of fatalities and GDP for a period of 38 years. From previous econometric models on economic growth in the EU, it is known that the Gross National Production deflated by the price index is non-stationary and integrated of order 1 I(1) (Arpaia and Turrini, 2008). The structural models of the number of fatalities developed in the European DaCoTA project include either a random level component or a random slope component, meaning that the time series on fatalities are non-stationary integrated of order 1 or 2 (Dupont *et al.*, 2012).

Table 4.3. **Significance of the level and slope variances in structural models of the number of fatalities and induced order of integration -- EU countries**

	Level	Slope	Integration
AT	NS	NS	0
BE	S	NS	1
BG	NS	NS	0
CH	NS	NS	0
CY	NS	NS	0
CZ	NS	S	2
DE	NS	NS	0
DK	NE	S	2
EE	NS	S	2
EL	S	S	2
ES	NS	S	2
FI	NS	NS	0
FR	NS	S	2
HU	NS	NS	0
IE	NS	NS	0
IS	NS	NS	0
IT	NS	NS	0
LT	NS	NS	0
LU	NS	NS	0
LV	S	S	2
MT	NS	NS	0
NL	S	S	2
NO	S	NS	1
PL	S	NS	1
PT	S	NS	1
RO	NS	S	2
SE	S	NS	1
SI	S	NS	1
SK	S	NS	1
UK	NS	S	2

Source: DaCoTA project, Deliverable 4.4.

Table 4.3 presents the significance of the level and slope variances in structural models of the number of fatalities and induced order of integration from models estimated within the DaCoTA project. There are:

- 13 countries integrated of order 0: AT, BG, CH, CY, DE, FI, HU, IE, IS, IT, LT, LU, MT;
- 7 countries integrated of order 1: BE, NO, PL, PT, SE, SI, SF; and
- 10 countries integrated of order 2: CZ, DK, EE, EL, ES, FR, LV, NL, RO, UK.

As we suspect some time-series to be I(2), we carried out a set of Augmented Dickey-Fuller (ADF) tests with and without trend on first-differenced time series of the number of accidents. The hypothesis of unit root, which in that case means that the time-series is I(2), is not rejected for three countries: CZ, ES, and UK. Then from another set of Augmented Dickey-Fuller tests with and without trend on all time series, the hypothesis of unit root is not rejected in all the countries but MT, which is supposed to be stationary.

Panel unit root tests have been run on both sets of time series transformed with logarithms (Table 4). The Im, Pesaran and Shin (IPS) test allows for some of the series to have a unit root under the alternative, because the short-term dynamic is heterogeneous. Some lags can be added. The time series are demeaned by the cross-sectional averages and a linear trend is introduced. This test assumes the independence of the countries.

Table 4.4. **Statistics and p-value for the Im, Pesaran and Shin (IPS) test (Stata procedure xtunitroot) and Pesaran's CADF test (Stata procedure pescadf)**

		Lags	Statistic	P-value
GDP	IPS (trend)	0	1.60	0.945
	CADF(trend)	0	5.65	1.00
Fatalities	IPS (trend)	1	-1.32	0.093
	CADF	1	-0.419	0.338
	CADF (trend)	1	-2.089	0.018

We accept the null hypothesis that both series contain a unit root, with a greater certainty for GDP. There is a greater variety of time-series models for the number of fatalities: deterministic linear trend, random walk plus drift (integrated of order 1), or random slope plus drift (integrated of order 2). Furthermore, these time-series are subject to breaks in the level due to national safety measure implementations. When the thirty countries are divided in three groups, the IPS tests confirm that in the first group we reject the hypothesis of unit root and we accept the hypothesis in the second and third groups.

Table 4.5. **Statistics and p-value for the Im, Pesaran and Shin (IPS) test (Stata procedure xtunitroot) for the number of fatalities without trend and lags**

Group	Statistic	P-value
I(0)	-3.36	0.0004
I(1)	-1.43	0.076
I(2)	0.17	0.57

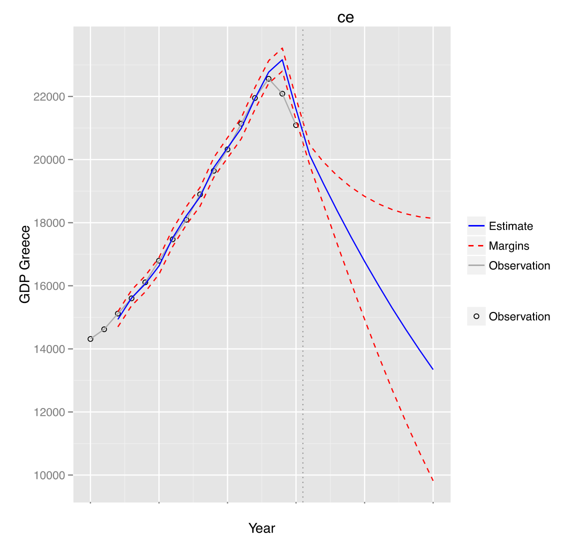
Analysis of individual countries

An example of analysis of the impact of GDP on the traffic fatalities in a single country can be found in Antoniou and Yannis (2013). In this analysis, latent-risk models are used to model the interaction between exposure and risk, using GDP and fatalities data from Greece between 1995 and 2010.

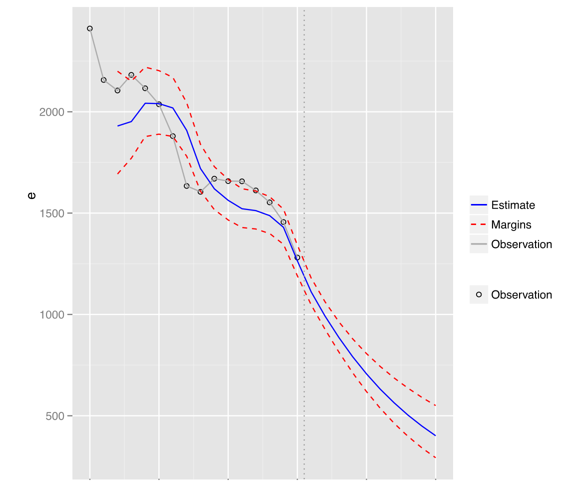
Figure 4.2 presents the forecast plots for a model without explicit modelling of recession (top) and a modified model that explicitly accounts for a recession, which at the time was projected to be over after 2013. There are several observations that can be made about this figure. Starting from the top left subfigure, the projection of the GDP for Greece appears to follow a downward trend all the way to 2020. While this is not impossible, it is highly unlikely. The reason for this trend is that the model detects the drop in the GDP in the last couple of years (due to the recession), but has no way to tell whether this trend will be reversed at some point. One way to overcome this would be to add an additional intervention variable to the model, which would indicate that the last few observations are part of a temporary recession phenomenon. This variable could then be used to indicate when the recession is expected to be over. Another way to indicate the same point (i.e. that these points are an intermediate disruption of an otherwise constant trend) would be to fix the slope of the exposure. However, the latter option would imply that the recovery would start from the first predicted point (i.e. 2011), which is clearly not the case. Therefore, the approach of an intervention recession variable has been selected, using 2013 as the last recession year. The bottom subfigures of Figure 4.2 show the results of this model, i.e. assuming that the recession is expected to last until 2013.

Figure 4.2. **The impact of the explicit modelling of recession for Greece**

Without modelling of recession:

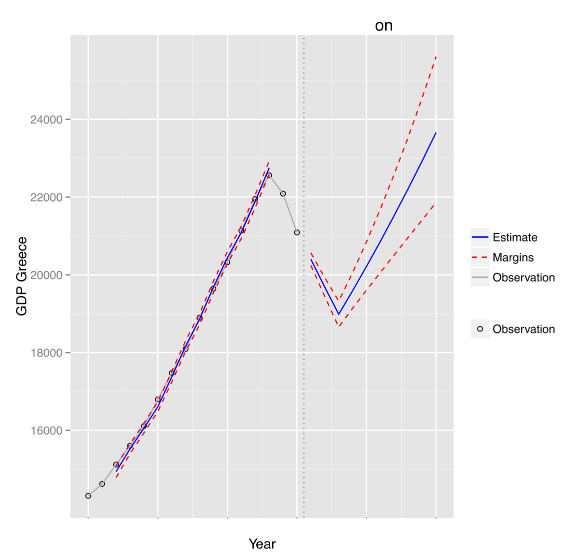


a. Gross Domestic Product (GDP)

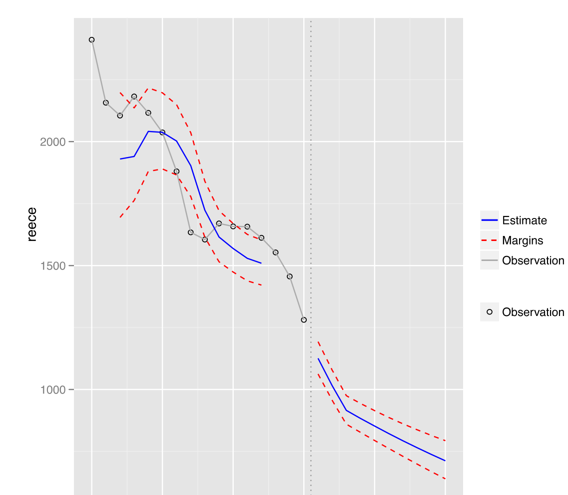


b. Fatalities

With modelling of recession:



c. Gross Domestic Product (GDP)



d. Fatalities

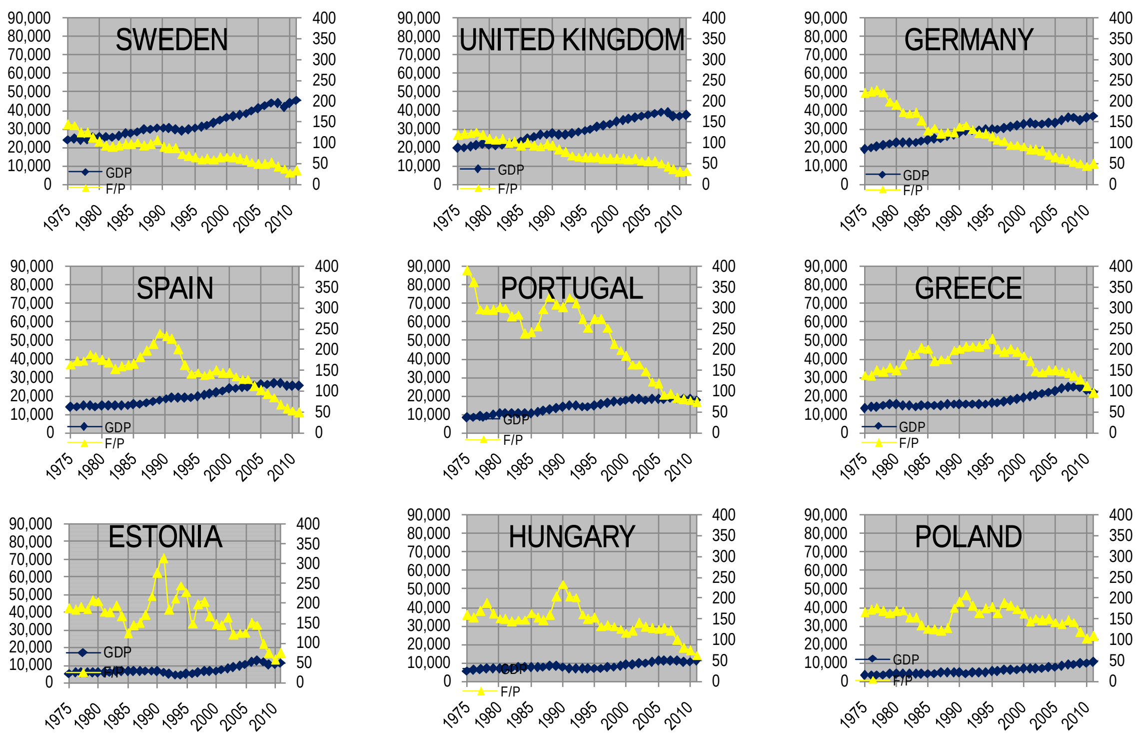
Source: Antoniou and Yannis, 2013.

Analysis of a panel of countries

In this section we look at the analysis of several countries, without explicitly developing a model that combines the data. However, such analyses are useful in understanding the underlying similarities of the various countries, which can in turn be useful in developing richer models.

Figure 4.3 shows the evolution of the per capita GDP and the number of fatalities per million population in selected European countries. The nature of the time series (most of which are integrated of order 1, that is to say following a random walk with or without drift) adds some difficulties to the exploratory analysis.

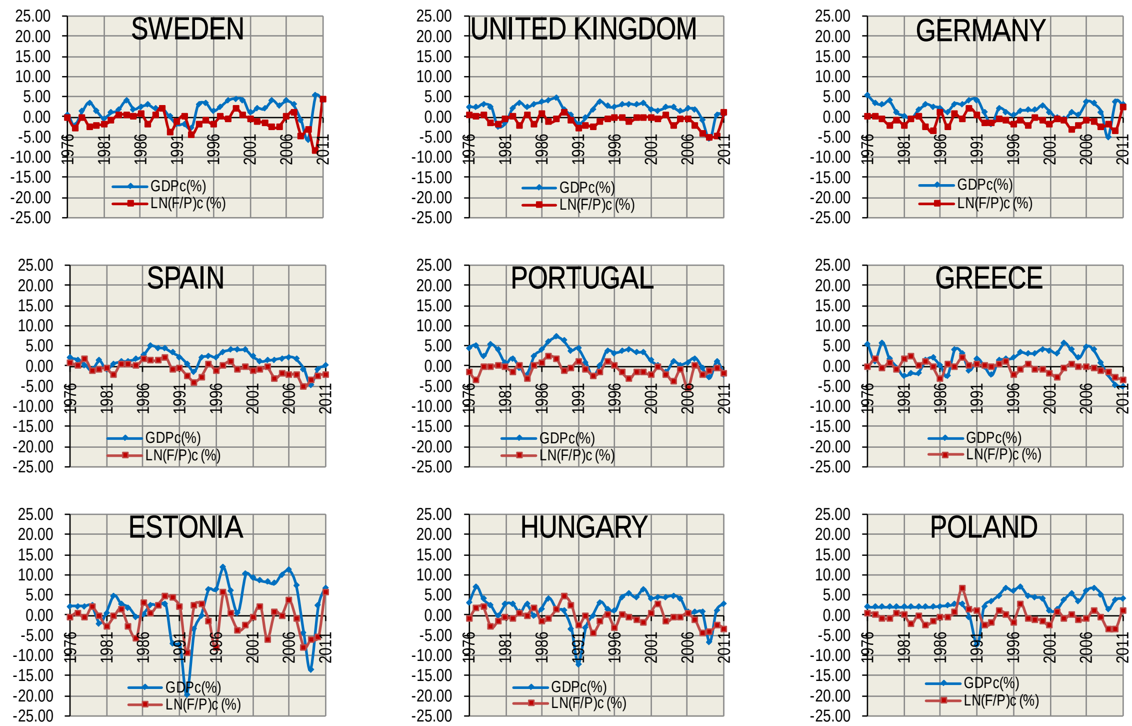
Figure 4.3. **Evolution of GDP per capita and number of fatalities in road crashes per million population in selected European countries**



Source: Yannis *et al*., 2014.

While some general trends can be visually inferred from this figure, transformations of the data are necessary to provide further insight to visualise the interactions. Such a transformation is to take the first difference in the logarithm of GDP and the number of fatalities, in order to obtain the relative change from one year to another. For example, Figure 4.4 shows the evolution of the annual change in per capita GDP and annual change in the number of traffic fatalities per million population in selected European countries, which provides a visual cue of the possible correlation of the two indicators.

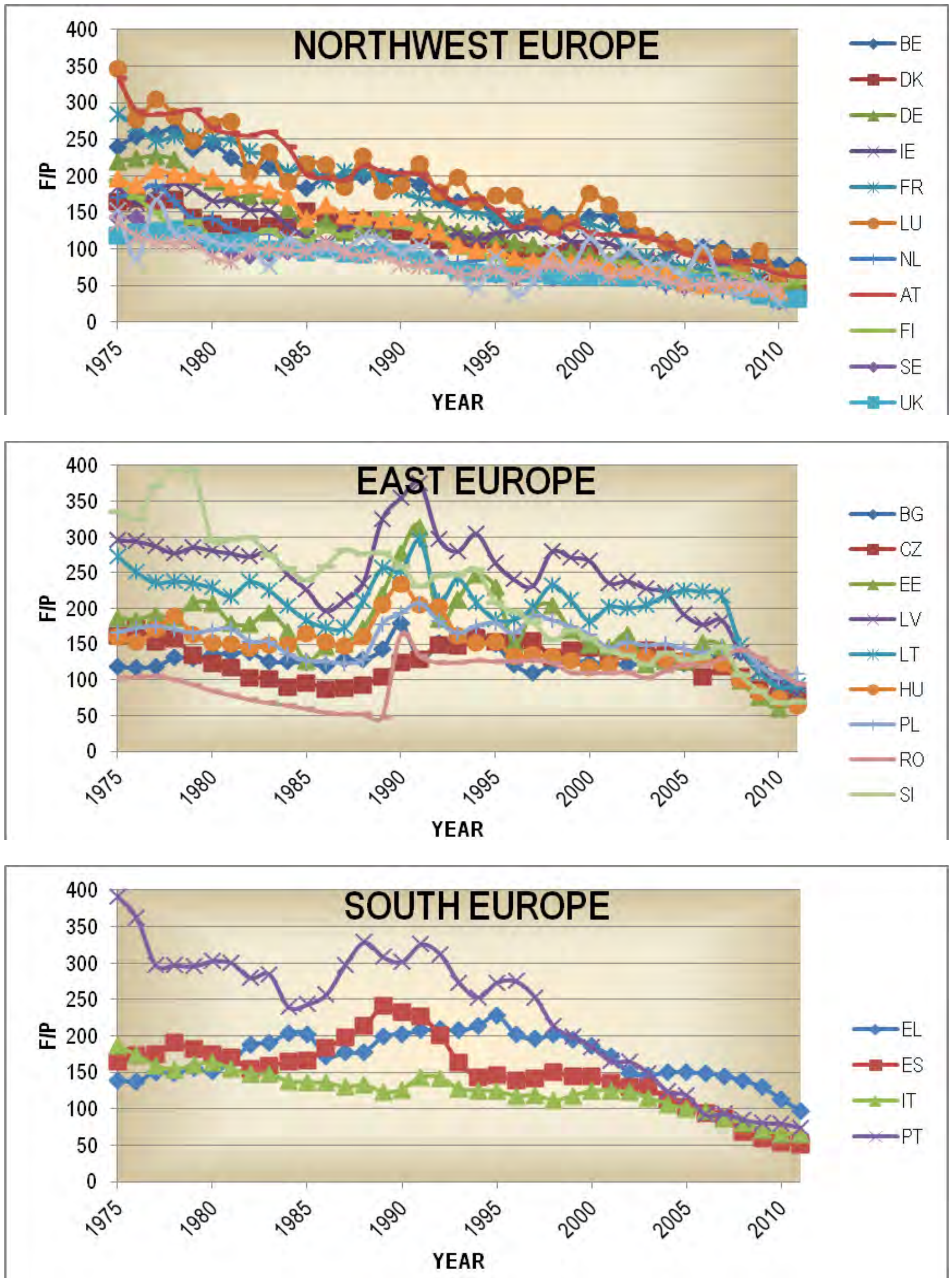
Figure 4.4. **Evolution of annual change in GDP per capita and annual change in the number of traffic fatalities per million population in selected European countries**



Source: Yannis *et al*., 2014.

Figure 4.5 provides a clustering of European countries in three somewhat homogeneous groups, in terms of the long-term trends of the number of fatalities, in a way that allows the extraction of some macroscopic patterns or stylised facts for a period of more than 35 years. The top subfigure includes northern and western countries, in which a decreasing trend in the fatality rate across the entire study period can be observed. The middle subfigure includes central and eastern countries, for which the fatality rate shows higher volatility. Furthermore, the effect of the changes in the political regimes in the early nineties is evident in this subfigure. The bottom subfigure includes southern countries, for which the decrease in the number of fatalities per population started later than the northern and western countries, following an initial increasing trend. (A discussion on this breakpoint can be found in Yannis *et al*., 2011.)

Figure 4.5. **Data exploration through grouping of countries**



Source: Yannis *et al*., 2014.

Short-term macro-panel regression

Most of the short-term models are estimated on one-country data with some ARIMAX models. Short-term macro-panel models are relatively rare in the literature about aggregated accident risk models. Yannis *et al*. (2014) provide such an example for a panel of European countries. The regressors of the first difference in the logarithm of the number of fatalities are the first difference in the logarithm of GDP and an indicator of the group of countries according to the pattern of the long-term trend of the mortality rate:

$$logFAT_{it} – logFAT_{i(t-1)} = \alpha+\beta_1[logGDP_{it} - logGDP_{i(t-1)}] + \beta_2 CountryGroup_{it}+\varepsilon_{it}$$

In fact, the effect of the change depends on its sign: increase or decrease, and is estimated by country groups. It is a linear model: two fixed coefficients are estimated relative to an increase and a decrease in GDP for each group of countries and the coefficients of the country group effect. The error-term follows an autoregressive structure of order 1. This model has also been fitted separately for each group of countries under the hypothesis of a homogeneous slope coefficient (or elasticity) among countries of each group and the results are summarised in Table 4.6.

Table 4.6. **Effects in % of changes for separate country regressions (** significant at 5%; * significant at 10%, NS non-significant)**

	Northern	**Eastern**	**Southern**
Mean change (0%)	-1.25	-0.96	-1.75
Effect of 1% increase	0.66 (**)	0.42(*)	0.45(**)
Effect of 1% decrease	-0.75(**)	-0.60(NS)	-0.15(**)
rho	-0.29(**)	0.34(**)	-0.04(NS)

There is a long-term linear decreasing trend, from 1.75% to about 0.95% per year, according to group of countries. The effects relative to an increase in GDP have similar amplitude according to the group of countries, from 0.42 to 0.66. In case of recession, the effect is similar in northern countries, not significantly different from 0 in eastern countries and weaker in southern countries. The effect value for a 1% change can be assimilated to the elasticity of the number of fatalities to GDP. There are some autocorrelations, positive for northern and negative for southern countries. It means that the predictions being one step ahead depend on the previous residual between the observed and predicted annual change in the number of fatalities.

When we estimate a first differenced model on the European panel data with a pooled model (homogeneous short-term elasticity) and a group-mean model (heterogeneous short-term elasticity) with fixed effect, we get estimates which are higher for the elasticity compared to the previous model, but comparable between the two kinds of model and greater for the mean-group estimation (Table 4.7).

Table 4.7. **Effects in % of change with their standard errors for pooled and mean-group models**

	Pooled	Mean-Group
Mean change (0 %)	-0.046 (0.005)**	-0.048 (0.044)**
Effect of 1% change	0.64 (0.11) **	0.79 (0.18)**
Sigma	0.137	0.134

** significant at 5%.

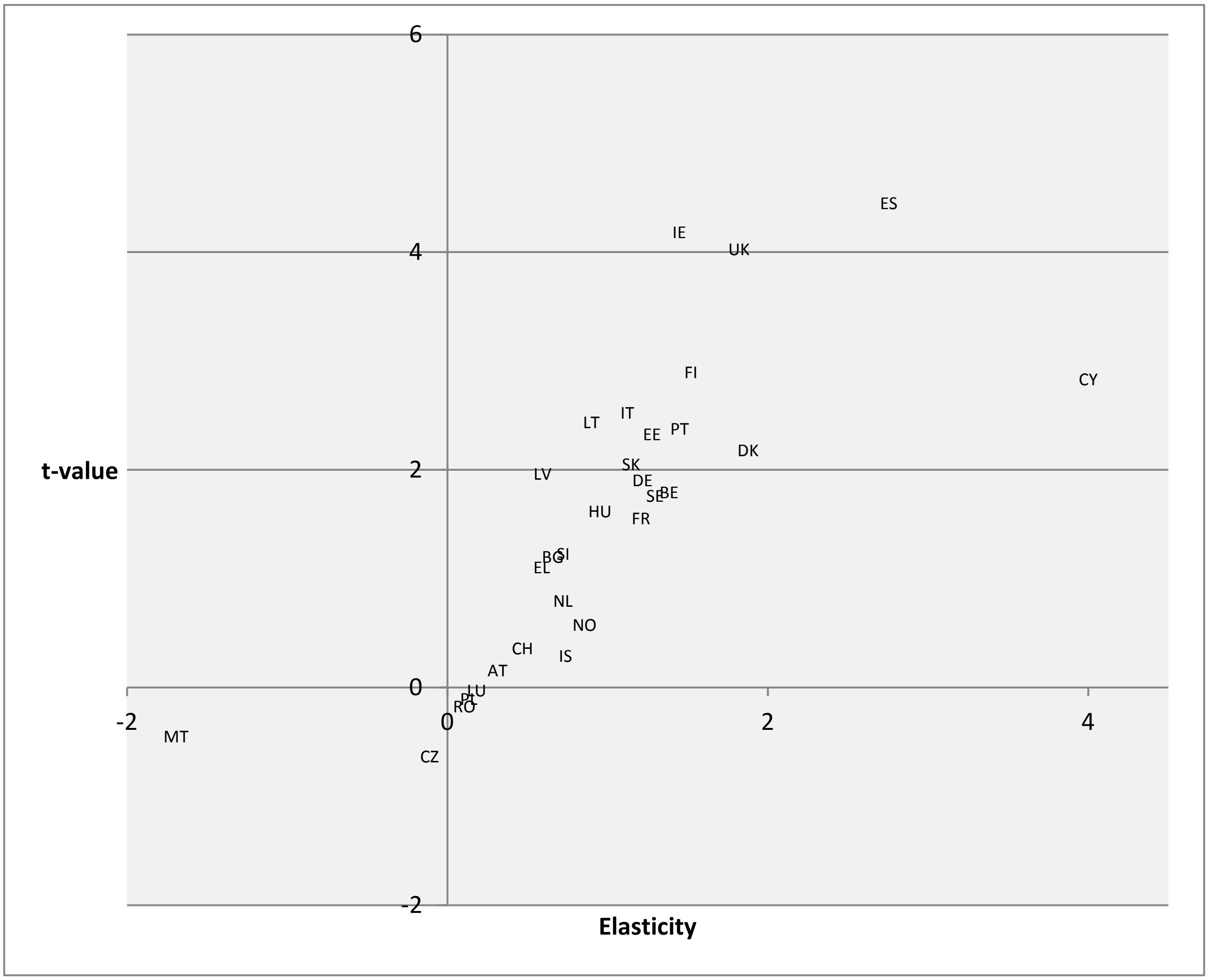
Table 4.8. **Estimates of intercept and elasticity with t value for mean group regressions without and with unemployment rate**

	intercept	tvalue	elasticity	tvalue	elasticity Elvik	tvalue
AT	-0.047	2.61	0.11	0.16	-0.051	0.61
BE	-0.055	3.52	1.18	1.80	0.34	0.53
BG	-0.020	1.06	0.45	1.21		
CH	-0.046	3.24	0.26	0.37	0.28	0.33
CY	-0.094	2.68	3.80	2.84		
CZ	-0.016	0.86	-0.31	-0.63		
DE	-0.062	4.45	1.01	1.91	0.54	0.71
DK	-0.070	3.52	1.67	2.19	0.36	0.3
EE	-0.052	1.59	1.08	2.33		
EL	-0.016	1.30	0.40	1.11		
ES	-0.078	5.33	2.56	4.45		
FI	-0.065	3.77	1.34	2.90	1.57	2.13
FR	-0.057	4.30	1.01	1.56	0.33	0.36
HU	-0.038	2.11	0.74	1.62		
IE	-0.083	5.51	1.26	4.19	1.21	2.33
IS	-0.050	0.66	0.56	0.30		
IT	-0.043	4.42	0.94	2.53		
LT	-0.038	1.78	0.70	2.44		
LU	-0.045	1.19	-0.02	-0.02		
LV	-0.041	2.23	0.40	1.97		
MT	0.014	0.10	-1.91	-0.44		
NL	-0.053	3.41	0.52	0.80	0.26	0.25
NO	-0.053	1.65	0.64	0.58	0.38	0.28
PL	-0.013	0.54	-0.06	-0.10		
PT	-0.071	4.07	1.25	2.38		
RO	0.000	0.00	-0.11	-0.17		
SE	-0.060	3.36	1.10	1.77	1.18	0.24
SI	-0.060	2.85	0.54	1.24		
SK	-0.058	2.02	0.95	2.06		
UK	-0.067	6.30	1.61	4.03	1.46	2.85

Source: Elvik, 2014.

The intercepts (Table 4.8) are mostly significantly negative, meaning that there is a decreasing deterministic linear trend with an average slope of 4.8% per year. Thirteen countries have a significant positive short-term elasticity: DK, DE, EE, IE, ES, IT, CY, LV, LT, PT, SK, FI, UK. For the remaining 17 countries, the elasticity is not significantly different from zero. Elvik (2014), with a regression model on first differences of GDP and unemployment plus a linear trend, found among 12 European countries three countries with a positive significant elasticity: FI, IE and UK (DK and DE have a non-significant elasticity).

Figure 4.6. **Short-term elasticities estimates versus t values**



Long-term macro-panel regression

Various researchers have developed long-term static models of the number of fatalities related to GDP, starting in 1996. A number of such studies have been summarised in Table 9. The main characteristic of these models is that the elasticity of the GDP related to the number of fatalities is homogeneous over the countries as a linear trend (when introduced). They differ in the form of the elasticity: either the elasticity is constant (linear) or depends monotonically on the GDP (decreasing or increasing). In this case, the function is either a spline function, or a linear function by pieces, or a quadratic and sometimes a cubic function of GDP.

As both time-series are I(1) integrated of order 1 over a macro-panel of 30 European countries, the estimation of the elasticity of the number of fatalities to the GDP requires various problems to be taken into account, such as error cross-section dependence and persistent autocorrelation. We suppose that the coefficients of the slope or the elasticities are heterogeneous among the countries. The cross-section dependence is introduced via some common factors, either related to the number of fatalities or to the GDP.

One of the most robust mean group type estimators is the Common Correlated Effects Mean Group estimator, which is based on individual regression augmented by the mean value of both dependent and independent variables (Pesaran, 2006; Coakley *et al.*, 2006). The mean values are instrumental and supposed to give information on the common factors, if present. Some interventions are introduced to take into account mostly breaks in the level of the number of fatalities due to important national safety measures taken, such as speed limits, for example.

Table 4.9. **Characteristics of the data and the model used in macro-panel analysis of the annual number of fatalities**

	Countries	**Data**	**Time**	**GDP**	**Motorisation**	**Other variables**
Ruhm, 1996	50 American states + District of Columbia	1972-1991	No	Homogeneous linear	No	Unemployment Socio-demographic
Van Beeck *et al.*, 2000	21 OECD	1962-1990	No	Homogeneous cubic in log	No (subject to same model form)	
Noland, 2003	50 US states	1984-1997	Homogenous linear trend	Homogeneous linear in log	No	Socio-demographic Infrastructure Health
Kopits, Cropper, 2005	88 worldwide	1963-1999	Regional linear trend	Homogeneous spline on log	No (subject to same model form)	
Kopits, Cropper, 2008	32 IRTAD OECD	1970-1999	Homogeneous linear trend	Homogeneous linear, quadratic, spline on log	Yes (fatalities per million miles travelled)	Socio-demographic Interactions with GDP
Anbarci *et al.*, 2006, 2009	79 (23 Africa, 12 America, 26 Europe, 18 Asia)	1970-2000	Homogeneous linear trend	Homogeneous quadratic on log	Yes	Inequality Corruption Health
Bishai *et al.*, 2006	41	1992-1996	No	Homogeneous linear on log (High/low income)	Yes	Population (Smeed)
Traynor, 2009	48 American states	1999-2003	No	Homogeneous linear on log	Yes (fatalities per million miles travelled)	Law Unemployment
Law *et al.*, 2010, 2011	60	1972-2004	Homogeneous linear trend	Quadratic on log for less/highly developed countries	Yes	Corruption Health
Castillo-Manzano *et al.*,	EU-27	1999-2009	Homogeneous linear trend	Quadratic	Yes	Health Passenger*kilometre
Grimm *et al.*, 2012	21 Indian states	1994-2006	Year effects	Quadratic in log	Yes	Socio-demographic

As a group mean estimate, the long-run elasticity of the number of fatalities to GDP is taken as the unweighted average of the respective coefficients. Similarly, we get the long-term linear trend (interpreted as an annual change) as the average of the respective coefficients. In that case the elasticity is supposed to be constant over the period and not depending on GDP. A non-linear dependence of the number of fatalities to GDP can be approximated by a polynomial of the second order. We get the Kuznets curve (a U inverted curve) with a concave parabola.

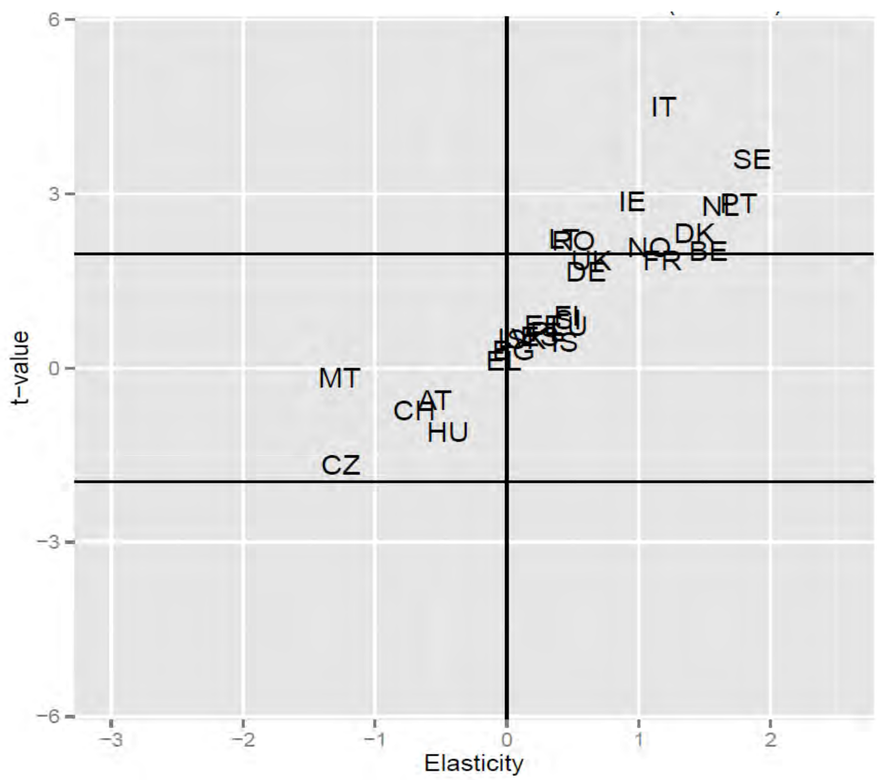
Table 4.10. **Pooled and group mean estimates of the coefficients of the regressions according to trends' forms and linear and non-linear relationships**

		Pooled +interventions	**GM linear**	**GM linear +interventions**	**GM linear**	**GM Non linear**
LGDP	coef	-0.28	0.45	0.63	0.61	14.2
	std. err.	0.062	0.25	0.23	0.16	8.8
	z	-4.53	1.81	2.72	3.82	1.62
t	coef	-0.024	-0.008	-0 .023	0.11	-0.002
	std. err.	0.0014	0 .008	0.008	0.14	0.014
	z	-16.2	-1	-2.75	0.74	-0.16
t^2	coef				-0 .0005	
	std. err.				0.00028	
	z				-1.64	
$LGDP^2$	coef					-0.68
	std. err.					0.46
	z					-1.48
RMSE(sigma)		0.239	0.107	0.080	0.097	0.120

The pooled estimate with fixed effects provides a negative value of -0.28, in total disagreement with the positive estimates of mean-group models, which are much better fitted according to the RMSE. In the case of a heterogeneous elasticity (linear effect), the basic model with a linear trend and no interventions leads to a lower estimate of the average elasticity 0.45 with a higher standard deviation. The model with a linear trend plus intervention and the model with a parabolic trend give an identical estimate of elasticity equal to 0.6. Both models help to capture the different patterns of evolution of the number of fatalities over time, as seen in Figure 4.5. The main incidence of interventions is to correct the estimation of negative elasticities for some countries into positive ones that take into account the special structure of the evolution of risk in those countries. The model with a non-linear effect in the form of a Kuznets curve has to be rejected, as the mean group coefficient of the square term is not significant.

The heterogeneity of the elasticity between countries from the best model fit (linear + interventions) can be explored in Figure 4.7. A great majority of the elasticities are positive. The elasticity is significant for 12 countries with positive values: BE, DK, FR, IE, IT, LT, NL, NO, PT, RO, SE, UK. For the 18 remaining countries, the elasticity is not significant from zero. The sensibility of the number of fatalities to the variations of GDP is rather different according to countries. It means that the predictions have to be based on individual regressions rather than using the mean group estimate of the elasticity.

Figure 4.7. **Individual elasticities' estimates versus the t-statistics of the estimates for the model with a linear trend and interventions**



Elvik (2014) gave the estimates of a Negative binomial individual regression model of the number of fatalities on the logarithm of GDP and of the unemployment rates for 12 European countries with some interventions. Four countries have a positive significant elasticity to GDP: BE, NL, SE, UK, while three have a nearly significant elasticity: AT, DE, NO. Two countries have a negative significant elasticity: CH, DK. For the remaining countries (FI, FR, IE), the elasticity is not significantly different from zero.

The results of both models are converging for six countries BE, DE, NL, NO, SE and UK and diverging for two countries: AT and DK.

Table 4.11. **Long-term elasticity's estimates with t-value and p-value for group-mean regressions without and with unemployment rate**

	Elasticity	t-value	Elasticity Elvik	p-value
AT	-0.55	-0.72	1.27	0.01
BE	1.53	1.84	1.35	0.008
BG	0.05	0.14		
CH	-0.70	-0.91	-4.09	0.001
CY	4.41	2.78		
CZ	-1.26	-1.83		
DE	0.60	1.48	1.1	0.07
DK	1.42	2.15	-1.75	0.06
EE	0.28	0.57		
EL	-0.02	-0.05		
ES	0.25	0.38		
FI	0.45	0.73	0.7	0.52
FR	1.18	1.68	0.7	0.54
HU	-0.45	-1.27		
IE	0.95	2.70	0.69	0.43
IS	0.44	0.27		
IT	1.19	4.33		
LT	0.43	2.04		
LU	0.47	0.54		
LV	0.06	0.35		
MT	-1.27	-0.34		
NL	1.62	2.62	1.27	0.05
NO	1.08	1.91	0.92	0.13
PL	0.31	0.45		
PT	1.76	2.66		
RO	0.50	2.02		
SE	1.86	3.43	1.43	0.02
SI	0.46	0.67		
SK	0.15	0.32		
UK	0.64	1.68	3.61	0.001

Source: Elvik (2014).

Conclusion

The relationship between road safety measured by the number of fatalities and the economic development measured by the GDP is not straightforward. If the GDP time series is integrated of order 1 I(1) for all the thirty European countries, there is a mixture of stationary I(0) and non-stationary I(1) and I(2) among the time series of the number of fatalities in the European countries. The different nature of the time series complicates the regressions between the time-series transformed by logarithm and leads to the use of special techniques of estimation on macro-panel data.

Concerning the short-term regression between the first differences, there is a strong heterogeneity of the short-term elasticity with a mean value of 0.79, which is significantly different from 0. Thirteen countries (out of thirty) have significant positive short-term elasticities: DK, DE, EE, IE, ES, IT, CY, LV, LT, PT, SK, FI, UK. The short-term relationship is found in only half of the European countries, but when it exists, the relationship is rather elastic with an average of 0.79.

Concerning the long-term relationship, there is a strong heterogeneity of the long-term elasticity with a mean value of 0.63, which is significantly different from zero. The long-term elasticity is significant and positive for 12 countries: BE, DK, FR, IE, IT, LT, NL, NO, PT, RO, SE, UK.

On both regression models, there is a constant decreasing linear trend of the number of fatalities for almost all countries, with some exceptions. It is equal to 2.3% per year in the long-term model and 4.8% per year for the short-term model.

Towards a joint short-term and long-term model

Modelling advances and the availability of software that allows the modelling of co-integration between macroscopic time-series panel data and error correction model formulations are valuable tools that open the road for more advanced models. They have the potential to provide better understanding of the short-term and long-term dynamics of the problem.

If the number of fatalities and GDP (logarithmically transformed) are co-integrated, the error term is stationary, I(0). In the error-correction model the short-term dynamics depend on the deviation from the equilibrium given by the linear long-term relationships. We expect that the coefficient is negative and if it is significant we can infer about the co-integration of the number of fatalities and GDP.

With a Pooled Mean-Group (PMG) estimation, there is a common long-run GDP elasticity and heterogeneous short-term dynamics.

When the hypothesis of elasticity and linear time trend homogeneity among countries is unacceptable, the Mean-Group estimation MG is preferred and the estimates are the unweighted means of the individual regression coefficients. Finally, we can pool all the estimates by imposing the homogeneity of the long-term elasticities, the linear trends, the speeds of adjustment and the short-term effects.

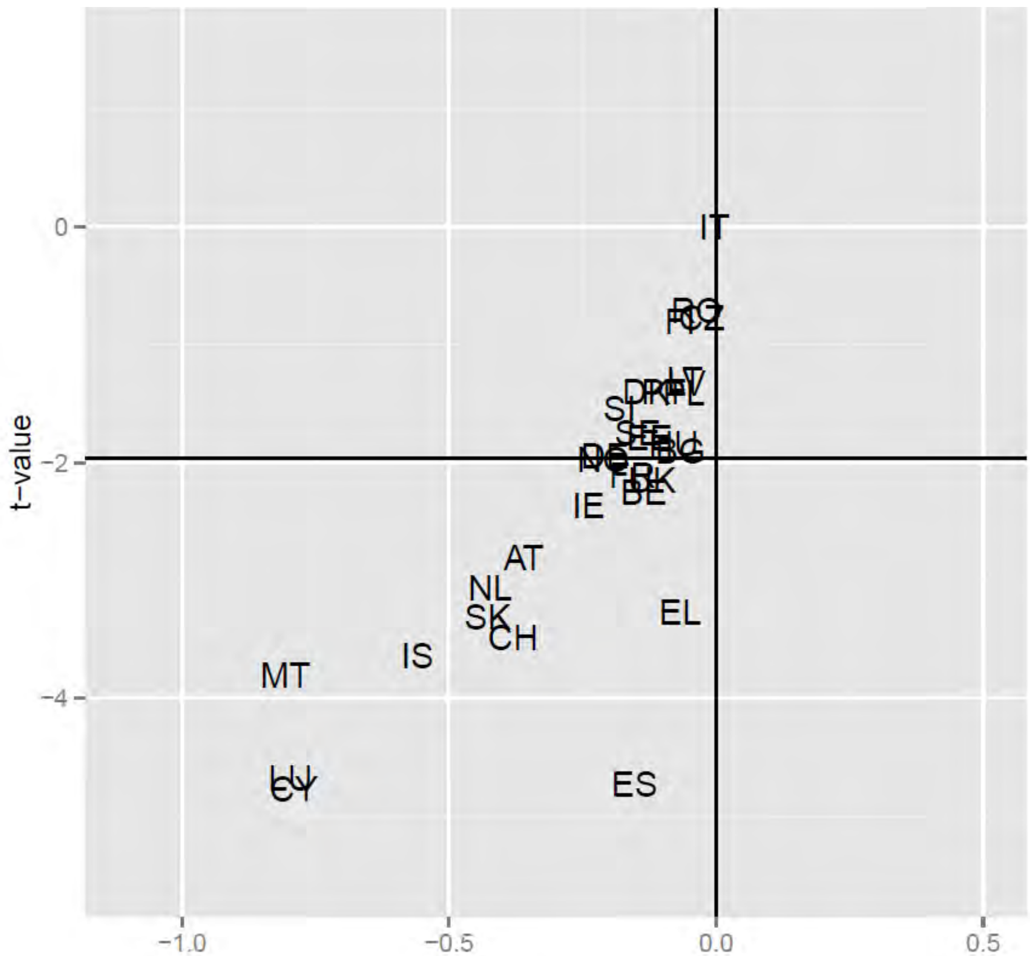
Table 4.12. **Estimates of the error-correction models with PMG, MG and P estimation (Stata procedure xtmpg)**

		PMG	MG	P
LGDP	coef	0.59	0.67	-0.35
	std. err.	0.11	0.49	0.29
	z	5.5	1.4	-1.22
t	coef	-0.057	-0 .026	-0.030
	std. err.	0.003	0.035	0.008
	z	-21.7	-0.75	-3.8
DLGDP	coef	0.49	0.34	0.68
	std. err.	0.29	0 .20	0.11
	z	1.66	1.69	6.15
EC	coef	-0.23	-0.38	-0.15
	std. err.	0.043	0.056	0.05
	z	-5.43	-6.65	-3.03
Log Likelihood		1078.4		

The elasticities are positive and similar to the estimates of the previous long-term models, slightly higher for the MG estimate. The hypothesis of homogeneous elasticity and linear time trend can be tested with a Hausmann test which gives the value 0.70, leading to an acceptance of this hypothesis. The speed of adjustment estimate given by the coefficient of the error-correction term is equal to 0.23, implying a return duration time of 4.3 years on average. The introduction of interventions (differenced) does not change the results. The pooled estimates give a negative, non-significant long-term elasticity.

Half of the countries have a significant negative speed of adjustment: MT, IS, CY, LU, ES, IS, CH, EL, SK, NL, AT, IE, BE, NO, FR, DE, UK. The first countries in this list have a very high speed of adjustment with a return duration time of around two years.

Figure 4.8. **Speeds of adjustment versus t-value from the PMG model by country**



The tests of the hypothesis of no co-integration can be performed using the Stata procedure xtwest, which implements the four statistics and tests designed by Westerlund (2007). The first two are based on group-mean estimates and the last two on panel estimates, without and with a correction on the standard deviations. The tests are not significant when we introduce a constant and a linear trend. We accept the hypothesis of no co-integration between the number of fatalities and GDP, which implies that the model on differences is the most appropriate for predictions.

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CHAPTER 5. THE IMPACT OF THE ECONOMIC CRISIS ON ROAD MORTALITY: AN EXPLORATORY APPROACH FOR SOME COUNTRIES IN EUROPE[1]

One positive outcome of the economic crisis, at least for some European countries, has been the relative improvement in road safety outcomes. It may be expected, however, that once the crisis comes to an end, road safety figures will worsen. This is a major concern for countries that are severely affected by the difficult economic climate.

This paper describes an exploratory approach focusing on several European countries, including France, Greece, Italy, Portugal and Spain. The objective is to highlight how the changes in road mortality are related to changes in economic variables. A comparative analysis of their development was carried out, and the relationship between the number of road fatalities and two key economic variables - unemployment rate and GDP per capita – was investigated.

The results of this exploratory approach are twofold. First, a long-term analysis of annual data for the period 1970-2012 highlights the fact that the current negative relationship of the number of fatalities to the GDP per capita is not reversible in times of economic recession. Second, a short-term analysis performed with monthly data for the period 1983-2012 for France shows a negative relationship between the number of fatalities and the unemployment rate. Further results show that the magnitude and significance of this relationship varies according to the country and the period of calibration

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Introduction

Economy and Transport

The link between the economy and transport has been extensively discussed and is well documented. Transport systems are strongly related to economic development, as seen by the correlation of macroeconomic indicators to the demand and supply of transport (Quinet and Vickerman, 2004). In the early stages of a country's development, transport investments stimulate growth from the demand side, and also contribute to the economic transformation of regions and urban areas affected on the supply side (OECD, 2006). In the later stages, the relationship becomes more complex and circular: transport affects economic conditions, but economic conditions influence transport (Norwood and Casey, 2002). However, much less attention has been given to the impact of economic conditions on traffic conditions in relation to infrastructure and driver behaviour.

Correlation effects can be found across all transport modes. However, with 65% of total passenger kilometres made by car in OECD Europe (Proost and Van Dender, 2010), *automobility* is predominant in all inherent economic implications of transport systems and has strong linkages with other parts of the economy. Road safety is a major automobility issue. According to Kuznet (1955), there is an inverse correlation between the number of fatalities in a country and its prosperity (the "inverse U-shaped curve"). Fatalities increase until a certain level of revenue or motorisation rate is attained and thereafter decrease (Bishai *et al*., 2006; Law *et al*., 2011). The initial positive correlation may well be explained by increased risk exposure. The negative correlation is more complex, but may be linked to greater investments in infrastructure, increasing household expenditure on cars, enhanced emergency and health services, and so on.

Recession and road fatalities

The term “crisis” refers to something more severe than a problem, or even a cluster of problems, reflecting the shock stimulated by the severity of changes (Johnston and Taylor, 1989). The 2008 global financial crisis is regarded as a major crisis in the history of capitalist development. Mayer (2009) considers it comparable to both the Great Depression and to the Crisis of Fordism. In 2009, the European Union’s (EU) real GDP growth rate was negative for the first time at -4.4%, since private final consumption has been shrinking and unemployment reached 11% in 2013 (Eurostat, 2013). In this changing financial context, transport demand and supply are being re-equilibrated, in the sense that both investments in infrastructure maintenance and household transport expenditure are shrinking. The car fleet is changing in size, mean age and type of vehicle (e.g. type of engine). Drivers have adopted risk-averse behaviours and travel at lower speeds in order to reduce fuel consumption (TRL report, 2012). Mobility patterns have evolved in terms of OD matrices, travel modes and purposes. Most importantly, automobility has shrunk and road traffic has decreased. In view of the above, it is reasonable to assume that recession generates numerous short- and long-term effects on road safety. While the former seems to have a positive effect on safety, the impact of the latter is so far inconclusive (ITF, 2013).

A number of authors have examined the relationship between road mortality and economic growth, mainly exploring the interaction between fatality rates or number of fatalities (at the national level) and macro-economic indicators such as GDP and GDP per capita (Thoresen *et al.,* 1992). Holló *et al.* (2010) show that revenue and unemployment rates are also critical when explaining fatality trends, while Wiklund *et al*. (2012) report a negative correlation between fatalities/km and the number of unemployed. Koornstra (2007) suggests a non-linear relationship between fatalities and revenue per capita, while Garcia-Ferrer *et al*. (2007) relate safety to industrial production and car fleet size. It should be noted that most of these studies use annual data and explore time series going back to the 1970s. Annual data, however, are not suitable for use in respect of the recent recession which was observed over a period of only four years. More finely grained data are needed to examine the effects over such a period of time.

Some authors have also studied the relationship between economic growth and unemployment, with approaches covering both the long- and short-term, and network categories such as rural/urban areas considered. According to all authors, GDP and unemployment rates are strongly linked and develop in an opposite way. As regards also the short-term relationship, a negative correlation between trends of both series is to be expected: among other findings; this was demonstrated by Stephan (2012) on quarterly data from France and the UK covering the last forty years.

Objectives

This work builds upon previous studies on the impact of recession on transport demand and road safety (Bergel, 1991; Bergel *et al.,* 1995; Christoforou and Karlaftis, 2011; Christoforou *et al.,* 2012). It allows for more robust aggregate predictions of casualty numbers as well as for important policy implications regarding road safety targets and measures.

The objective here is to explore the impact of recession on road mortality, mainly for its timing and magnitude. We define recession as negative economic growth and use fatalities as a key road safety indicator. We calibrate Kuznet's curves for five European countries that have been affected by the crisis, i.e. Greece, France, Spain, Portugal and Italy (Section 2). We then develop local linear trend models based on monthly data of fatalities in relation to the industrial production index or to the unemployment rate (section 3). Finally, we discuss the coherence and consistency of the results (section 4) and conclude by providing research perspectives (Section 5).

Long term approach with annual data

The data

Annual data on road fatalities and macro-economic indicators (the GDP per capita) have been retrieved mainly from IRTAD and Eurostat, and cover the period 1970-2012. In a few cases, data has been directly collected from national official sources.

The method

For each country, the relationship of the environmental Kuznets curve (EKC) (Kuznets, 1955) between the number of fatalities and GDP per capita was estimated using the following model:

$$F_t = a.(GDP/h)^2 + b.(GDP/h) + c + \varepsilon_t$$

with:

F_t the annual number of fatalities at national level,
a,b and c the three real values,
and ε_t the error term.

The results

Figures 5.1 to 5.5 show the number of fatalities over annual GDP per capita for France, Greece, Italy, Portugal, and Spain. We should note that these are not time-series. The points in red correspond to recession years. In the case of France and Italy, the ascending limb of the inverse U-curve is situated prior to 1973. The peak occurs in 1986 for Portugal, in 1989 for Spain , and in 1996 for Greece. This time-lag effect is caused by the countries achieving a certain level of development at different times. Approximations of the Kuznets curves are estimated and shown in the graphs.

The peaks occurred when the GDP per capita reached around EUR 5 000 in France and in Italy, EUR 9 000 in Portugal, EUR 12 000 in Spain and EUR 18 000 in Greece. After correcting these values from the inflation rate, it appeared that the peaks arose once each country had reached a similar level of GDP nominal value – in other words, a comparable level of development.

It is worth noting that this relation is not reversible. Once a country enters the second phase of the curve, the annual number of fatalities decreases while the GDP per capita increases. In the case of the recent economic crisis, however, the number of fatalities continued to decrease in years of negative growth at a higher rate than in other years.

Figure 5.1. **Fatalities over GDP per capita - France**

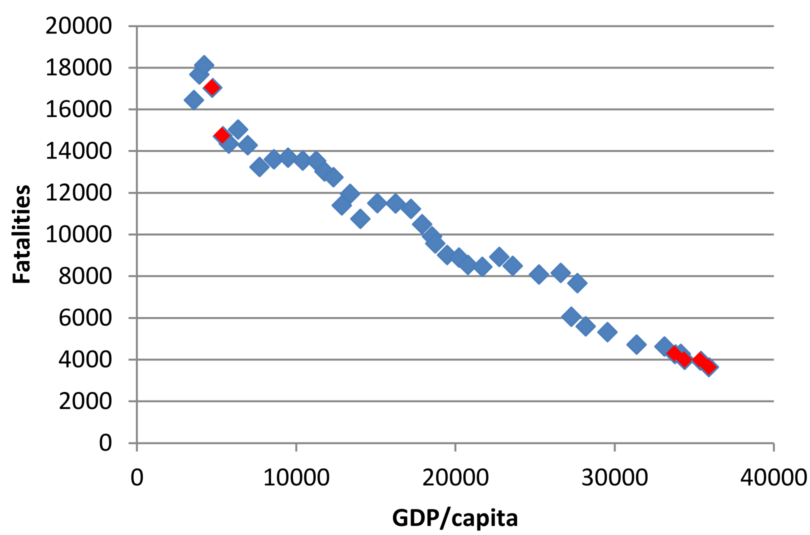


Figure 5.2. **Fatalities over GDP per capita - Greece**

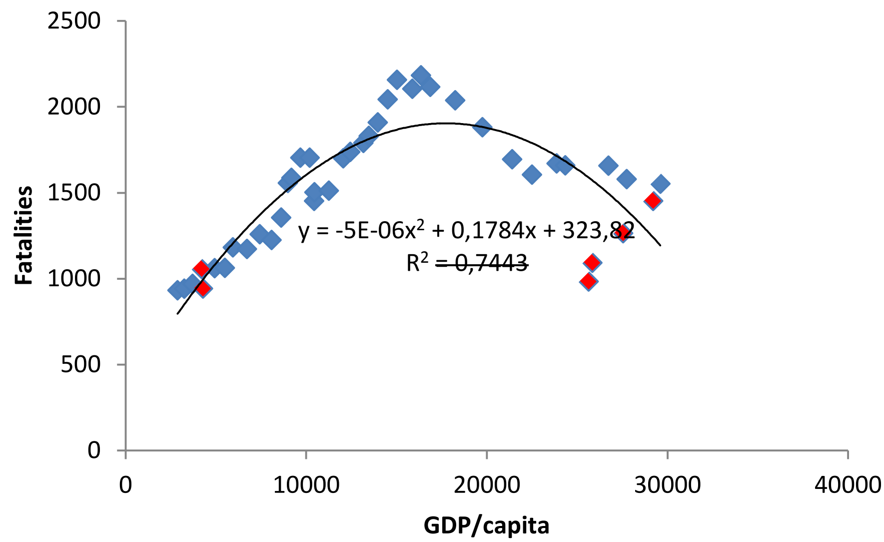


Figure 5.3. **Fatalities over GDP per capita – Italy**

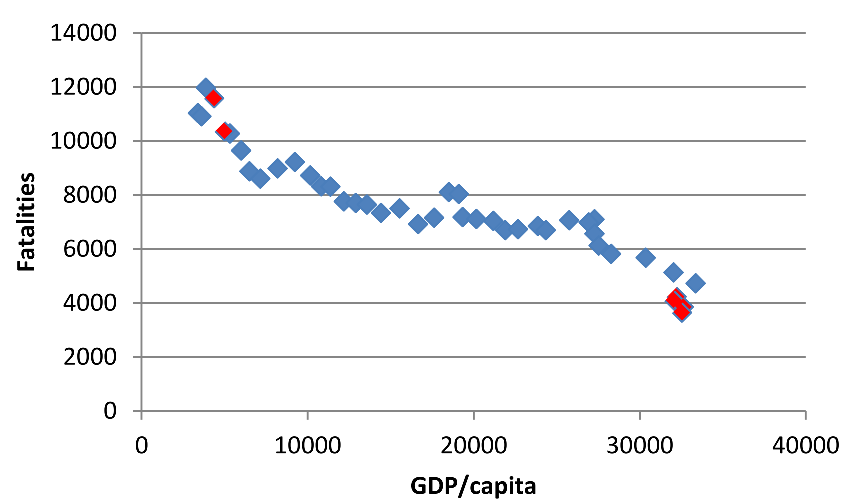


Figure 5.4. **Fatalities over GDP per capita – Portugal**

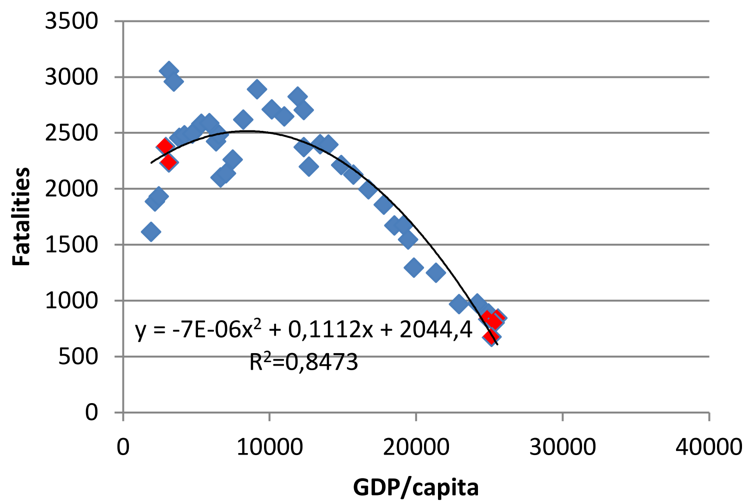
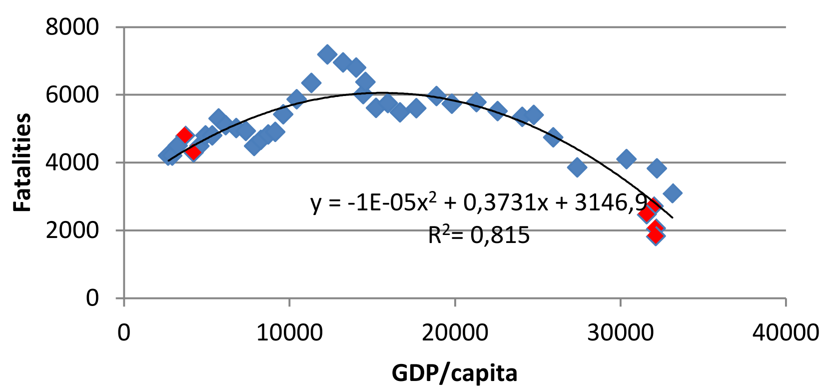


Figure 5.5. **Fatalities over GDP per capita – Spain**



Short term analysis with monthly data

The data

Monthly or quarterly data on road fatalities and macro-economic indicators have been retrieved from different sources; mainly IRTAD, Eurostat and national statistical agencies.

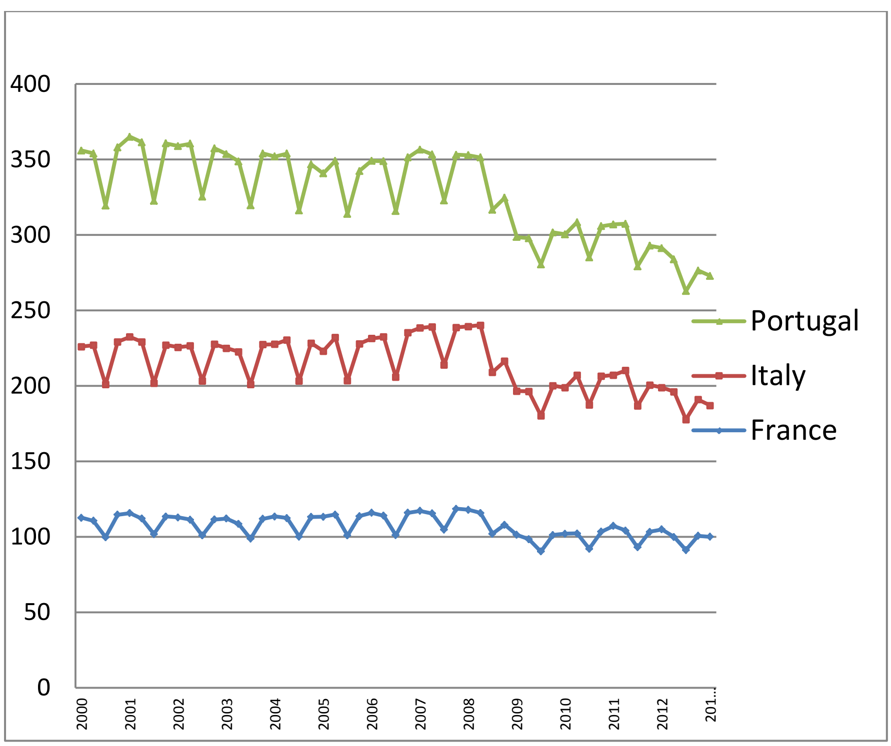
Macro-economic variables are generally measured at national level on both yearly and quarterly bases. Macro-economic variables initially included GDP per capita, unemployment rates, and the industrial production index for the five countries. In some cases, data unavailability limited our research to specific time frames. However, in order to capture changes in economic trends, we focused on short-term changes at a monthly level. We therefore limited the macro-economic variables to the two indicators that were measured and available on a monthly basis: *the industrial production index* (IPI) and *the unemployment rate* (UR). It should be noted that these indicators were not available on a monthly basis for all five countries.

Later in this section we shall refer to the IPI as a growth indicator, and the UR as an indicator of economic climate.

Focus on the on-going recession

In order to illustrate the on-going recession, we plot the evolution of the industrial production index over the period 2000-2012 on a quarterly basis for France, Italy and Portugal (Figure 5.6). For each year, the data plotted correspond to the first, second, third, and fourth quarter of the year respectively, Q1,2,3,4. For each country, the index is normalised on 2010Q1 data and at the value of 100 ; for Italy and Portugal, the index has been increased by 100 and 200 respectively. This figure first illustrates the strong seasonality of the industrial cycles due to lower summer production. It also illustrates the severe effect of the financial crisis that appears simultaneously in all three countries at 2008Q4. A first local minimum is observed at 2009Q3. Since then, French production appears to have stabilised around a lower average, Portuguese production has continued to shrink further, while Italy is somewhere in-between. Finally, the seasonal effect stands equally during the recession.

Figure 5.6. **Industrial production index for France, Italy and Portugal (*)(2000-2012)**



(*) For each country, the index is normalised on 2010Q1 data and at the value of 100. For Italy and Portugal, the index has been increased by 100 and 200 respectively.

Source: Eurostat.

The on-going recession can also be illustrated using GDP figures, whether quarterly or annually. When considering the quarterly evolution of the GDP per capita for the five countries studied, the crisis becomes evident in the first quarter of 2009; i.e. a quarter after the shrinkage of industrial production. Of course, this evidence is not sufficient to infer a cause-effect relationship, nevertheless it can be reasonably assumed that not all macroeconomic indicators are affected simultaneously. Furthermore, the crisis effect is expressed as a lower year minimum, while year maximum values show greater stability. Turning to the annual evolution of the GDP per capita for the five countries considered, we observe a decreasing GDP in 2008 and a return to 2007 values in 2009. From 2009 onwards, the trend is different for each country.

With regard to short-term links which could be highlighted on a monthly basis, the severe effect of the crisis is not only visible on industrial production figures, but is also clearly shown in all unemployment figures. However, not all unemployment rates stabilise *post*-2008 (as in the case of Spain and Greece), and where this *does* occur, not at the same level as *pre*-2008.

Industrial production index or unemployment rate?

In the case of Spain, for the period 1975-2005, the short-term link between industrial activity and road safety was investigated by Garcia-Ferrer *et al* (2007) on a monthly basis, and the changes in both short-term trends were compared. The authors demonstrated that the number of injury accidents, fatalities and injured developed in phase with the IPI, along with common expansion/recession cycles. However, common cycles could not be found in the same systematic way for France over the period 1982-2012. The difference in results could be explained by differences in the type of economic growth of both countries.

The unemployment rate develops in an opposite way to the economic activity, and is known to be a good indicator of the climate of the economy (in most cases in European countries, unemployment increases with low economic growth, and decreases when the economic growth increases). So we suggest that the unemployment rate could evolve contrary to road safety level, and moreover that this could be the case whichever the country.

The method

A state space model or – more precisely – local linear trend model plus seasonal (or structural) model is commonly used for modelling the monthly numbers of fatalities in relation to explanatory and intervention variables. This time series analysis method, initially proposed by Harvey and Durbin (1986) – who modelled the monthly number of persons killed and seriously injured in the UK for the period 1969-1984 – is used increasingly for analysing aggregate trends in road safety. It allows a convenient representation of a linear trend which is no longer considered deterministic (the same applies to seasonal trends) and thus captures an additional part of the overall variance of the observations. Intervention analysis is carried out in order to gauge the impact of road safety-related measures or events and a small number of explanatory variables may also be used.

In our case, this technique was adopted for modelling the relationship between the numbers of fatalities in the month in relation to the monthly unemployment rate. More precisely, the structural model was fitted to *the number of fatalities -- corrected for the effect of the unemployment rate -- taking into account a few intervention variables.*

The following specification was used:

$$LogF_t = \mu_t + \gamma_t + \beta\, x_t + \sum_{k=1}^{K} \lambda_k w_{kt} + \varepsilon_t \qquad \varepsilon_t = N(0, \sigma_\varepsilon^2)$$

$$\mu_t = \mu_{t-1} + \sum_{l=1}^{L} \lambda_l w_{lt} + \eta_t \qquad \eta_t = N(0, \sigma_\eta^2)$$

$$b_t = b_{t-1} + \zeta_t \qquad \zeta_t = N(0, \sigma_\zeta^2)$$

$$\gamma_t = -\sum_{j=1}^{s-1} \gamma_{t-j} \qquad \zeta_t = N(0, \sigma_\zeta^2)$$

where:

F_t is the monthly number of fatalities,

x_t is the unemployment rate in the month, with coefficient β,

w_{kt}, k =1,..,K, and w_{lt}, l =1,..,L, are K+L intervention variables, with coefficients λ_k and λ_l,

μ_t and b_t are the level and slope of the local linear trend,

γ_t is the seasonal component written under a dummy form,

ε_t, η_t, ζ_t and ω_{it}, i =1,..,I, are error terms, with variances σ_ε^2, σ_η^2, σ_ζ^2 and $\sigma_{\omega_{it}}^2$ which are not mutually correlated, for $t = 1,...,n$,

n is the number of months of the period of calibration.

The results

The periods for calibrating the models were in phase with the monthly data available: 1983-2012 for France, 1986-2006 for Spain and 1998-2012 for Greece. It should be noted however that in the case of Spain, the data sample was not updated as modifications were made to the way in which the number of fatalities are counted in 2011, thus making it difficult to analyse changes in recent years.

As expected, a negative relationship between the monthly number of fatalities and unemployment rate was found. While this was the case for all three countries, it was only significant for France and Spain.

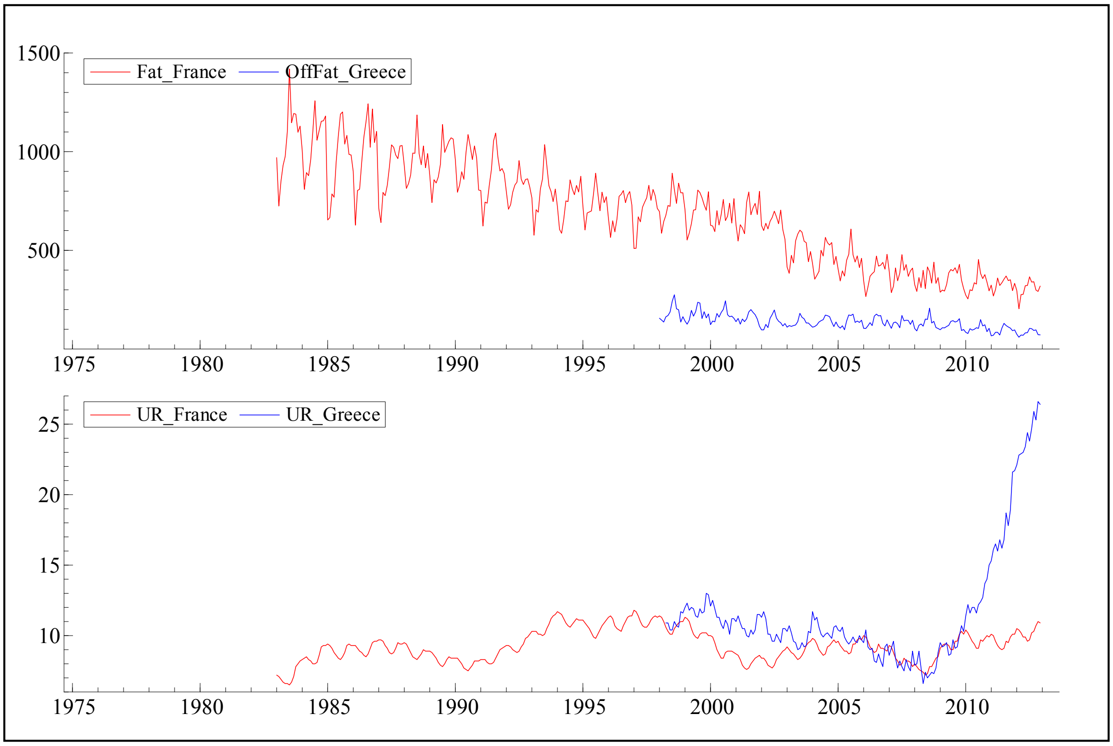
In the case of France, for the period 1983-2012, it was shown that an increase of 0.1 point in the unemployment rate in the month was associated with a decrease of 0.31% in the number of fatalities in the month. When using another model for France for the period 2009-2012 (after the recession began), the response to the number of fatalities in the month was estimated at -0.4 or -0.4%. This means that about half of the decrease of 7.8% in the total number of fatalities in 2012, compared with 2011, could be explained by the fact that the unemployment rate increased by 1 point at the same time.

In Spain, for the period 1986-2006, the number of fatalities in the month was estimated at -0.27, which is very close to the estimated coefficient of -0.31% found for France. This coefficient was not significantly different for the period 1986-2006 as compared with the coefficient found for France for the period 1983-2012.

No significant relationship could be found for the period 1998-2012 for Greece. When considering the period before the crisis 1998-2007, the coefficient of interest was found negative but with a level of significance beneath the usual acceptance limits.

Figures 5.7, 5.8 and 5.9 show the developments of the number of fatalities and unemployment rates for France and Greece for long-time periods, and Table 1 shows the models outputs for France.

Figure 5.7. **Number of fatalities and unemployment rates for France for 1983-1992 (in red) and Greece for 1998-2012 (in blue)(*)**



Source: Eurostat, Sources nationales officielles.

Table 5.1. **Results and performance criteria of the models fitted on the log of the monthly numbers of fatalities in France for the period January 1983-December 2012**

Parameters	**France 1983-2012**
σ_{ε}^2	0.00427546
σ_{η}^2	0.000335005
σ_{ζ}^2	6.07321e-007
$\sigma_{\omega_u}^2$	0.00 0.000000
μ_T	6.00463]
b_T	-0.00371
UR	**-0.03097**
t-value	**-1.82067]**
shift_12.2002	-0.18432
t-value	-3.68197 [0.00027]

Figure 5.8. **Number of fatalities and unemployment rates, France, 1998-2012**

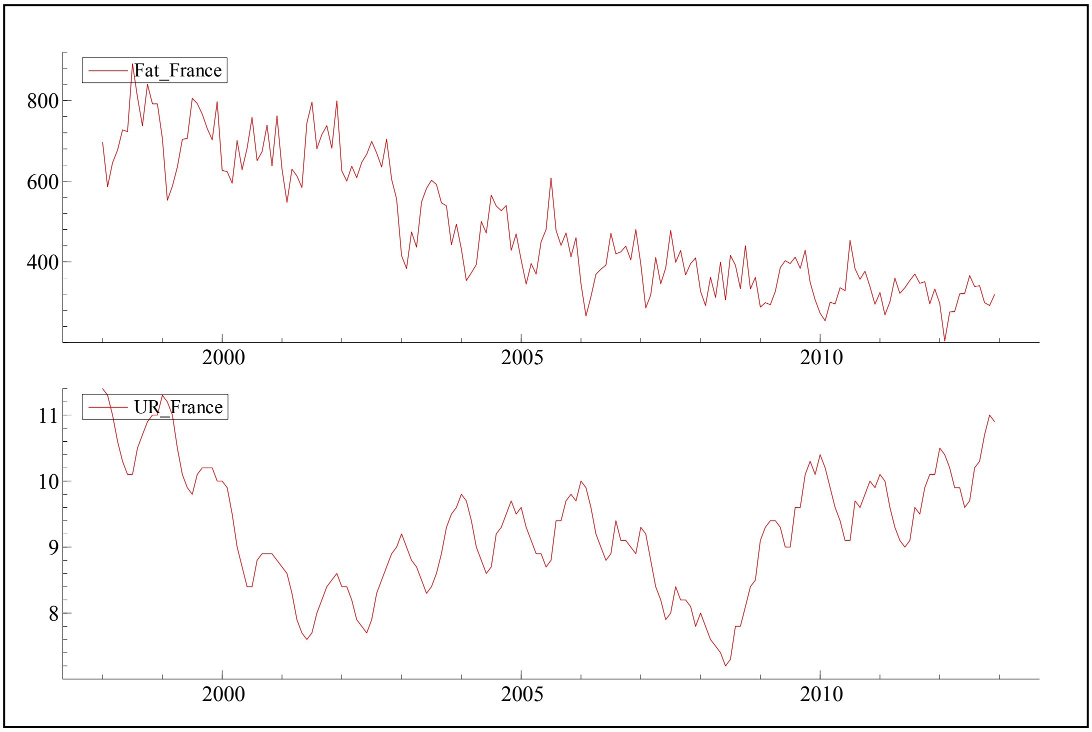
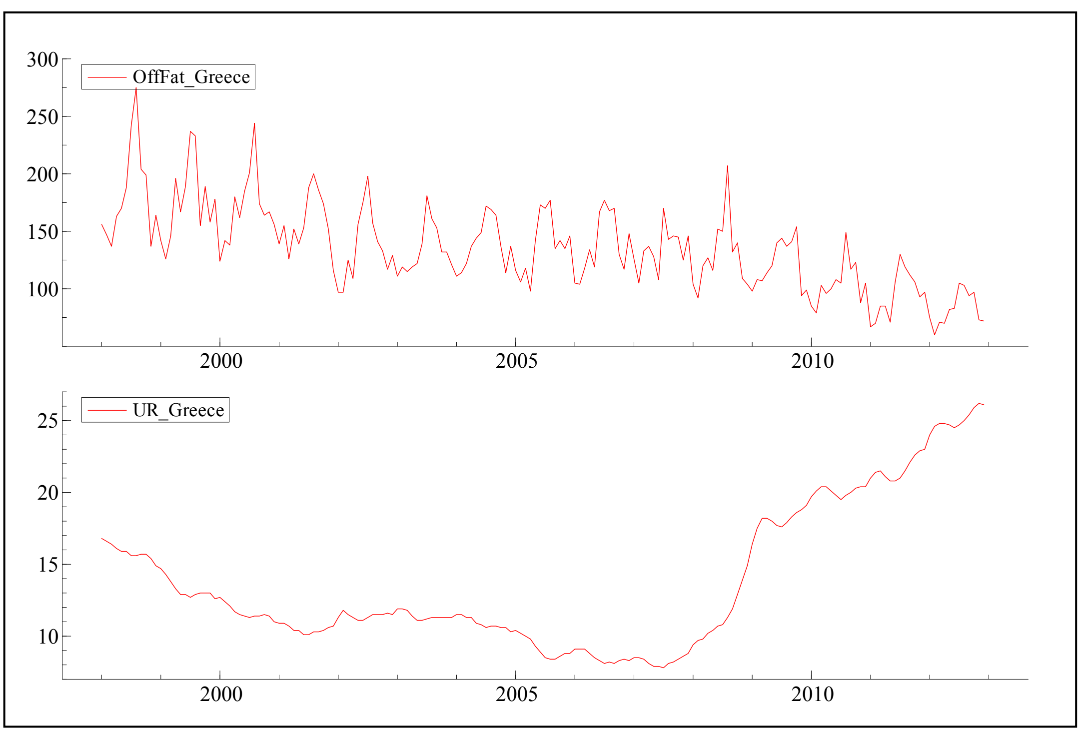


Figure 5.9. **Number of fatalities and unemployment rates Greece, 1998-2012**



Discussion

This section discusses the coherence of our results and compares findings for the short and long term with previous results found in the literature.

Over the long-term perspective, it is well know that since the numbers of road fatalities in European countries have started to decrease, they have kept on decreasing even in times of increasing economic prosperity. This is well explained in the literature. When considering short term changes, such as the changes that occur from one month to the next one, a negative relationship is not obvious, as the short-term changes, being measured on a shorter scale of time, capture a different type of relationship between road fatalities and economic growth.

Many previous findings were based on annualised data with models including more than one explanatory variable. This means that the work included in this study are not consistent with and cannot be compared with many earlier analyses. In all previous cases were only one explanatory variable was used (whether GDP, GDP per capita, income, income per capita) for fitting the annual number of fatalities (or fatalities per capita), similar curves with U-inverted shape were found and intensively discussed.

However, there are very few previous analyses of road mortality based on monthly data and, where they do exist, they rarely refer to unemployment rates.

Conclusion

In this analysis, the relationship between aggregated mortality and the recent economic crisis was investigated for five European countries. The results of this exploratory approach are twofold:

- First, a long-term analysis was carried out with annual data of the period 1970-2009 which highlights the fact that the negative relationship between the number of fatalities and the GDP per capita is not reversible in times of economic recession.

- Second, a short-term analysis performed with monthly data for France, Spain and Greece demonstrates a negative relationship between the number of fatalities and the unemployment rate, which varies according to the country and the period of calibration.

Further work is required to validate the short-term results, as less attention has been devoted on this research topic to short-term rather than long-term analysis. This should include studying the robustness of the relationship between employment rates and the number of fatalities as it is to be expected that the times before and after the crisis periods should be considered separately.

For the analysis to be valid, countries have to be classified in groups that show the same type of relationships and responses to the economic crisis. In addition, the short-term and long-term approaches should be considered altogether. Finally, providing forecasts of fatality numbers remains a challenge, as the targets established for 2010 were set before the beginning of the crisis and need to be updated (ITF, OECD, 2013).

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CHAPTER 6. ANALYSIS OF FATAL ACCIDENTS DURING A PERIOD OF SEVERE ECONOMIC RECESSION IN SWEDEN[1]

During the winter 2008-2009, a substantial drop in the number of fatal road accidents coincided with an economic recession in Sweden. The correlation between the state of the economy and the traffic mortality rate are well established by several researcher but the underlying explanations of the relationship are not fully understood. Therefore, in order to test hypotheses about the relationship, data collected from fatal accidents during the recession in the winter 2008/9, were compared to the same period in 2005/6, 2006/7 and 2007/8 during which the economy was stronger.

The results showed that not only the number of fatalities but also the average number of persons killed per fatal accidents was higher in the winters with economic growth. A related observation is that a collision between two motor vehicles was significantly more frequent in the fatal accidents in the winters experiencing a better economic climate.

Moreover, the rate of suspected suicides was higher in the period of low economic activity. A closer inspection shows that the number of suicides each winter is fairly constant hence the rate increased when the total number of accidents decreases during a recession. Furthermore, a higher share of the fatal accidents during the recession period was involving drivers lacking a valid driving license. No significant differences was found respect to time of day, age and gender distribution, road owner, type of traffic elements, speeding, seat belt wearing, driving while intoxicated or quality of tyres

Introduction

There are convincing reasons to assume that the business cycle influences traffic safety. There is less demand for transportation in a period of low economic activity, which implies that there is less traffic on the roads. Less traffic means that the road-users are less exposed to the risk of having a traffic accident. Thus the traffic safety tends to improve in a recession and deteriorate in times of economic growth.

The above reasoning is supported by several research studies that found a negative association between economic development and traffic safety. Examples of such studies from different countries are: Australia (Haque, 1993; Newstead *et al*., 1998; Tay, 2003), Norway (Fridstrøm, 1997), Switzerland (Wilde and Simonet, 1996), Germany (Neumayer, 2004), and the US (Farmer, 1997; Joksch, 1984; Partyka, 1991; Peltzman, 1975; Reinfurt *et al*., 1991; Wagenaar, 1984).

The state of the economy may affect traffic safety in other ways than just the sheer amount of mileage and a number of theories have been suggested as reasons for the change in the accident rate. One

1. This research was funded by the Swedish Transport Administration. Authors: Åsa Forsman, Lennart Simonsson,Mats Wiklund, Ylva Berg from the Swedish Transport Administration.

theory is that HGV road use increase during an economic growth. A higher number of HGVs on the roads may have an impact on traffic safety as accidents involving HGVs often has severe consequences.

Other theories are that that our behaviour as road-users is influenced by economic conditions and that our mode and habits of travel is different in a recession compared to in economic growth. A particular example of the latter is that younger people are worse affected by unemployment in a recession and tend to reduce their car driving more than older people.

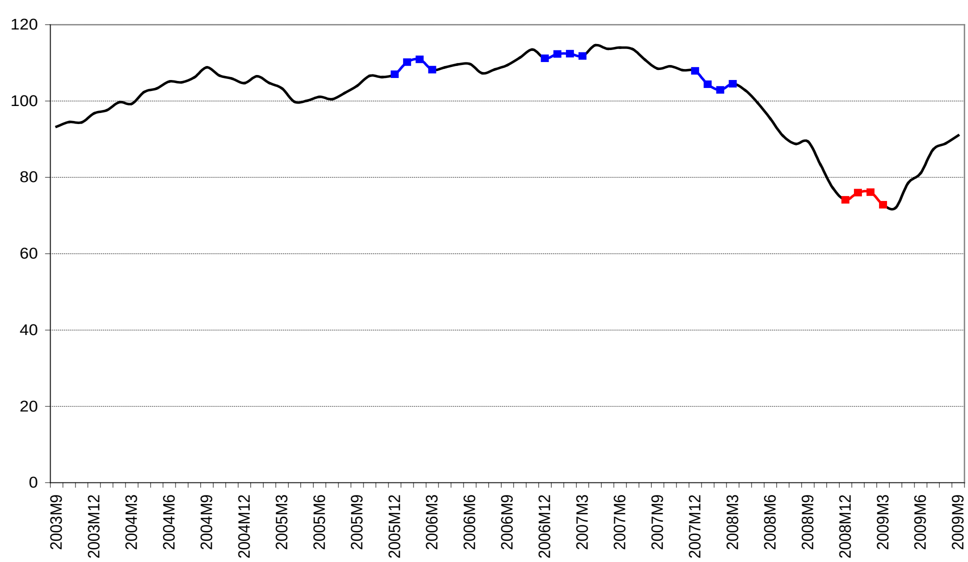
The purpose of this study is to test some of the theories of the underlying explanations of the relationship between the state of the economy and traffic safety. The analyses are based on data from the winter 2008/2009, where a substantial drop in the number of fatal road accidents coincided with an economic recession in Sweden. These data are compared with data from earlier periods with better economic conditions.

Method

During the period December 2008 to March 2009, there was a substantial decrease in the number of traffic fatalities compared with the same period in earlier years. Since this period coincided with economic recession in Sweden, it is a suitable period to use for studying the association between economic development and traffic safety. Data from this period is compared with the corresponding time period one, two and three years earlier (control period). During the control period there was economic growth. This is illustrated by Figure 6.1 showing the Economic Tendency Survey of the National Institute of Economic Research (NIER), which compiles business and consumers' view of the economy and pictures the economic situation. By using the same months, problems with seasonal variation is avoided. Furthermore, keeping to a relatively short period of time decreases the risk of long-term trends becoming a nuisance factor in the comparisons. There may however be a small effect from different weather conditions between the four winters that this study does not attempt to take into account.

Figure 6.1. **The Economic Tendency Survey of the National Institute of Economic Research, monthly from September 2003 to September 2009**

Red dots represent the studied period and blue dots represent the control periods



Source: NIER.

The analysis is divided in two parts. The first part is focused on travel patterns and traffic composition and based on accidents that have been reported to the Swedish Traffic Accident Data Acquisition (STRADA) by the police. This analysis includes the number of fatalities, the number of vehicles of different types per fatal accidents, and collision accidents compared with single-vehicle accidents. As journeys made by young persons and during non-working hours are assumed to be more common in times of economic growth, the age distribution of persons killed in traffic and the time at which the accidents occurred are also examined.

The second part of the analysis is focused on driver behaviour and based on data from in-depth studies of fatal accidents conducted by the Swedish Transport Administration. It has been suggested that periods of economic growth may induce a higher level of stress in society and one theory is that there may be more road-users adapting risky driving behaviour on the roads in times of economic growth. Examples of risky behaviour studied in this section are: speeding, driving under the influence of toxic substances and driving with tyres unsuitable for the road conditions (it is mandatory in Sweden to fit all cars with winter tyres between December 1st and March 31st). The number of fatal accidents involving an unlicensed driver was also studied.

The results are presented in tables which include P-values from Z-test (Table 1) and chi-square tests. Prior to testing, the data from the three periods of economic growth was combined. Relative change means a change in the number of accidents between the period of growth and the period of recession, defined as *#(accidents during recession) / mean[#(accidents during growth)] - 1*, where *mean[#(accidents during growth)]* is the average number of accidents of the three periods of economic growth.

Results

Travel patterns and traffic composition

The results concerning travel patterns and traffic composition are based on police records of fatal accidents. Table 6.1 shows the number of fatal accidents and the number of fatalities for each time period. The number of fatalities has relatively decreased more than the number of fatal accidents. During the recession period there are only two cases with more than one fatality per accident.

Table 6.1. **Number of fatal accidents and corresponding number of fatalities**

	High06	**High07**	**High08**	**High average**	**Low09**	**Relative change**	**P-value**
Number of fatal accidents	104	123	102	109.7	69	-37.1%	< 0.001
Number of fatalities	121	136	122	126.3	71	-43.8%	< 0,001

High06 means the period December 2005–March 2006; High07 means December 2006–March 2007, etc.

In Table 6.2 we see a significant difference between the High and Low periods with respect to the proportion of fatal accidents with more than one fatality per accident. This could be because of changes in accident types as well as fewer passengers per vehicle during the Low period.

Table 6.2. **The number of killed persons per fatal accident**

	High06	High07	High08	High average	Low09	P-value
Number of fatalities/ fatal accident	1.16 (1.09)*	1.11 (1.07)*	1.20	1.15	1.03	
Prop. of fatal accidents with 2 or more fatalities	8.7 %	6.5 %	16.7 %	10.3 %	2.9 %	0.05

* Each of High06 and High07 includes a serious bus accident involving several persons killed. Results exclusive of these accidents are shown within brackets.

Type of accident

Concerning the distribution across collision types there is a significant difference between the High and Low periods (Table 3). Moreover, the largest relative decrease in the number of accidents is within the category pedestrian/cyclist/mopedist (p/c/m) road-users in collision with motor vehicles; collisions between motor vehicles comes next, followed by single vehicle collisions. The fact that collision accidents decrease more than single vehicle accidents when traffic mileage decreases is inherent, since the number of oncoming vehicles decreases roughly in proportion to the square of the traffic mileage. However, it is unclear why the largest decrease is seen within the class p/c/m road users in collision with motor vehicles.

Table 6.3. **Number (proportion) of fatal accidents by collision type, P=0.04**

Collision type	Economic activity		Relative change in the number of accidents
	High	Low	
p/c/m and motor vehicles	86 (26.1 %)	13 (18.8 %)	-54.6%
Motor vehicles	143 (43.5 %)	25 (36.2 %)	-47.6%
Single vehicle	78 (23.7 %)	20 (29.0 %)	-23.1%
Other	22 (6.7 %)	11 (15.9 %)	50.0%
Total	329 (100.0%)	69 (100.0%)	-37.1%

Time of day

The High and Low time periods have also been compared with respect to the distribution of accidents by the hours of the day. The day was split into three parts and the results are presented in Table 6.4. The difference between the distributions is not significant, but the observed relative decrease is largest during evenings.

Table 6.4. **The number (proportion) of fatal accidents by time of day, P=0.30**

Time of day	Economic activity		Relative change in the number of accidents
	High	Low	
Day (6-18)	221 (67.2%)	50 (73.5%)	-32.1%
Evening (18-23)	65 (19.8%)	8 (11.8%)	-63.1%
Night (23-6)	43 (13.1%)	10 (14.7%)	-30.2%
Total	329 (100.0%)	68 (100.0%)	-38.0%

Road authorities

All Swedish highways and major rural roads are maintained by the Swedish Transport Administration while streets in built-up areas are maintained by each District Council. Minor roads in Sweden are maintained by the land owners with the support of government funds. The road authority variable in STRADA can be used as a proxy for whether the accident occurred within a built-up area.

The results presented in Table 6.5 show no statistically significant difference between the High and Low period with respect to different road authorities (Table 5).

Table 6.5. **The number (proportion) of fatalities by road authority. P=0.75**

Road authority	Economic activity		Relative change in the number of accidents
	High	Low	
District Council	74 (19.5%)	12 (16.9%)	-51.3%
State	294 (77.6%)	56 (78.9%)	-42.9%
Private	11 (2.9%)	3 (4.2%)	-18.2%
Total	379 (100.0%)	71 (100.0%)	-43.8%

Age and gender

Concerning discussions about traffic safety and the economic situation, one common theory is that accidents involving young drivers would decrease more than others since young persons (according to the theory) are more affected by an economic recession. Table 6.6 shows the proportion of killed drivers of private cars by age group. No significant difference is found between the High and Low periods.

Table 6.6. **The number (proportion) of killed drivers of private cars by age group, P=0.29**

Age group	Economic activity		Relative change in the number of accidents
	High	Low	
18-24	29 (16.6%)	8 (20.0%)	-17.2%
25-39	47 (26.9%)	6 (15.0%)	-61.7%
Others	99 (56.6%)	26 (65.0%)	-21.2%
Total	175 (100.0%)	40 (100.0%)	-31.4%

To obtain a complete picture, the proportion of men and women were compared. No significant differences were found between the High and Low periods.

Traffic elements

During economic recession, HGV traffic decreases more than passenger traffic. However, this is not mirrored in accident statistics, since the per-accident number of vehicles of a certain type is more or less constant for all periods (Table 6.7). There was no significant difference between the High and Low periods for any of the vehicle types.

Table 6.7. **The number of vehicles of a specific type per fatal accident**

	Economic activity	
	High	Low
HGV	0.22	0.22
Car	1.12	1.07
Bus	***0.06***	***0.03***

Driver behaviour

The analyses with respect to driver behaviour are based on data from in-depth studies. The number of studied accidents are 313 during economic growth and 67 during the recession. The number of fatalities is 362 and 69, respectively, during the two periods.

The driver behaviour studied in this section includes: suicide[2], non-use of seat belt, unlicensed driving, speeding, use of toxic substances, and using tyres unsuitable for wintery road conditions. At the time of the study the material from the in-depth studies were being made available electronically. The interface was however not fully developed yet so it was not always possible to search specifically for the occurrence of risky behaviour. Therefore the comments and supplements had to be examined for each accident. Unfortunately, due to time restraint when perusing the material, accidents involving risky behaviour might have been overlooked. Speeding was the most difficult to detect examining the comments and supplements.

2. As of 2010, suspected suicides are no longer classified as road accidents in the official statistics.

Table 6.8 shows a significant difference in the rate of suspected suicides among the traffic fatalities between the High and Low periods. A larger proportion of the killed drivers were suspected suicides during the period with low economic activity.

Table 6.8. **Suspected suicides among the traffic fatalities, P=0.02**

	Economic activity		**Relative change in the number of accidents**
	High	**Low**	
Suspected suicides	20 (5.5%)	9 (13.0%)	35.0%
Other fatalities	342 (94.5%)	60 (87.0%)	-47.4%
Total	362 (100.0%)	69 (100.0%)	-42.8%

Table 6.9 shows seat belt use among persons killed in a car or HGV. No significant difference can be detected between the two periods.

Table 6.9. **Seat belt use in fatalities in cars or HGVs, P=0.54**

	Economic activity		**Relative change in the number of accidents**
	High	**Low**	
Seat belt not used	72 (27.9%)	18 (34.0%)	-25.0%
Other fatalities	158 (72.1%)	35 (66.0%)	-33.5%
Total	230 (100.0%)	53 (100.0%)	-30.9%

Driving under the influence of toxic substances is not significantly different among the fatal accidents in the High and Low periods (Table 6.10).

Table 6.10. **Fatal accidents where at least one driver tested positively for toxic substances, P=0.45**

Alcohol or drug use	Economic activity		
	High	Low	Relative change in the number of accidents
At least one intoxicated driver	74 (23.6%)	13 (19.4%)	-47.3%
Other fatalities	239 (76.4%)	54 (80.6%)	-32.2%
Total	313 (100.0%)	67 (100.0%)	-35.8%

Illegal driving and suspicion of speeding was studied in accidents where at least one of the following vehicles was involved: car, bus, lorry or motorcycle. Vehicles that do not require a comprehensive training to obtain a driving license or are not allowed for use on roads were not considered. This criterion ruled out 8 accidents involving snow mobiles, 3 accidents involving bicycles and 2 moped accidents. According to Table 11 there is a significant difference in the share of accidents involving an unlicensed driver between the High and Low periods. There are, relatively, more unlicensed driver during the recession.

Table 6.11. **Fatal accident where at least one driver was unlicensed, P=0.02**

	Economic activity		
	High	Low	Relative change in the number of accidents
Unlicensed driver in the accident	23 (7.6%)	11 (17.2%)	43.5%
Other accidents	280 (92.4%)	53 (82.8%)	-43.2%
Total	303 (100.0%)	64 (100.0%)	-36.6%

No difference can be detected between the two periods with respect to speeding (Table 6.12).

Table 6.12. **Fatal accidents where at least one driver was suspected of speeding, P=0.57**

	Economic activity		Relative change in the number of accidents
	High	Low	
Suspected speeding before the accident	66 (21.8%)	16 (25.0%)	-27.3%
Other accidents	237 (78.2%)	48 (75.0%)	-39.2%
Total	303 (100.0%)	64 (100.0%)	-36.6%

Further inappropriate behaviour is using tyres unsuitable for current road conditions. The category unsuitable tyres in Table 6.13, comprise both vehicles fitted with tyres of low and illegal quality and cases where the investigator made a complaint (the most common being that the tyres were heavily worn or had too few studs left). There is a shortfall because it was not always possible for the investigator to inspect the tyres of all vehicles involved in an accident. The third category in Table 13, are accidents where one vehicle had tyres of unknown quality, unless there was another vehicle involved in the accident with unsuitable tyres. In the last case the accident was put in the “unsuitable” category.

Table 6.13. **Quality of tyres of the vehicles involved in fatal accidents, P=0.55**

	Economic activity		Relative change in the number of accidents
	High	Low	
At least one vehicle had unsuitable tyres	71 (23.4%)	11 (17.2 %)	-53.5%
All vehicles had good tyres	186 (61.4 %)	42 (65.6 %)	-32.3%
Some vehicle had tyres of unknown quality	46 (15.2 %)	11 (17.2 %)	-28.2%
Total	303 (100.0%)	64 (100.0%)	-36.6%

Discussion

There was a much greater decrease in the number of road fatalities in Sweden than could be expected from the reduction of traffic mileage at the time of the financial crisis in the turn of the year 2008-2009. These data was therefore analysed with respect to several theories about the relationship between the state of the economy and the traffic mortality rate. Data from the corresponding time period one, two and three years earlier were used as control periods. During the control period there was economic growth.

The results showed that not only the number of fatalities but also the average number of persons killed per fatal accidents was higher in the winters with economic growth. A related observation is that a collision between two motor vehicles was significantly more frequent in the fatal accidents in the three winters experiencing a better economic climate. A reduction in the mileage during a recession lessens the number of conflict situations between vehicles however some of the effect may also be due to the safety improvements of the roads e.g., constructing lane dividers.

No significant difference was found with respect to time of day, road owner, age, gender, or traffic elements.

A summary of the comparisons concerning driver behaviour shows that two out of six comparisons showed a significant difference between periods of high and low economic activity. These two were suspected suicides and unlicensed driving. The rate of suspected suicides is higher in the period of low economic activity. A closer inspection shows that the number of suicides each winter is fairly constant hence the rate increases when the total number of accidents decreases during a recession. Furthermore, in two of the accidents not classified as suspected suicides during the recession in 2008-2009, the investigator mentions that the victims may have had economic problems and that they had also displayed extremely reckless driving behaviour prior to the accident. It is therefore possible that the number of suicides may have been underestimated in the recession period.

Furthermore, a higher share of the fatal accidents during the recession period was involving drivers lacking a valid driving license which may partly be explained by many people driving illegally due to not being able to afford to pay for courses required for passing a driving licence. On the other hand, an accident involving a driver who has had the license revoked due to a traffic offence has no direct link to the economic situation.

The theory that the road-users would be more prone to risk taking behaviour in a period of economic growth could not be confirmed. None of the risky behaviour such as driving while intoxicated, exceeding the speed limit and not using a seat belt was more common in the fatal accidents in the three winters of economic growth.

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CHAPTER 7. FATAL ROAD CASUALTIES IN GREAT BRITAIN: TWO STUDIES RELATING PATTERNS TO WIDE-RANGING EXPOSURE FACTORS[1]

There has long been interest in identifying factors at the macro-level which affect the systematic patterns observed in fatality numbers resulting from road crashes. There is interest in investigating causal relationships affecting fatal numbers both within individual countries through time, but also understanding the differences in the magnitude of road deaths between countries at the international level. The recent global recession has clearly affected patterns in road fatalities markedly in a number of countries; this has renewed interest in this area of study.

The mechanisms by which recession conditions actually influence road safety levels are not well understood. Clearly there is generally a reduction in overall kilometres driven, but there are a wide range of more subtle effects which are less readily characterised which may have a significant role to play. The state of the economy can affect numbers of new drivers, the average age of the vehicle fleet and patterns in alcohol consumption for example.

The following chapter summarises two complementary studies which have been conducted to better understand patterns in road fatalities in Great Britain. Both studies investigated a wide range of exposure measures and risk factors which can potentially influence road safety and the approaches have gone beyond simply focussing on traffic levels and broad economic metrics. The studies particularly address in a detailed way how a wide range of behaviourally related factors may have contributed to recent decreases in road crash related fatalities in Britain.

The work outlined complements other studies which have mainly investigated broader patterns across a range of countries simultaneously but in less detail; or which concentrated on very specific risk aspects which may have influenced patterns within single countries.

These works both add significant support to the theory that a wider series of behavioural changes by road users, and particularly drivers, which are influenced by recession conditions have had a major role leading to the large reductions in road deaths apparent in Britain associated with the recent recession.

Introduction

There has long been interest in comparing, and even trying to predict, broad road safety levels in countries. This work typically takes the form of relating numbers and rates of road fatalities to economic development level. Well known work in this area was developed first by Smeed [e.g. Smeeds' law (Smeed 1949)], more recently by Kopits and Cropper (2005) and very recently by Koren and Borso (2013). These works suggest that there is an inverse U-shaped relationship between the economic

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development levels of countries and road safety levels. The studies indicate that when a particular level of prosperity is achieved this is associated with the introduction of more effective and better funded efforts to tackle road safety issues. As a consequence of greater investment in safety, fatalities per registered vehicle begin to fall despite continued increases in the magnitude of the vehicle fleet as the economy grows further.

In addition to this coarse relationship between safety levels and Gross Domestic Product (GDP) per capita across countries, it is also known that road safety within countries is also affected at a finer level by shorter term economic fluctuations such as recessions. Whereas the relationship between economic development level and overall road safety levels is reasonably clear at a gross level, the details of the underlying mechanisms which can act to improve safety in association with periods of recession have not been clearly disentangled to identify the causal effects associated. This lack of clear insight into the actual mechanisms by which the economic state affects road safety is due, in major part, to the limited availability of a wide range of data relating to exposure and risk factors, and particularly the availability of data classifying behavioural patterns.

The remit of this publication is to clarify and state the relationship between economic recession conditions and road fatality patterns in countries primarily using some widely available but relatively simple economic indicators. Some of the papers in this wider report indicate that the availability of a range of more detailed data sets for a range of exposure factors and road user behaviour related information would be useful to enable a better understanding of the mechanisms for observed relationships to be elucidated. These stated limitations mean that there is relatively restricted scope from these studies to really identify the underlying casual factors and relationships.

The studies described here fill this gap to a good extent. In Great Britain a number of data sets are available relating to socio-economic and travel/transport patterns. These data can help to clarify the underlying causal determinants of the relationship between gross road safety levels and the economy.

The two pieces of work described here have much in common; they have both investigated patterns in British road casualty figures with a focus on the possible influences of recent negative and low GDP growth. Both studies use the officially reported fatality numbers for Great Britain, and importantly they also use a wide range of the available national data sets to investigate and explain the patterns observed. There were also some important differences between these studies. The TRL study investigated patterns in both fatal and serious casualty numbers with some modelling approaches applied; whereas the analyses performed by the UK Department for Transport (DfT), which were initiated specifically for IRTAD, examine trends in road fatalities more descriptively.

Both pieces of research examined the associations between observed variation in fatality numbers with the economic conditions and also with changes in exposure and known risk factors. These studies made use of data sets which are less commonly measured relating to variations in specific driving population behaviours, which were likely to be influenced by the economic conditions.

The TRL study was funded by a local authority (Surrey County Council) and had a focus on fatal numbers and also serious casualties primarily between the years 2000 and 2010. Some relatively complex modelling and statistical approaches were applied. The work was not undertaken specifically for IRTAD, however, the study area and results are extremely relevant for this current publication.

The DfT study was specifically instigated for IRTAD; it addressed a longer time frame of data than the TRL study; investigating patterns primarily in fatalities from 1970 to 2012. This more extended time period included multiple recession episodes.

Both studies investigated relationships between fatality numbers and the following main exposures and influencing factors:

- gross Domestic Product
- weather patterns
- vehicle flows
- vehicle speeds
- trip patterns
- in-Vehicle secondary safety system improvements
- driver demographic patterns.

The main data sources used in both the DfT and TRL studies are summarised in the sections that follow.

Data analysed

Crash and injury Data

The STATS19 system holds injury road crash data reported to the police in Great Britain. This was the main source of the fatality figures in both studies. The database comprises details of the crash circumstances, together with data on the vehicles and casualties involved in the collision, and also underlying contributory factors which are the (to some extent subjective) possible reasons why the crash occurred.

Exposure and risk factor data

Data for various risk factors were analysed to determine if they contributed to the observed fatality reduction. The key sources and types were as follows:

- **National Traffic Estimates:** The DfT collects traffic counts on a large selection of roads in Great Britain. These counts are combined with road network lengths in order to estimate the total vehicle kilometres travelled each year. Traffic flow can be approximately disaggregated by time, month, road type, region, and vehicle type. The data used in this research was vehicle flow from during the study periods on different road types, by different vehicle types.

- **Registered Vehicle Data**: The Driver and Vehicle Licensing Agency (DVLA) holds information on each registered vehicle in the UK, including the make and model of the vehicle and its year of registration. This information can be used to categorise the UK car fleet into six subgroups by car size. These data were used to classify the vehicles that were involved in STATS19 crashes. In addition, the number of registered cars by car type, age and year from 2000-2010 has been used as an exposure measure for the TRL study.

- **National Travel Survey**: The National Travel Survey (NTS) is a continuous household survey collecting interview and travel diary data on personal travel in Great Britain. Data are collected for each journey travelled in a week by mode type, distance, cost and time. Interviews are conducted with people to collect other factors such as car availability, driving licence holding and access to key services (Department for Transport, 2011). The NTS also allows the volume of pedestrian travel by road to be estimated each year, in addition to providing greater detail about travel patterns by vehicle.

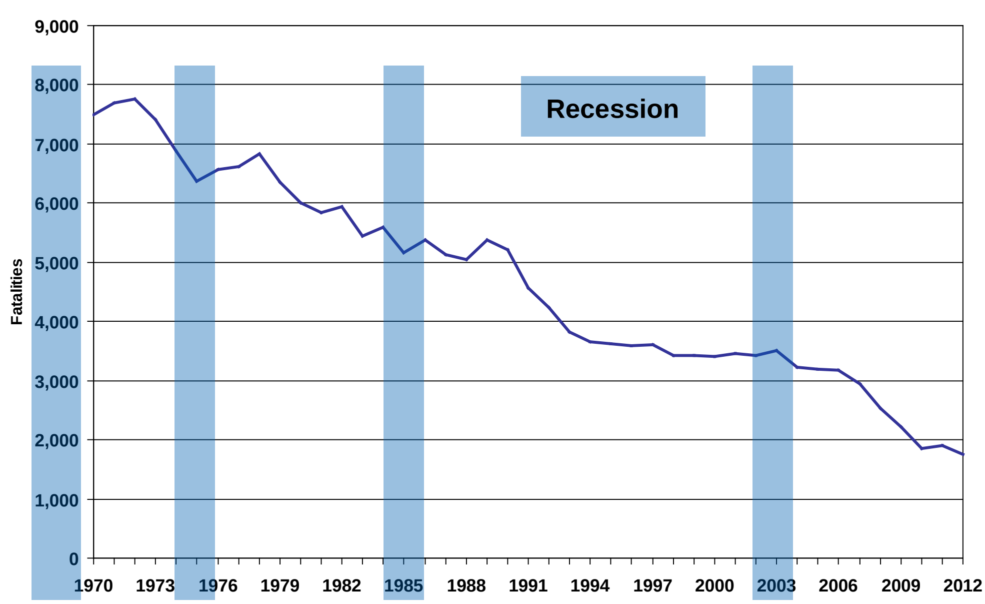
- **MAST**: MAST online (Road Safety Analysis, 2012) is a web based data analysis tool which combines STATS19 data with the Index of Multiple Deprivation (IMD) which is used to identify how deprived an area is. It uses a range of economic, social and housing data to create a single deprivation score for each small area of the country

- **Coroners' Data**: TRL collect, on behalf of DfT, blood alcohol levels from the national coroners systems for all road fatalities aged 16 or over who died within 12 hours of a road crash. Data from 2002 to 2010 were received for 82% of the fatalities in STATS19 aged over 16. Over this period we received 14,683 records that could be matched to STATS19, with blood alcohol information. These 14,683 fatalities consisted of 10,445 driver/rider fatalities, 1,839 passengers and 2,399 pedestrians.

Longer Term Patterns in Fatal Casualties in Britain

It is clear that there have been significant falls in road deaths which correspond to periods of economic downturn in Great Britain in the past. Most of the most marked reductions in road fatality numbers over the last 40 years have either occurred in times of recession directly, or times of economic challenges associated with recessions (see Figure 7.1).

Figure 7.1. **Fatality numbers and episodes of recession for GB, 1970 to 2012 (from DfT)**



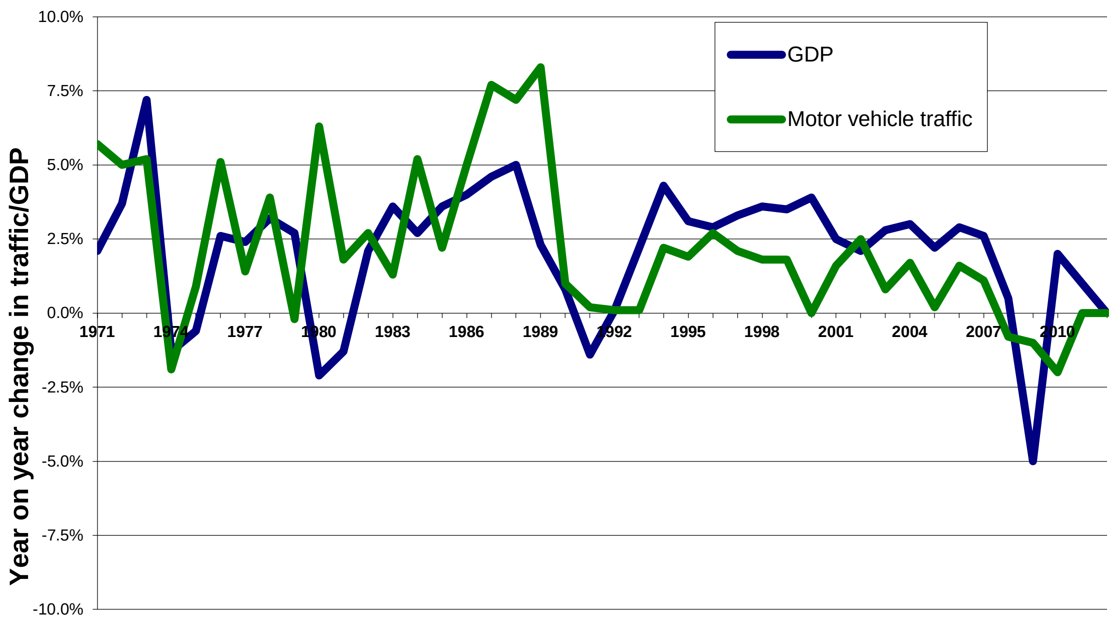
Understanding better these interesting and apparently systematic patterns was the main motivation behind both the studies reported here. A concern is that the year-on-year reduction in fatalities could reduce markedly once sustained economic growth returns. Understanding the causal mechanisms for the reductions in fatalities associated with recession may better help road safety professionals to identify effective strategies to enhance road safety in times when the economy is growing more strongly.

Department for Transport: Fatality Monitoring Patterns and Results

The following section summarises the patterns identified in fatalities and risk factors investigated by Department for Transport staff for Britain, particularly in relation to the recent economic difficulties. There was an emphasis on identifying factors which may have contributed significantly to the observed reduction in road deaths and particularly those that could be causal and which may be influenced by the recession conditions.

The key long-term patterns between road deaths and in periods of recession in Great Britain are shown in Figure 7.2.

Figure 7.2. **Year on year change in traffic and GDP: Great Britain 1970-2012**



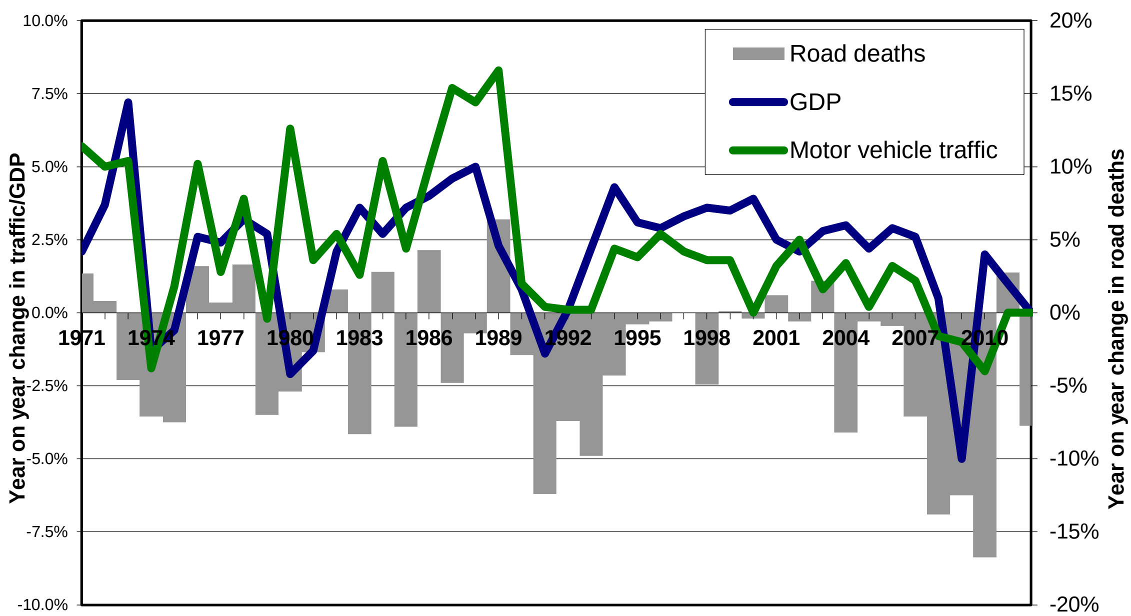
Traffic

Overall, traffic has varied broadly in line with the fluctuations in GDP from year-to-year (Figure 7.2); thus the overall flows have generally fallen during periods of economic recession, but the relationship has not always been exactly direct. The complexity of the relationship between flows and the economy is illustrated by the fact that the recession period around 1980 did not have a corresponding reduction in traffic which actually increased markedly; however there was a fall in the previous year which was probably related to the OPEC oil crisis which occurred at that time.

Other perceptible shorter term factors have also probably had an observable influence on the overall mileages driven in Great Britain. These episodes include a series of industrial protests by lorry drivers which took the form of fuel blockades in 2000 which resulted in widespread petrol and diesel shortages. Periods of widespread, sustained and heavy snow in the winters of 2006 and 2010 were also likely to have significantly decreased traffic volumes compared with expected levels.

Figure 7.3 shows the year-on-year changes in GDP, total vehicle flows and road deaths shown together from 1970 to 2012. This figure shows clearly that the biggest falls in road deaths coincided very consistently with periods of negative economic growth.

Figure 7.3. **Year-on-year change in traffic, road deaths and GDP: GB 1970-2012**



Changes in Deaths by Road User Group and Crash Character

Figure 7.4 shows the relative changes in fatalities for some of the key crash sub-groups which were associated some of the largest relative changes in the number of road deaths in 2008 and 2009 compared to the 2007 numbers.

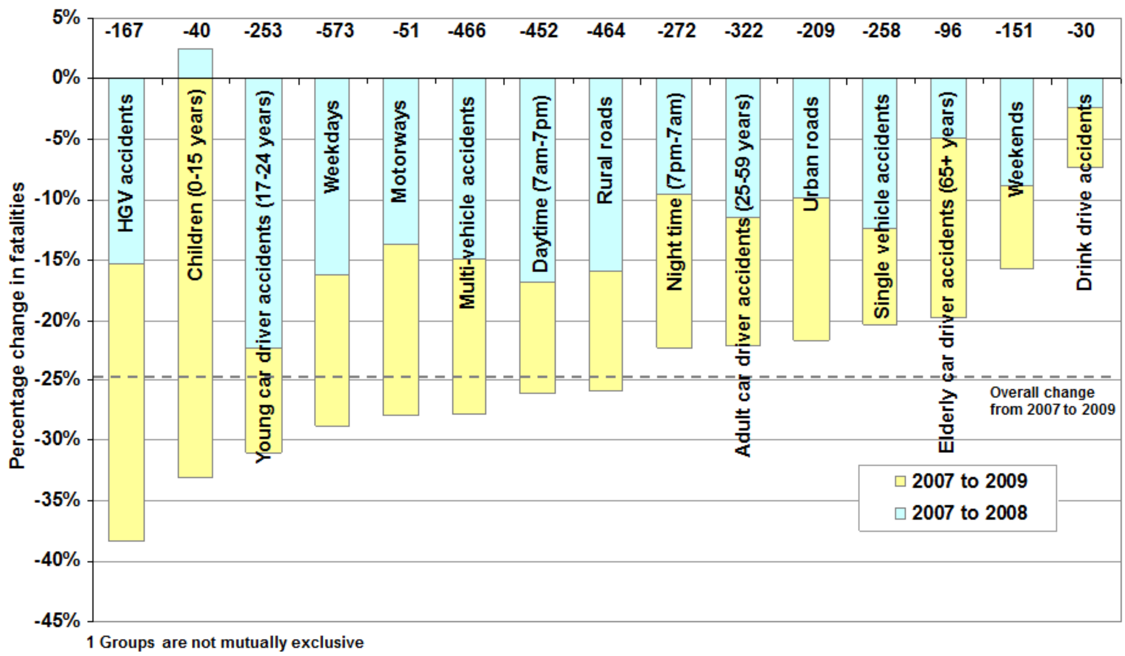
The changes shown in the figure on the Y axis are relative, so these groups do not necessarily impact the overall changes in the numbers of road deaths equally. It is clear that large relative reductions were apparent in fatal crashes involving heavy goods vehicles and those involving younger drivers; these groups however represented a moderate contribution to the overall reductions in total road deaths during the most recent recession.

There was also a welcome marked fall in child road deaths from 2007 to 2009 but a small increase from 2007 to 2008, for this sub group there is likely to be greater variation since the numbers of crashes are small and are thus subject to greater random fluctuations.

The largest decreases in actual fatality numbers were experienced in groups where speed and a decrease in commercial activity are likely factors; these groups were weekday crashes, day time crashes, crashes on rural roads, multi vehicle crashes and crashes involving drivers aged 25-59.

It should be noted that the subsets shown in the figure are not mutually exclusive and the total fatality reductions are thus shared unevenly across these sub groupings.

Figure 7.4. **Change in number of fatalities for selected groups: GB 2007-2009**



Heavy Goods Vehicles

Fatality patterns in Heavy Goods Vehicle (HGV) related crashes were investigated in more depth since the levels of heavy traffic will logically tend to follow changes in the economy more closely than car traffic. This is because the requirement to transport goods by road will relate very directly to levels of commerce, consumption and production within the country.

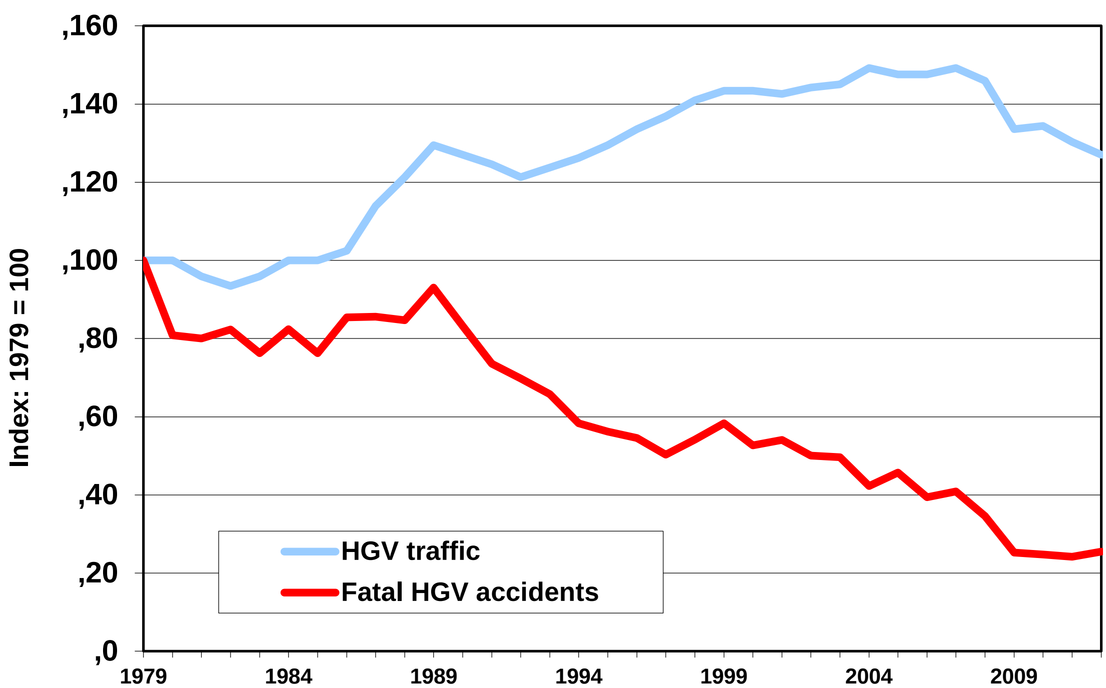
There has been a strong downward trend in fatal HGV crashes since the early 1990s despite an overall trend for heavy traffic to increase over that period; however the falls have been largest when the reductions in HGV traffic has also been greatest.

There was initially a very marked reduction in HGV traffic in the most recent economic recession (Figure 7.5) and this was associated with the observed very large reduction in the number of fatal crashes in which heavier lorries were involved between 2007 and 2009. From 2008 to 2009, overall Heavy Goods Vehicle traffic fell by 8%, but fatalities fell by 39% over the same period. Since 2009, fatalities which occurred in crashes involving HGVs remained steady despite a continued but less marked fall in heavy vehicle traffic.

The number of fatalities in crashes involving HGVs was 263 in 2010, 257 in 2011 and 271 in 2012, whilst HGV traffic dropped by 3% in 2011 and 2.5% in 2012. This indicates that the number of related fatal crashes was basically unchanging in the latter years when continued reductions might have been expected after 2009 given the previous observed trend.

This failure for further marked falls in fatalities arising in HGV crashes could potentially be due to a number of factors. The significantly lower fatality total of the 2009 figure was associated with relatively large reductions in HGV traffic. There may also have been limited scope for further large reductions since the main sensitive crash types most readily affected by recession related factors may have been largely reduced in the prior years. There may also have been a change in driver behaviour by the lorry drivers or even by car drivers to greater risk taking since the most acute recession conditions eased off after 2009.

Figure 7.5. **Fatal crashes involving HGV: GB 1979-2012**



Young Drivers

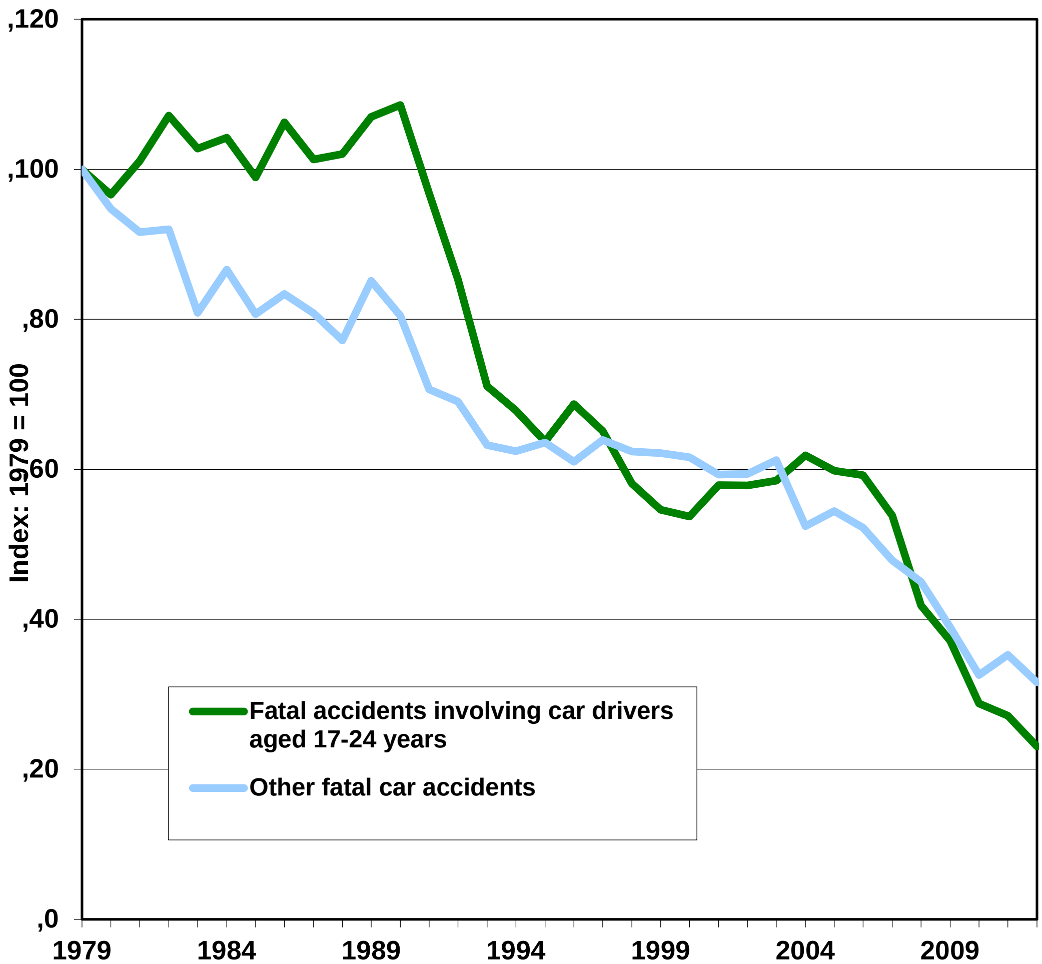
Fatal crashes involving young car drivers also appeared to be more affected by the state of the economy than those involving other sub groups or with the other population of car drivers. Fatalities in crashes which involved young car drivers were identified to have much larger relative falls than for other fatal car crashes during the recessions of the early 1990s and the late 2000s, though this was not the case during the recession of the early 1980s (Figure 7.6). As with the patterns in road deaths associated with HGV crashes the association between young driver crashes and fatality numbers has been investigated in greater detail, especially with respect to the patterns in the most recent recession.

Some of the underlying factors associated with the decreased exposure (presence) of younger drivers on the roads which may in turn have led to the observed reduction in associated road deaths in the most recent economic down-turn were examined. These factors were:

- The number of new drivers who passed their driving test stayed at the same level as 2005/6 (these had been rising year-on-year before then).
- The average distance driven by young drivers, and particularly males, decreased after 2007 (from National Travel Survey, Figure 7.7). Although all drivers irrespective of age drove less after the latest recession started young male drivers decreased their average driving distance the

most. The decrease seems to have started in 2008, just before the period of recession commenced.

Figure 7.6. **Fatal crashes involving young car drivers (17-24 years): GB 1979-2012**



Mode of transport

Based on the National Travel Survey (2013) data which include information detailing average distance travelled per person by different mode, there has been a large relative growth in rail and underground travel since 1995. There has also been more recent growth in cycling. Correspondingly there have been decreases in car and van usage, and also the mean distance walked.

One could speculate that large decreases in road casualties, and particularly road deaths, might also be due in part to people shifting from road use to other forms of transport, particularly rail. This modal shift may be driven by the economy and the higher expense of running cars, though other factors may also have influenced the trend such as improved public transport standards and services. This is particularly the case for London where car ownership per capita is already far lower than in the rest of the country.

Figure 7.7. **Average distance driven by car drivers per year**

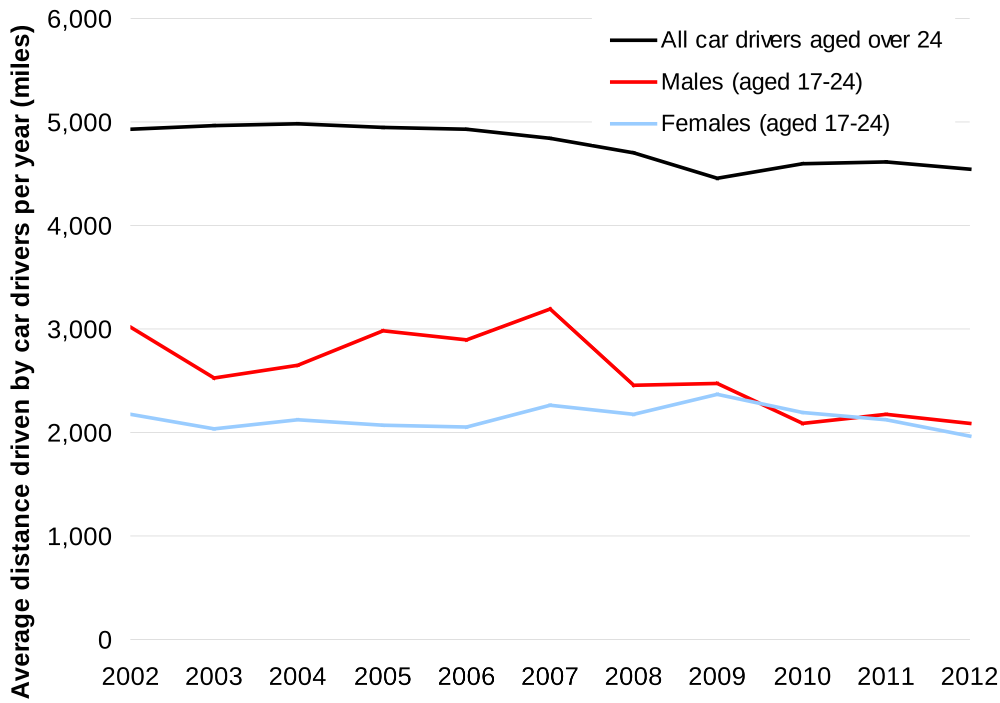
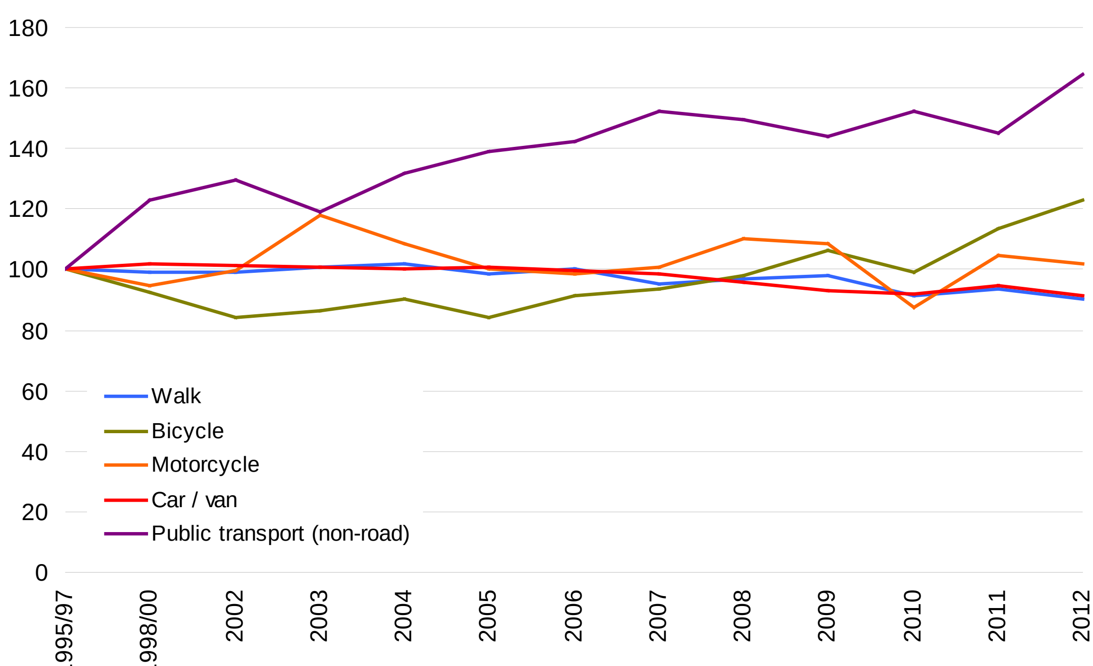
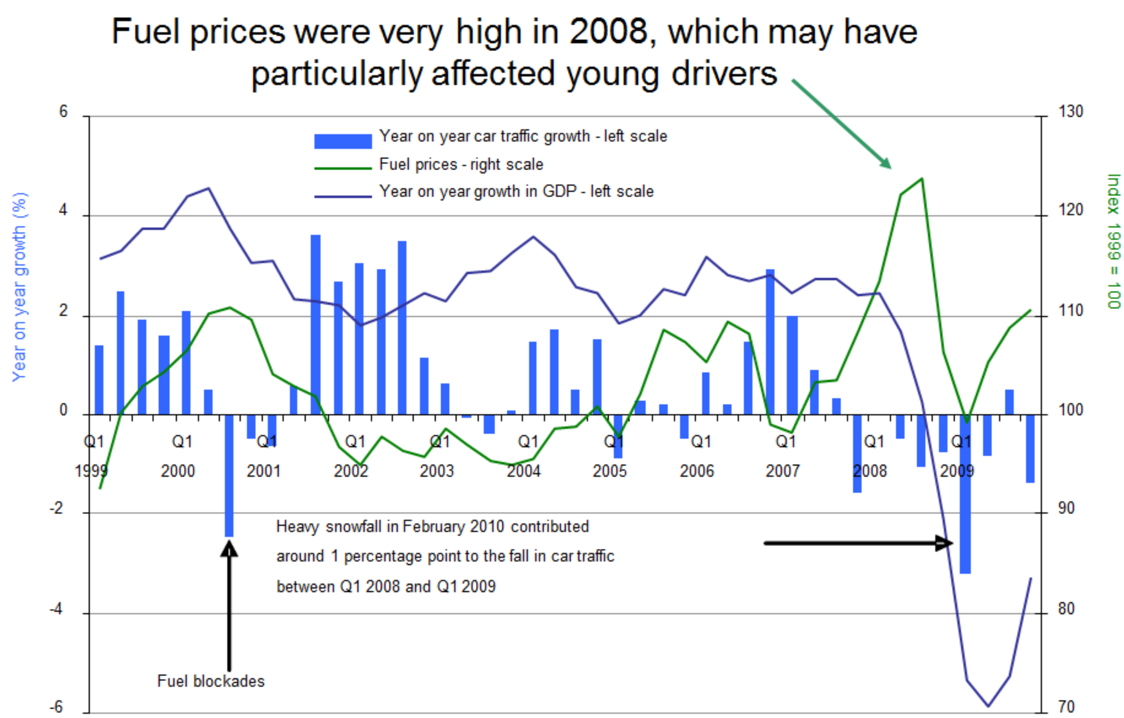


Figure 7.8. **Some indication of modal shifts in GB from the mid-2000s**



Other factors may also have affected recent falls in road deaths. Higher fuel prices and less availability of disposable income (Figure 7.9) may have contributed to drivers driving lower mileages as the relative cost of driving has increased. Driver may also be adopting more economical driving habits to achieve increased fuel efficiency through adoption of lower speeds (lower traffic speeds are known to reduce crash occurrence and severity).

Figure 7.9. **The possible effect of fuel prices on driving patterns**



Vehicle fleet

The Police have recently increased seizures of vehicles that are unlicensed or uninsured; these illegal vehicles are acknowledged to be more likely to be involved in road crashes than vehicles which are legally on the road hence a reduction in these vehicles on the roads should help reduce crashes. It is estimated that unlicensed vehicles made up around 0.5 per cent of the vehicle fleet whilst the proportion of uninsured vehicles in much higher.

A government-funded Car Scrappage scheme initiated in 2009 specifically to stimulate sales of new cars (which had been stagnating) as a measure to improve the economy could also have increased the proportion of safer newer vehicles on the roads as older vehicles are replaced. The Car Scrappage Scheme specifically encouraged drivers to replace cars that were over 10 years old by partially subsidising the cost of new replacement cars.

Conclusions of the DfT study

Road deaths in Great Britain have generally fallen over the past 40 years, with a much greater rate of decline being experienced in association with periods of economic recession. This suggests that factors associated with the conditions linked with a shrinking economy have played a major part in reducing road deaths.

During the latest extended recession periods, which encompassed a "double dip" in Britain, broadly occurring from 2007 to 2012, there was a 40% reduction in road deaths overall. A wide range of factors have been implicated by this study by DfT to influence the observed reductions in road deaths.

Relative reductions in the deaths resulting from crashes involving HGVs and young drivers in particular appear to be more closely related to economic patterns than other types of crash. A range of reasons why these two groups in particular may be more affected by the state of the economy were identified.

A range of other short-term factors (e.g. longer periods of adverse weather and disruption to fuel supply availability) can also influence traffic levels and hence road deaths. Government and enforcement policy were also identified as potential contributing factors to the improvement in road safety.

The wide range of data used to investigate this issue indicated that behavioural changes by road users such as modal shifts and the adoption of less risky driving styles may also be factors that may have contributed to the reduction observed in road deaths. Some of these changes may well relate to the shorter term changes in the state of the economy whilst aspects such as the indications of modal shift to rail from road travel might be longer term patterns.

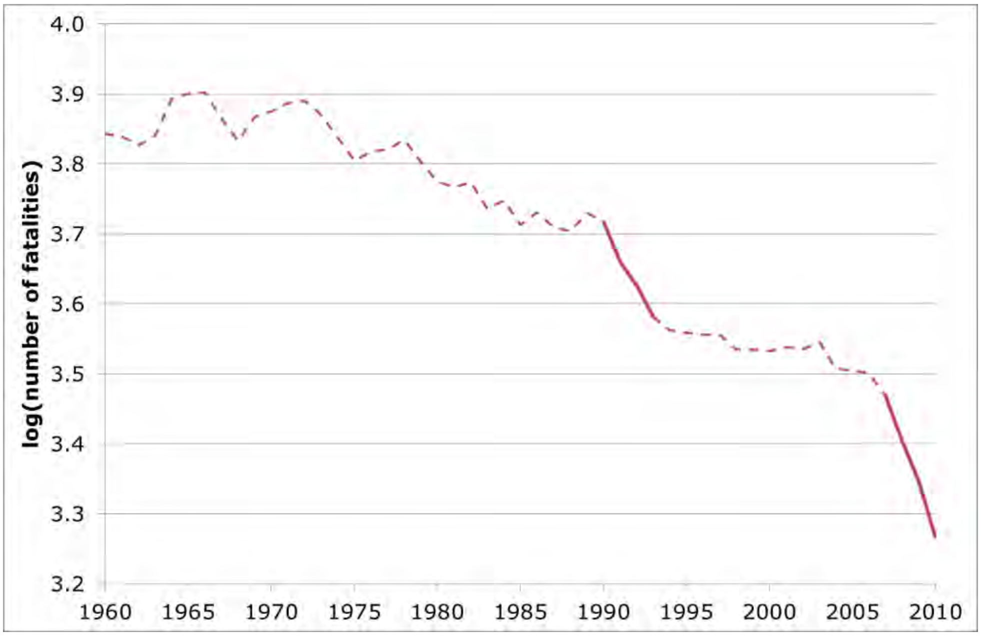
It has not been possible to identify any direct effects of the economic downturn on reductions in road deaths with absolute certainty; there are many factors which can affect the trends observed in recorded fatalities and it is hard to disentangle them with the data available. However the strong circumstantial evidence from this investigation indicates that a range of effects of the recession; for example on the numbers of riskier drivers/vehicles on the roads and also changes in driving behaviours have been influenced by the economic climate, which have resulted in significant reductions in road deaths.

TRL investigation into road fatality patterns and recession in Britain

The following sections summarise a major study carried out by TRL for Surrey County Council. This work primarily aimed to obtain a better understanding of the underlying reasons for the recent marked decrease in fatalities in Britain since 2007.

Figure 7.10 shows the logarithm of the annual fatality numbers from 1960 to 2010. This shows year-on-year changes particularly clearly. It is apparent that apart from a reduction from 1990-1992 (again during recession conditions), the reduction in fatalities from 2007 to 2010 is the most pronounced.

Figure 7.10. **Logarithm of fatality numbers for Great Britain 1960-2010**



Whilst this reduction in road deaths has been welcome, there has not been a firm understanding of how the reduction has been achieved and through what causal relationships. There has also been some concern that the reduction in fatalities would be reversed once the British economy returned to strong growth. It was considered that gaining a better understanding of the causal factors which led to the reduction in road deaths could help the authorities in Britain to identify measures which could help to avoid a major increase in fatalities post-recession.

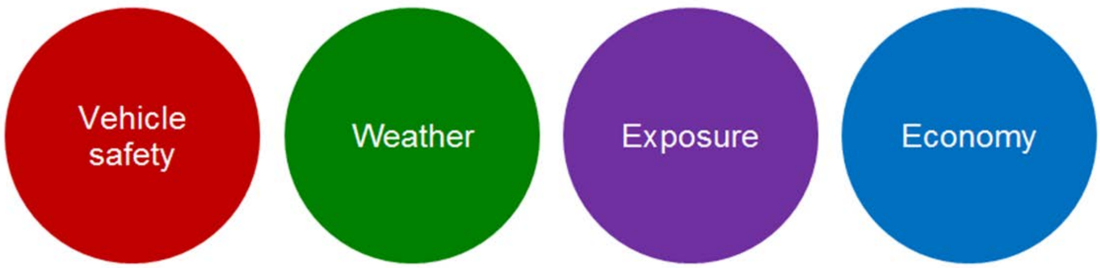
The original study also addressed longer-term variation in serious casualty numbers which have recently differed from the fatality patterns; this digest of the longer report will focus on road deaths primarily in line with the overall focus of the other papers. The full report is available from the TRL web site (Lloyd *et al* 2012). The extended summary presented here concentrates on the areas where the clearest results were obtained, and also on those aspects which contributed most to our understanding of why the numbers of fatalities decreased so markedly from 2007 to 2010.

Approach

Four key variables were identified as broad factors that have been recognised to influence levels of road deaths from a survey of a range of previous studies and publications.

- developments in vehicle safety
- weather patterns
- a change in the amount and type of traffic (exposure)
- economic recession.

These factors and their influence on road safety are unlikely to be entirely unrelated or mutually exclusive; interactions are likely. For example, economic recessions are likely to be associated causally with decreases in road journeys and decreased purchases of newer cars (which have better safety features). Another example of the possible complexity is that prolonged poor weather can also have a negative impact economic growth.

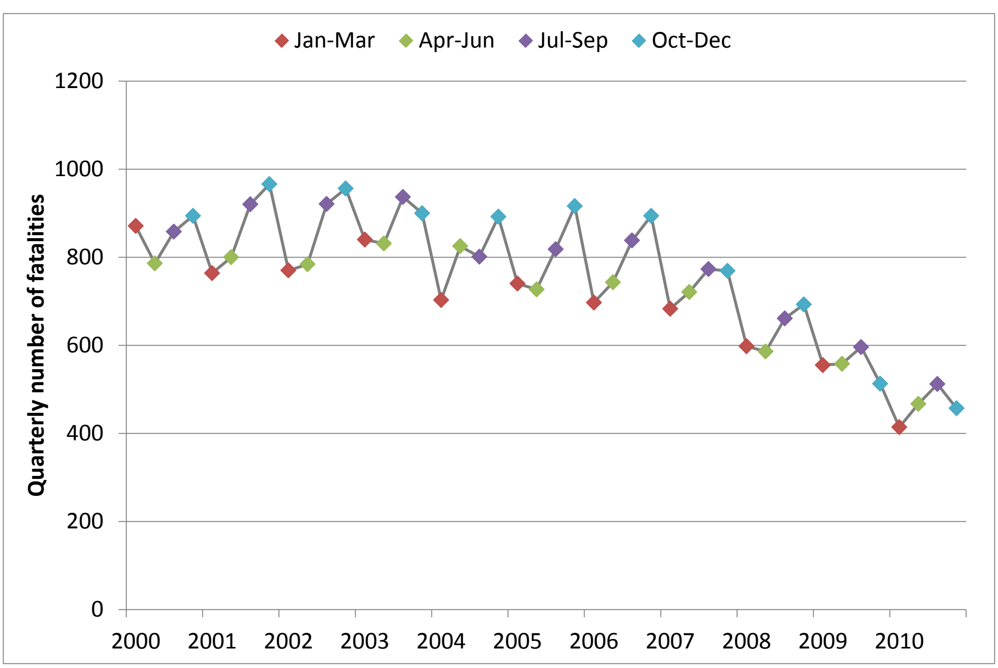


A large selection of exposure and potentially explanatory data (See above), sourced primarily from DfT and other Government departments, was assessed in conjunction with the road crash and fatality information reported to the British police. This was done in order to better understand the more fundamental factors that affected the occurrence of road deaths; and the relationships between identified risk factors and the recession.

Temporal observations and weather effects

The quarterly pattern of road fatalities (Figure 7.11) shows that quarter 4 (October to December) was commonly the quarter with the most fatalities although this changed to quarter 3 (July to September) in the two latest years. Patterns of road crashes change during the year due to many factors including type of driving (e.g. leisure driving in summer) and weather.

Figure 7.11. **Killed casualty trend by quarter, 2000-2010**



The change in the ranges is shown in Figure 7.12. This shows the difference between the numbers of fatalities occurring in consecutive quarters each year. If the pattern of fatal casualties was the same each year across the quarters then the Figure would show straight lines slowly converging as the annual total reduces. The plot is very mixed until 2007 when the Q1-Q4 difference rises quickly and consistently. This shows that the difference between the number of fatal casualties in Q1 and Q4 is decreasing over time, suggesting that the major reductions driving the overall decrease in annual fatal trend were occurring primarily in Q4.

Figure 7.12. **Quarterly change in fatal casualties, 2000-2010**

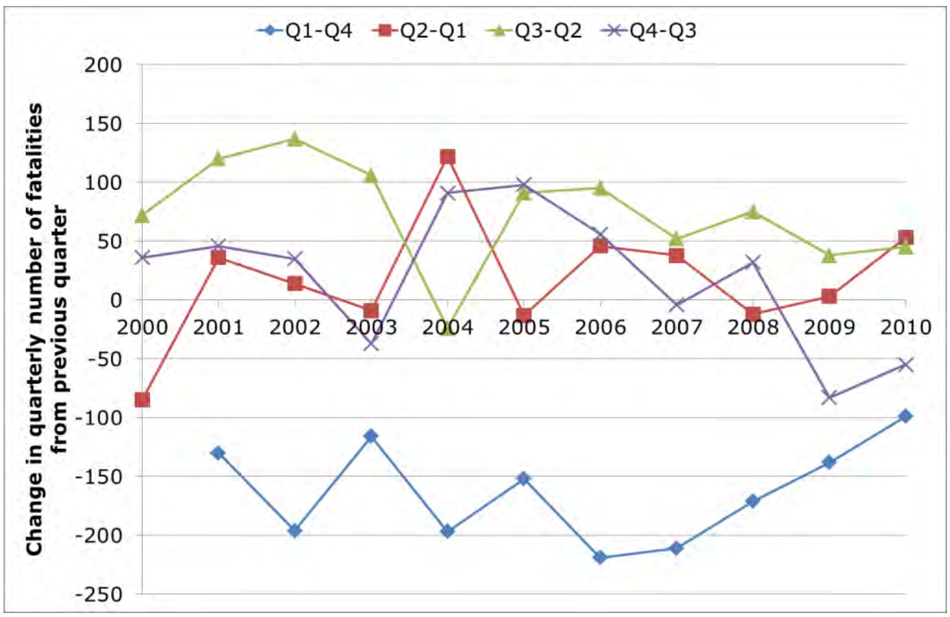


Figure 7.13. **Average minimum temperature by quarter, 2000-2010**

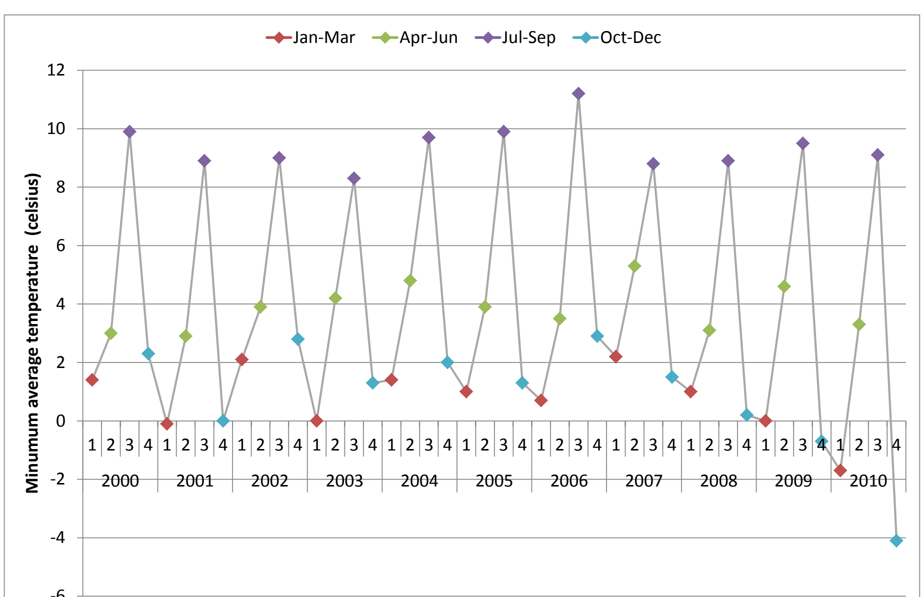


Figure 7.13 shows the average of the minimum daily temperatures throughout each quarter. Over the last five years there have been progressively colder winters, and it is suggested that drivers may drive less and also more cautiously when roads are visibly more risky. This may explain the reductions in Q4 results over the same period.

Weather	There is a correlation between the drop in fatal casualties and colder winter periods. We suggest that people drive less and more carefully in wintry conditions and this has some influence on the fatality trend.

Road type

The fatality trends have changed in different ways on the various road types in Britain.

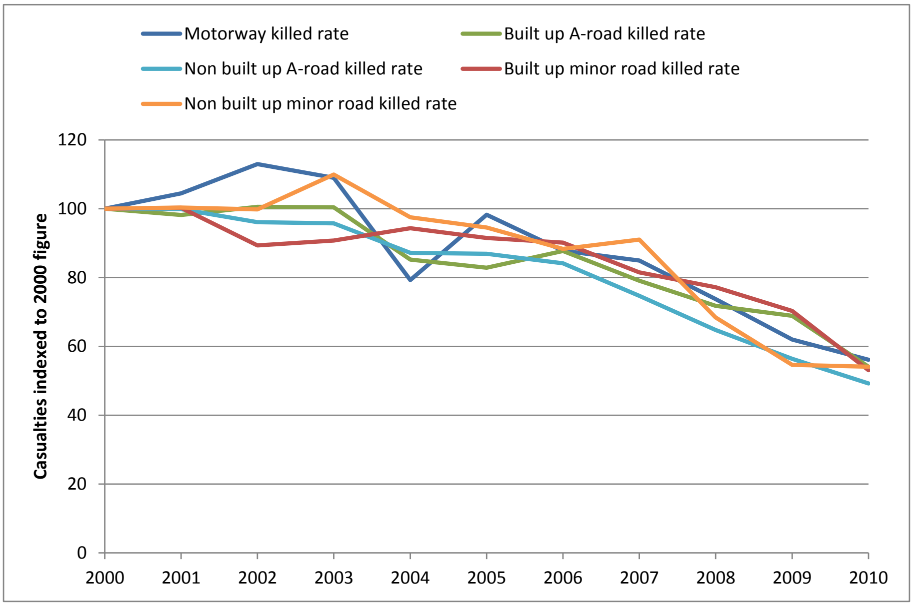
Table 7.1 shows that the number of fatal casualties on non-built up roads dropped most in the latter part of the decade. The reductions in road deaths between 04-06 and 08-10 were very much larger than between the 00-02 and 04-06.

Table 7.1. **Total number of and change in fatal casualties**

Road type	Fatalities			Change in fatalities	
	2000-02	2004-06	2008-10	2004-06 compared to 2000-02	2008-10 compared to 2004-06
Motorway	616	555	408	-10%	-26%
BU A road	2093	1803	1335	-14%	-26%
NBU A road	3903	3633	2390	-7%	-34%
BU minor	2099	2034	1442	-3%	-29%
NBU minor	1579	1569	1035	-1%	-34%

Figure 7.14 shows that the declines in fatalities were more gradual from 2007 on the other road types. This pattern could result from a reduction in flow on the non-built up roads or less risky driving behaviours on these roads where speeds tend to be faster.

Figure 7.14. **Killed and seriously injured casualty trend by road type, 2000-2010**

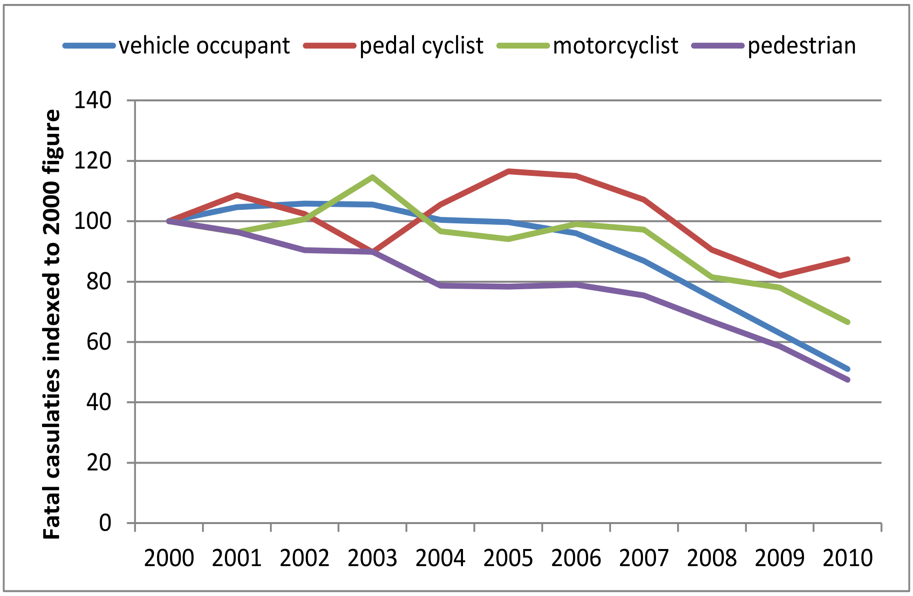


Road user groups

There were significant differences in the changes in relative fatality numbers by major road user mode (Figure 7.15). There have been steady reductions in pedestrian fatalities since 2002, whereas the more significant decreases in motorcyclist road deaths occurred from 2007 onward. The trend in pedal cyclist fatality numbers fluctuate markedly which may be due primarily to random variation associated with the relatively low numbers of fatalities for this mode. There was however an upward trend in pedal cyclist fatalities in 2010 which may be partly due to a rise in the amount of pedal cycle traffic (Figure 7.16).

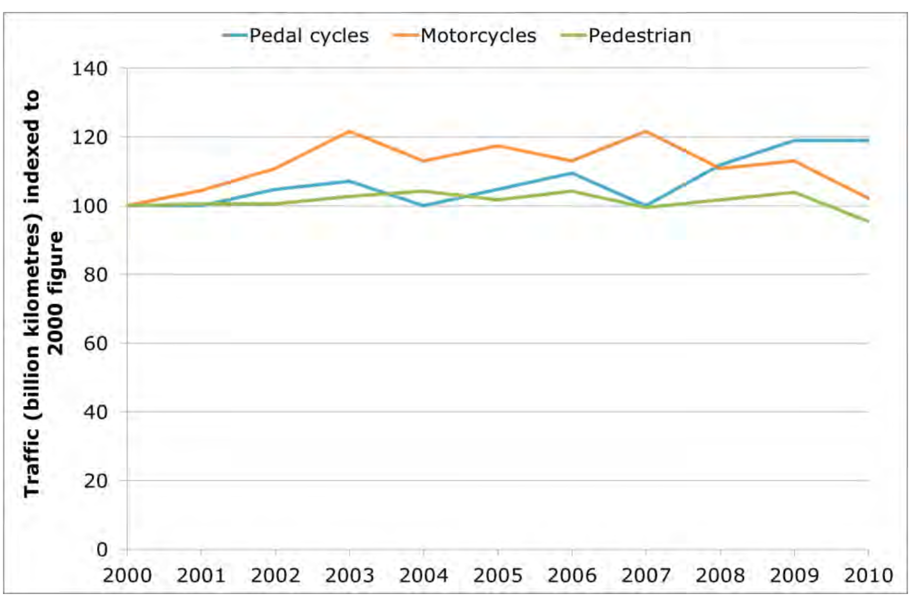
Most people who die on UK roads are vehicle occupants and the number of fatal casualties for this group has decreased at a fast pace since 2007.

Figure 7.15. **Changes in fatality by major road user type**



These patterns are in line with the data shown by the DfT study which showed that there were reductions in walking and increasing use of rail. This work also indicated an increase in bicycle trips since 2007 (see Figure 7.8). People may be increasing their cycling because it is an inexpensive mode of transport.

Figure 7.16. **Exposure of vulnerable road users, 2000-2010**

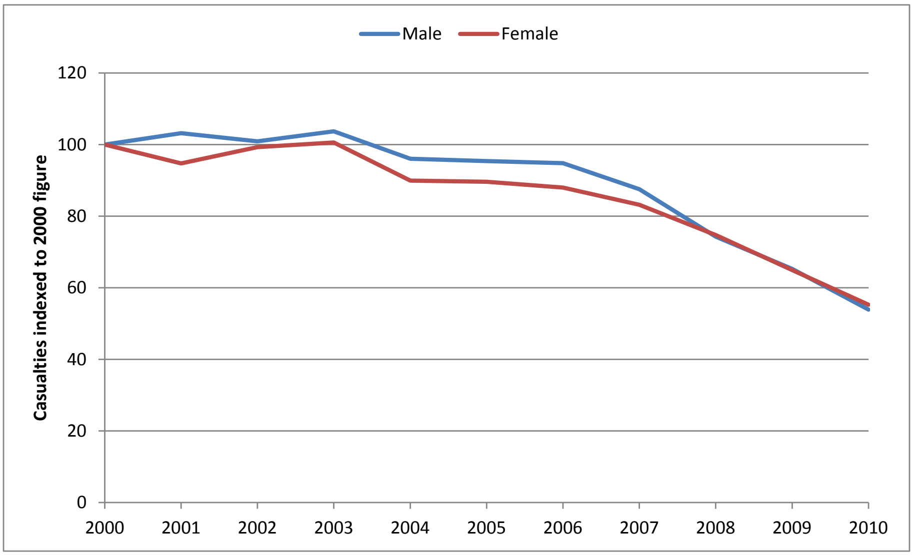


Demographic patterns

There were clear differences in the extent of the reductions in fatalities which occurred within particular sub groups of the population.

The reduction in male road fatalities was less pronounced in the earlier years relative to reductions in female deaths. A steeper drop in male deaths in 2007 and 2008 brought them back in line resulting in a similar proportional drop in deaths of both genders from 2000 by 2010 (Figure 7.17).

Figure 7.17. **Killed and seriously injured casualty trend by casualty gender, 2000-2010**

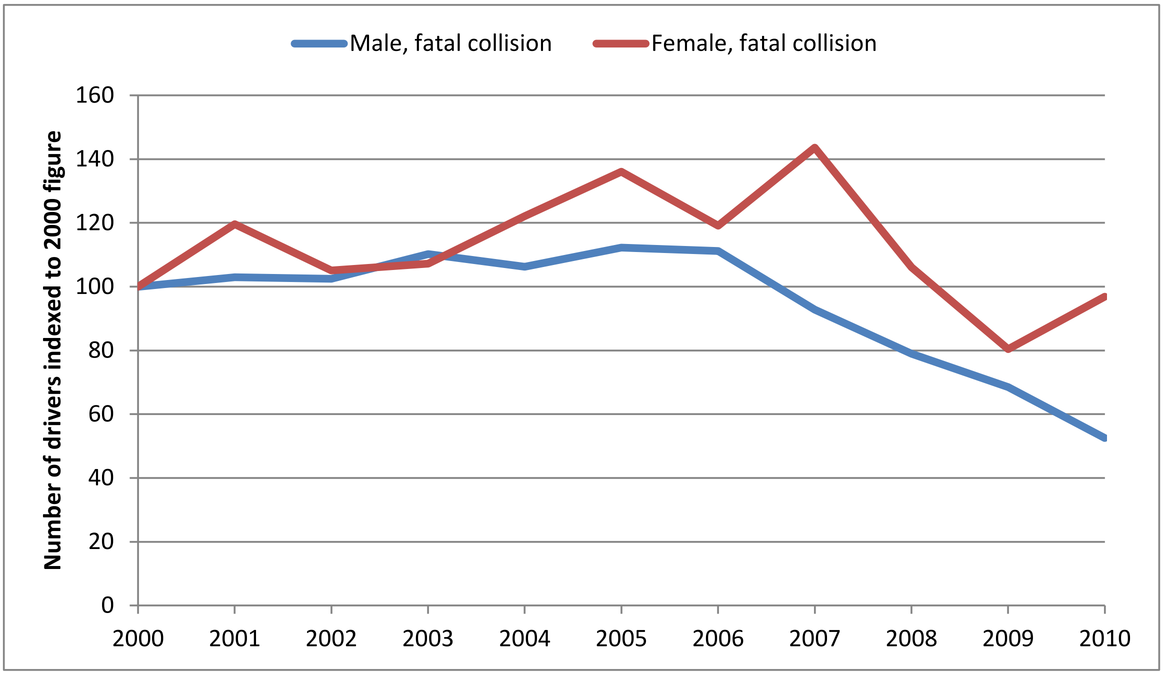


Fatality reductions analysed by age group is of particular interest (Table 7.2). There were large reductions in the numbers of younger people aged 16 to 30 being killed, and this drop was most marked in the later years of the decade. Road deaths of older adults also reduced over this time. There was a marked reduction in child fatalities, but the underlying numbers are low and hence more subject to random fluctuation. The trend in young people killed (aged 16-30) appeared to have changed greatly after 2007 and this group appeared to have been affected more so than older people (31+) whose trends also changed in 2008.

Table 7.2. **Number and change in fatal casualties in 3-year periods by age**

Casualty age	Fatalities			Change in fatalities	
	2000-02	2004-06	2008-10	2004-06 compared to 2000-02	2008-10 compared to 2004-06
0-15	593	478	260	-19%	-46%
16-30	3646	3579	2305	-2%	-36%
31-60	3845	3550	2564	-8%	-28%
61+	2206	1987	1481	-10%	-25%

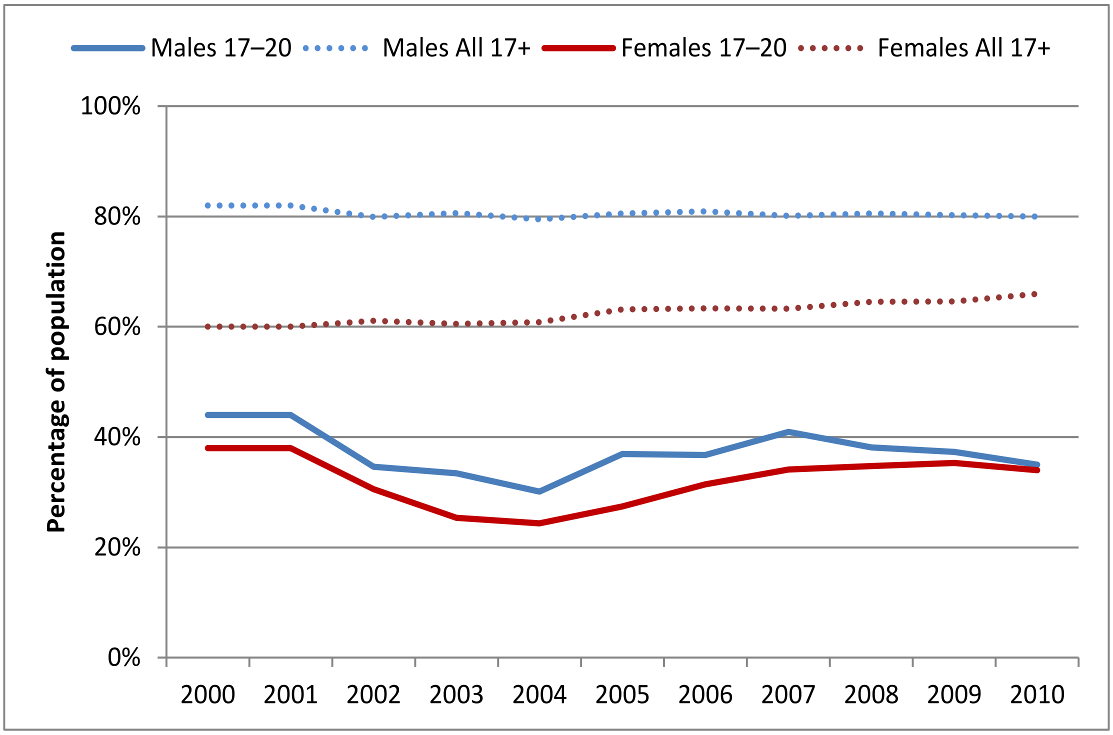
Figure 7.18. **17-20 year old drivers in fatal and serious collisions by gender, 2000-2010**



Within the strong pattern of changes occurring to the number of younger persons killed after 2007, there was a sharp decrease in 17 to 20 year olds being killed from 2007; this was especially marked for young males after 2006 to 2010 (Figure 7.18).

This pattern matched the reduction in the proportion of young male drivers attaining their full car driving licence (Figure 7.19).

Figure 7.19. **Proportion of the population with full car driving licences by age group**



Socio-demographic Analyses

MAST online (Road Safety Analysis, 2012) is a web based data analysis tool which combines STATS19 data with the Index of Multiple Deprivation (IMD) which is used to identify how deprived an area is. It uses a range of economic, social and housing data to create a single deprivation score for each small area of the country.

MAST data are only available from 2004 onwards so the casualty numbers have been indexed to the 2004 figure and this shows that, since 2004, the indexed number of killed casualties in each quartile has dropped more than the number of seriously injured casualties. Table 7.3 shows that the number of fatal casualties from the most deprived quarter has (proportionately) dropped the most, and at a steady rate since 2007.

Table 7.3. **Total number of and change in fatal casualties in three-year periods by IMD quartile**

IMD group	Fatalities 2004-06	Fatalities 2008-10	Change in fatalities 2008-10 compared to 2004-06
Q1 most deprived	2300	1527	-34%
Q2	2446	1702	-30%
Q3	2673	1854	-31%
Q4 least deprived	2175	1527	-30%

In summary, there is some suggestion that the least affluent demographic group has seen a marginally bigger reduction than the other groups; however the general pattern is similar for all groups.

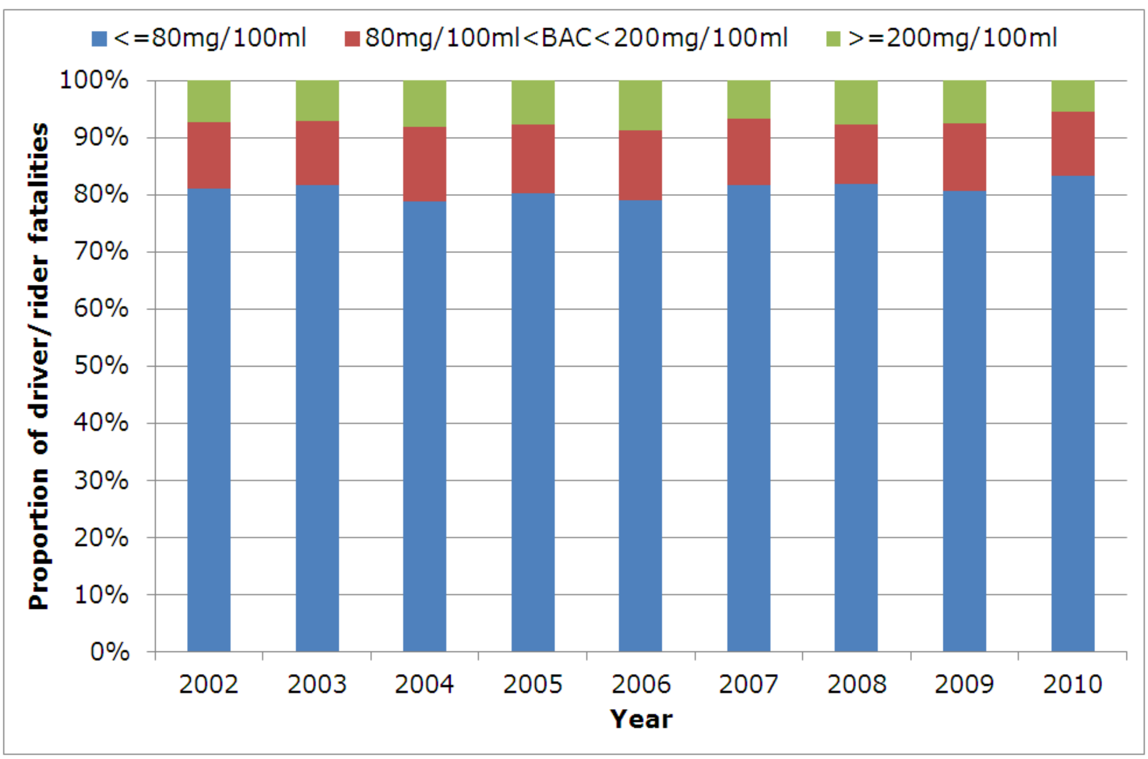
Behavioural factors

Drink driving

The crash risks associated with the consumption of alcohol are well understood for riders and drivers. Figure 7.20 shows the distribution of the level of alcohol that was found in the blood for a national sample of driver and rider fatalities from the Coroner's database.

The legal limit for alcohol was 80mg per 100ml of blood in the UK throughout the period studied.

Figure 7.20. **STAT19 drivers/riders aged over 16, who died within 12 hours and have known BAC**

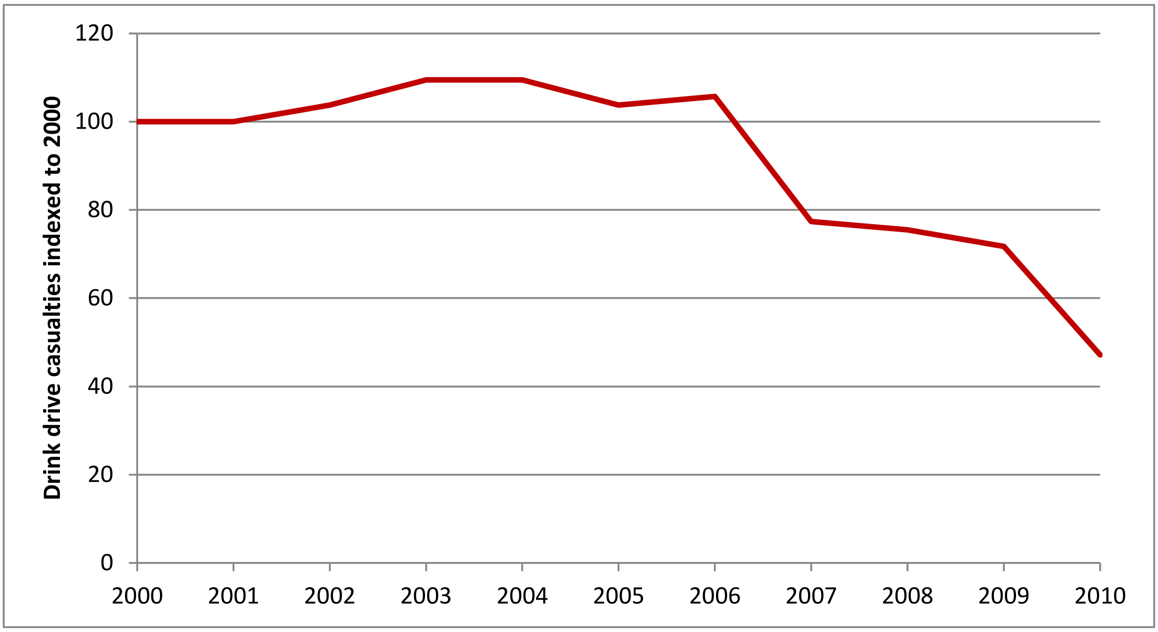


The majority of driver/rider fatalities were in the lowest "legal" alcohol level category (less than and equal to 80mg/100ml), varying from a low of 79% up to 83%. The proportions above the legal limit fluctuated. The proportion with a blood alcohol level of 200mg/100ml or more (the most risky drinkers) varied between 5.5% and 8.8% with a decrease over the latter years studied. There is some suggestion that there has been a reduction over the last few years in fatalities with a blood alcohol (BAC) content above the legal limit of 80mg/100ml.

The distribution of level of alcohol found in pedestrian fatalities shows a similar pattern.

The DfT (Department for Transport, 2011) estimates the number of drink drive crashes each year and the trend in these estimated numbers is shown in Figure 7.21. The estimated number of fatalities due to drink driving dropped dramatically in 2007 and again in 2010.

Figure 7.21. **DfT estimates from failed/refused alcohol tests and coroners reports**



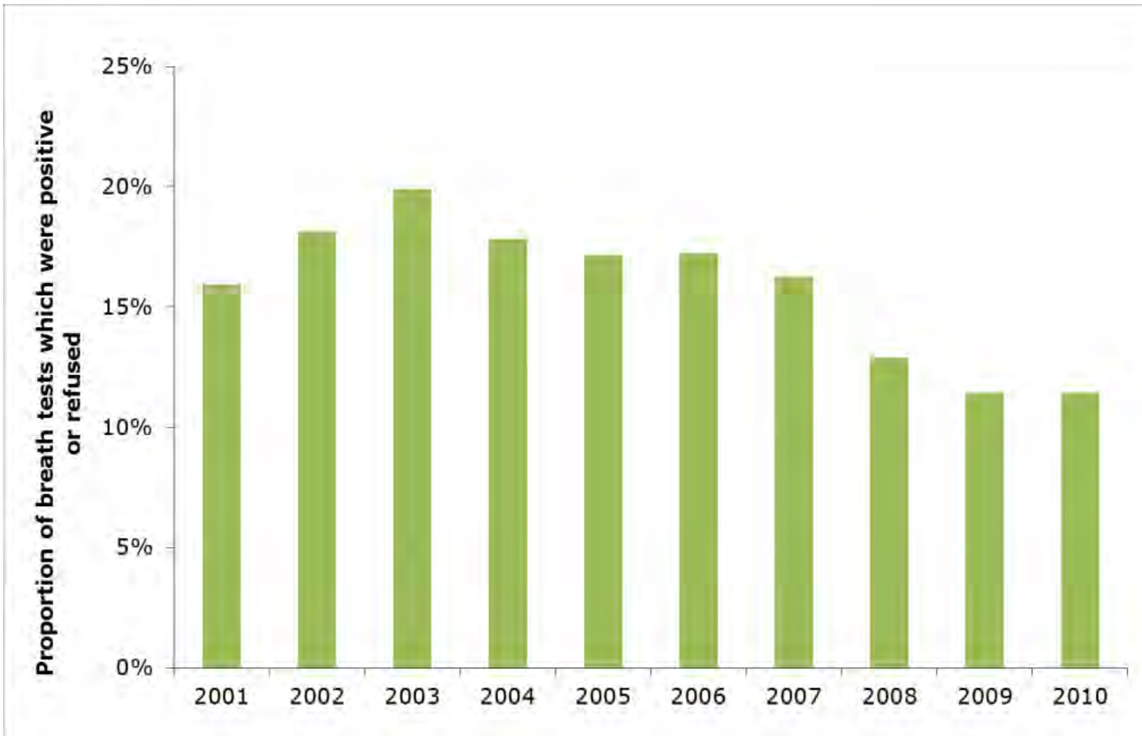
These figures show there was a large reduction in fatalities due to drink driving over the last four years of the study period; suggesting there may have been a reduction in the number of drunk drivers and riders on the roads.

One indicator of the prevalence of drink driving in general traffic is the results of roadside breath testing by police officers. Around 600,000 breath tests are carried out each year (Home Office, 2012) at the road side generally as a result of a traffic offence, a road traffic collision or suspicion that a driver might be drunk. The proportion of positive test results (shown in Figure 7.22) are therefore likely to be artificially high (because the police are targeting those that are more likely to be drunk) compared to the overall level of drink driving on the roads, however they likely give a relative indication of the trend in drinking and driving levels. This trend shows a clear reduction in the proportion of drivers using the road whilst over the drink drive limit (or those who refused a test) from 2007. A smaller reduction occurred in 2004.

DfT estimates show a very clear reduction in alcohol related road deaths since 2006. The assumption is that anti drink-drive campaigns have had some success, but economic pressure on family budgets mean that people are drinking less and are choosing to drink at home instead of at pubs, bars and restaurants.

Over the last four years the prevalence of drink-driving and consequently the estimated number of fatalities caused by drivers over the legal drink drive limit has reduced. This is likely to be at least partly due to the economic instability of the country, resulting in more people opting to stay at home rather than 'going out' to drink.

Figure 7.22. **Proportion of road-side breath tests results which were positive or refused**



Source: Home Office, 2012

Speed

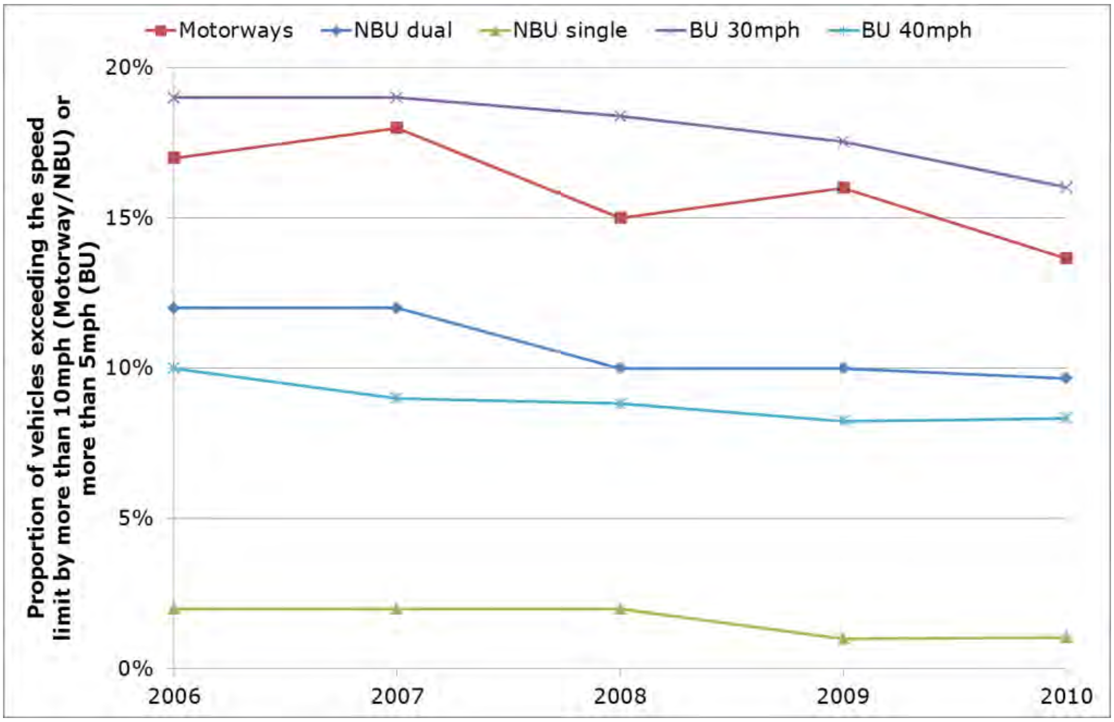
Exceeding the speed limit or travelling too fast for conditions are two of the most common contributory factors in crashes. Inappropriate speed is known to increase the severity of injuries resulting from crash involvement (Aarts and Schagen, 2006).

Figure 7.23 shows the proportion of car drivers exceeding the speed limit by a substantial amount on a sample of roads across Britain (Department for Transport, 2011). Road types were separated into Motorways, non-built up (NBU) dual carriageways, non-built up single carriageways, built up (BU) roads with a 40mph speed limit and built up roads with a 30mph speed limit. Since 2006, the proportion of vehicles measured at 10mph (Motorways and NBU roads) or 5mph (BU roads) above the speed limit has dropped on all road types.

There has been a noticeable reduction in excessive speeds across all road types after the recession started. This suggests that in times of recession, people drive more economically by reducing their speeds. This general reduction in speed, and specifically the reduction in excessive speeds, reduces numbers and severities of crashes. Compared to a general reduction in vehicle speeds, reductions in excessive speeds have been proposed to have a disproportionately positive effect on high severity crashes (Nilsson 2004, Cameron and Elvik 2008).

The increased use of speed enforcement technology and speed awareness courses attended by drivers detected exceeding posted limits over this period was also likely to have contributed.

Figure 7.23. **Proportion of drivers exceeding the speed limit by 10mph (motorways and non-built up area roads) or 5mph (Built-up area roads)**

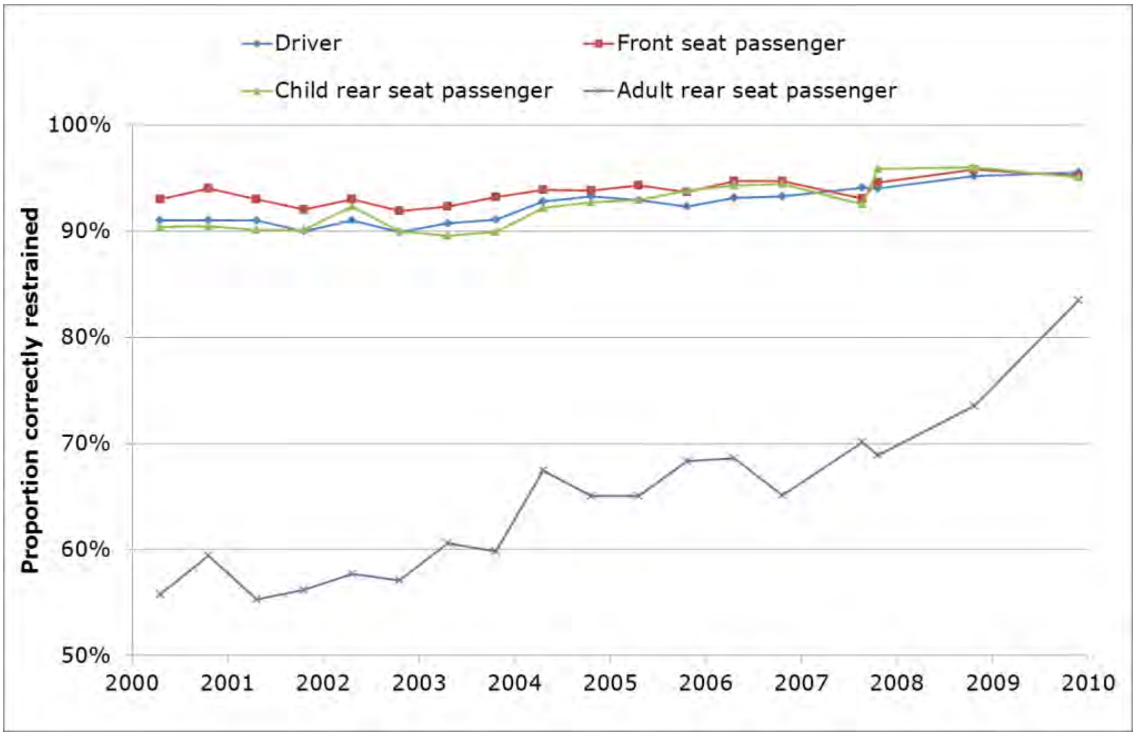


Seatbelt wearing

The wearing of seatbelts has been shown to reduce the severity of injury when involved in a crash (Broughton and Walter, 2007), and therefore the higher the proportion of vehicle occupants wearing a seatbelt, the lower the severity rate.

TRL carried out seatbelt surveys for the DfT from 1988 to October 2009 and the results for car occupants over the last decade are shown in Figure 7.24.

Figure 7.24. **Restraint wearing rates for car occupants (Walter, 2009)**

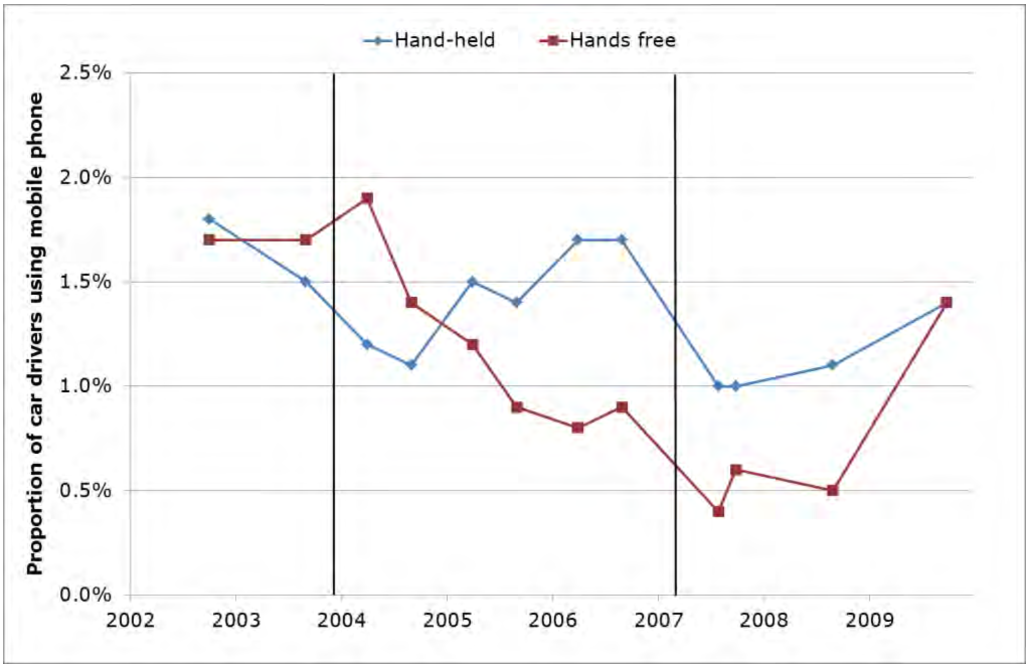


The wearing rates of seatbelts for drivers, front seat passengers and child rear seat passengers have been around 90% and have risen steadily since 2000. There were much larger rises in the (smaller) proportion of adults seated in the rear of vehicles over this period from a low base level of about 55% in 2000. There is little evidence that the recession conditions have affected wearing rates to any clear extent and thus this aspect of safety is unlikely to have played a part a part in the reduction observed in fatalities which occurred after 2007.

Drivers' use of mobile phones

Unlike a seatbelt which affects the severity of an injury once an crash has occurred, use of a hand-held or hands free mobile phone whilst driving has been shown to increase the chance of being involved in a crash (Redelmeier and Tibshirani, 1997). Mobile phone surveys were carried out by TRL for DfT from 2002 to 2009, the results from which are shown in Figure 7.25.

Figure 7.25. **Hands-free and hand-held mobile phone usage rates for car drivers (Walter, 2009)**



New legislation banning the use of hand-held mobile phones whilst driving was introduced in December 2003 and the penalties for ignoring this law were increased in February 2007, both are indicated in Figure 7.25 with a black line. The use of hands-free phones whilst driving remains legal, although research has shown that this is also distracting and dangerous for drivers.

Use of hand-held phones has remained fairly stable over time, with drops in use at times of introduction and changes to legislation. This is presumably due to increased awareness of the dangers of using a phone whilst driving and an increased perception of apprehension. Until 2008, the use of hands free phones decreased over time.

The most recent survey, based in Surrey in 2012, shows that the use of hand-held and hands free phone use has increased substantially since 2009 (Scoons, 2012).

Mobile phone use was seen to grow substantially over the years since 2007, suggesting that, if all else had remained the same, there should have been a rise in the number of crashes and fatalities over this period associated with this behaviour.

Exposure

Reductions in young males learning to drive, alcohol consumption by drivers and a decline in the amount of traffic will all have had a positive effect on the number of high severity accidents occurring in Britain.

Economy

The state of the economy is likely to have influenced driver behaviour patterns such as speed choice and these changes will have directly affected the fatality trend.

Vehicle safety factors

Up to 90% of all the vehicles involved in injury and fatal crashes are cars, so the inherent effectiveness of vehicular systems designed to enhance the protection and safety of road users when a crash occurs is likely to be a critical issue.

The proportion of drivers killed or seriously injured in the newest cars (e.g. those 0-2 years old) has been reported to be decreasing in recent decades, from 11.1% in 1995 to just 6.3% in 2010.

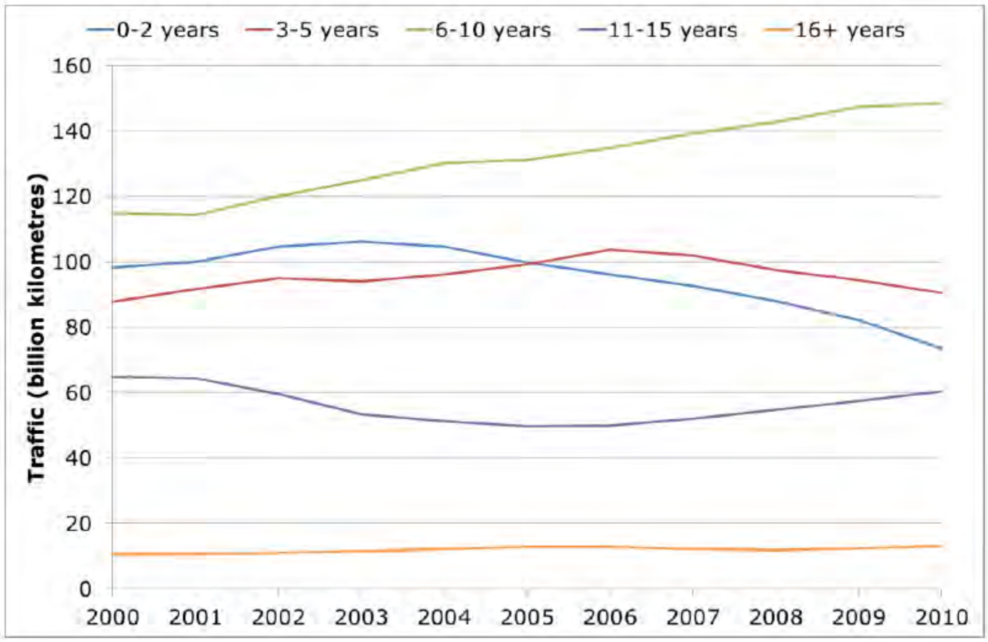
Broughton (2003) showed that this effect can be attributed to developments in car design which have improved their secondary safety. The likelihood of death is known to be significantly lower in crashes involving newer cars. More recent "new cars" are also known to give more protection than "new cars" built ten years earlier (Table 7.4).

Table 7.4. **Proportion of fatalities in KSI casualties by car age**

Car age (years)	Accident year 2000	Accident year 2010
0-2	8.7%	6.3%
3-5	8.5%	6.5%
6-10	9.1%	7.5%
11-15	11.3%	8.2%
16+	13.4%	10.3%

Figure 7.26 shows that the use of older cars has increased since the economic problems started, because the purchase of new cars slowed significantly. It is therefore difficult to explain why road fatality numbers have decreased so sharply at the same time that the exposure of older cars in terms of kilometres driven is increasing and correspondingly fewer kilometres are being driven in the newest cars. It is possible that accelerated improvements in vehicle related secondary safety features in recent years have counter-acted the problems associated with the issue of there being more old vehicles being driven. If this is the case it could contribute to the marked decrease in road fatalities after 2007. This issue was investigated by modelling the proportion of fatalities and vehicle ages as follows.

Figure 7.26. **Changes in vehicle kilometre for cars of differing ages**

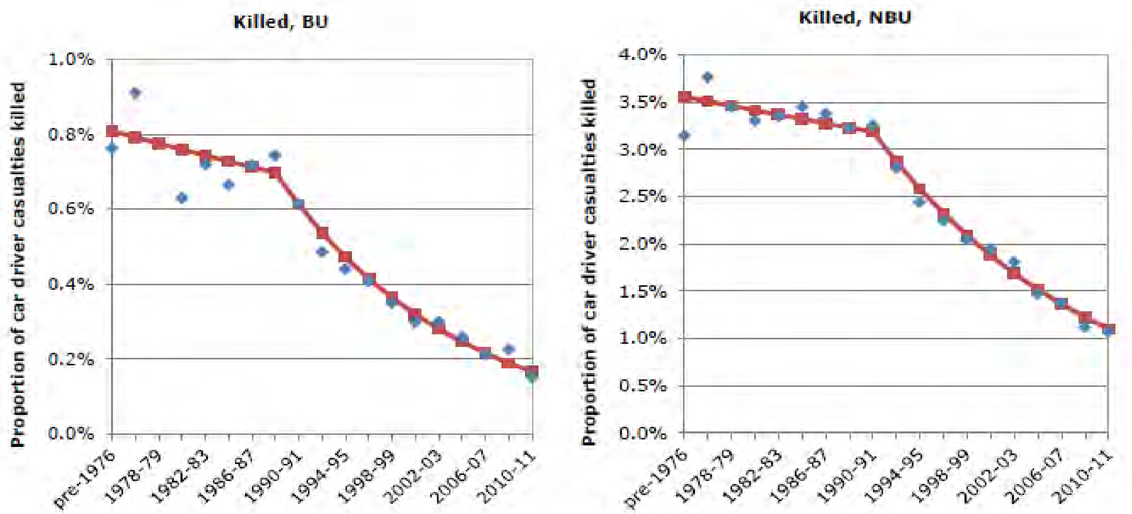


A statistical model was used to analyse car driver casualties by vehicle registration year in order to demonstrate how car secondary safety has improved over recent decades to separate this effect from the decreasing proportion of newer vehicles on the roads. Data from crashes occurring between 1990 and 2010 were analysed using a Generalised Linear Model (GLM) fitted to the severity proportion, i.e. the proportion of drivers killed.

Car registration year was used to estimate the reduction in the severity of drivers' injuries linked to changes in succeeding 'cohorts' in the car fleet. It is known that older drivers tend to be more seriously injured than younger drivers for physiological reasons and they are also more likely to drive older cars, so age/sex by road type was included in the model. The inclusion of this variable also gave the opportunity to examine whether developments in car secondary safety have benefited some age/sex groups more than others.

The results of the modelling exercise (Figure 7.27) indicated that secondary safety seems to have continued to improve on both built up and non-built up roads, and faster since 1990-1991 registered cars; basically fatalities (for car drivers) are less likely in newer cars and this pattern has improved for more recent years. Crucially there was no detected change in trend in 2007-2010, so developments in new cars are either not making cars any more safe than expected, or that the inflow of new cars into the fleet has not been sufficient to have had a dramatic effect.

Figure 7.27. **Proportion of car drivers killed on built up and non-built up roads**



The statistical model contained the variable 'year of crash' to allow for the possibility that changes in traffic conditions and independent improvements in road safety may also have reduced the severity of drivers' injuries. By examining the proportion of drivers killed or seriously injured in a particular age group and year of registration across the crash years, changes to the risks faced by car drivers were investigated.

The model showed that developments in car secondary safety have benefited some age/sex groups more than others over the period studied:

- For middle-aged (25-59) drivers, the proportion of casualties in 2010-11 registered cars who were killed was only three-fifths of the proportion in 2000-01 registered cars (a reduction of 40%).
- The benefits were slightly less for young (<25) and older (≥60) drivers, but the benefits for men and women were similar.

These changes occurred steadily over the decade, with no particular development from 2007.

Conclusions of the TRL study

The hypotheses posed at the start of the research were that changes in the fatality trend are due to changes in traffic; developments in vehicle safety; financial stability; or weather.

It can be stated with some certainty that:

- There have been some changes in traffic, in particular there was
  - a reduction in overall traffic
  - a large reduction in HGV traffic
  - a substantial increase in pedal cyclist traffic, suggesting a small modal shift, and
  - a reduction in young male drivers.

- Developments in vehicle safety continue to be vital for the continual reduction of severity and collision reduction; however the change in fatality trend is not wholly related to vehicle safety improvements. The reason that the fatality trend was not decreasing up to 2006 whilst vehicle safety improvements continued may be due to driver confidence – additional safety features in and on vehicle provide additional confidence and some drivers may have adapted their behaviour (i.e. drive more recklessly) as a result.

- The economic instability of the country during this period appears to have had a dramatic effect not only on traffic patterns but also on driver behaviour with, in particular:
  - a reduction in speeding
  - a reduction in drink driving.

- Other behaviours do not appear to have been affected by the recession greatly, such as mobile phone use and seatbelt wearing.

- The effect of weather on the fatality trend is not so certain – people may have driven more cautiously in the progressively colder winters since 2007 but colder winters earlier in the decade did not result in the same reduction.

In general and over time, continuous and vital improvements in road safety including new regulations, developments in vehicle safety, improved enforcement strategies, more effective education campaigns and enhanced medical treatment have reduced the likelihood of crashes and the injury severity once involved in a crash. However, from the mid-1990s to 2007, the number of fatalities did not decline to any great extent and this period was then followed by a dramatic drop. These sorts of step patterns in the fatality trend must be influenced by other factors that change in a discrete way.

An obvious change during this period was the recession; this research has shown that there is an indirect link between fatalities and the recession. The recession appears to have caused changes in driver behaviour (for example speed choice and drink driving) which, in turn, make drivers safer and reduces collisions, and in particular, high severity collisions. It is suggested that drivers tend to behave more cautiously when uncertain about their financial future which tends to restrict the types of extreme behaviour that can lead to fatal crashes. This would also help to explain why the number of fatalities failed to fall in line with serious casualties in the relatively prosperous years up to 2007 but have caught up during the years of recession.

Not all observed changes were positive for road safety – an increase in the age of the car fleet was observed, and there was no evidence to suggest that the recession has had any positive effect on seatbelt use or mobile phone use. The number of fatalities fell between 2007 and 2010 in spite of this.

There remains the possible added effect of weather on the fatality trend. Obviously weather patterns cannot be influenced, but we speculate that cold weather also encourages people to change their behaviour and drive more cautiously; extremely cold weather will also reduce traffic volumes. Changing drivers' behaviour in a similar way to the effect of weather is (at least in theory) possible.

The important lesson here may be that drivers and road users in general will change their behaviour if they see an economic benefit (specifically through speed choice for example) or perhaps also if they can understand the risks involved (for example when there is snow on the road). The challenge going forward is to influence driver behaviour in the way that the recession has affected behaviour, whilst maintaining the vital continual improvements in vehicle and road design, enforcement and hospital treatment. If this cannot be achieved there is a risk of increase in road deaths as the economy recovers or at best there may be little change in future fatality trends.

Overall conclusions from the studies

Neither of these studies could test any of the hypotheses with full scientific rigour since it is impossible to manipulate any of the national recession conditions of interest to any degree so that meaningful “controls” could be created. Both studies primarily identified and investigated relationships in the variation apparent between a range of datasets which characterised or represented exposure levels and which relate to particular road users behaviours with variation in road death numbers.

However, there was broad agreement between the findings of the two studies which produced strong circumstantial evidence supporting the supposition that a number of behavioural risk factors and exposure levels which are clearly and logically influenced by the recession conditions are responsible for the step change reduction in road deaths which was apparent.

Both studies acknowledged that a general reduction in traffic was partially responsible for the reduction in road deaths but this could only explain a small amount of the decrease. Direct effects of the recession decreased the kilometres driven of particularly risky vehicle types and drivers, namely young (male) drivers and Heavy Goods Vehicles. Excessive speeding reduced generally which was likely related to more economical driving which would have a major impact reducing fatalities. In addition there was evidence that other risky behaviours reduced; critically drink driving reduced during the recession which resulted in a reduction of drink related road fatalities.

It was also emphasized by both studies that other factors largely unrelated to recession such as a run of harsh winters may also have influenced the occurrence of road deaths. Again snow and ice during extended poor winter weather may reduce the number of road trips made but also lead to drivers adopting less risky driving practices.

The clear result of both studies is that a multiple range of factors were influenced by the recession and these resulted in the reduction in road deaths reported. The reduction has clearly not just resulted simply as a consequence of reduced traffic alone; there is compelling evidence from the studies that a range of risky behaviours were effectively curbed by the difficult economic conditions in Britain over the period studied.

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International Transport Forum

Why Does Road Safety Improve When Economic Times Are Hard?

This report examines the relationship between economic performance and road safety. It demonstrates that the economic downturn that started hitting many OECD countries in 2007/8 has had a significant impact on the reduction in the number of road fatalities. The six papers that compose this report, written by renowned experts, explain the mechanisms by which indicators of economic development influence road safety and quantify their impact.

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