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The turning point in the number of traffic fatalities: two hypotheses about changes in underlying trends

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ABSTRACT

The number of traffic fatalities reached a peak in many highly motorised countries around 1970. Some previous studies have suggested that the turning point in the number of traffic fatalities was inevitable and did not reflect a change in the underlying trends influencing the number of traffic fatalities. Other studies suggest that trends in traffic growth and fatality rate changed from before to after the turning point. This paper proposes two hypotheses about the turning point in the number of traffic fatalities. One hypothesis is that the long-term trends in traffic growth and fatality rate were the same before and after the turning point. The other hypothesis is that the long-term trends in traffic growth and fatality rate were different before and after the turning point was reached, in particular that the annual percentage decline in fatality rate became greater after the turning point than before. Such a change would suggest that road safety policy became more effective. Analysis of data for six countries (Denmark, Great Britain, Netherlands, Norway, Sweden, United States) lends stronger support to the latter hypothesis than to the former. The lesson for policy makers, in particular in countries where the number of traffic fatalities is still growing, is that they should not expect a turning point to be reached without policy interventions.

Key words: traffic fatalities; long-term trends; turning point; traffic growth; fatality rate

1 INTRODUCTION AND RESEARCH PROBLEM

The long-term development in the number of traffic fatalities is very similar in many highly motorised countries. The number of fatalities increased almost without interruption from about 1945 until about 1970. After 1970, there has been a reduction in the number of traffic fatalities, in some countries by 70-80 percent. Figure 1 shows this development for six highly motorised countries that are included in the study reported in this paper.

Figure 1 about here

The absolute number of traffic fatalities varies enormously between countries; Figure 1 therefore shows relative numbers to enable comparison between countries. The general shape of the curves in Figure 1 is similar for all countries, although both the rate of increase before the peak and the rate of decline after it clearly differ between countries. There are two hypotheses about why the number of traffic fatalities stopped increasing and started to decline. One hypothesis is that the underlying trends that determine the number of traffic fatalities, in particular annual changes in traffic volume and fatality rate (fatalities per billion vehicle kilometres), changed around the time when the peak in the number of traffic fatalities was reached. More specifically, traffic growth may have slowed down and fatality rate started to decline more rapidly.

The other hypothesis, originally put forward by Oppe (1989, 1991A), is that the turning point in the number of fatalities was simply a mathematical necessity, following from stable underlying trends in traffic growth and fatality rate. This hypothesis is explained in greater detail in section 2 of the paper.

Shortly after 1945, a long period of traffic growth started. Early in this period, traffic grew rapidly, sometimes at a rate of more than 10 percent per year. Gradually, traffic growth slowed down. As long as the annual percentage traffic growth is greater than the annual percentage decline in fatality rate (fatalities per billion vehicle kilometres of travel), the number of fatalities will increase. Conversely, if traffic grows more slowly (in percentage terms) than the decline in fatality rate, the number of fatalities will decline. Once the annual percentage traffic growth becomes smaller than the annual decline in fatality rate, a turning point is reached and the number of traffic fatalities starts to decline.

The objective of this paper is to determine whether the trends in traffic growth and fatality rate were different before and after the turning point in the number of traffic fatalities. Models of the trends in traffic growth and fatality rate were fitted to data for the period before the turning point was reached. Model predictions were then made for the period after the turning point. If the models accurately predict the number of traffic fatalities for the period after the turning point, the hypothesis that underlying trends did not change is supported. If the model predictions of the number of traffic fatalities after the turning point are systematically wrong, this supports the hypothesis that the underlying trends did change from before to after the turning point.

2 REVIEW OF PREVIOUS STUDIES

2.1 Models developed by Oppe

Models of the long-term trends in traffic volume and fatality rate in a number of countries were first developed around 1990 by Siem Oppe (1989, 1991A, 1991B). All models that were developed had the same mathematical form. Traffic growth was modelled as a sigmoid curve (logistic function). This means that traffic volume initially grows slowly, then faster, then again slower until a saturation level is reached. Fatality rate (fatalities per million vehicle kilometres of travel) was modelled by means of an exponential function. This means that fatality rate declines by the same percent each year.

According to the models developed by Oppe, a turning point in the number of traffic fatalities is inevitable. This follows with logical and mathematical necessity from the data and the model specification. The models were fitted to data including the period both before and after the turning point in the number of traffic fatalities. The models reproduced the history of traffic fatalities with remarkable accuracy for the countries that were included in the second generation of the models (Oppe 1991A, 1991B). In discussing the models, Oppe stated (1991A): "…The fall in the number of fatalities, noticed in almost all developed countries after a steady increase until 1970, does not need a special explanation. It follows from the combination of the monotonically increasing traffic volumes and the monotonically decreasing fatality rates."

In a similar vein, Hauer (2010) writes: "In truth, a "fatality mountain" such as the French one … characterises all developed countries. … It most likely has nothing to do with any action or initiative and is merely the logically necessary consequence of a constantly rising amount of travel and a constantly declining risk of fatality per unit of travel." This interpretation of the models is, at best, imprecise. A turning point cannot arise from the combination of a constant increase in traffic volume and a constant decrease in fatality rate. If, for example, traffic grows at the constant rate of 6 percent per year and fatality rate declines at the constant rate of 5 percent per year, there will never be a turning point, just an endless increase in fatalities.

A closer inspection of model predictions reveals some anomalies. For most of the countries included, the following observations applied:

1. The peak of the curve fitted to the data passed below the actual peak number of fatalities. Thus, the models consistently predicted a lower peak number of fatalities than the actual number.
2. In most countries, the residuals for the last years before the peak were positive, indicating that fatalities grew more rapidly than predicted by the models.
3. In most countries, the residuals after the peak were more often negative than positive, indicating that fatalities dropped more rapidly than predicted by the models.

These anomalies at least suggest that the underlying trends could have been different before and after the turning point. It is therefore fruitful to examine if this is indeed the case. Before presenting the design of a study intended to test this, a review of other relevant studies will be made.

2.2 Other studies of long-term trends in road safety

Following the pioneering study by Oppe, a number of other studies have been made to model long-term changes in traffic fatalities. Van Beeck, Borsboom and Mackenbach (2000) fitted log-linear trend lines to data on motor vehicles per 1,000 person-years (indicating exposure) and deaths per motor vehicle (indicating fatality rate) for 21 OECD-countries for the period 1962-1990, dividing the period into six sub-periods. The fitted trend lines did not have the same slope in all sub-periods, thus indicating that neither annual traffic growth nor annual change in fatality rate remained unchanged over time. The model reproduced the turning point in the number of traffic fatalities in the OECD-countries around 1970.

Kopits and Cropper (2005) studied the relationship between economic growth and traffic fatalities, finding that up to a per capita income of about 8,600 US dollars (1985 international prices) the number of traffic fatalities per inhabitant increases. At higher levels of income, the number of traffic fatalities goes down. Data for 88 countries for 1963-1999 were used in the analysis. Bishai et al. (2006), using data for 41 countries during 1992-1996 found results resembling those found by Kopits and Cropper.

Quddus (2008) analysed long-term trends in traffic fatalities in Great Britain 1950-2005. He developed four different models, one of which, the integer-valued autoregressive Poisson model, was a time-series model with Poisson-distributed residual terms. Although fitted values were not shown for the entire period, it is clear that the models reproduced the turning point in the number of traffic fatalities in Great Britain.

Yannis et al. (2011A) modelled long-term trends in traffic fatalities in eight European countries, using data for 1960-2009. Exposure was indicated by the number of motor vehicles per 1,000 inhabitants, risk was indicated by the number of traffic fatalities per 100,000 inhabitants. Trends were modelled by means of segmented linear models, which are able to detect changes in slope and thus determine the presence of turning points. The models developed reproduced the observed turning points in fatality rate (fatalities per 100,000 inhabitants) very accurately, using either motorisation rate or time as the independent variable. Some of the countries included in this data set (Czech Republic, Poland, Spain) had more than one turning point, and analysis successfully identified all turning points.

In a subsequent paper, Yannis et al. (2011B) applied autoregressive non-linear time-series modelling to estimate long-term trends in fatalities per motor vehicle in 16 European countries. The study covered the period from 1970 to 2002. Models were fitted to data for 1970-1994 and validated by predicting values for the years 1995-2002. The period covered by this study is mostly after the turning point in the number of traffic fatalities was reached. An interesting feature of this analysis is that model predictions were made for years that were not included when developing the models. These predictions provide a test of the stability of the trends.

Borsos et al. (2012) reported an analysis of long-term trends in road safety, inspired by the "law" proposed by Smeed in 1949 (Smeed 1949). Borsos et al. fitted models to the data covering the period both before and after the turning point in the number of traffic fatalities. The analysis included 26 countries with data from 1965 to 2009. In most countries, the period before the turning point in the number of fatalities (per

100,000 inhabitants) was shorter than the period after the turning point. However, by varying the periods to which the models were fitted, Borsos et al. were nevertheless able to show that the underlying trends were not the same before and after the turning point.

Antoniou and Yannis (2013) present a state-space time-series analysis of long-term trends in traffic fatalities in Greece. The analysis covers the period from 1960 to 2011. The turning point in the number of traffic fatalities in Greece occurred as late as 1996 (in most OECD countries it occurred between 1965 and 1975); thus the period after the turning point was much shorter than before the turning point. Three different models were fitted to data for 1960-2007 and predictions based on the models made for the years 2008-2011. A latent risk model with dummy variables representing interventions made in 1986, 1991 and 1996 best fitted the data. After accounting for the effects of the economic recession from 2008 onwards, predictions of the number of traffic fatalities in Greece were made for the years 2012 to 2020.

In a mainly methodological paper, Commandeur et al. (2013) argue for using state-space time-series models when analysing long-term trends in road safety. Examples are given of such analyses, showing that state-space models fit the data considerably better than other models. However, the assumption made in state-space models that residuals are normally distributed can be problematic in samples characterised by a low mean number of accidents per unit of time, as shown in the paper by Quddus (2008; quote above).

Dupont et al. (2014) present latent risk and trend models for traffic fatalities in 30 European countries, fitted by means of state-space time-series analysis. The period included differed between the 30 countries, ranging from 1950-2010 in the Netherlands to 2001-2010 in Bulgaria and Lithuania. In most countries, only the period after the turning point in the number of traffic fatalities was included. The analysis included predictions of future trends. By re-examining the data some years from now, the accuracy of these predictions can be determined.

Neither of the studies reviewed above make the same bold claim as Oppe did about the inevitability of the turning point in the number of traffic fatalities. Some of the recent studies include tests of the stability of trends in the form of predictions made for years that were not included when developing the models. From a logical point of view, this is the best way of testing the stability of trends, since the outcome could be both a confirmation (past trends accurately predict future outcomes) and a falsification (past trends do not accurately predict future outcomes) of the stability of trends.

3 DATA AND METHODS

Data on traffic fatalities and vehicle kilometres (in the United States: miles) of travel were collected for six countries: Norway, Denmark, Sweden, Great Britain, the Netherlands and the United States. These countries were selected because data on traffic volume was available at least back to about 1950. To reliably estimate trends before the turning point, one needs about 20 years of data before this point was reached. To avoid the extraordinary conditions during World War II, the period analysed did not start before 1948 in any of the countries. The years included were 1952-2013 for Norway, 1950-2012 for Denmark and Sweden, 1948-2010 for the

Netherlands, 1949-2011 for Great Britain, and 1948-2012 for the United States. Data on traffic fatalities and traffic volume were taken from official statistics published in each country. For Denmark, these data were kindly provided by Stig Hemdorff at the national road directorate.

The approach taken to analysis is explained using Norway as a case. A model was first fitted to describe traffic growth. This model was based on annual percentage changes in vehicle kilometres of travel from 1953 to 1970 (18 data points). The following functions were tested: linear, logarithmic, inverse, power and exponential. The exponential model best fitted the data (R-squared = 0.61). Predictions based on this model were then extrapolated to the period 1971-2013. A predicted annual percentage growth in traffic was thus obtained for all years from 1953 to 2013. Using actual traffic volume in the first year, 1952, as a starting point, traffic volume for the years 1953-2013 was estimated by applying the annual growth predicted by the model.

Next, the annual changes in fatality rate (fatalities per billion vehicle kilometres) were modelled based on data for 1952-1970. Only functions that do not have turning points were tested, as it is highly unlikely that the long-term trend in fatality rate would have any turning points that could be meaningfully interpreted, or that would not lead to absurd predictions if extrapolated. An exponential model was once again found to best fit the data (R-squared = 0.76). It was extrapolated to the years 1971-2013. By multiplying the model-predicted annual traffic volume by the model-predicted fatality rate, an annual predicted number of fatalities was produced.

The analysis was then repeated using data for all years (1953-2013 for traffic growth, 1952-2013 for fatality rate). Traffic growth was found to be adequately modelled by a logarithmic function (R-squared = 0.70). A quadratic function (second degree polynomial) fitted slightly better, but was rejected because an extrapolation of it produced nonsensical predictions. The trend in fatality rate was very well described by an exponential function (R-squared = 0.98). Figure 2 shows model predictions.

Figure 2 about here

Several observations can be made. First, the model based on data for the years 1952-1970 fits the actual count of fatalities during that period much better than the model based on data for the years 1952-2013. Second, the model based on data before the turning point does predict a turning point, but much later than it actually occurred. The maximum number of fatalities, 611, was predicted for the year 1985. Third, the model based on data for the entire period also predicts a turning point, in 1975, at 408 fatalities. The actual maximum number of fatalities was 560 in 1970. Fourth, the model fitted to data for the entire period predicts the number of fatalities quite accurately for the years after about 1980.

It seems clear, therefore, that if the trends before 1970 had continued after that year, the number of traffic fatalities in Norway would have been considerably higher than it actually turned out to be. A comparison of the two models shows that the long-term trends did change from before to after the turning point. Figure 3 shows the two models for traffic growth.

Figure 3 about here

The two models predicted about the same traffic volume in 1970 and produced very similar predictions until about 1980. From then on, the model fitted to the data for 1953-1970 predicted less growth in traffic than the model fitted to data for 1953-2013. For the year 2013, the model fitted to data before the turning point predicted a traffic volume of 30.8 billion vehicle kilometres of travel, considerably less than the actual value (42.5 billion vehicle kilometres of travel). The model fitted to data for the entire period predicted 43.1 billion vehicle kilometres of travel in 2013, only 1.4 percent more than the actual value.

There was thus a more rapid growth in traffic in Norway after 1970 than the declining trend in traffic growth before that year would lead one to predict. A larger traffic volume is, ceteris paribus, associated with a higher number of traffic fatalities. However, since the number of traffic fatalities in Norway after 1970 was considerably lower than predicted by the model based on pre-1970 data, the long-term trend in fatality rate must also have changed. Figure 4 examines the trend in fatality rate.

Figure 4 about here

According to the model fitted to data for 1952-1970, fatality rate declined by 2.8 percent per year. According to the model fitted to data for 1952-2013, fatality rate declined by 5.0 percent per year. It is therefore clear that fatality rate declined more rapidly after 1970 than before 1970. An estimate for the period 1970-2013 indicates an annual decline in fatality rate of 5.2 percent. There was thus a change in the underlying trend, and this has contributed to the reduction of traffic fatalities in

Norway after 1970. Note that the year 1970 was included in both models (1952-1970 and 1970-2013).

4 RESULTS

Analyses identical to the one presented for Norway above were made for Denmark, Sweden, the Netherlands, Great Britain and the United States. Figure 5 presents the results for Denmark.

Figure 5 about here

The turning point for the number of traffic fatalities in Denmark was reached in 1971. The two curves fitted to the data – one for 1950-1971, extrapolated to 1972-2012, and one for the entire period (1950-2012) are located close to each other. Both of them have a turning point. For both curves this occurred in 1970, one year before the actual turning point, but at a considerably lower number of fatalities than the actual peak value of 1213 in 1971. The similarity of the two curves fitted for Denmark lends some support to the hypothesis that no real change in underlying trends occurred from before to after the turning point was passed.

The turning point for the number of traffic fatalities in Sweden was reached in 1966. 1313 fatalities were recorded both in 1965 and 1966. A model was fitted to describe traffic growth and fatality rate during 1950-1966 and extrapolated to 1967-2012. Annual percentage traffic growth from 1950 to 1966 was best described by a logarithmic function ($R^2 = 0.72$). Fatality rate declined by 6.7 percent per year according to an exponential function ($R^2 = 0.92$).

Figure 6 about here

The model predicts a turning point in 1966. Extrapolation to the period 1967-2012 gives a predicted number of fatalities for 2012 of 134. The actual number was 286. It would therefore seem that, although the model correctly predicts a turning point, the actual decline in traffic fatalities in Sweden after 1966 has been smaller than predicted by the model. A new model was fitted for the entire period from 1950 to 2012. Traffic growth was best described by a logarithmic function ($R^2 = 0.77$). Fatality rate was best described by an exponential function ($R^2 = 0.99$) with an annual decline of 5.2 percent. This model also predicts a turning point at 1275 fatalities in 1971. The predicted number of fatalities in 2012 was 324. As can be seen from Figure 6, the model fitted to data for the entire period consistently predicts a too high number of fatalities after the turning point until about the year 2000.

Thus, somewhat surprisingly, the annual percentage decline in fatality rate in Sweden after the turning point appears to be smaller than before the turning point. There is, in that sense, no support for the idea that road safety policy became more effective after the turning point than it was before. The turning point was predictable from trends established before it was reached, and there has been a slower decline in traffic fatalities after the turning point than predicted on the basis of pre-turning point trends. Yet, both models fit the data rather poorly as indicated by the systematic prediction errors found in Figure 6.

For the Netherlands, results of the analyses are shown in Figure 7.

Figure 7 about here

A model based on pre-turning point trends once again predicts a turning point, but much later than it actually occurred and at a higher number of fatalities (1997 and

3888, versus the actual turning point in 1972 at 3264 fatalities). Traffic growth in the period before the turning point was reached was very irregular and no model fitted it very well. An exponential model ($R^2 = 0.09$) was chosen (a second degree polynomial fitted slightly better, but predicted negative traffic growth only a few years into the period the model was extrapolated to). Fatality rate declined exponentially in the period before the turning point ($R^2 = 0.96$), at an annual percentage rate of 4.6 percent.

A model fitted to data for the entire period (1948-2010) is also shown in Figure 7. It predicts a turning point in 1974 at 2213 fatalities. The model fits the data quite poorly both before and after the turning point. A comparison of the two models nevertheless makes it clear that a genuine turning point was reached in the Netherlands in 1972. The development of traffic fatalities after that year was not simply a continuation of prior trends. There was, in particular, a larger annual decline in fatality rate after 1972 than before 1972, which may be the result of a more effective road safety policy.

Figure 8 shows results for Great Britain. The turning point was reached in 1966 at 7985 fatalities.

Figure 8 about here

Pre-turning point trends gave no hint of a turning point. On the contrary, an extrapolation of these trends shows an accelerating growth in the number of traffic fatalities. Traffic growth in the period before the turning point was very irregular and no good model could be fitted to it. A logarithmic model was adopted ($R^2 = 0.05$). Fatality rate declined by 4.3 percent per year before the turning point ($R^2 = 0.97$).

A model fitted to data for the entire period (1949-2011) shows a turning point in 1971 at 6672 fatalities. Although the general shape of this model is consistent with actual development, it does not fit the data well. It has a turning point which is both later than the actual turning point and occurs at a lower number of fatalities than the actual turning point. Nevertheless, the rate of improvement of road safety in Great Britain has been greater after the turning point than before. In that sense, the turning point was a real change, not simply a continuation of pre-turning point trends.

The last country to be examined is the United States. Figure 9 shows results for the United States.

Figure 9 about here

The overall pattern is very similar to that found for Great Britain. Pre-turning point trends did not predict a turning point. A second degree polynomial best fitted pre-turning point traffic growth; however it made absurd predictions when extrapolated. A power model was therefore preferred ($R^2 = 0.09$). Fatality rate declined by 1.9 percent per year ($R^2 = 0.81$) before the turning point was reached.

A model fitted to data for the entire period did, as expected, have a turning point. This occurred in 1981 at 49,192 fatalities. The real turning point was in 1972 at 55,600 fatalities. Thus, the model based on data for the entire period did not fit the data well. At any rate, comparison of the two models clearly indicates that a change in underlying trends took place from before to after the turning point. The declining trend in traffic fatalities after the turning point is, however, much weaker in the United States than in the other countries included in this study.

Table 1 brings together the results for all countries with respect to the long-term trend in fatality rate. Fatality rate is, arguably, the best indicator of road safety performance, since road safety policy principally seeks to influence fatality rate rather than traffic volume per se. Thus, safety performance is improved if the annual reduction of fatality rate becomes greater.

Table 1 about here

In four of the six countries, the annual percentage reduction of fatality rate was greater after the turning point than before. In two countries, Denmark and Sweden, the annual percentage reduction of fatality rate was smaller after the turning point than before.

5 DISCUSSION

The models developed and discussed above are very simple, indeed so simple that it seems obvious that they will not fit the data very well. Yet, the models that were developed by Oppe about 25 years ago were almost as simple as the models presented here, differing principally by the fact that Oppe assumed a logistic function for traffic growth, i.e., a function which was flat at the beginning, then grew more steeply, then flattened out again. What, then, is the point of developing and discussing these simple models?

The main reason for revisiting models of the turning point in the number of traffic fatalities is that the models that were developed by Oppe have been misinterpreted by both himself and others. These models have been invoked to argue that there was no real turning point in the number of traffic fatalities, merely a continuation of trends implying that, sooner or later, a turning point would be reached. It is, however, obvious that a turning point follows when you fit the model to data for years both before and after the turning point occurred. Any reasonably well-fitting model will then reproduce the turning point found in the data used to fit the model. It could not be otherwise. The model cannot be falsified, i.e. no set of parameter values estimated from the data could possibly result in a model not showing a turning point.

To determine if the turning point in the number of traffic fatalities follows with necessity from stable underlying trends, one must estimate these trends on the basis of data referring to the period before the turning point occurred. If a projection of the trend fitted by a model shows a turning point, ideally speaking one closely reproducing the actual turning point, one may conclude that the trends have remained stable and nothing fundamental has changed. If this is not the case, the turning point is not simply the result of stable underlying trends.

For the six countries included in this study, pre-turning point trends extrapolated to future years indicated a turning point in four of the countries, but this turning point occurred much later than the actual turning point in three of the countries. For the remaining two countries, an extrapolation of pre-turning point trends gave no hint of a future turning point. It therefore seems clear that the underlying trends are not stable. Clearly, these trends changed around the time of the turning point in the number of traffic fatalities, and may have changed again one or more times after the turning point was passed. It is undoubtedly possible to fit more sophisticated models to the data that will reproduce even short-term changes in underlying trends more precisely than the very simple models discussed in this paper – see for example the concise presentation of state-space time series analysis in a SWOV Fact sheet (SWOV 2013). However, the purpose of this paper was not to develop models that fit the data very well. It was simply to point out the fact that models need to be empirically testable to support any conclusions about long-term trends based on the models. Models are tested by using them to predict data that did not serve as the basis for developing the model. If the models predict the data well, they are verified and general conclusions can be drawn from them. If the models do not predict the data well, they are falsified and give, at best, only a locally valid historical description of the data that served as the basis for developing them and have no general validity outside the range of these data.

This paper does not try to explain why the long-term trends changed in many countries around 1970. It is, however, not unreasonable to suggest that the changes are related to changes in road safety policy. In the United States, things started happening with Ralph Nader's book "Unsafe at any speed" in 1965 and the creation of the National Highway Traffic Safety Administration, headed by William Haddon, in 1966. It was not until 1973/74, however, that there was a major drop in traffic fatalities in the US, as a response to the energy crisis and the national 55 MPH speed limit imposed to conserve energy.

In Sweden, the change to right-hand driving in 1967 was an impetus for more effective road safety policies. In Great Britain, the introduction of the blood alcohol limit in 1967 was an important initiative. In Denmark, like the US, the energy crisis in

1973-74 lead to the introduction of speed limits. As for Norway, the country had a Minister of Transport during 1971-72 who took a particular interest in road safety and brought it higher on the agenda than it had been before.

On the whole, therefore, road safety policies changed in many countries around 1970. It is likely that this gave a major contribution to the change in trend. On the other hand, evaluating the exact contribution of policy changes in any rigorous manner is difficult, if not impossible.

5 CONCLUSIONS

The main conclusions from the study presented in this paper is that, for five of the six developed countries that were included, a real turning point in the underlying trends determining the number of traffic fatalities appears to have occurred at about the time when the number of traffic fatalities reached its all-time peak level. In four of the countries, the annual decline in fatality rate was greater after the turning point than before. In the Denmark and Sweden, it was, surprisingly, smaller.

Although only six countries were included in this study, it is well-known that the number of traffic fatalities has been greatly reduced in many other countries. The main lessons are therefore that: (1) A country does not at any time have an “optimal” or “acceptable” number of traffic fatalities; (2) In countries with a growing number of traffic fatalities, one cannot count on this trend to turn by itself; active policy interventions are needed to turn the trend.

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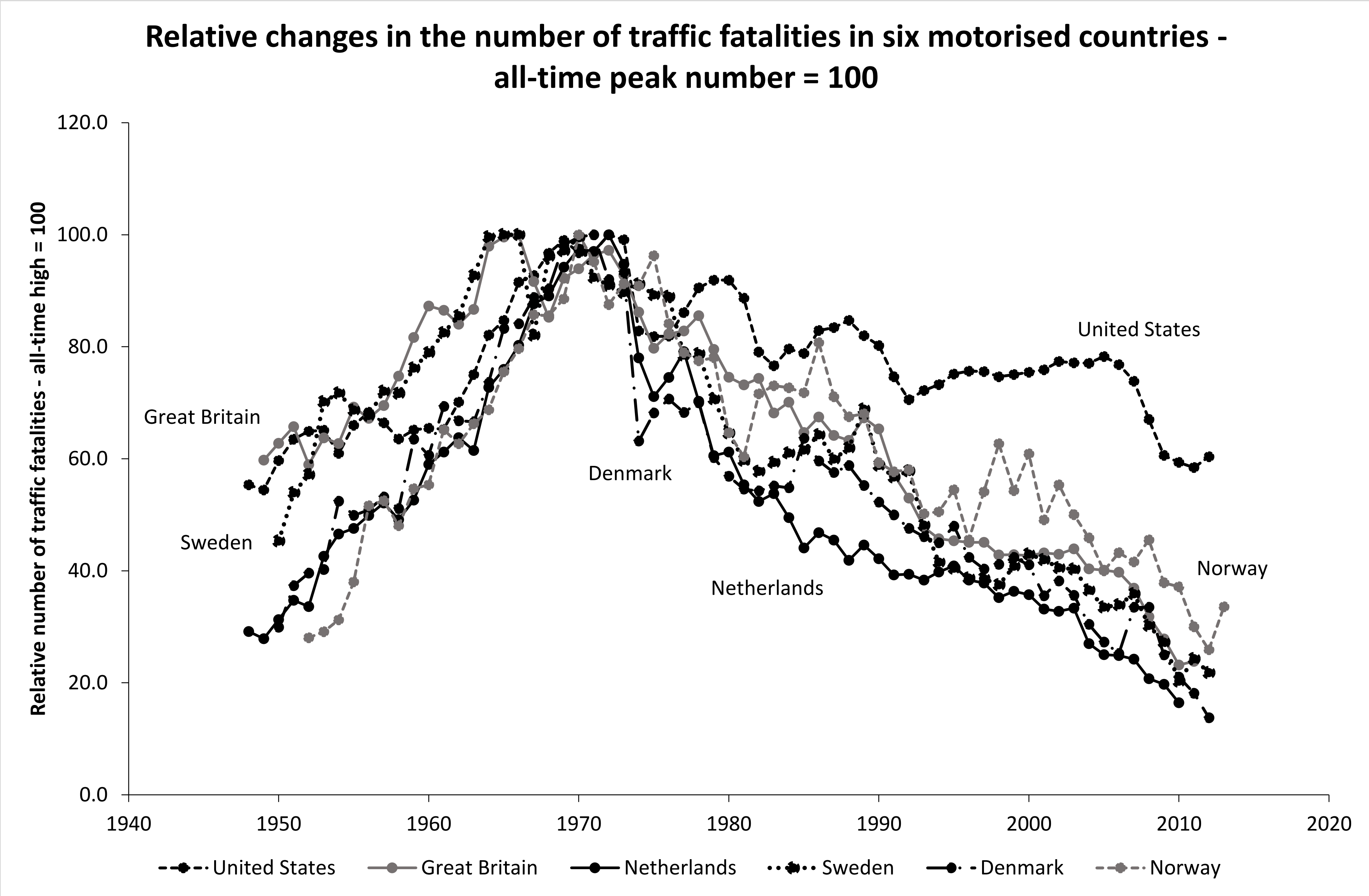
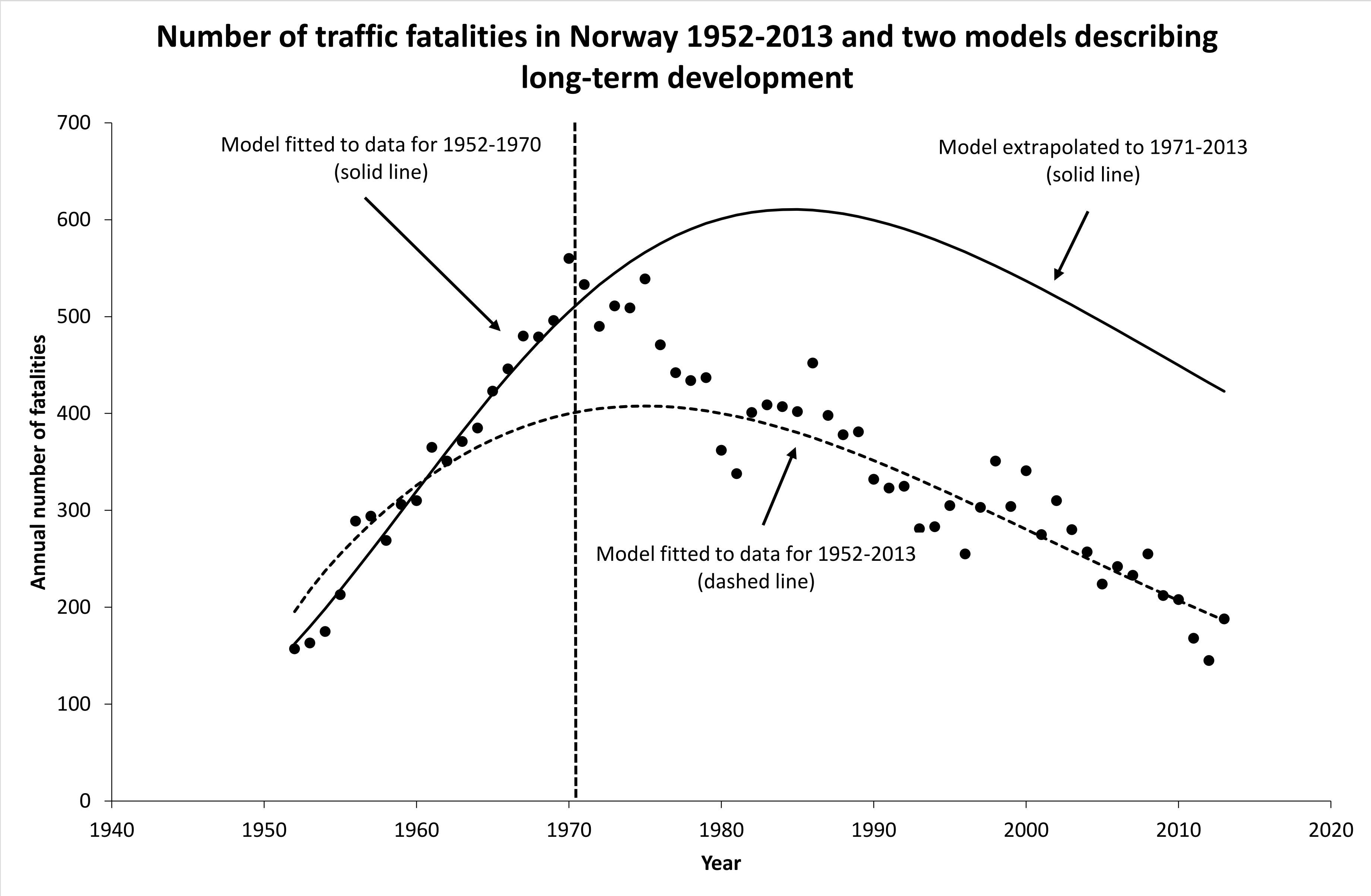
LIST OF FIGURES AND TABLES

Figure 1:



Relative changes in the number of traffic fatalities in six motorised countries - all-time peak number = 100
Relative number of traffic fatalities - all-time high = 100
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1940
1950
1960
1970
1980
1990
2000
2010
2020
Great Britain
Sweden
Denmark
United States
Netherlands
Norway
United States
Great Britain
Netherlands
Sweden
Denmark
Norway

Figure 2:



Number of traffic fatalities in Norway 1952-2013 and two models describing long-term development
Model fitted to data for 1952-1970 (solid line)
Model extrapolated to 1971-2013 (solid line)
Model fitted to data for 1952-2013 (dashed line)
Annual number of fatalities
0
100
200
300
400
500
600
700
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Figure 3:

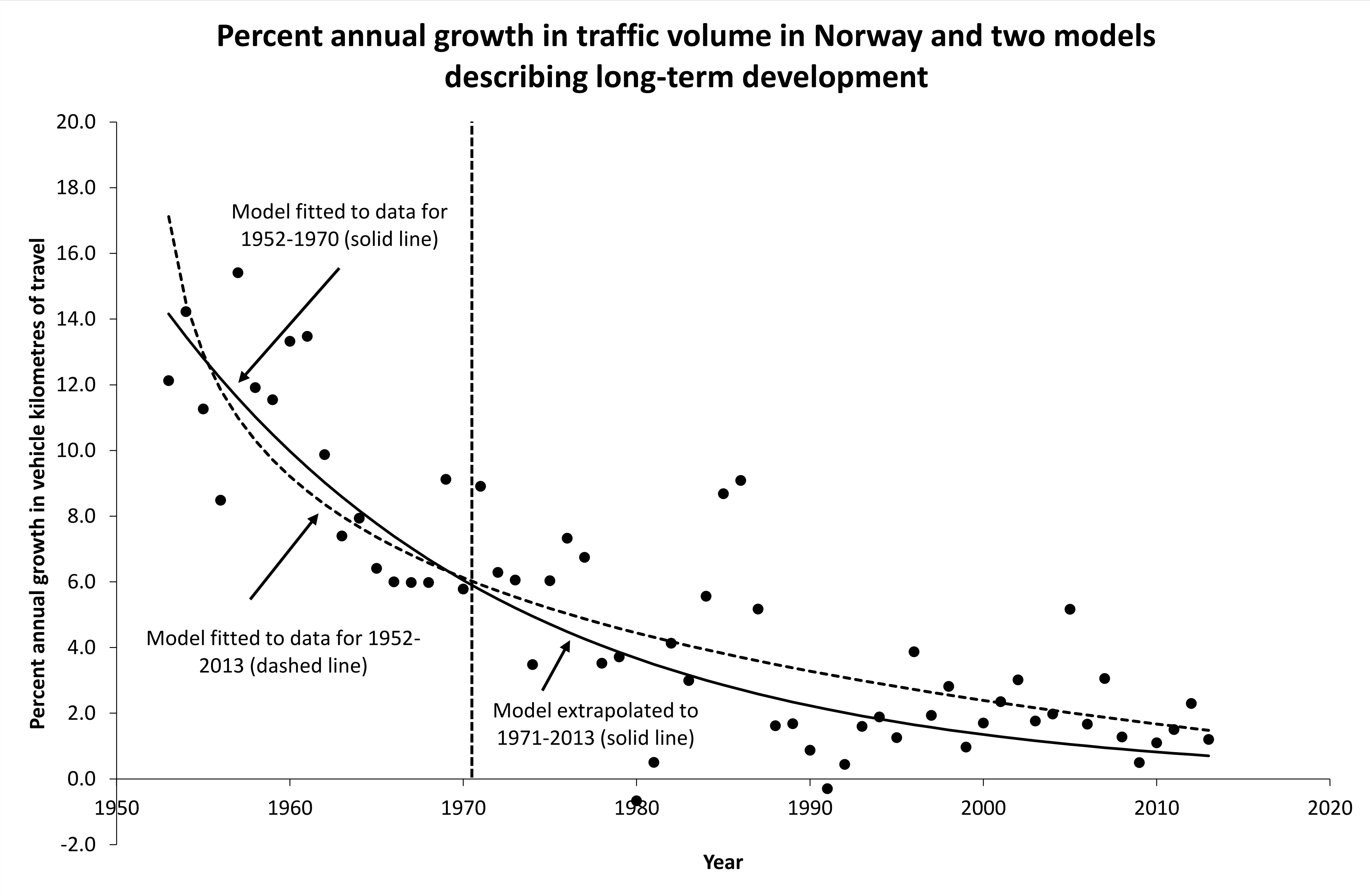

Percent annual growth in traffic volume in Norway and two models describing long-term development
Model fitted to data for 1952-1970 (solid line)
Model fitted to data for 1952-2013 (dashed line)
Model extrapolated to 1971-2013 (solid line)
Percent annual growth in vehicle kilometres of travel
Year
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
1950
1960
1970
1980
1990
2000
2010
2020

Figure 4:

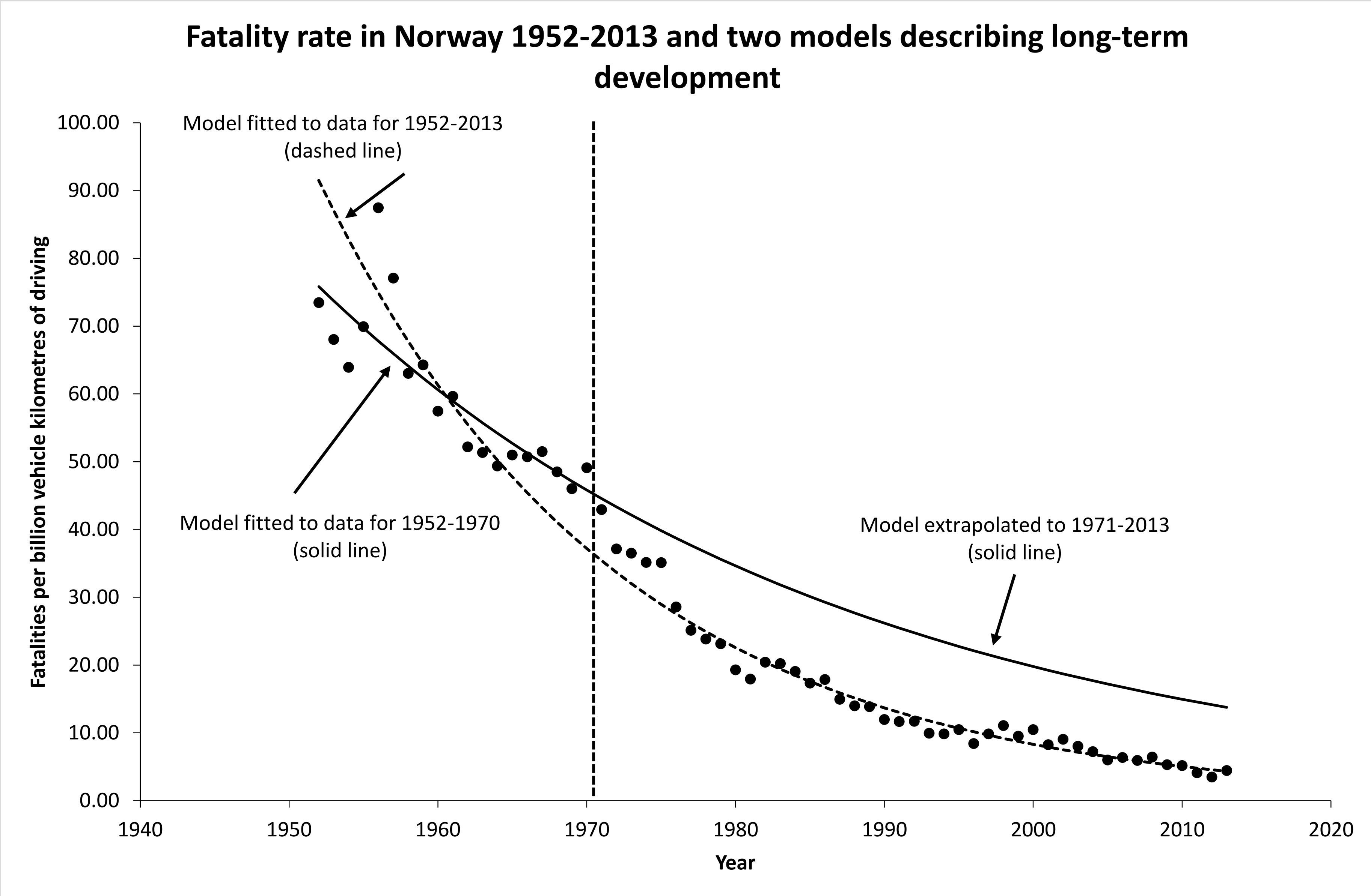

Fatality rate in Norway 1952-2013 and two models describing long-term development
Model fitted to data for 1952-2013 (dashed line)
Model fitted to data for 1952-1970 (solid line)
Model extrapolated to 1971-2013 (solid line)
Fatalities per billion vehicle kilometres of driving
Year
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 5:

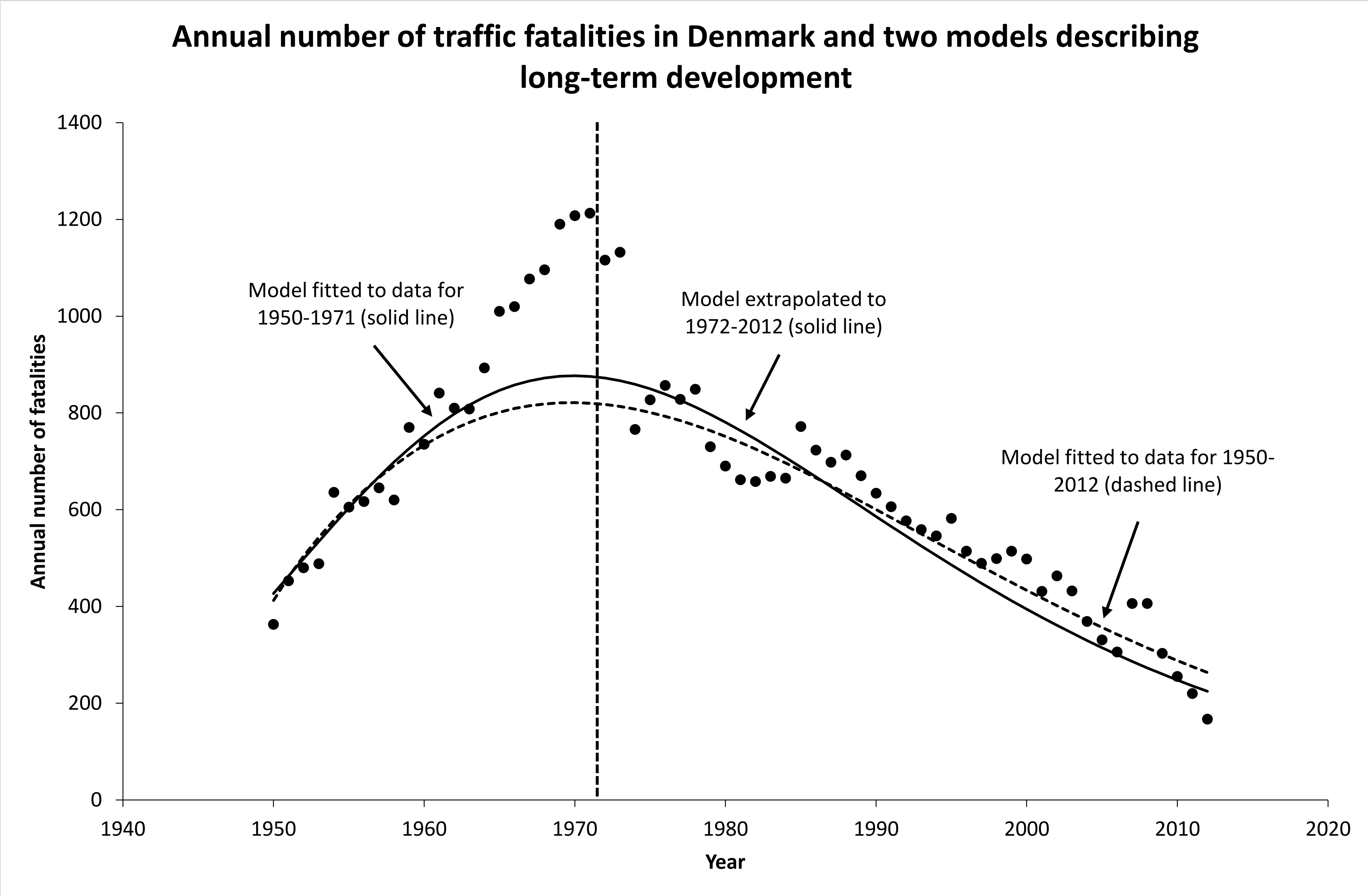

Annual number of traffic fatalities in Denmark and two models describing long-term development
Model fitted to data for 1950-1971 (solid line)
Model extrapolated to 1972-2012 (solid line)
Model fitted to data for 1950-2012 (dashed line)
Annual number of fatalities
Year
0
200
400
600
800
1000
1200
1400
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 6:

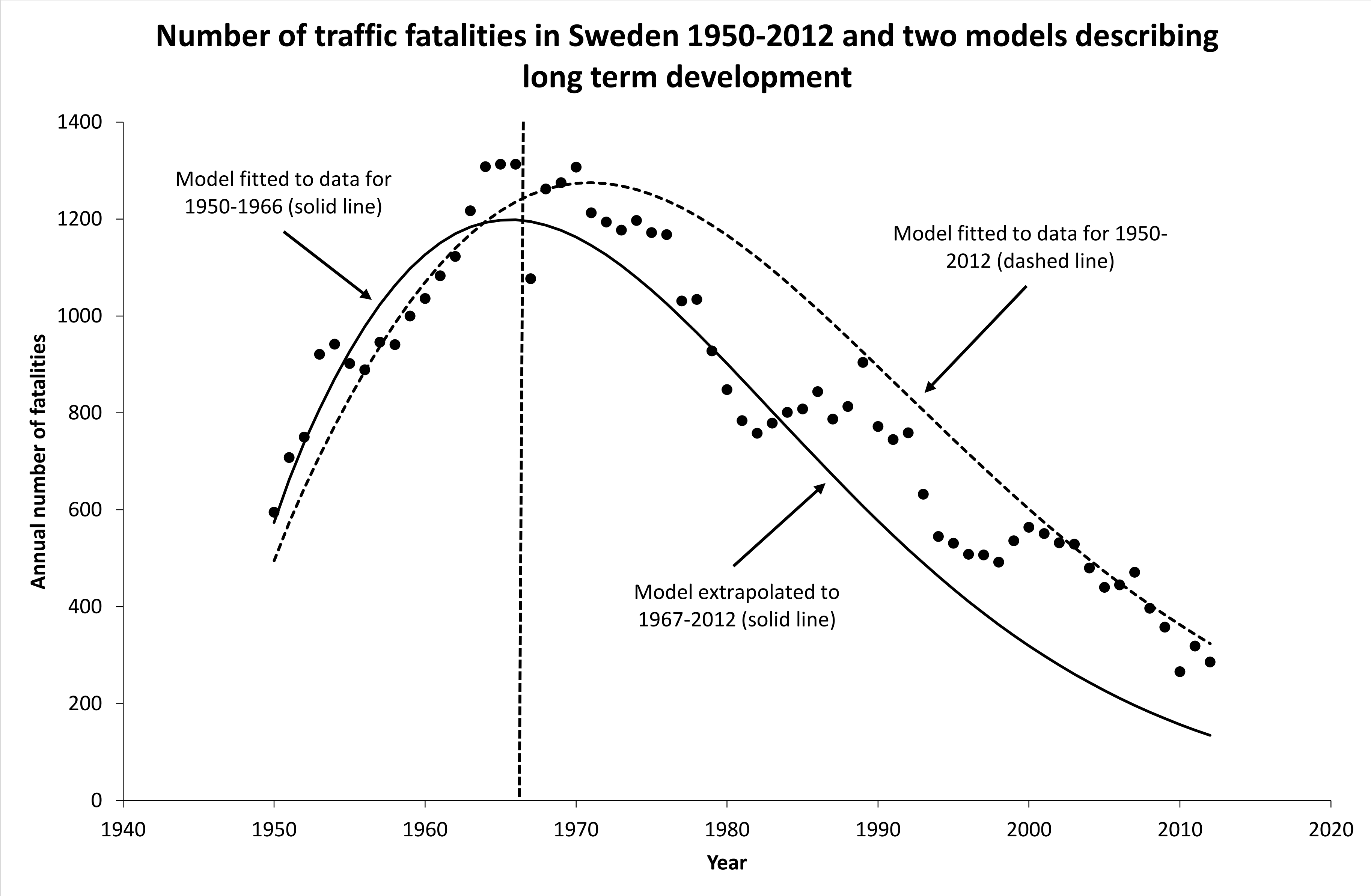

Number of traffic fatalities in Sweden 1950-2012 and two models describing long term development
Model fitted to data for 1950-1966 (solid line)
Model fitted to data for 1950-2012 (dashed line)
Model extrapolated to 1967-2012 (solid line)
Annual number of fatalities
Year
0
200
400
600
800
1000
1200
1400
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 7:

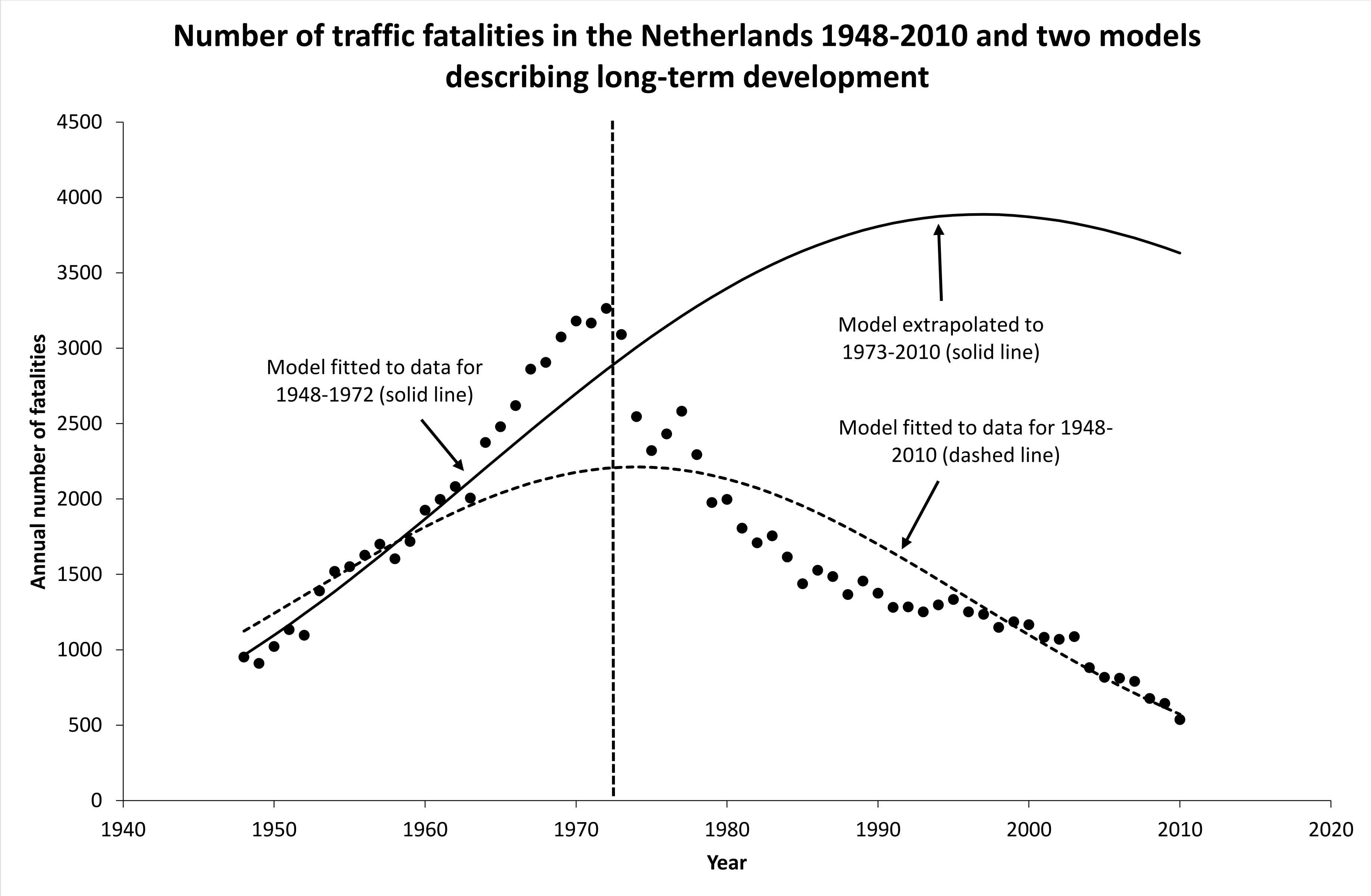
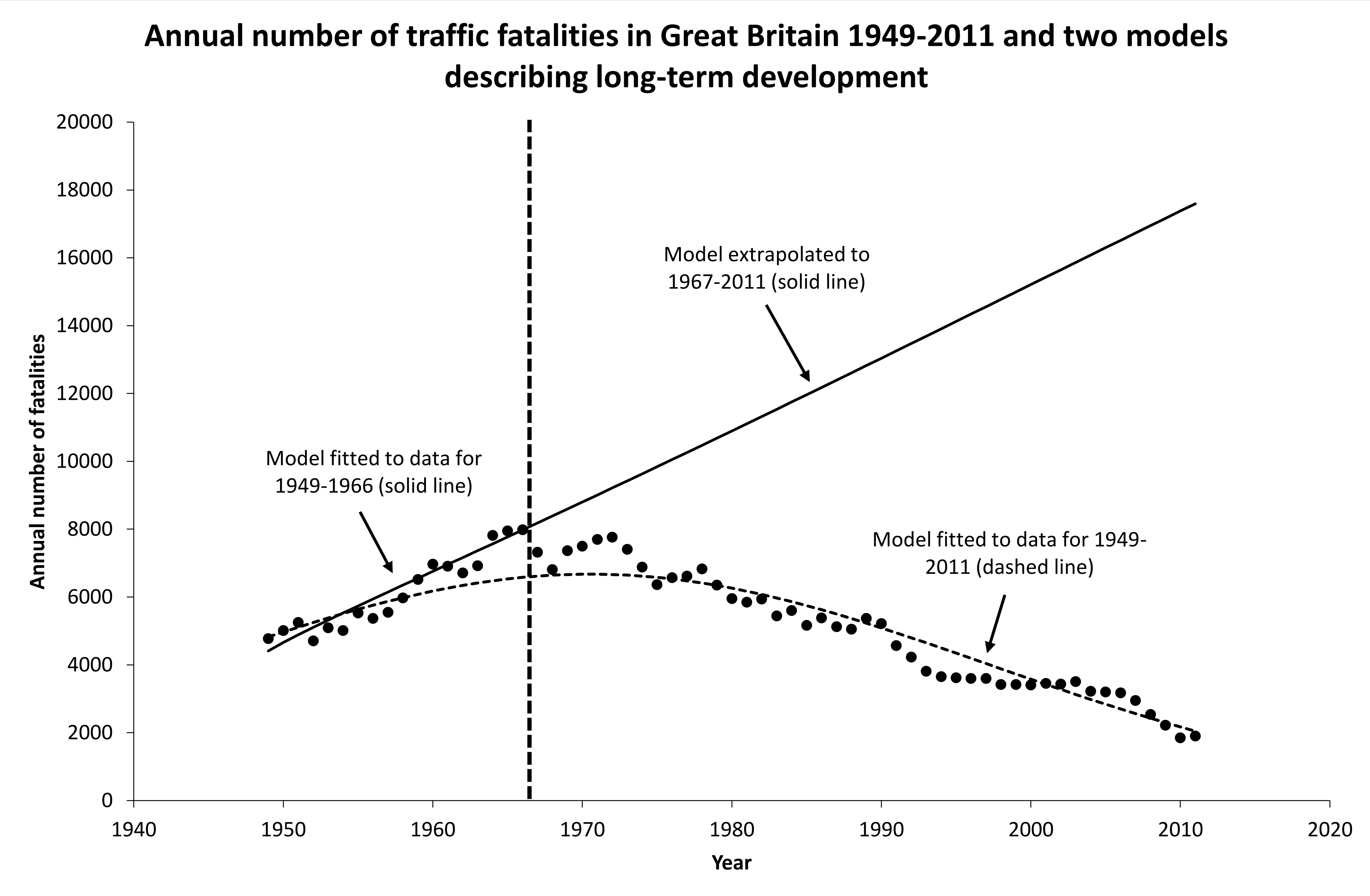
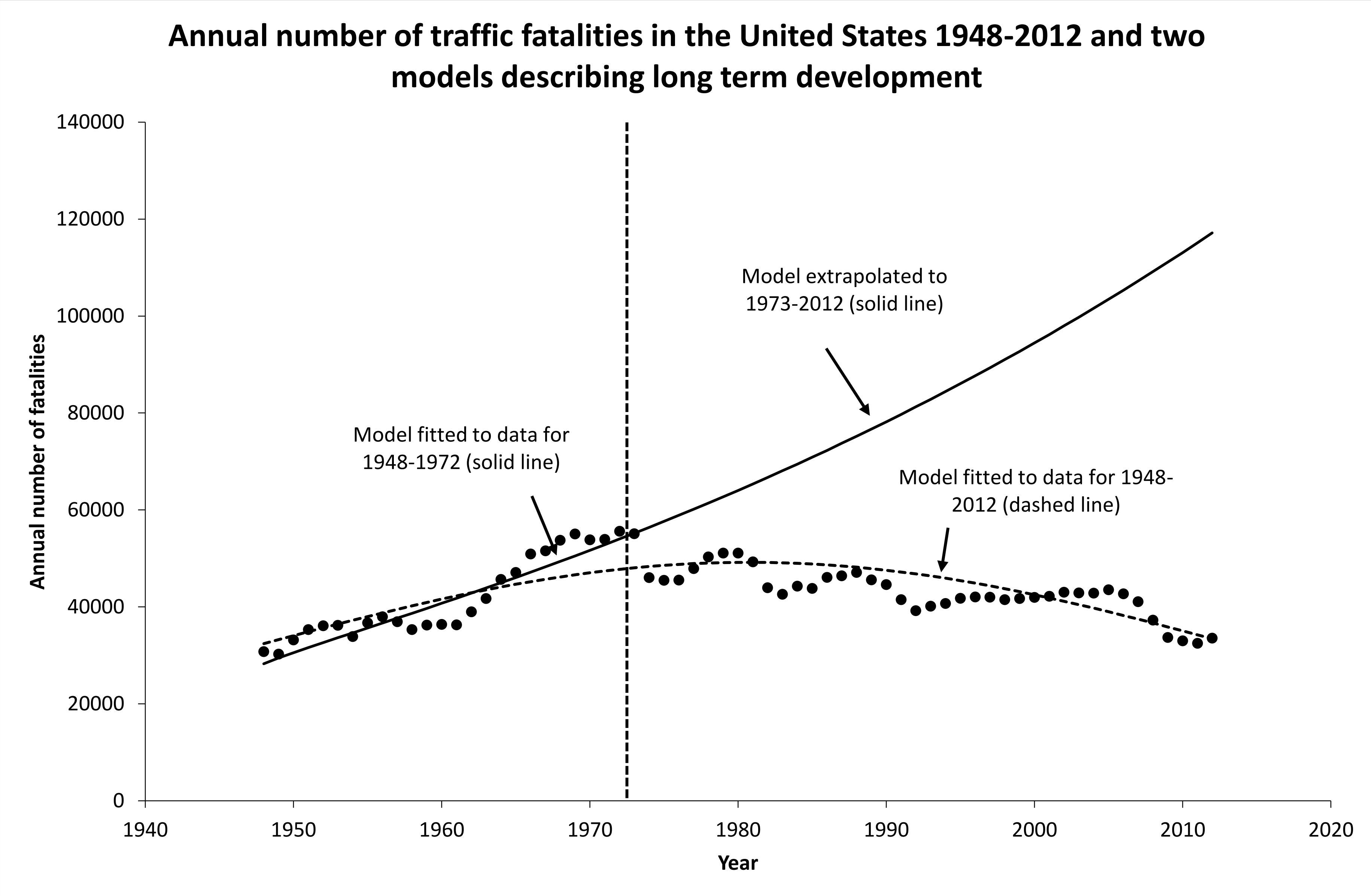

Number of traffic fatalities in the Netherlands 1948-2010 and two models describing long-term development
Annual number of fatalities
Year
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1940
1950
1960
1970
1980
1990
2000
2010
2020
Model fitted to data for 1948-1972 (solid line)
Model extrapolated to 1973-2010 (solid line)
Model fitted to data for 1948-2010 (dashed line)

Figure 8:



Annual number of traffic fatalities in Great Britain 1949-2011 and two models describing long-term development
Annual number of fatalities
Year
Model extrapolated to 1967-2011 (solid line)
Model fitted to data for 1949-1966 (solid line)
Model fitted to data for 1949-2011 (dashed line)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
1940
1950
1960
1970
1980
1990
2000
2010
2020

Figure 9:



Annual number of traffic fatalities in the United States 1948-2012 and two models describing long term development
Annual number of fatalities
140000
120000
100000
80000
60000
40000
20000
0
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year
Model extrapolated to 1973-2012 (solid line)
Model fitted to data for 1948-1972 (solid line)
Model fitted to data for 1948-2012 (dashed line)

Table 1:

Country	Before turning point	Annual change in fatality rate (percent)	Standard error	After turning point	Annual change in fatality rate (percent)	Standard error	Significance of difference in annual change
Denmark	1950-1971	-5.8	0.004	1972-2012	-5.5	0.002	T=-0.67; p=0.220
Great Britain	1949-1966	-4.3	0.002	1967-2011	-5.3	0.001	T=4.47; p=0.015
Netherlands	1948-1972	-4.6	0.002	1973-2010	-6.1	0.002	T=5.30; p=0.011
Norway	1952-1970	-2.8	0.004	1971-2013	-5.2	0.001	T=5.82; p=0.009
Sweden	1950-1966	-6.7	0.005	1967-2012	-5.0	0.001	T=-3.33; p=0.026
United States	1948-1972	-1.9	0.002	1973-2012	-3.3	0.001	T=6.26; p=0.008

APPENDIX 1: DATA FOR COUNTRIES INCLUDED IN STUDY

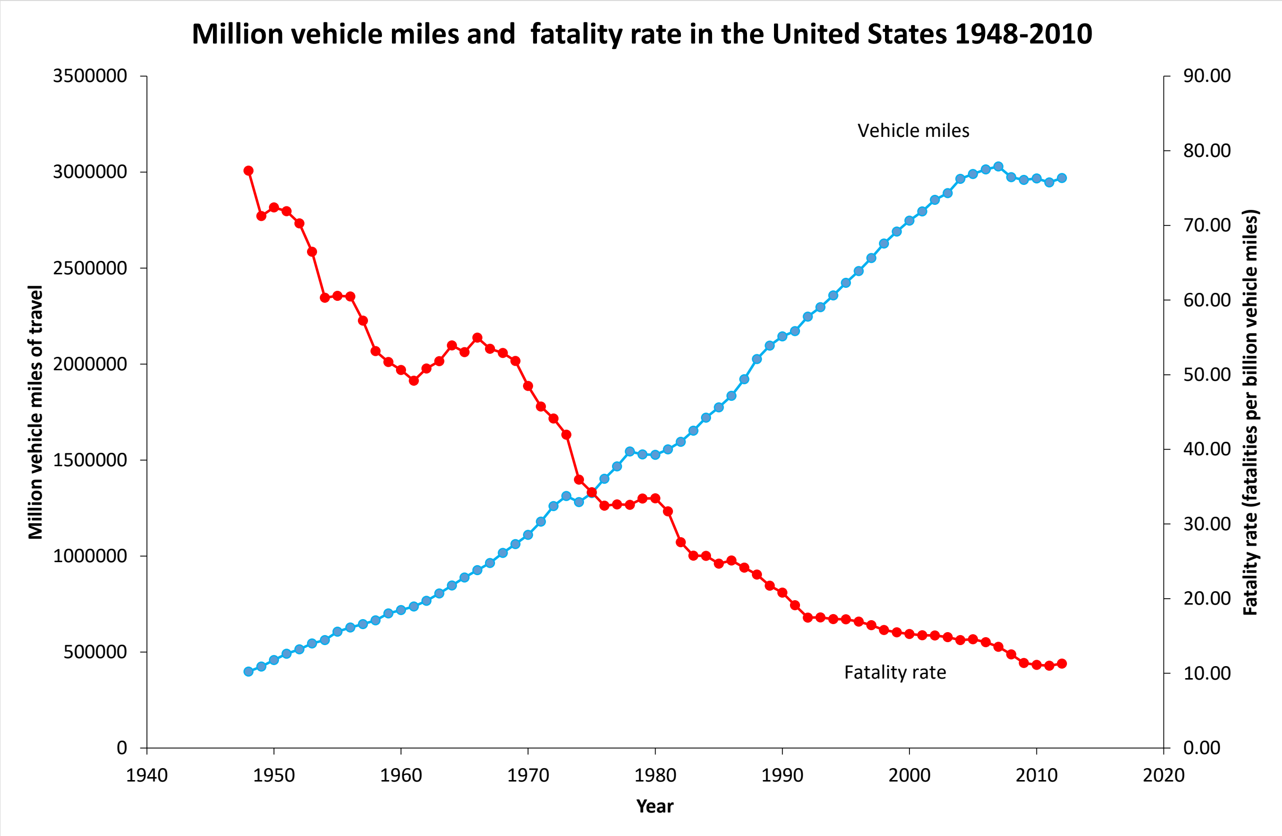
United States			Great Britain		Netherlands		Sweden	
Year	Fatalities	Million vehicle miles	Fatalities	Million vehicle kilometres	Fatalities	Million vehicle kilometres	Fatalities	Million vehicle kilometres
1948	30775	397957			952	5000		
1949	30248	424461	4773	46500	910	5730		
1950	33186	458246	5012	53100	1021	6330	595	5143
1951	35309	491093	5250	58900	1134	6960	708	6429
1952	36088	513581	4706	60800	1097	7570	750	7251
1953	36190	544433	5090	64900	1390	8100	921	8640
1954	33890	561963	5010	69700	1520	9050	942	10286
1955	36688	605646	5526	77000	1552	10240	902	11674
1956	37965	627843	5367	80800	1628	11660	889	13114
1957	36932	645004	5550	80300	1701	12790	946	15069
1958	35331	664653	5970	93000	1604	13870	941	16817
1959	36223	700480	6520	104200	1718	14960	1 000	18669
1960	36399	718762	6970	112300	1926	15650	1 036	20413
1961	36285	737421	6908	122400	1997	17380	1 083	21514
1962	38980	766734	6709	128300	2082	19440	1 123	23429
1963	41723	805249	6922	136300	2007	21860	1 217	24157
1964	45645	846298	7820	152300	2375	25100	1 308	26847
1965	47089	887812	7952	162700	2479	28620	1 313	29332
1966	50894	925899	7985	172900	2620	32550	1 313	31234
1967	51559	964005	7319	180000	2862	35790	1 077	32433
1968	53763	1015869	6810	187700	2907	39820	1 262	33689
1969	55043	1061791	7365	192500	3075	43920	1 275	35267
1970	53816	1109724	7499	200500	3181	45040	1 307	37065
1971	53907	1178811	7699	212000	3167	49170	1 213	38854
1972	55600	1259786	7763	222500	3264	51120	1 194	40730
1973	55096	1313110	7406	234000	3092	54040	1 177	44831
1974	46049	1280544	6883	229700	2546	54600	1 197	42625
1975	45500	1327664	6366	231700	2321	59020	1 172	43342
1976	45523	1402380	6570	243500	2432	62780	1 168	46733
1977	47878	1467027	6614	246800	2583	66060	1 031	48989
1978	50331	1544704	6831	256500	2294	69220	1 034	50277
1979	51093	1529133	6352	255900	1977	70710	928	51249
1980	51091	1527295	5953	271900	1997	71870	848	51573
1981	49301	1555308	5846	276900	1807	71510	784	51231
1982	43945	1595010	5937	284500	1710	73250	758	51863
1983	42589	1652788	5445	288100	1756	75820	779	52709
1984	44257	1720269	5599	303100	1615	78720	801	53222

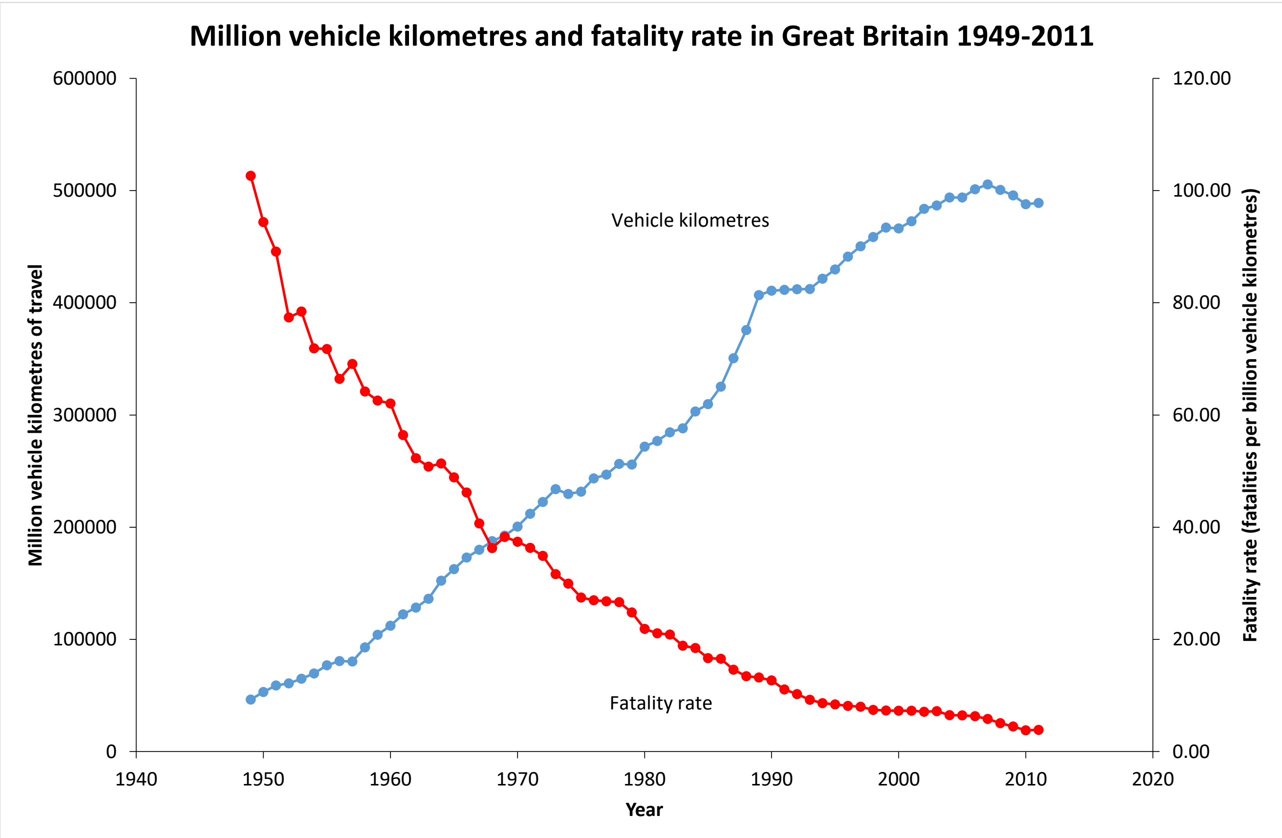
	United States		Great Britain		Netherlands		Sweden	
Year	**Fatalities**	**Million vehicle miles**	**Fatalities**	**Million vehicle kilometres**	**Fatalities**	**Million vehicle kilometres**	**Fatalities**	**Million vehicle kilometres**
1985	43825	1774826	5165	309700	1438	79610	808	54888
1986	46087	1834872	5385	325300	1528	84040	844	55291
1987	46390	1921204	5125	350500	1485	87260	787	58639
1988	47087	2025962	5052	375700	1366	92530	813	61763
1989	45582	2096487	5373	406900	1456	95470	904	65052
1990	44599	2144362	5217	410800	1376	95340	772	64310
1991	41508	2172050	4568	411600	1281	99220	745	64867
1992	39230	2247151	4229	412100	1285	102690	759	65537
1993	40134	2296378	3814	412300	1252	103740	632	64135
1994	40718	2357588	3650	421500	1298	107720	545	64905
1995	41770	2422823	3621	429700	1334	108700	531	65700
1996	42065	2484080	3598	441100	1251	109480	508	66029
1997	42013	2552233	3599	450300	1235	113870	507	66227
1998	41501	2628148	3421	458500	1149	114960	492	66955
1999	41717	2690241	3423	467000	1186	121305	536	68637
2000	41945	2746925	3409	466200	1166	125390	564	69667
2001	42196	2795610	3450	472600	1083	126100	551	70642
2002	43005	2855508	3431	483700	1069	126300	532	72973
2003	42884	2890221	3508	486700	1088	126940	529	73860
2004	42836	2964788	3221	493900	881	127700	480	74599
2005	43510	2989430	3201	493900	817	128440	440	74140
2006	42708	3014371	3172	501100	811	129080	445	76431
2007	41059	3029822	2946	505400	791	129730	471	79384
2008	37261	2973509	2538	500600	677	126390	397	80833
2009	33683	2958764	2222	495800	644	125730	358	81372
2010	32999	2967266	1850	487900	537	124960	266	82273
2011	32479	2946131	1901	488900			319	83507
2012	33561	2968815					286	83006
2013								

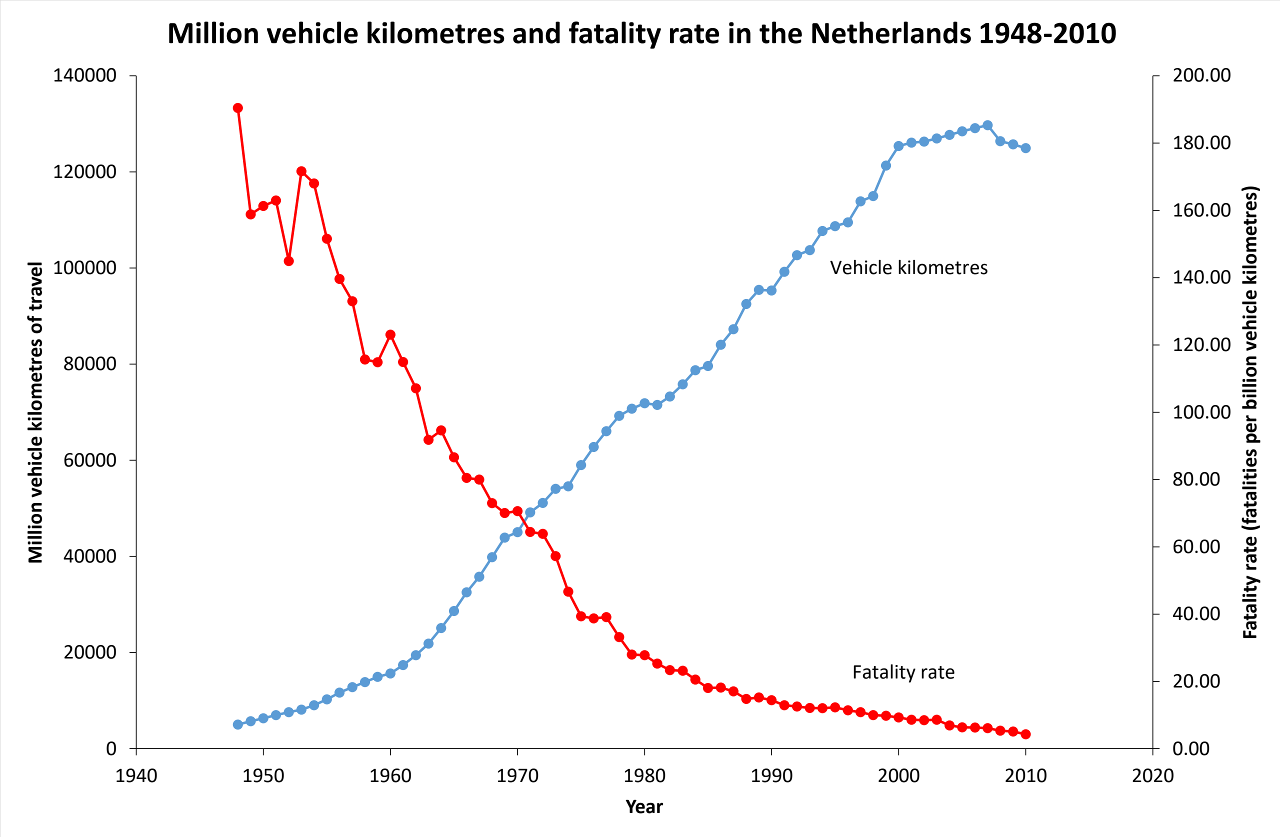
Denmark			Norway	
Year	Fatalities	Million vehicle kilometres	Fatalities	Million vehicle kilometres
1948				
1949				
1950	363	2800		
1951	453	3000		
1952	480	3200	157	2137
1953	488	3700	163	2396
1954	636	4300	175	2737
1955	605	5000	213	3046
1956	617	5800	289	3304
1957	645	6100	294	3813
1958	620	6800	269	4268
1959	770	7900	306	4760
1960	735	9100	310	5394
1961	841	10400	365	6121
1962	810	12300	351	6726
1963	808	13800	371	7223
1964	893	15500	385	7797
1965	1010	16800	423	8297
1966	1020	18300	446	8794
1967	1077	18900	480	9320
1968	1096	19500	479	9878
1969	1190	21700	496	10779
1970	1208	22600	560	11403
1971	1213	23400	533	12419
1972	1116	24600	490	13200
1973	1132	25400	511	13999
1974	766	24300	509	14486
1975	827	25300	539	15360
1976	857	26800	471	16486
1977	828	27700	442	17598
1978	849	28300	434	18218
1979	730	27900	437	18895
1980	690	26444	362	18769
1981	662	25792	338	18863
1982	658	26045	401	19642
1983	669	26877	409	20230
1984	665	28226	407	21355

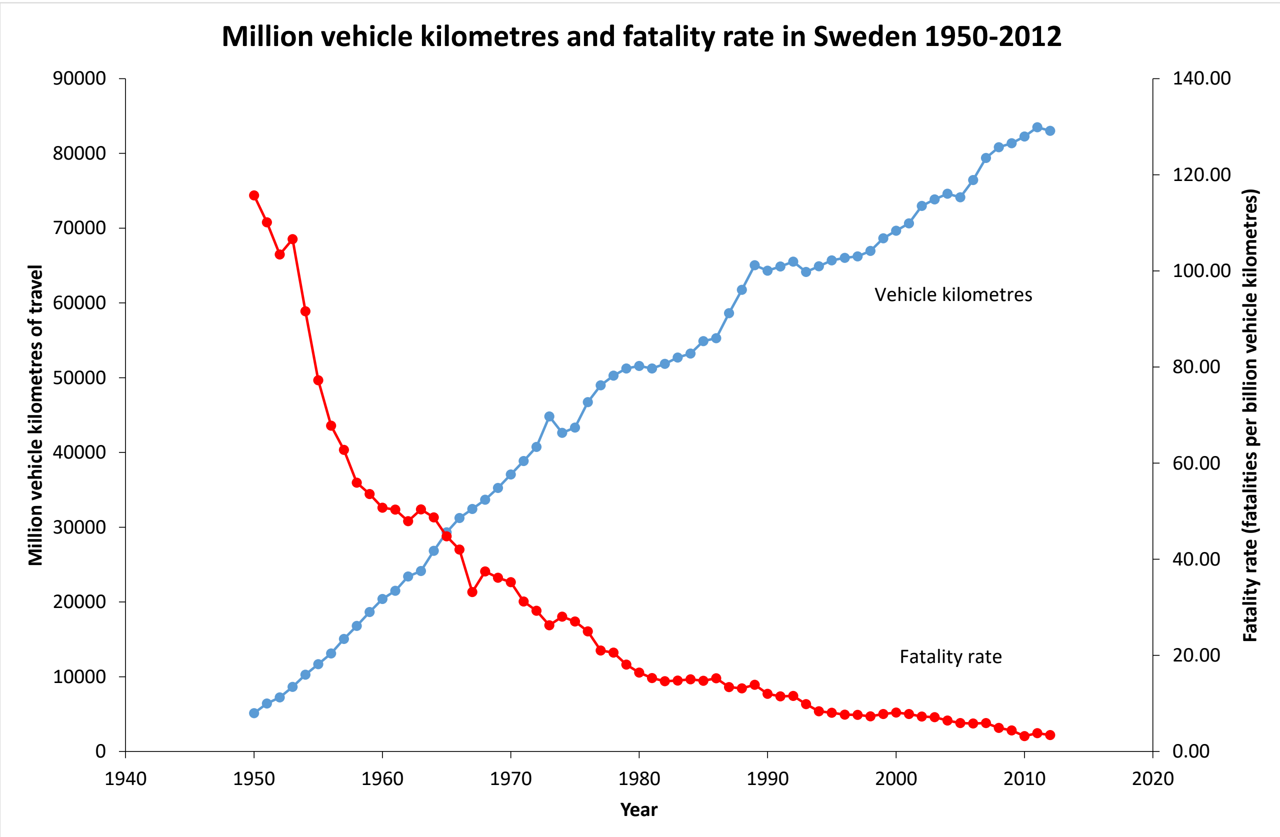
Denmark			Norway	
Year	Fatalities	Million vehicle kilometres	Fatalities	Million vehicle kilometres
1985	772	29572	402	23210
1986	723	31265	452	25319
1987	698	32966	398	26629
1988	713	34491	378	27060
1989	670	35490	381	27515
1990	634	36071	332	27755
1991	606	36968	323	27673
1992	577	37697	325	27795
1993	559	38150	281	28240
1994	546	39147	283	28772
1995	582	40659	305	29133
1996	514	41872	255	30261
1997	489	43217	303	30847
1998	499	44394	351	31716
1999	514	46024	304	32024
2000	498	46384	341	32569
2001	431	46323	275	33335
2002	463	47572	310	34341
2003	432	48226	280	34947
2004	369	49019	257	35638
2005	331	49486	224	37479
2006	306	50653	242	38104
2007	406	52287	233	39269
2008	406	52427	255	39771
2009	303	51634	212	39969
2010	255	50978	208	40409
2011	220	51793	168	41015
2012	167	51830	145	41958
2013			187	42461

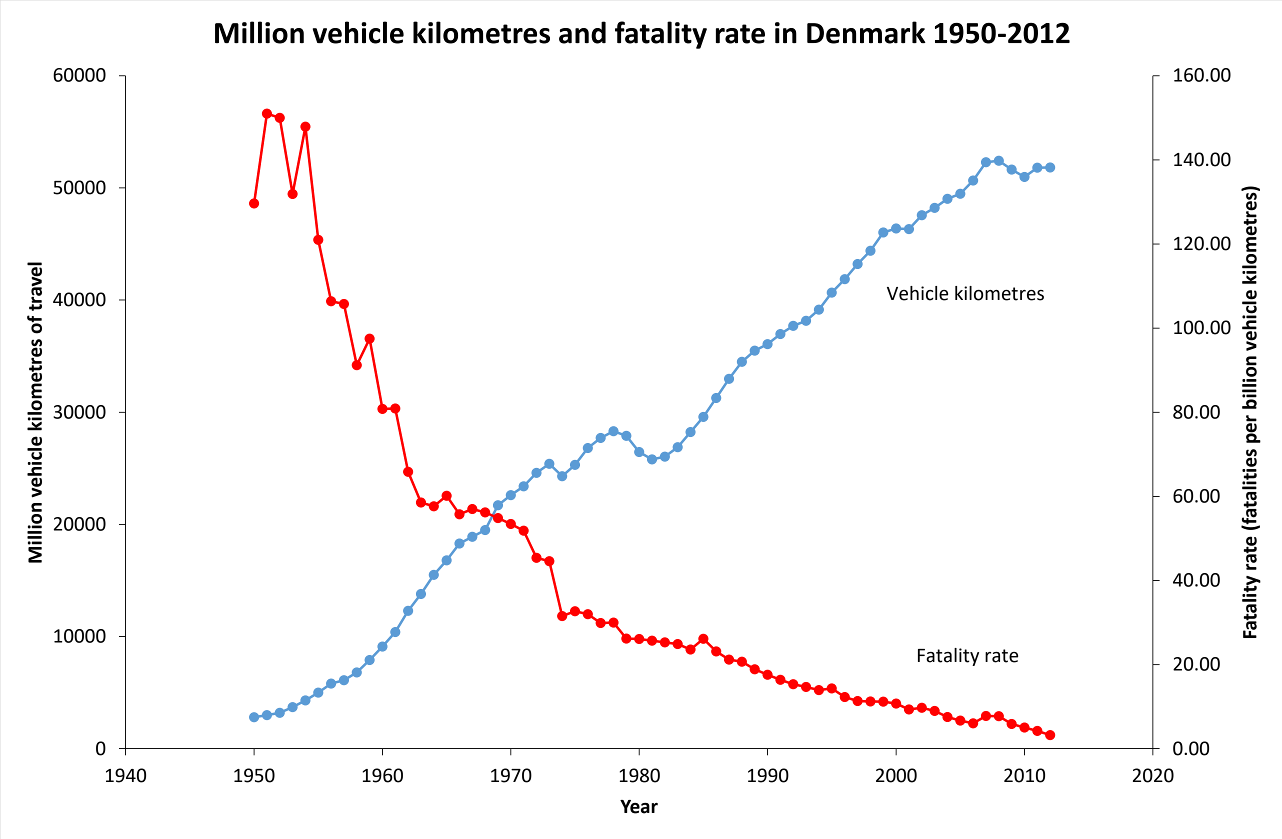
APPENDIX 2: CURVES FOR TRAFFIC VOLUME AND FATALITY RATE

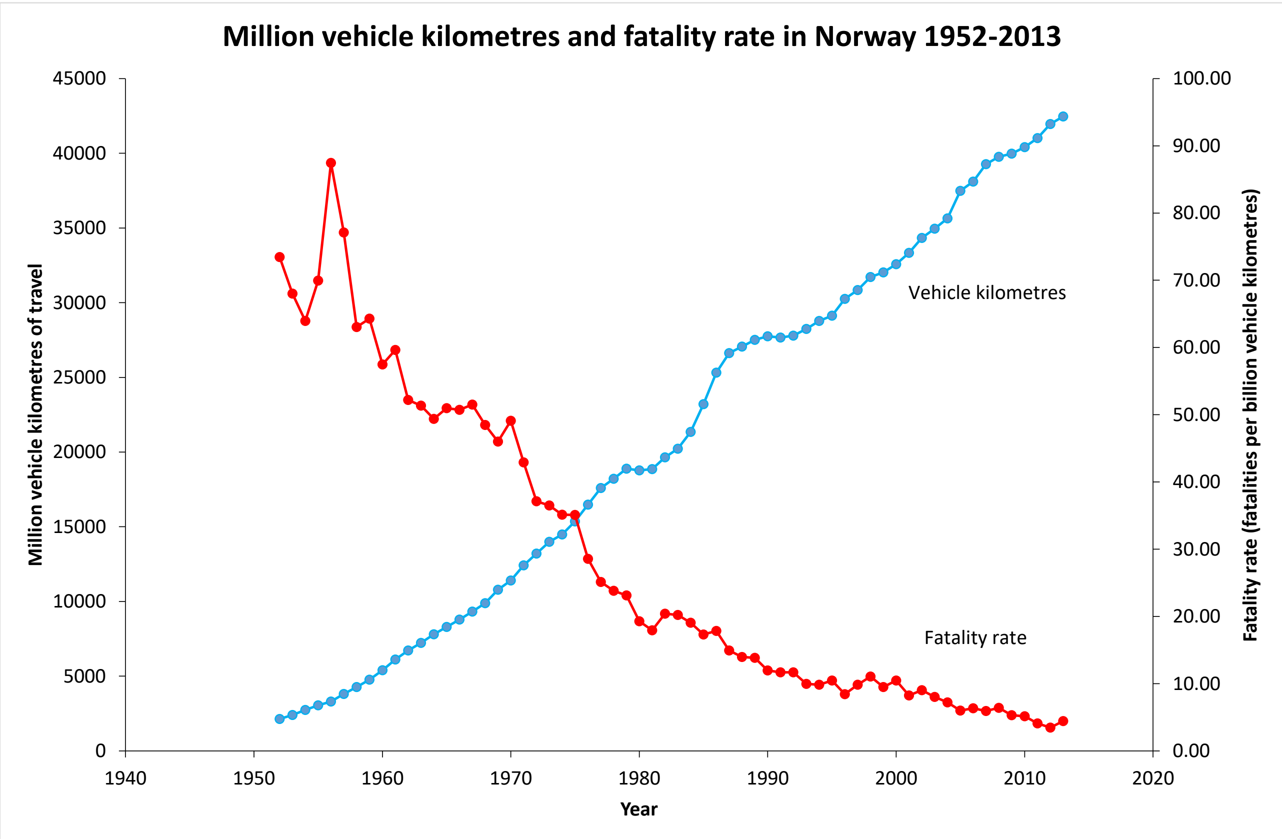





Million vehicle kilometres and fatality rate in the Netherlands 1948-2010
Million vehicle kilometres of travel
Fatality rate (fatalities per billion vehicle kilometres)
Vehicle kilometres
Fatality rate
Year
0
20000
40000
60000
80000
100000
120000
140000
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
1940
1950
1960
1970
1980
1990
2000
2010
2020


Million vehicle kilometres and fatality rate in Sweden 1950-2012
Million vehicle kilometres of travel
Fatality rate (fatalities per billion vehicle kilometres)
Vehicle kilometres
Fatality rate
Year
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
1940
1950
1960
1970
1980
1990
2000
2010
2020


Million vehicle kilometres and fatality rate in Denmark 1950-2012
Million vehicle kilometres of travel
Fatality rate (fatalities per billion vehicle kilometres)
Vehicle kilometres
Fatality rate
Year
0
10000
20000
30000
40000
50000
60000
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
1940
1950
1960
1970
1980
1990
2000
2010
2020


Million vehicle kilometres and fatality rate in Norway 1952-2013
Million vehicle kilometres of travel
Fatality rate (fatalities per billion vehicle kilometres)
Vehicle kilometres
Fatality rate
Year
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
1940
1950
1960
1970
1980
1990
2000
2010
2020