Working paper 1

Cost-Benefit Analysis of Police Enforcement

The "Escape" Project

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Bundesanstalt für Strassenwesen (BASt)
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Kuratorium für Verkehrssicherheit (KfV)
Institute for Road Safety Research (SWOV)
The Institute of Traffic Planning and Traffic Engineering (TUW-IVV)
Institute of Transport Economics (TØI)
University of Groningen (RUG)
Transport Research Foundation (TRL)
Swedish National Road and Transport Research Institute (VTI)
Aristotle University of Thessaloniki (AUTH)
Centrum Dopravniho Vyzkumu S.A. (CDV)

Author:
Rune Elvik, TØI

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1 BACKGROUND AND PROBLEM STATEMENT

1.1 BACKGROUND

Violations of road traffic law contribute to increasing the number of road accidents in all countries. An estimate for Norway (Elvik 1997A) indicates that if 16 of the most frequent traffic law violations were eliminated, the number of road accident fatalities could be reduced by 48%. The number of road accident casualties could be reduced by 27%, according to this study. Similar estimates for Sweden (Elvik and Amundsen 2000) indicate that violations of road traffic law is an even greater problem in that country. It has been estimated that by eliminating traffic violations, the number of road accident fatalities in Sweden could be reduced by 63% and the number of road accident casualties by 37%. There is little doubt that safety improvements of a similar magnitude could be attained in most motorised countries if road users complied with the rules of the road. Evans (1991), for example, has estimated that the number of traffic fatalities in the United States could be reduced by about 40% if driving with an illegal blood alcohol content was eliminated.

One of the most effective ways of making road users comply with road traffic law, is to increase police enforcement. There is little doubt that increasing enforcement, or making it more effective, could contribute substantially to reducing the number of road accidents in many countries. It is, however, not obvious that a massive increase of police enforcement, designed to eliminate violations, would be optimal from society's point of view. Increasing traffic police enforcement would likely bring benefits in terms of fewer accidents. But the resources allocated to traffic police enforcement could alternatively be used for other road safety measures. Beyond a certain point, it is likely that the additional benefits of further increases in enforcement become too small compared to the benefits that other road safety measures would give. It is by no means certain that an optimal amount of enforcement in this sense will be sufficient to ensure perfect compliance with the law.

The very idea that it can be regarded as optimal to tolerate a certain amount of violations may strike many people as strange and indefensible. Surely, it may be argued, once a law has been passed, people are morally obliged to comply with it. If they do not, it is the duty of the police to enforce the law as effectively as they can. But law enforcement agencies have many duties. The resources they have at their disposal may be insufficient to carry out all these duties in an ideal fashion. Hence, priorities must be set and ideal solutions may be unattainable. One way of setting priorities for police enforcement is to conduct cost-benefit analyses of alternative levels and forms of enforcement. The purpose of this report is to present a framework for cost-benefit analysis of traffic police enforcement and give some examples of such analyses.

1.2 PROBLEMS DISCUSSED IN THIS REPORT

The main research problems that are discussed in this report can be stated as follows:

1. What are the basic principles of cost-benefit analysis? Is the application of these principles to cost-benefit analyses of traffic police enforcement straightforward, or does it involve problems that may lead us to reconsider these principles?

2. Are the effects of various types of traffic police enforcement sufficiently well known to determine the optimal amount of enforcement by means of cost-benefit analyses?

3. Do the benefits of increased police enforcement exceed the costs, or are current cost-benefit analyses unable to give credible answers to this question?

In the following sections, each of these problems will be elaborated.

2 APPLICATION OF THE PRINCIPLES OF COST-BENEFIT ANALYSIS TO TRAFFIC POLICE ENFORCEMENT

2.1 BASIC PRINCIPLES OF COST-BENEFIT ANALYSIS

Cost-benefit analysis is based on welfare economics. According to welfare economics, every effect of an action, including a safety measure introduced by government, should be included in a cost-benefit analysis if it affects individual utility (Hanley and Spash 1993). Utility can be defined as the satisfaction of preferences. According to standard economic theory, preferences are revealed in choices. The strength of preferences for the provision of various goods is determined according to the amounts individuals are willing to pay for the provision of those goods. These rules are implied by the principle of consumer sovereignty, on which cost-benefit analysis is based. The fact that consumers may not always be perfectly informed, nor always make perfectly rational choices, is not necessarily regarded as an argument for rejecting the principle of consumer sovereignty. Thus, Mishan (1972, 229) remarks:

"People's imperfect knowledge of economic opportunities, their imprudence and un-worldliness, have never prevented economists from accepting as basic data the amounts people freely choose at given prices. Such imperfections cannot, therefore, consistently be invoked to qualify people's choices when, instead, their preferences are exercised in placing a price on some increment of a good or 'bad'".

Economists apply the same basic principle both to the purchase of marketed goods and to actions that confer other kinds of benefit. Exceeding the speed limit, for example, provides the benefit of saving travel time. This benefit can be measured in monetary terms by modelling the trade off road users make in their choice of speed, relying on the assumption that road users maximise utility (that is, choose their most preferred speed). Hence, according to the standard interpretation of the economic theory of welfare, there is little doubt that the benefits of violating the law should be included in a cost-benefit analysis of measures designed to deter violations of the law. This means that the possibility cannot be ruled out that enforcing a law is not worthwhile if there are great benefits in violating it.

But, many people are likely to ask, what are the benefits that are lost by complying with road traffic law? How could the benefits of violations, whatever they are, possibly be relevant in assessing the costs and benefits of increasing traffic police enforcement? The answer given to this question according to economic theory is that cost-benefit analysis ought to be based on the preferences of the population. It is generally assumed that these preferences are revealed in choices that involve trading off competing values against each other. Hence, by committing violations of road traffic law, road users reveal that these violations, from the violators' point of view, confer benefits that are greater than the costs. By speeding, for example, travel time is saved at the cost of an increased risk of accident. Measures that force road users to comply with the law eliminate these benefits.

Very many people are likely to find this line of reasoning outrageous. Surely, society cannot allow widespread violations of road traffic law to go on simply because violators get some benefit from these violations. But there are laws and regulations whose costs are greater than their benefits. History shows that enforcing laws may come to be regarded as too expensive, leading to their repeal. The story of prohibition in the United States and some other countries is a case in point. There is no doubt that excessive consumption of alcohol creates many problems. But the attempt to solve these problems by banning altogether the use of alcohol failed. In the end, these laws were given up both in the United States and other countries.

2.2 VIOLATOR BENEFITS: A DISCUSSION OF THEIR LEGITIMACY AS AN ELEMENT OF COST-BENEFIT ANALYSIS

Violations of road traffic law and measures taken to enforce the law can have a number of impacts. Potentially relevant impacts in a cost-benefit analysis include impacts on:

- The number of accidents
- Travel time
- Vehicle operating costs
- Noise and air pollution
- Traffic volume
- Other types of crime (than traffic offences)
- General deterrence

The objective of a cost-benefit analysis is to determine the optimal amount of enforcement by comparing monetary valuations of these impacts to the costs of enforcement. Several arguments can be given for including the benefits that violators get from violations in a cost-benefit analysis of enforcement.

First, it must be assumed that most violations are committed because there are benefits from committing them. Enforcement and penalties have to take these benefits into consideration, in order to provide sufficient deterrence to outweigh them. Second, there is little point in trying to enforce regulations that almost everybody violates, especially if the violations do not cause much harm to violators or society in general. Third, in order to allocate their resources efficiently between different types of crime, enforcement agencies need to know both the benefits and harm done by various types of violations.

In general, economic theory does not necessarily regard an act as unconditionally wrong simply because it is illegal, at least if the act does not violate widely held moral norms. Illegal acts may provide benefits to society, which outweigh their costs. In that case, the acts ought to be legalised. This line of reasoning is based on the general principles of welfare economics, including consumer sovereignty, the assumption that consumers are rational and efficient allocation of resources as the overall objective of cost-benefit analysis. However, it is not obvious that the standard assumptions of economic welfare theory can be applied uncritically in cases involving acts that many people regard as ethically wrong. Harsanyi (1982, 55) remarks:

"Any sensible ethical theory must make a distinction between rational wants and irrational wants, or between rational preferences and irrational preferences. It would be absurd to assert that we have the same moral obligation to help other people in satisfying their utterly unreasonable wants as we have to help them in satisfying their very reasonable desires. ... In actual fact, there is no difficulty in maintaining this distinction even without an appeal to any other standard than an individual's own personal preferences. All we have to do is to distinguish between a person's manifest preferences and his true preferences. His manifest preferences are his actual preferences as manifested by his observed behaviour, including preferences possibly based on erroneous factual beliefs, or on careless logical analysis, or on strong emotions that at the moment greatly hinder rational choice. In contrast, a person's true preferences are the preferences he would have if he had all the relevant factual information, always reasoned with the greatest possible care, and were in a state of mind most conducive to rational choice. ... In my opinion, social utility must be defined in terms of people's true preferences rather than in terms of their manifest preferences."

In other words, some illegal acts are widely regarded as unconditionally wrong. Examples include violent assaults and homicide. It would be absurd to include the benefits for the perpetrator of committing these acts as a societal benefit. Moreover, violations of the law are not always perfectly rational acts. Gottfredson and Hirschi (1990, xv) argue that "the offender appears to have little control over his or her own desires. When such desires conflict with long-term interests, those lacking self-control opt for the desires of the moment, whereas those with greater self-control are governed by the restraints imposed by the consequences of acts displeasing to family, friends, and the law." They add that (1990, 12) "the carefully planned and executed crime will be extremely rare."

Another objection to granting a normative status to the preferences of offenders, by counting lost benefits of violations as a societal loss in cost-benefit analyses, is that not everybody violates the law. Preferences in this respect are highly heterogeneous. Many violations have negative external effects that are not considered by violators, even if there is not always an identifiable victim of the crime. Violations of road traffic law, for example, increases the number of accidents. Everybody shares the cost of these accidents. To count the benefits that violators get from violations as a societal benefit is in a sense, to favour their preferences at the expense of the preferences of those who comply with the law.

To sum up, there are arguments both for including and for excluding violator benefits from violations in cost-benefit analyses of police enforcement. But does it matter whether or not violator benefits are included? Gottfredson and Hirschi (1990) claim that the benefits of violations are typically very small and do not last very long. If this point of view is correct, perhaps it does not matter much whether or not these benefits are included in a cost-benefit analysis. The next section of the report develops three alternative frameworks for cost-benefit analysis of traffic police enforcement, designed to shed light on this question.

2.3 ALTERNATIVE FRAMEWORKS FOR COST-BENEFIT ANALYSIS OF TRAFFIC POLICE ENFORCEMENT

Different perspectives can be taken in cost-benefit analysis (Udvarhelyi, Colditz, Rai and Epstein 1992). Table 1 compares two possible perspectives for the analysis of speeding: the perspective of the motorist and the societal perspective.

Table 1: The private and societal balance sheet for speeding

Benefits	**Costs**
For motorists	
Saving of travel time	Increased risk of accident Increased vehicle operating cost Outlays for traffic tickets
For society	
Income from traffic tickets	External costs of accidents External environmental costs Costs of enforcement Opportunity costs of taxes

The motorist is assumed to trade off the saving in travel time, and perhaps the extra fun involved in driving fast, against the increased risk of accident, increased vehicle operating costs (fuel and wear), and the risk of getting caught by the police and having to pay a traffic ticket. It is assumed that part of the cost of accidents is paid for by society, not by the motorist as such (Elvik 1994). This share of the cost of accidents does not enter the trade off made by the motorist and is an external cost from the motorist's point of view. From the societal perspective, both the external costs of accidents and other impacts of speeding that the motorist is likely to neglect, including costs of environmental impacts have to be included in a cost-benefit assessment. According to the conventional framework for cost-benefit analysis, a societal perspective should be adopted, which includes both the items considered by motorists and impacts not considered by motorists.

Notice that the outlays that motorists have for traffic tickets reappear as an income from traffic tickets in the public sector. Obviously these two items cancel, and should therefore not be included in a cost-benefit analysis adopting a societal perspective. According to the conventional interpretation (Sager 1974), outlays for traffic tickets is simply a transfer of money from the private sector to the public sector. It does not represent consumption of scarce resources with alternative uses. But another interpretation of what outlays for traffic tickets represent is possible. A traffic ticket is a sanction, imposed for the purpose of deterring violations. The cost of sanctions, irrespective of whether these costs are paid by violators or by the public sector (in the case of imprisonment), can be interpreted as a representation of the value attributed to general deterrence. The amount of resources society is willing to expend to punish violators, including the cost of fines that violators are forced to pay, can reasonably be interpreted as a measure of the value of general deterrence. Deterrence has value to society, because the more effective it is, the less enforcement is needed.

This interpretation of the costs of punishment is perhaps particularly relevant if the benefits violators get from violations are included in a cost-benefit analysis of enforcement. Including violator benefits may, as noted above, be regarded as favouring the interests of violators at the expense of everybody else. If the benefits that violators get from violations are to be included in a cost-benefit analysis, then so should the costs society imposes on violators, for example in the form of traffic tickets. This point of view implies that there can be three alternative frameworks for cost-benefit analysis of traffic police enforcement. These frameworks differ with respect to the treatment of violator benefits and outlays for traffic tickets in cost-benefit analyses of police enforcement. Table 2 displays the three frameworks.

Table 2: Three alternative frameworks for cost-benefit analysis of traffic police enforcement

Cost or benefit items	**Alternative frameworks for cost-benefit analysis. Items included denoted by black dot (•)**		
	Alternative 1: Framework consistent with welfare economics	Alternative 2: Framework in which deterrence is valued per se	Alternative 3: Framework consistent with normative ethics
Benefits of violations	•	•	
Outlays for traffic tickets		•	

The first of these, which is the one that is most consistent with the principles of welfare economics as usually applied to cost-benefit analysis, includes violator benefits from violations, but excludes outlays for traffic tickets. In the second possible framework, outlays for traffic tickets is interpreted as a measure of the value of deterrence per se, and is therefore included in cost-benefit analyses as a benefit. The third framework, which is perhaps the one most consistent with normative ethics, leaves out both violator benefits from violations and outlays for traffic tickets from the analysis.

In a subsequent section of the report, results of cost-benefit analyses relying on these three frameworks will be compared. Before coming to that, the effects of traffic police enforcement on accidents will be discussed.

3 EFFECTS OF TRAFFIC POLICE ENFORCEMENT ON ROAD SAFETY

3.1 SUMMARY ESTIMATES OF EFFECTS BASED ON META-ANALYSES

The effects on accidents and levels of injury of several traffic safety measures involving police enforcement have been estimated in recent meta-analyses (Elvik et al 1997). The following summary is based on a working paper prepared for ESCAPE by Truls Vaa (2000). References to the original studies are not provided in this report, but can be found in the paper by Vaa. The following measures are included:

- Stationary speed enforcement
- Speed enforcement by patrolling (mobile)
- Speed cameras
- Automatic enforcement of red light violations
- Enforcement of drinking and driving
- Seat belt enforcement
- Warning letters, penalty point systems and licence revocation

Before presenting the results of the meta-analyses of studies that have evaluated the effects on road safety of these measures, the following points should be noted:

1. The results that are presented are statistically weighted mean results based on all studies that have evaluated the effects of a certain measures. The results of each evaluation study do not necessarily coincide with the mean results.

2. Whenever possible, a distinction is made between three levels of accident severity: fatal accidents, injury accidents and property-damage-only accidents. Information regarding effects on fatal accidents is not always available. Fatal and injury accidents have then been combined into one category.

3. The results in general refer to effects observed in the area, and during the period, in which enforcement was carried out. In most cases, the before and after periods have a duration of not more than two years.

3.2 STATIONARY SPEED ENFORCEMENT

The literature on the effects of police enforcement on speeding behaviour, accidents and injuries has often failed to give precise descriptions of the enforcement methods used (ETSC 1999). In addition, many studies consider experiments involving the use of more than one method which makes it impossible to attribute the effects to any specific enforcement method.

However, a clear finding is that it is necessary to make a distinction in operations between stationary and mobile methods of speed enforcement. This distinction is important because these two groups of methods seem to have different effects on behaviour and accidents.

A stationary method generally involves a configuration including an observation unit, typically an unmarked police car more or less hidden at the roadside, and an apprehension unit comprising one or more marked police cars, clearly visible, at which speeding drivers are stopped. The effects of this type of enforcement have been extensively studied. The estimates of effect given in Table 3 are based on 16 evaluation studies.

Table 3: Best estimates and confidence intervals (95% CI) of the effects of stationary speed enforcement/composite enforcement with stationary elements on accidents. Percentage change of the number of accidents (from: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity	**Accident types affected**	**Best estimate**	**95% CI**
Fatal accidents	All	– 14	(–20; –8)
Injury accidents	All	– 6	(–9; –4)
Property-damage-only accidents	All	+ 1	(–1; +3)

The best estimates of the mean effects of stationary speed enforcement are a reduction of 14% in the number of fatal accidents, a reduction of 6% in the number of injury accidents, and no statistically significant change in the number of property-damage-only accidents. The variability of these effects around the mean effect will be discussed in a subsequent chapter of the report.

3.3 MOBILE ENFORCEMENT

Mobile methods are defined as enforcement of traffic behaviour, and apprehension of offenders from a moving unmarked or marked car. There are few studies dealing with the effects of pure mobile enforcement. Mobile speed enforcement has been used together with stationary speed enforcement, but in such cases it is impossible to know what type of enforcement that was effective, if any. Only four studies have been found where pure mobile enforcement seems to have been the used. The results of these four studies (see Vaa 2000) vary substantially, and it does not make sense to combine their results into a summary estimate of effect.

Only one of the four studies reported statistically significant changes in the number of accidents. This study evaluated mobile enforcement of drinking and driving on weekend nights. None of the other three efforts have resulted in any lasting, measurable effect on speed behaviour, nor on the number of accidents. The results indicate that mobile methods are not effective for enforcing speed. In the following sections, this type of enforcement will therefore not be considered further.

3.4 SPEED CAMERAS

Nine studies that have evaluated the effects on accidents of speed cameras have been retrieved. Table 4 summarises the mean effects on accidents of speed cameras based on these studies.

Table 4. Best estimates and confidence intervals (95% CI) of the effects of automatic speed enforcement on accidents. Percentage change of the number of accidents (from: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity	**Accident types affected**	**Best estimate**	**95% CI**
Fatal and injury accidents	All	– 17	(–19; –16)
Property-damage-only accidents	All	– 12	(–38; +26)

Fatal and injury accidents have, on the average, been reduced by 17 %. The accident data do not allow a separate estimation of the effect on fatalities. There is a tendency for property-damage-only accidents to go down, but the reduction is not statistically significant.

3.5 AUTOMATIC ENFORCEMENT OF RED LIGHT VIOLATIONS

Only a few reports have evaluated the effects on accidents of automatic enforcement of red light violations. Three reports formed the base of estimating the effects of red light cameras. The best estimates of the red light cameras on accidents are presented in table 5.

The best estimate of the effect of red light cameras on injury accidents is a reduction of 12%, which is statistically significant. There are tendencies in the direction of accident reductions with respect to fatal accidents and property-damage-only accidents, but none of these tendencies were statistically significant.

Table 5: Best estimates and confidence intervals (95% CI) of the effects on accidents of automatic surveillance of red light violations. Percent change of the number of accidents. (From: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity	**Accident types affected**	**Best estimate**	**95% CI**
Fatal accidents	Accidents at signalised junctions	– 45	(–91; +260)
Injury accidents	Accidents at signalised junctions	– 12	(–20; –2)
Property-damage-only accidents	Accidents at signalised junctions	– 9	(–22; +7)

3.6 ENFORCEMENT OF DRINKING AND DRIVING

Enforcement of drinking and driving comprises more than just the pure enforcement on the road. The enforcement of drinking and driving is sometimes seen as one component among several others, which in sum may constitute the total package of enforcement efforts, designed to reduce drinking and driving. Some of the measures are standardised with regard to the components they comprise, and they are sometimes given a specific name or abbreviation. Examples of this include the renowned ASAP (Alcohol Safety Action Projects) and STEP (Selective Traffic Enforcement Project) programmes in the United States, and RBT (Random Breath Testing) programmes in Australia and Sweden.

The meta-analysis is based on a total of 39 studies. A majority of these – 26 – have evaluated drinking and driving enforcement alone or in combination with another measure, for the most part some kind of an accompanying campaign. Table 6 presents estimates of the effects on accidents of enforcement.

Table 6: Best estimates and confidence intervals (95% CI) of the effects on accidents of drinking and driving enforcement. Percent change of the number of accidents. (from: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity	**Accident types affected**	**Best estimate**	**95% CI**
Fatal accidents	All	– 9	(– 11; – 6)
Injury accidents	All	– 7	(– 8; – 6)
Property-damage-only accidents	All	– 4	(– 5; – 3)

The overall effects of enforcing drinking and driving are reductions of 9% and 7% in the number of fatal and injury accidents, respectively. There is less evidence with respect to effects on property-damage-only accidents, but it has been assumed that the effect is close to that found for all levels of accident severity combined, in data sets that include a mixture of injury accidents and property-damage-only accidents. This effect amounts to a reduction of 4% in the number of accidents. All reductions are statistically significant.

3.7 SEAT BELT ENFORCEMENT

Concerning the use of seat belts, several measures are relevant:
- Making seat belt use mandatory by law
- Issuing fines or traffic tickets for not wearing seat belts
- Enforcing the law of mandatory seat belt use

All these measures affect the wearing rates for seat belts. Seat belts are not intended to prevent accidents, only to reduce the likelihood and severity of personal injuries when an accident has occurred. The effects of increased wearing rates for seat belts may nevertheless manifest themselves in the form, of a reduced number of accidents at a given level of severity. For example, accidents that were fatal without seat belts become survivable when seat belts are worn, leading to a reduction in the number of fatal accidents. Fourteen studies that have evaluated the effects of seat belt enforcement have been retrieved. Most of these studies have evaluated the effects on the wearing rates for seat belts. Two studies have in addition considered the effect on accidents. Table 7 shows the effects on accidents of seat belt enforcement of seat belt use.

Table 7: Best estimates and confidence intervals (95% CI) of the effects on accidents of seat belt enforcement. Percent change in the number of accidents. (From: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity	**Accident types affected**	**Best estimate**	**95% CI**
Fatal accidents	Car occupants	– 6	(–21; +14)
Injury accidents	Car occupants	– 8	(–18; +4)
Property-damage-only accidents	Car occupants	– 4	(–9; +1)

There are tendencies for a reduction of accidents at all levels of severity. The observed changes in the number of accidents are, however, not statistically significant. Evidence from studies that have evaluated laws requiring mandatory seat belt wearing, confirm that increased seat belt wearing reduces the number of fatalities and injuries (see Elvik et al 1997).

3.8 WARNING LETTERS, PENALTY POINT SYSTEMS, AND LICENCE REVOCATION

Twelve reports concerning the effects of warning letters, penalty point systems and licence revocation on accidents, have been identified. Table 8 presents the results from meta-analyses based on these studies.

Table 8: Best estimates and confidence intervals (95% CI) of the effects on accidents of warning letters, penalty point systems and revocation of driving licence. Percent change of the number of accidents. (From: Elvik et al 1997)

	Percentage change of the number of accidents		
Accident severity/measure	**Accident types affected**	**Best estimate**	**95% CI**
All/Warning letters	All	– 15	(–18; –13)
All/Penalty points	All	– 5	(–11; 0)
All/License revocation	All	– 17	(–19; –16)

The effects of warning letters and revocation of driving licence are of about the same magnitude, and are about three times greater than the effect of penalty point systems, i. e. reductions in the number of accidents of 15%, 17% and 5% respectively. The effects of all three subgroups of measures are statistically significant (Elvik et al 1997).

3.9 SUMMARY OF EFFECTS OF ENFORCEMENT

Table 9 summarises the best estimates of the effects on accidents of the various types of enforcement. Sanctions, such as warning letters or penalty points, have not been included.

Table 9: Summary of estimated effects of enforcement on accidents. Percent change of the number of accidents

	Percent change of the number of accidents		
Type of enforcement	**Fatal accidents**	**Injury accidents**	**PDO-accidents**
Speed enforcement	–14	–6	+1
Speed cameras		–17	–12
Red light cameras	–45	–12	–9
Random breath testing	–9	–7	–4
Seat belt enforcement	–6	–8	–4

4 DETERMINING THE MARGINAL EFFECTS OF TRAFFIC POLICE ENFORCEMENT

4.1 THE DISTINCTION BETWEEN AVERAGE EFFECTS AND MARGINAL EFFECTS

The estimates of the effects on accidents of traffic police enforcement given in the last chapter refer to the average effects of enforcement, according to the studies that were included in the meta-analyses. What is needed as a basis for cost-benefit analyses of police enforcement are estimates of the marginal effects of enforcement, that is estimates of the effects specific increases in the amount of enforcement from a known baseline level.

Increasing traffic enforcement is likely to be subject to diminishing returns to scale (Bjørnskau and Elvik 1992). The optimal amount of enforcement according to a cost-benefit analysis is likely to be at a level that will not be sufficient to eliminate traffic law violations. The objective of this chapter is to assess whether an objective basis for determining the optimal amount of police enforcement can be defined on the basis of studies that have evaluated the effects of different amounts of enforcement. The main question to be discussed in this chapter is:

What is the relationship between the amount of police enforcement and the size of the effect of enforcement on accidents or the rate of violations?

More specifically, the shape of the relationship between enforcement and accidents will be examined, in order to determine if it exhibits declining returns to scale.

4.2 EVALUATION OF DOSE-RESPONSE FUNCTIONS FOR TRAFFIC POLICE ENFORCEMENT

In order to determine the shape of the relationship between police enforcement and the number of accidents, studies that have investigated the effects on accidents or speed of different amounts of police enforcement were retrieved. The studies were retrieved from the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), and from a previous literature survey (Vaa 1993). The following studies were identified:
Munden 1966 (Great Britain)
Cirillo 1968 (United States)
Shoup 1973 (United States)
Engdahl and Nilsson 1983 (Sweden)

Andersson 1991 (Sweden)
DeWaard and Rooijers 1994 (Netherlands)
Vaa 1995 (Norway)
Knoflacher 1998 (Austria)

All these studies except the studies by DeWaard and Roijers (1994) and Vaa (1995) are about the effects of enforcement on accidents. The studies by DeWaard and Roijers (1994) and Vaa (1995) are about the effects of enforcement on speed.

A dose-response function is a function that relates the amount of enforcement (X-axis) to changes in violation rate, accident rate or the number of accidents (Y-axis). Testing for a dose-response relationship between police enforcement and road safety involves determining if there is a statistical relationship at all between the amount of enforcement and the size of its effects, and, if there is a relationship, determining the shape of that relationship.

There are several problems in analysing dose-response relationships for traffic police enforcement. In the first place, the “dose”, or amount of enforcement, is not measured the same way in all studies. No standardised way of measuring the amount of police enforcement exists. In the second place, the “response”, that is changes in behaviour and/or accidents is also measured in different ways in different studies. In the third place, the absolute levels of enforcement vary substantially from one study to another, making it difficult to compare the results across studies. In the fourth place, the techniques and objectives of enforcement vary from one study to another. All the studies that were selected deal with speed enforcement. Finally, in the fifth place, basic data like speed measurements and accident data are not always perfectly reliable.

These problems make it impossible to summarise the results of the studies by means of the standard techniques of meta-analysis, according to which the results of a number of studies are summarised formally in the form of a mean result. In view of the heterogeneity of the studies, it was decided to evaluate the dose-response relationship separately for each study. These evaluations applied the definitions of dose and response used by each study. The following functional relationships were tested:

Linear:	$Y = \alpha + \beta x$
Logarithmic:	$Y = \alpha + \beta \ln(x)$
Exponential:	$Y = \alpha \exp^{\beta x}$
Geometric:	$Y = \alpha x^{\beta}$
Polynomial:	$Y = \alpha x^2 + \beta x + \lambda$
Hyperbolic:	$Y = \alpha / x + \beta$

In all these functions Y denotes the response (effects on accidents or speed), X denotes the dose (amount of enforcement), and α, β and λ are parameters to be estimated. The fit of the various functions was assessed in terms of the squared correlation coefficient (Pearson's r).

The presence of outlying data points was determined informally, by visual inspection of scatter plots of the dose-response relationships. In some cases, analyses were repeated, omitting the outlying data points. The results of the analyses are presented in Figures 1 through 11. Figures 1 and 2 are based on the study of Munden (1966).

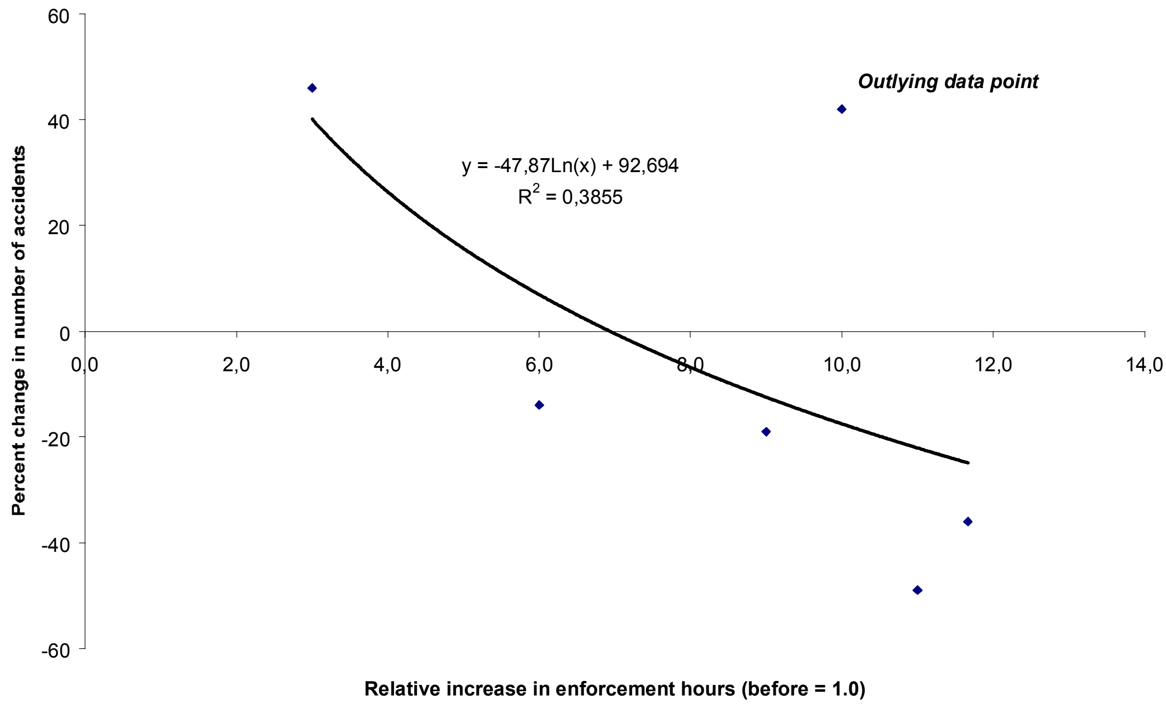

Figure 1: Relationship between increase in police enforcement and changes in the number of accidents according to Munden 1966

The amount of enforcement was stated in terms of the increase compared to the baseline level. Setting the baseline level of enforcement equal to 1.0, increases by varying factors up to about 12 (12 times the baseline amount of enforcement) were observed. The baseline amount of enforcement was measured in terms of the number of hours of patrolling by car and motorcycle. Effects were stated as the percentage change in the number of accidents (all levels of severity combined). Figure 1 shows the results of the study when all data points are included. There are six data points. The relationship between the amount of enforcement and the effect on accidents fits a logarithmic function. However, the data points do not fit this function very well. The squared correlation coefficient is just 0.39. There is clearly an outlying data point.

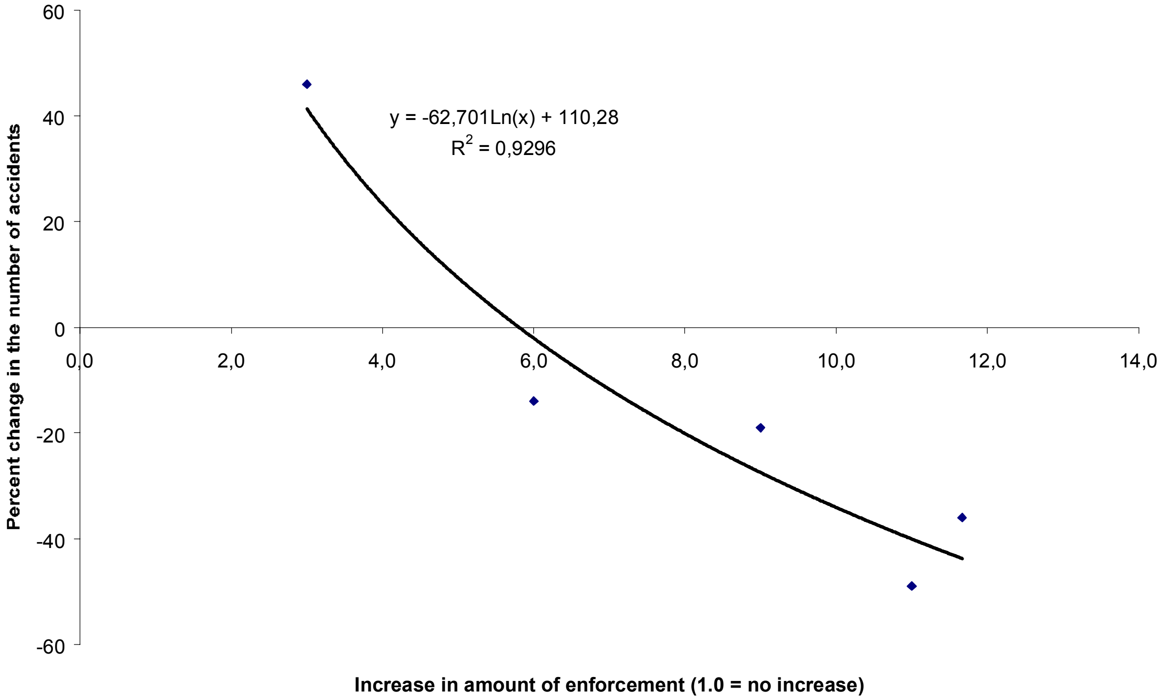

Figure 2: Relationship between increase in police enforcement and changes in the number of accidents according to Munden 1966, omitting one outlying data point

Figure 2 shows the results when the outlying data point is omitted. The dose-response relationship now fits the logarithmic function a lot better. The squared correlation coefficient is now 0.93, but there are only five data points. It should be noted that the results indicate that the number of accidents increases at low levels of enforcement that is when the increase effected during the experiment was less than a factor of about six times the baseline.

Cirillo (1968) studied the relationship between the amount of enforcement and accident rate on Interstate highways in the United States. The amount of enforcement was measured in terms of the number of patrol hours per mile per year. Accident rate was measured as the number of accidents per 100 million vehicle miles (all levels of severity combined). Figure 3 shows the results of this study.

According to Figure 3, there is a positive relationship between the amount of enforcement and accident rate. The more enforcement, the higher becomes the accident rate. The relationship fits a second order polynomial quite well (squared R = 0.77). The validity of this relationship may, however, be questioned for three reasons. First, the measure used for the amount of enforcement is incompatible with the definition of the dependent variable (accident rate). A more compatible measure would be the number of patrol hours *per vehicle mile per year*, not per mile of road. Second, the presence of a high number of police patrols on a road could by itself affect accident reporting. Accidents are perhaps more likely to be reported, when a police patrol can reach the accident site quickly than when it takes more time. Third, confounding variables affecting both the amount of enforcement and the accident rate, such as the degree of urbanisation, could disturb the relationship.

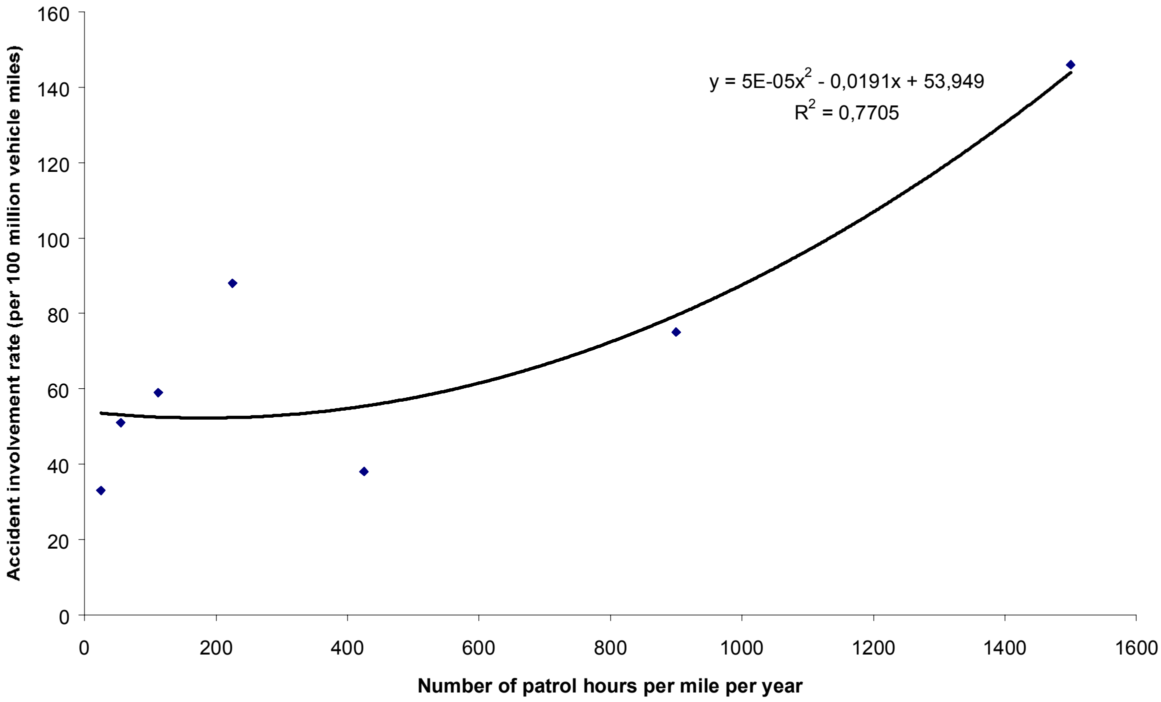

Figure 3: Relationship between number of patrol hours per mile per year and accident rate on US Interstate highways according to Cirillo 1968

Figure 4 shows the results of a study made by Shoup (1973). The amount of enforcement was stated in terms of the number of officers per mile. The effects were stated in terms of the percent change in the number of accidents (all levels of severity combined). The relationship between the amount of enforcement and changes in the number of accidents fits a second order polynomial quite well (R-squared = 0.75).

This relationship indicates that more enforcement improves safety up to a certain point, but reduces safety beyond that point. Intuitively, this seems highly implausible. Inspection of Figure 4 shows that there is an outlying data point. When this is omitted, the shape of the relationship between the amount of enforcement and the effects on accident changes, as shown in Figure 5.

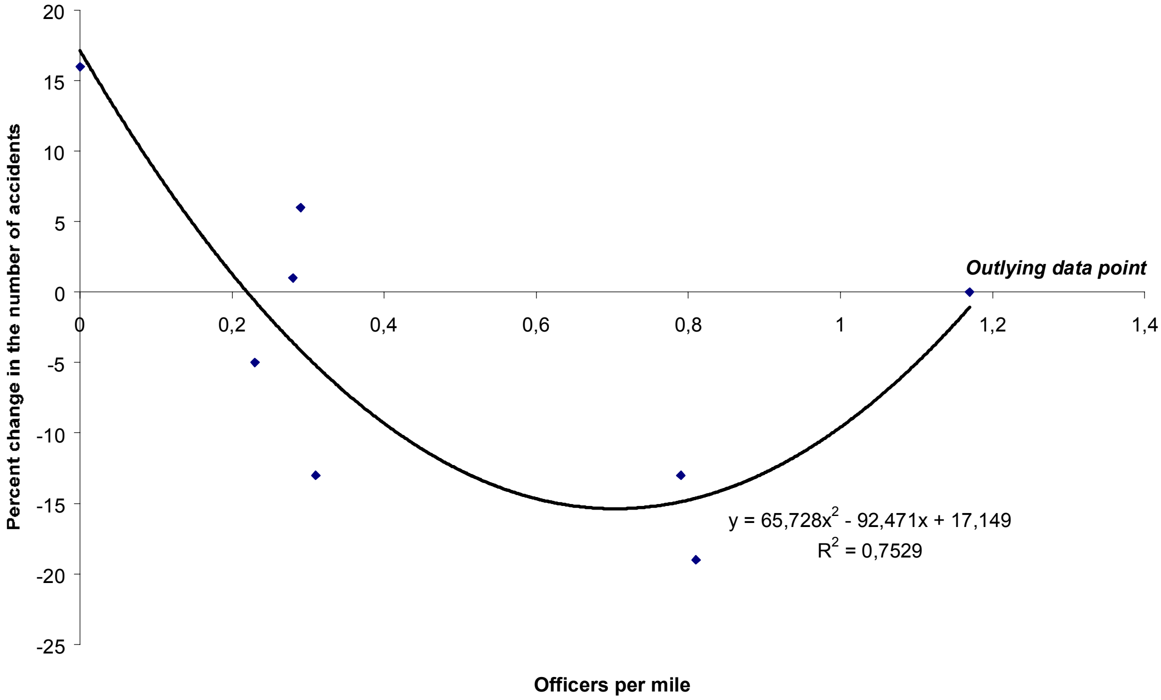

Figure 4: Relationship between number of officers per mile and change in the number of accidents according to Shoup 1973

The relationship still fits a second order polynomial, which implies that very high levels of enforcement reduce safety. However, within the range of the data points observed in Figure 5, the polynomial declines throughout and does not display a marked turning point like the one observed in Figure 4. Moreover, the fit of the relationship is marginally improved compared to Figure 4 (R-squared = 0.76).

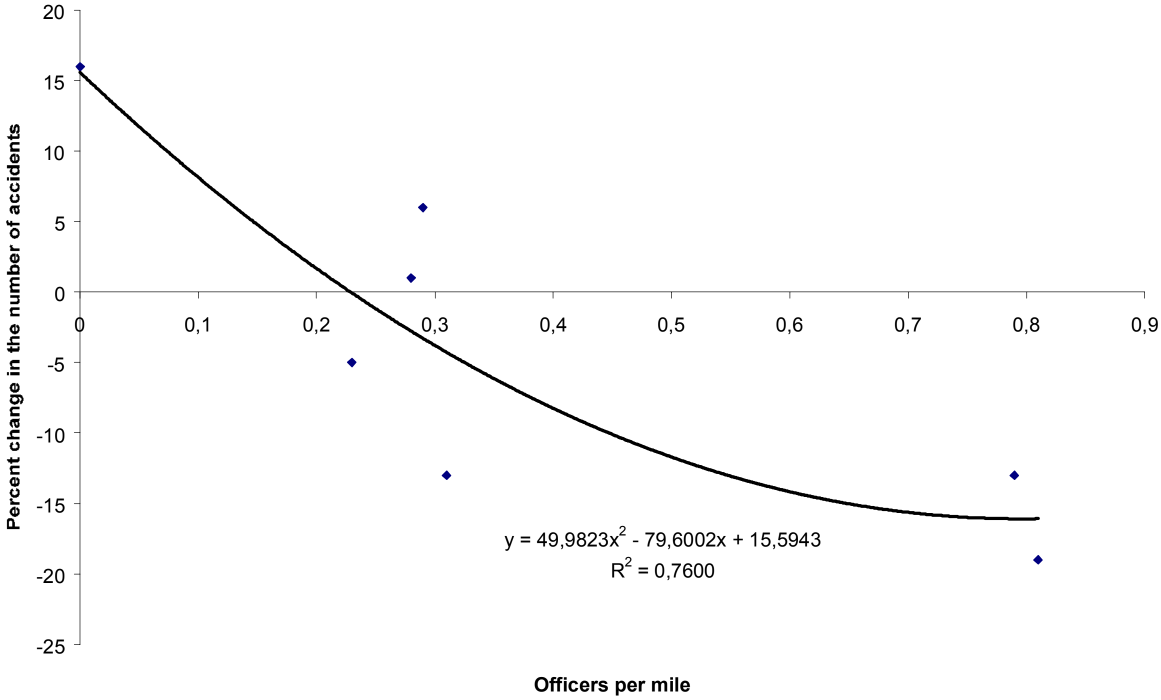

Figure 5: Relationship between number of officers per mile and change in the number of accidents according to Shoup 1973, omitting one outlying data point

Engdahl and Nilsson (1983) studied the effects on accidents of a programme of increased police enforcement in Sweden. The study even included some road sections where the amount of enforcement was reduced. The amount of enforcement was defined as the number of hours of enforcement activity, per kilometre of road per year. Effects were stated in terms of the percentage change in the number of injury accidents. Figure 6 shows the results of the study.

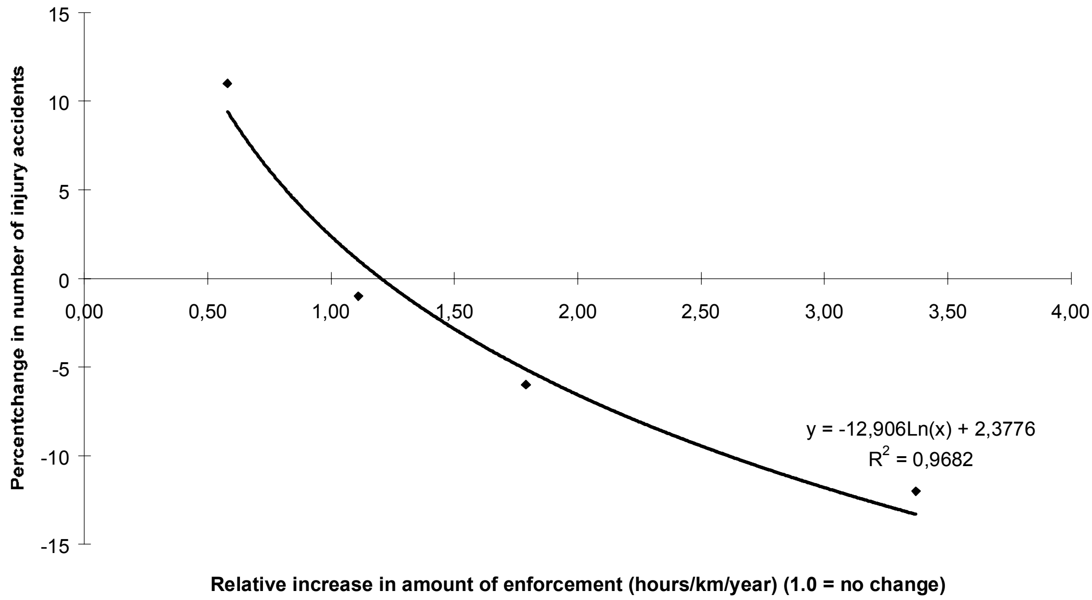

Figure 6: Relationship between change in amount of enforcement and change in the number of accidents according to Engdahl and Nilsson 1983

There is a very clear relationship between the relative change in the amount of enforcement and the change in the number of injury accidents. The change in the amount of enforcement spans a range from a reduction to nearly half the baseline level to an increase by a factor of nearly 3.5. It is seen that a reduction in the amount of enforcement was associated with an increase in the number of accidents, whereas increasing enforcement was associated with a reduction in the number of accidents. The relationship fits a logarithmic function very well (R-squared = 0.97).

Andersson (1991) tried to replicate the results of the study by Engdahl and Nilsson (1983), but did not succeed. Andersson studied the effects of police enforcement in urban areas. The amount of enforcement was measured in terms of the annual number of radar hours within a certain urban area. Effects were stated in terms of the percentage change in the number of accidents. Figure 7 shows the results of the study.

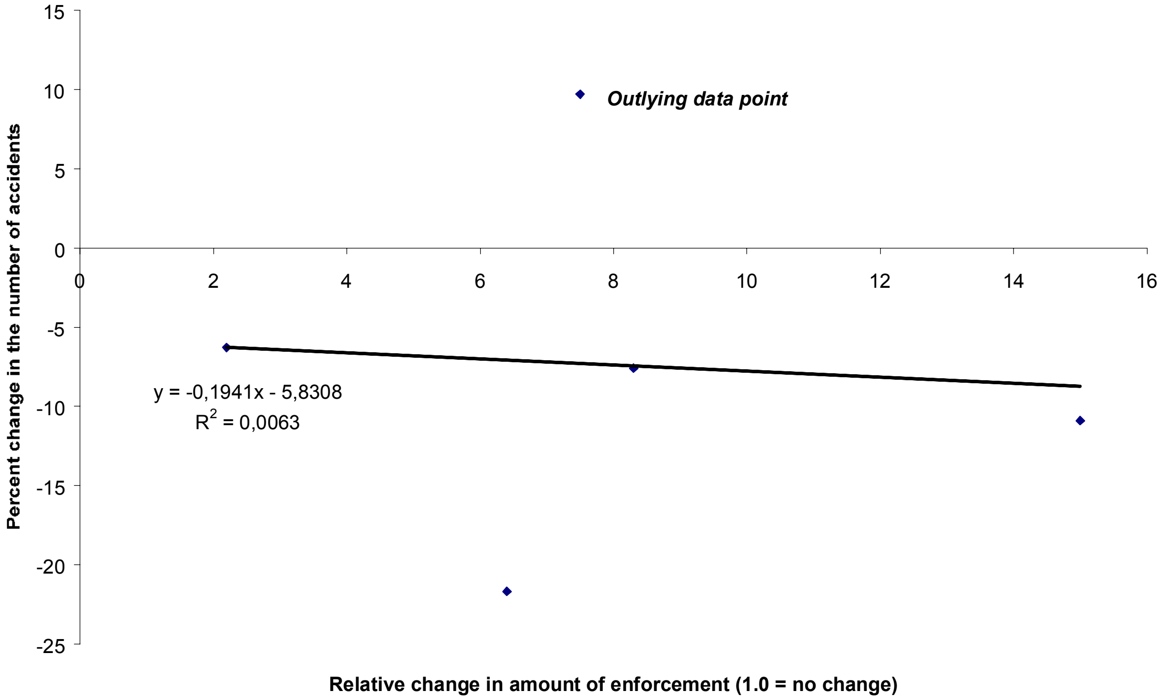

Figure 7: Relationship between change in amount of enforcement and change in the number of accidents according to Andersson 1991

There is, according to Figure 7, virtually no relationship between the change in the amount of enforcement and the percentage change in the number of accidents. Enforcement was increased to levels varying from twice to fourteen times the baseline level. Yet, a clear and consistent reduction in the number of accidents did not obtain. There is, however, clearly an outlying data point in Figure 7. Omitting this data point, the results are as shown in Figure 8.

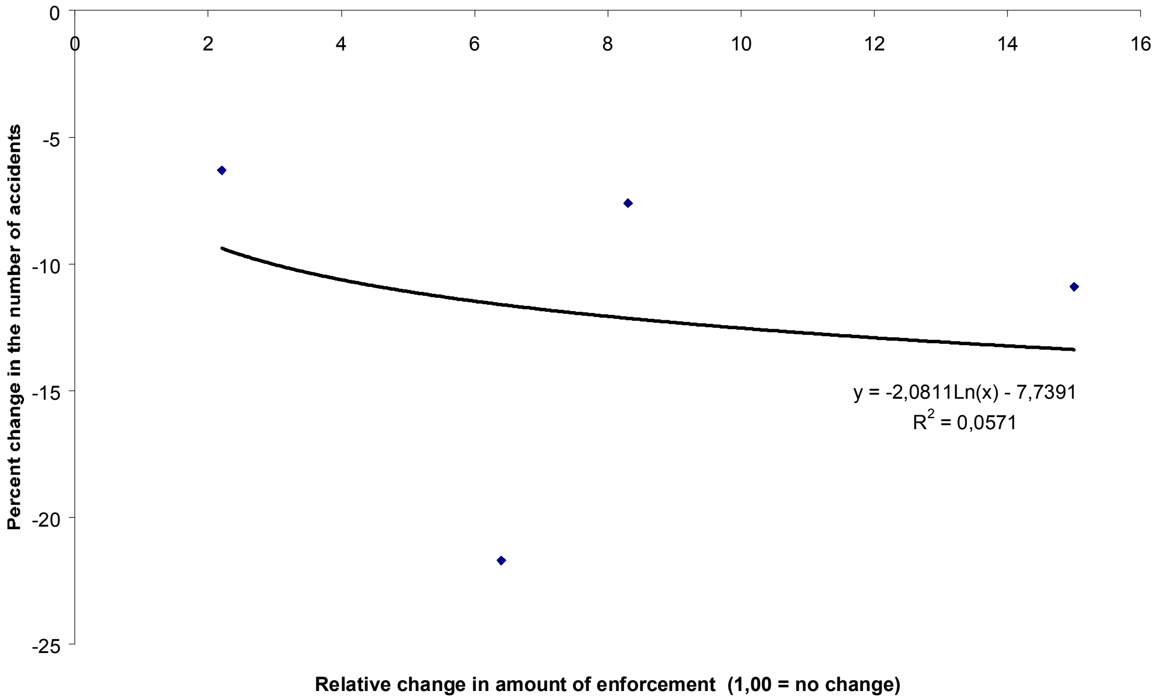

Figure 8: Relationship between change in amount of enforcement and change in the number of accidents according to Andersson 1991, omitting one outlying data point

There is a weak statistical relationship between changes in the amount of enforcement and changes in the number of accidents. The relationship fits a logarithmic function, but it is based on just four data points, and is clearly rather noisy (R-squared = 0.06).

DeWaard and Roijers (1994) conducted an experimental study on motorways in the Netherlands. The proportion of speeders who were stopped by the police was varied systematically from nobody, through one in six (0.167). Changes in the mean speed of travel were measured and compared to a motorway section where there was no speed enforcement. The results are shown in Figure 9.

There is a strong linear relationship between the risk of apprehension to which speeders were exposed (varying from 0 to 0.167) and changes in the mean speed of travel (R-squared = 0.99). The mean speed of travel was reduced by about 4.5% at the highest level for risk of apprehension. Applying functions for the relationship between changes in mean speed and changes in the number of accidents derived by Nilsson (1984), this corresponds to an expected reduction in the number of injury accidents of about 9%. This estimate is consistent with the effects on injury accidents found in other studies, for example Engdahl and Nilsson (1983).

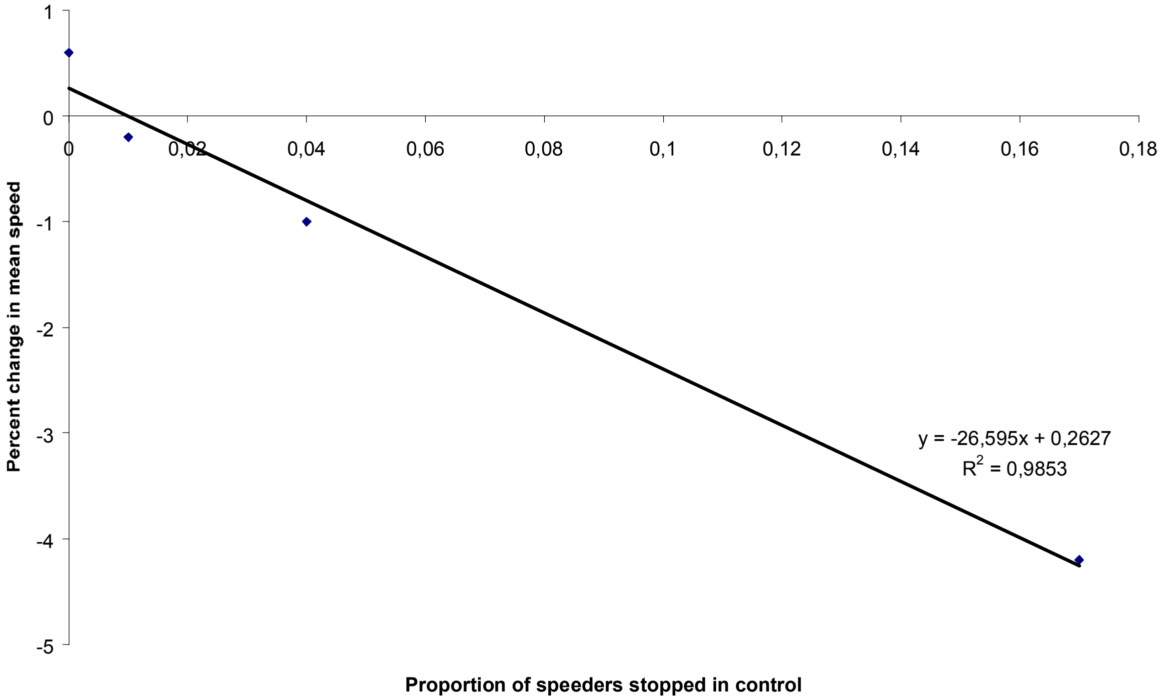

Figure 9: Relationship between proportion of speeders stopped in control and percentage change in mean speed on Dutch motorways according to deWaard and Roijers 1994

Vaa (1995) conducted an experiment on four road sections in Norway, designed to determine the smallest amount of enforcement that would suffice to deter speeding. The amount of enforcement was stated in terms of hours of enforcement activity per road section per day. Effects were stated in terms of changes in the mean speed of travel. Each day was divided into several periods. Figure 10 shows a representative example of the results, applying to daytime conditions (9 AM to 3 PM).

Figure 10 shows that mean speed was reduced if there was more than three hours of enforcement per day. There is a dose-response relationship, fitting a logarithmic function quite well (R-squared = 0.81). The reduction in mean speed obtained at the highest level of enforcement corresponds to an expected reduction in the number of injury accidents of about 4%.

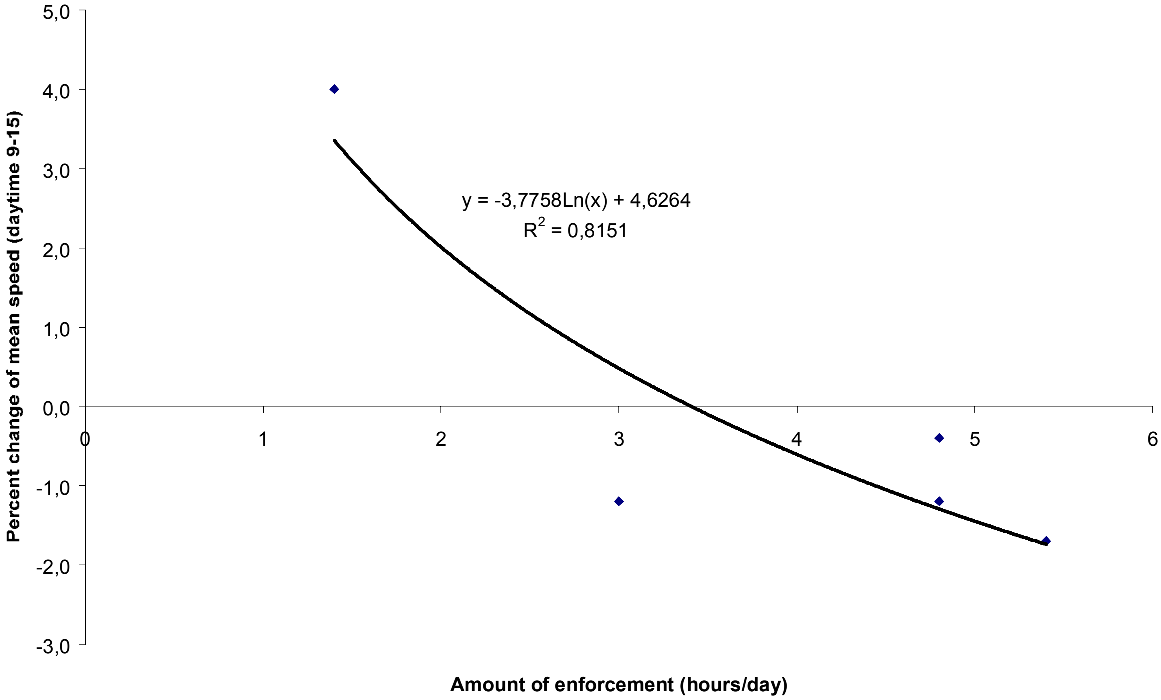

Figure 10: Relationship between amount of enforcement (hours per day) and percentage change in mean speed during daytime according to Vaa 1995

Knoflacher (1998) studied the relationship between the number of police officers per 1,000 inhabitants and the number of injury accidents per 1,000 inhabitants in Austrian provinces (Bundesländer). Figure 11 displays the results of his study.

There seems to be a rather weak relationship between the number of police officers per inhabitant and the number of accidents per inhabitant. The relationship fits a second order polynomial, but the polynomial explains only about 10% of the variance in the number of injury accidents per 1,000 inhabitants (R-squared = 0.11). In a cross section study employing aggregate data, like this one, a simple bivariate relationship is very vulnerable to omitted variable bias. A re-analysis of Knoflacher's study, in which a number of potentially confounding variables were added and multivariate techniques applied (Cerwenka, Hauger and Klamer 1998) did not reproduce his results.

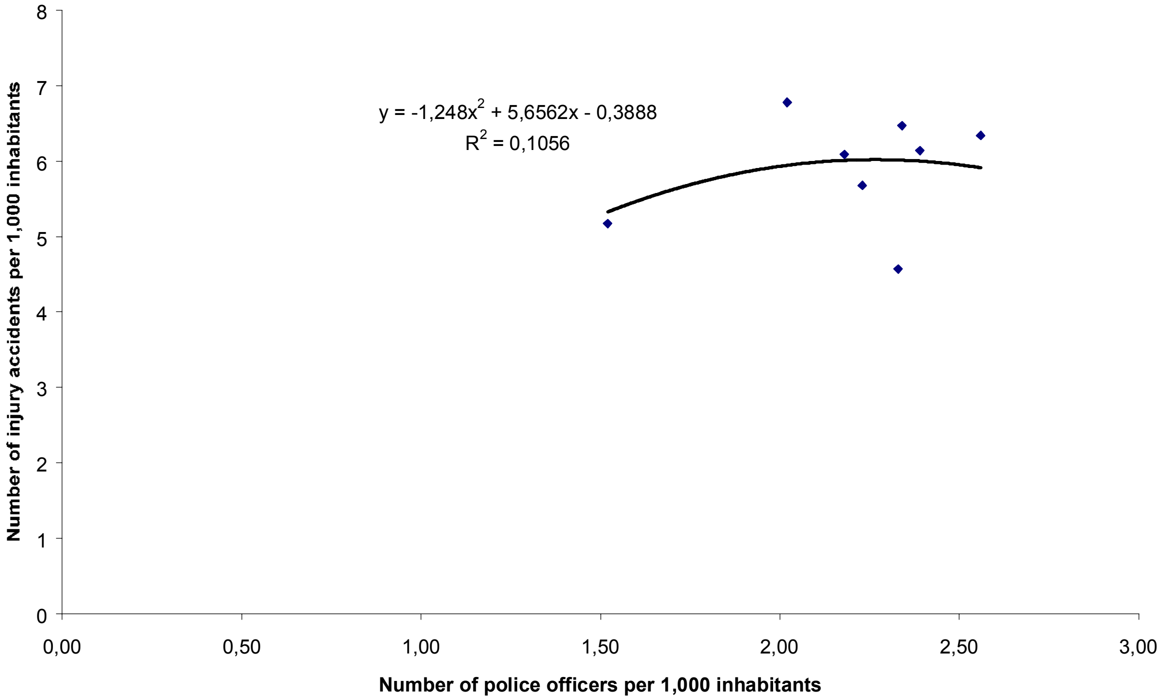

Figure 11: Relationship between number of officers per inhabitant and number of accidents per inhabitant in Austrian länder according to Knoflacher 1998

Table 10 summarises the findings of the studies presented in Figures 1 through 11. Most of the studies, 9 out of 11, show that there is a negative relationship between traffic police enforcement and the number of accidents, which means that the more enforcement there is, the greater is the reduction in the number of accidents. The relationship between changes in the amount of enforcement and changes in the number of accidents is logarithmic in five cases, implying that the marginal effects of increasing enforcement are declining.

Each estimate of the dose-response relationship between police enforcement and accidents, (or speed) is based on the average, on 5.7 data points. The best fitting functions explain, on the average about 59% of the variance in the dependent variable. Although the number of data points used to estimate the dose-response relationship in each study is small, the overall pattern found supports the idea that there is a dose-response relationship between the amount of police enforcement and the level of road safety.

Table 10: Summary of findings of studies quoted in Figures 1 through 11

Study	Number of data points	Strength of relation-ship (R-squared)	Main direction of enforcement-accident relationship	Shape of relationship	Main effect on accidents of enforce-ment	Marginal effect on accidents of increasing enforcement
Munden 1966	6	0.3855	Negative	Logarithmic	Negative	Monotonically declining
Munden 1966	5	0.9296	Negative	Logarithmic	Negative	Monotonically declining
Cirillo 1968	7	0.7705	Positive	Polynomial	Positive	Monotonically increasing
Shoup 1973	8	0.7529	Negative	Polynomial	U-shaped	Declining, then increasing
Shoup 1973	7	0.7600	Negative	Polynomial	Negative	Monotonically declining
Engdahl and Nilsson 1983	4	0.9682	Negative	Logarithmic	Negative	Monotonically declining
Andersson 1991	5	0.0063	Negative	Linear	Negative	Constant
Andersson 1991	4	0.0571	Negative	Logarithmic	Negative	Monotonically declining
DeWaard and Roijers 1994	4	0.9853	Negative	Linear	Negative	Constant
Vaa 1995	5	0.8151	Negative	Logarithmic	Negative	Monotonically declining
Knoflacher 1998	8	0.1056	Positive	Polynomial	Inverted U-shaped	Increasing, then declining
Summary of studies	Mean: 5.7	Mean: 0.5942	9 out of 11 are negative	5 logarithmic, 4 polynomial, 2 linear	8 out of 11 are negative	7 out of 11 are monotonically declining

4.3 DISCUSSION OF DOSE-RESPONSE RELATIONSHIPS

In order to use the resources at their disposal for maximum benefit, police chiefs would ideally like to know the answer to, for example, the following question:

What is the size and duration of the effects on compliance and accidents that can be expected by assigning a patrol of three men to four hours of speed enforcement every day for a period of, say, ten weeks?

The studies examined in this report do, unfortunately, not provide a sufficient basis for answering this question, or similar questions asking for very specific and detailed information about the effects of traffic police enforcement. Research on the effects of police enforcement has not relied on standardised definitions of the amount of enforcement and a standard method of measuring its effects. Moreover, the effects of a certain amount of enforcement are likely to depend on a number of factors that few studies describe in detail, including:

1 The incidence and nature of violations before enforcement is introduced,
2 The prevailing risk of apprehension (the current amount of enforcement),
3 The severity of the penalties administered to violators,
4 The way in which enforcement is carried out, for example, according to a random or systematic pattern.

The effects of these, and other, factors are likely to confound any estimate of a simple dose-response relationship between the amount of police enforcement and the size of its effects. Notwithstanding this, the findings of the studies presented in this paper display a sufficiently clear pattern to at least clarify some issues.

Some previous reports (Østvik and Elvik 1991, Bjørnskau and Elvik 1992) have suggested that there are marked thresholds with respect to the effects of police enforcement on traffic accidents. It has been suggested, for example, that the amount of enforcement must be increased by a factor of at least three in order have an effect on accidents. The studies reviewed in this report do not support the existence of marked threshold effects. The relationship between the amount of enforcement and the level of road safety appears to be quite smooth, with no sharp discontinuities.

There is, moreover, little doubt about the direction of the relationship between the amount of enforcement and the number of accidents. Most of the studies show that there is a negative relationship. Two studies (Cirillo 1968, Knoflacher 1998) indicate a positive relationship. Both these studies are cross section studies whose lack of control of confounding factors make their results highly suspect. Some studies indicate that very low levels of enforcement, or a reduction in the amount of enforcement, may worsen safety. This is a credible finding, in view of the highly likely possibility that road users adapt to the absence of police enforcement by committing more violations. The paper by Bjørnskau and Elvik (1992) applies game theory in discussing how road users adapt their behaviour to varying levels of enforcement.

Despite the heterogeneity of the studies reviewed in this report, it is not altogether impossible to generalise the main trends in the findings by relying on the following set of assumptions:

1 The present level of enforcement maintains the present level of road safety ("the basic equilibrium condition").
2 Reducing enforcement worsens safety (violations increase).
3 Increasing enforcement improves safety (violations decrease).
4 The marginal effect of increasing enforcement is gradually declining.

These assumptions are all quite reasonable and supported by the studies reviewed in this paper. Taken together, the assumptions imply that the dose-response relationship between changes in the amount of police enforcement and changes in the number of accidents has to look like the one shown in figure 12.

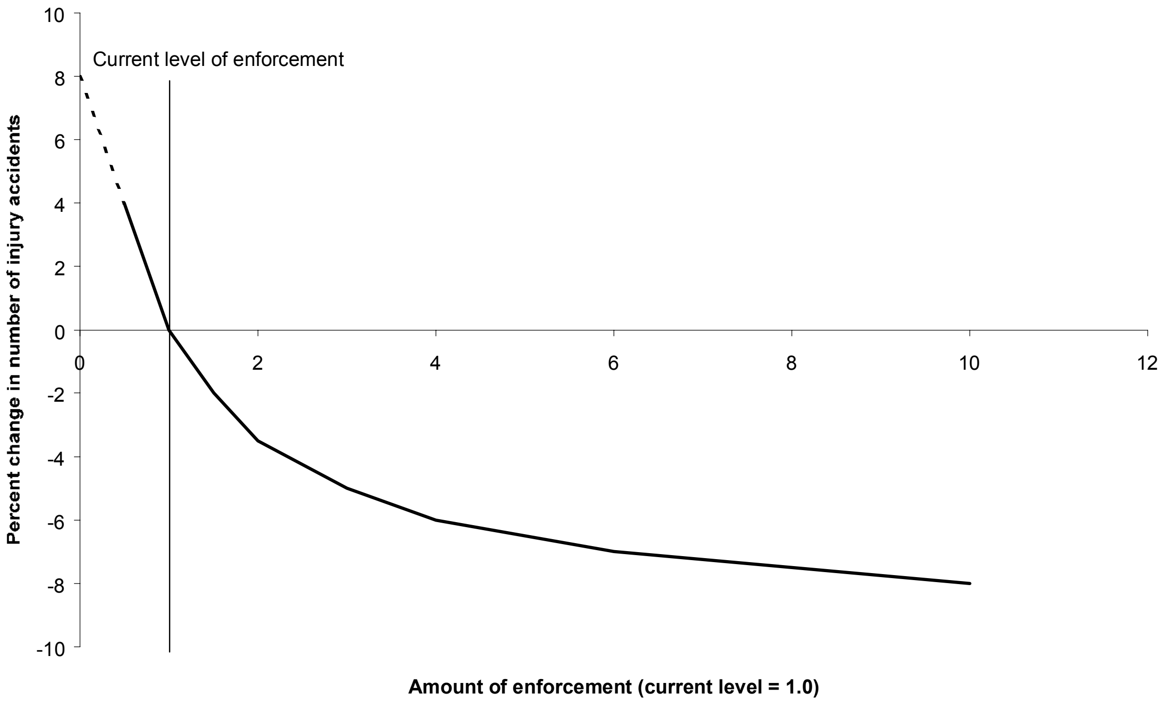

Figure 12: Idealised summary relationship between amount of enforcement and change in the number of accidents based on studies quoted in Figures 1 through 11

If one examines available studies in detail, one will not find a relationship looking exactly like the one shown in Figure 12 in any study. One will, however, find a sample of relationships that are similar to the relationship shown in Figure 12 in important respects. Knowing this relationship may not always suffice as a basis for planning police enforcement at its most detailed level. It may, however, constitute an important basis for planning at a more general level.

4.4 CONCLUSIONS CONCERNING MARGINAL EFFECTS OF ENFORCEMENT

The main findings of the study reported in this chapter support the following conclusions:

The objective of this study was to determine if there is a dose-response relationship between the amount of police enforcement and the level of road safety. A dose-response relationship is found if a greater amount of enforcement has a larger effect on road safety than a smaller amount of enforcement. Knowing the dose-response relationship between enforcement and accidents is important in order to deploy the optimal amount of enforcement according to the marginal utility principle of economic theory.

Eight studies, containing a total of eleven estimates of the dose-response relationship between police enforcement and accidents were reviewed. These studies were different in important respects and their results could not be statistically combined by means of a standard meta-analysis.

Most of the studies indicate that there is a dose-response relationship between police enforcement and road safety. Increasing the amount of enforcement appears to reduce the number of accidents. The marginal effects of increasing the amount of enforcement appear to be declining, meaning that the additional effects of successively increasing enforcement tend to become gradually smaller. There is also evidence that reducing the amount of enforcement may lead to more accidents.

Based on the findings of the studies reviewed in the paper, and a set of reasonable assumptions, a “generalised and idealised” dose-response function for police enforcement is proposed. Knowing this function is useful for planning police enforcement at a master plan level, but may not suffice as a basis for a very detailed planning of enforcement.

5 CHOICE OF FRAMEWORK FOR COST-BENEFIT ANALYSIS

In chapter two, three different frameworks for cost-benefit analysis of traffic police enforcement were proposed. In this chapter, the choice between these frameworks will be discussed. Before starting the discussion, the basis of current economic valuations of relevant impacts of traffic police enforcement will be briefly presented.

5.1 ECONOMIC VALUATION OF IMPACTS IN COST-BENEFIT ANALYSES

Which are the relevant impacts of safety measures that ought to be included in cost-benefit analyses? In general, the answer to this question is that every impact to which a preference is attached should be included, irrespective of whether the impact is intentional or not. This means that, in addition to impacts on the number of accidents or the number of injured people, cost-benefit analyses should generally include impacts on mobility, the costs of travel and the environment. No standard taxonomy of relevant impacts exists. A preliminary list of potentially relevant impacts of measures is shown in Figure 13.

Main categories	*Subcategories*
MOBILITY	The number and length of trips
	The speed of travel
TRAVEL COST	The direct outlays for travel
ROAD SAFETY	The number of accidents
	The severity of accidents
	The accident rate (accidents/km of travel)
	The insecurity (subjective safety) of road users
ENVIRONMENT	The emission of noise
	The emission of air pollution (all types)
	The visual intrusion of road systems
	The use of scarce land for transport

Figure 13: Taxonomy of relevant impacts of safety measures

When making such a list of impacts, it is important to avoid double counting of them. The problem of double counting is particularly relevant for environmental impacts, since there are many of them that are closely related. It is tempting to include, for example, both the insecurity (subjective safety or anxiety) of road users and the barrier effect of a road as environmental impacts. However, as these impacts are likely to overlap to a significant extent, including both of them would probably introduce an element of double counting into the list of impacts. In Figure 13 only security has been included. The list is likely to be incomplete with respect to environmental impacts.

The most difficult part of a cost-benefit analysis is often to obtain theoretically correct and empirically valid and reliable monetary valuations of all relevant impacts. Literally hundreds of studies have been made to determine the value of goods that do not have market prices, like the reduction of environmental pollution. There are a few basic principles of valuation of non-marketed goods in cost-benefit analysis. Foremost among these is the principle that the valuation of a good should be based on the willingness-to-pay of the potential purchasers of the good. In order to estimate the willingness-to-pay for a non-marketed good, a hypothetical market is set up, in which people are asked to state their willingness-to-pay for a certain amount of the good, or choose between various options that provide different amounts of the good. There is a host of methodological pitfalls in such studies. It would go beyond the scope of this report to discuss all these difficulties in detail. Fairly extensive discussions can be found in, for example, Elvik (1993), Kidholm (1995) and Schwab-Christe and Soguel (1995).

An important item in cost-benefit analyses of road safety measures is road accident costs. A survey of current practice in estimating road accident costs in most of the EU countries and a few countries not members of the EU has been made by an international group of experts as part of the COST-research programme established by the European Union. The report from this survey (project COST-313) was published in 1994 (Alfaro, Chapuis and Fabre 1994). In addition to describing current practice in the countries included in the survey, the report discusses methods for estimating road accident costs from a theoretical point of view and presents some recommendations with respect to the choice of method of cost estimation.

The COST-report contains recommendations with respect to the cost items that ought to be included in estimates of road accident costs and with respect to the methods for estimating the various cost items. Five major cost items were identified:

1. Medical costs
2. Costs of lost productive capacity (lost output)
3. Valuation of lost quality of life (loss of welfare due to accidents)
4. Costs of property damage
5. Administrative costs

These five major cost elements can be divided into two main groups. The first group includes cost items 1, 2, 4 and 5. The other group consists of cost item 3, the valuation of lost quality of life. Whereas market prices exist for the four former cost elements, this is obviously not the case for the valuation of lost quality of life. It is only recently, which means during the latest ten or fifteen years, that any motorised country has tried to estimate the monetary value of lost quality of life. The other four cost items have, however, been estimated in many motorised countries for a long time, starting in the nineteen fifties in the United States, Great Britain and Sweden.

It is beyond the scope of this study to carry out a survey of the literature dealing with the valuation of non-marketed goods. This literature is vast and surveying it would be a major project by itself. Rather than trying to undertake such a project, a set of illustrative valuations of impacts to be included in cost-benefit analyses is given in Table 11.

Table 11: Valuation of impacts for use in cost-benefit analyses. Norwegian kroner (NOK). 1999-prices (source: Elvik 1999A). 1 NOK = 0.125 US Dollars

Main policy objective	**Unit of valuation**	**Valuation per unit (NOK 1999 proces)**
Road safety	1 fatality	18,600,000
	1 serious injury	5,400,000
	1 slight injury	560,000
Travel time	1 vehicle hour of travel – light cars	95.80
	1 vehicle hour of travel – heavy cars	392.50
Transport cost	1 kilometre vehicle operating cost – car	0.93
	1 kilometre vehicle operating cost – truck	2.76
	1 kilometre vehicle operating cost – bus	4.50
Environmental impacts	1 kg emission of CO2	0.30
	1 kg emission of SO2 in urban areas	34
	1 kg emission of SO2 in rural areas	17
	1 kg emission of NOx in urban areas	70
	1 kg emission of NOx in rural areas	35
	1 kg emission of NMVOC in urban areas	70
	1 kg emission of NMVOC in rural areas	35
	1 kg emission of PM10 in urban areas	600
	1 kg emission of PM10 in rural areas	100
	Noise emission per vehicle kilometre – light cars	0.06
	Noise emission per vehicle kilometre – heavy cars	0.60

The table shows the current (1999) economic valuation of impacts used in cost-benefit analyses of road investment projects in Norway, including projects that have impacts on road safety (Elvik 1999A). It should be noted that official values for accident costs vary substantially between countries. These differences have been discussed in the report from the PROMISING project (Elvik 1999B).

5.2 MEASURES OF EFFICIENCY IN COST-BENEFIT ANALYSES

Cost-benefit analysis is based on the principle of social efficiency. Social efficiency is a technical term in welfare economics. A policy or a programme is regarded as efficient if it improves the welfare of at least one person without reducing it for anybody else. Policies that are efficient in this sense satisfy the criterion of Pareto-optimality. It has long been recognised, however, that Pareto-optimality is a much too stringent criterion of social efficiency.

Most economists therefore subscribe to a less demanding criterion (potential Pareto-improvement) stating that a project improves welfare if those who benefit from it can, at least in theory, compensate those who lose from it and still retain a net benefit. This is equivalent to saying that projects for which the monetary value of the benefits, estimated according to the willingness-to-pay principle, exceed the monetary value of the costs, estimated according to the opportunity cost principle, are efficient, whereas projects for which the benefits are smaller than the costs are inefficient.

Two measures of efficiency are used in cost-benefit analysis. These are the net present value of a project and the benefit-cost ratio. The net present value of a project is defined as:

Net present value = Present value of all benefits – Present value of all costs

The benefit term includes all effects that are valued monetarily in an analysis. Different benefits are usually added to obtain total benefits. Negative benefits, for example increased travel time are subtracted. The cost term usually denotes the implementation costs of a measure, expressed in terms of the opportunity cost from a social point of view. The benefit cost ratio is defined as:

$$\text{Benefit-cost ratio} = \frac{\text{Present value of all benefits}}{\text{Present value of implementation costs}}$$

As is easily seen, there is a simple definitional relationship between net present value of benefit-cost ratio. When the net present value is positive, the benefit-cost ratio exceeds the value of 1.0.

5.3 IMPLICATIONS OF CHOICE OF FRAMEWORK FOR COST-BENEFIT ANALYSIS

The implications of the choice of framework for the results of cost-benefit analyses of traffic police enforcement will be illustrated by means of four examples based on Norwegian data. A more complete description of the analyses is given in a report issued by the Institute of Transport Economics (Elvik 1997A, available in Norwegian only).

The first example refers to trebling the amount of speed enforcement carried out by police patrols in Norway. Table 12 gives estimates of the effects of such an increase in speed enforcement. All effects have been converted to monetary terms and are stated in Norwegian kroner (NOK; 1 NOK = 0.125 US Dollars in December 1999).

Table 12: Cost-benefit analysis of increased speed enforcement in Norway according to alternative frameworks

		Alternative frameworks for cost-benefit analysis – amounts in million NOK		
Benefits and costs (two items at bottom) of enforcement	**Amounts in million NOK**	**Alternative 1: Welfare economics**	**Alternative 2: Value of deterrence**	**Alternative 3: Normative ethics**
Accident costs	1046	•	•	•
Vehicle operating costs	195	•	•	•
Environmental costs	164	•	•	•
Costs of travel time	–1232	•	•	
Outlays for traffic tickets	–250		•	
Costs of enforcement	166	•	•	•
Opportunity cost of taxes	33	•	•	•
Total benefits (million NOK)		173	423	1405
Total costs (million NOK)		199	199	199
Benefit-cost ratio		0.87	2.13	7.06

1 NOK = 0.125 US Dollars

If a cost-benefit analysis is carried out according to the conventional framework of welfare economics, the net benefits come to 173 million NOK. This results is obtained by adding the savings in accident costs (1,046 million NOK), the savings in vehicle operating costs (195 million NOK) and the savings in environmental costs (164 million NOK), and then subtracting the costs of travel time (1,232 million NOK). The additional costs of travel time represent the loss of benefits from speeding to the speeders. The costs of enforcement amount to 199 million NOK, consisting of direct outlays (166 million NOK), and an estimate of the opportunity cost of taxes (33 million

NOK), raised to finance public expenditures. According to this analysis, the benefits (173 million NOK) of increasing enforcement are smaller than the costs (199 million NOK).

Including the outlays for traffic tickets as a measure of the value of deterrence increases the total value of the benefits to 423 million NOK. Benefits are now greater than costs. If both violator benefits from violations and violator outlays for traffic tickets are excluded from the analysis, benefits increase to 1,405 million NOK, and exceed costs by a wide margin. These results show that the choice made with respect to the treatment of violator benefits from violations can have major importance for the results of a cost-benefit analysis of enforcement.

It is of some interest to note in passing what the balance sheet for increased enforcement looks like from the speeders' point of view. Assuming, for the sake of the argument, that the valuations given in Table 12 correctly represent the preferences of speeders, the benefits of speeding (savings in travel time) come to 1,232 million NOK. Costs include about 60% of the accident costs (Elvik 1994), all vehicle operating costs and the outlays for traffic tickets. It is assumed that environmental costs are external from the speeders' point of view (meaning that nobody abstains from speeding for the sake of protecting the environment). The costs then amount to 1,073 million NOK (628 million NOK for accidents, 195 million NOK for vehicle operation and 250 million NOK for traffic tickets). The benefits of speeding still outweigh the costs from the speeders' point of view.

Table 13 shows another example, referring to the current use of speed cameras (automatic speed enforcement) in Norway (Elvik 1997B).

The results of applying the three alternative frameworks for cost-benefit analysis are broadly speaking the same as those obtained for the case of traditional speed enforcement. Benefits exceed costs in all three frameworks, but the lowest benefit-cost ratio is obtained within the conventional framework of welfare economics.

Table 13: Cost-benefit analysis of current use of automatic speed enforcement in Norway according to alternative frameworks

Benefits and costs (two items at bottom) of enforcement	Amounts in million NOK	Alternative frameworks for cost-benefit analysis – amounts in million NOK		
		Alternative 1: Welfare economics	Alternative 2: Value of deterrence	Alternative 3: Normative ethics
Accident costs	124.1	•	•	•
Vehicle operating costs	37.5	•	•	•
Environmental costs	5.3	•	•	•
Costs of travel time	–128.8	•	•	
Outlays for traffic tickets	–36.5		•	
Costs of enforcement	15.7	•	•	•
Opportunity cost of taxes	3.1	•	•	•
Total benefits (million NOK)		38.1	74.6	166.9
Total costs (million NOK)		18.8	18.8	18.8
Benefit-cost ratio		2.03	3.97	8.88

1 NOK = 0.125 US Dollars

The third case, concerning seat belt enforcement, is presented in table 14. The estimates given refer to a trebling of seat belt enforcement in Norway. It has been assumed that the principal benefit gained in not wearing seat belts is the time saved in not having to buckle and unbuckle them. This time has been set to 8 seconds (4 seconds to fasten seat belts and 4 seconds to unfasten them) per car occupant per trip (Blomquist 1979).

It can be seen from table 14 that the choice of framework for cost-benefit analysis does not matter much for the results in this case. Providing the assumptions made are correct, the benefits from the car occupants' point of view of wearing seat belts are greater than the costs. The wearing rate for seat belts in Norway is around 85-90% (Leite 1998).

Table 14: Cost-benefit analysis of increased seat belt enforcement in Norway according to alternative frameworks

Benefits and costs (two items at bottom) of enforcement	Amounts in million NOK	Alternative frameworks for cost-benefit analysis – amounts in million NOK		
		Alternative 1: Welfare economics	Alternative 2: Value of deterrence	Alternative 3: Normative ethics
Accident costs	270	•	•	•
Time spent fastening seat belts	–21	•	•	•
Outlays for traffic tickets	–25		•	
Costs of enforcement	60	•	•	•
Opportunity cost of taxes	15	•	•	•
Total benefits (million NOK)		249	274	270
Total costs (million NOK)		75	75	75
Benefit-cost ratio		3.23	3.65	3.60

1 NOK = 0.125 US Dollars

The fourth example deals with drinking and driving, and is presented in Table 15. The analysis refers to the effects of trebling random breath testing in Norway. Benefits are slightly greater than costs in all three frameworks for analysis. Inclusion of violator benefits from violations does not affect the results of analysis decisively. In this case, the explanation for this fact is the opposite of that given for seat belts. Drinking and driving is a bad bargain from the violators' point of view. The gain of 42.6 million NOK (the consumer surplus of driving while drunk) is small compared to the outlays for traffic tickets (170 million NOK) and the increased risk of accident (although the latter is highly likely to be underestimated, or perhaps disregarded altogether, by violators). A roadside survey carried out in 1981-82 (Glad 1985) indicated that drivers with an illegal amount of alcohol in their blood perform only about 0.27% of all driving in Norway. There are indications that there is even less drinking and driving today than at the time of the roadside survey (Elvik 1997A).

Table 15: Cost-benefit analysis of increased use of random breath testing (drinking and driving enforcement) in Norway according to alternative frameworks

Benefits and costs (two items at bottom) of enforcement	Amounts in million NOK	Alternative frameworks for cost-benefit analysis – amounts in million NOK		
		Alternative 1: Welfare economics	Alternative 2: Value of deterrence	Alternative 3: Normative ethics
Accident costs	312.1	•	•	•
Environmental costs	1.9	•	•	•
Loss of consumers' surplus	–42.6	•	•	
Outlays for traffic tickets	–170.0		•	
Costs of enforcement	22.0	•	•	•
Opportunity cost of taxes	44.0	•	•	•
Total benefits (million NOK)		271.4	441.4	314.0
Total costs (million NOK)		266.0	266.0	266.0
Benefit-cost ratio		1.02	1.66	1.18

1 NOK = 0.125 US Dollars

Table 16 brings together the results of the four case illustrations. It can be seen that the results of the cost-benefit analyses are greatly influenced by the choice of framework for analysis as far as speed enforcement is concerned. The choice of framework for analysis appears to be of less importance for the results as far as seat belt wearing, and drinking and driving are concerned.

Table 16: Summary of cost-benefit analyses of increasing traffic enforcement in Norway according to alternative frameworks

Measures that have been analysed	Benefit-cost ratio according to alternative frameworks for analysis		
	Alternative 1: Welfare economics	Alternative 2: Value of deterrence	Alternative 3: Normative ethics
Increased speed enforcement	0.87	2.13	7.06
Current use of automatic speed enforcement	2.03	3.97	8.88
Increased seat belt enforcement	3.23	3.65	3.60
Increased random breath testing	1.02	1.66	1.18

In general, all types of enforcement become less cost-effective when violators benefits from violations is included in the analysis. This is not surprising, since all violations have been assumed to provide some kind of benefit for violators. When this benefit is lost, the total benefits of enforcing a law are reduced.

5.4 DISCUSSION OF THE CHOICE OF FRAMEWORK FOR COST-BENEFIT ANALYSIS

Cost-benefit analysis is based on the principle of consumer sovereignty. Roughly speaking, this means that the choices consumers make about how to spend their time and income, are taken for granted. These choices are treated as data. No attempt is made to judge whether the choices made by consumers are wise or stupid. There is, of course, much to be said in favour of respecting consumer sovereignty. Not respecting it would inevitably involve some sort of dictatorship, with somebody telling other people how they ought to behave.

But is not this exactly what any law or regulation does? It prescribes what constitutes legal behaviour and prohibits all other kinds of behaviour. In this sense, of course, any law or regulation limits individual freedom. But this does not mean every law is dictatorial. Freedom is a concept that makes sense only to the extent that one person's freedom is consistent with a similar freedom for everybody (Rawls 1971). An individual's right to spend his or her income whatever way he or she pleases has little value without, for example, protection of property rights. If burglars were equally entitled to keep what they steal as are those who have bought it legally, the right to spend one's own money the way one likes would soon cease to have any value.

It is easy to imagine to cases of criminal activity for which the notion of "benefits" to the perpetrator hardly makes any sense. Consider, as an example, the following hypothetical, but not unrealistic scenario. Rivalry has broken out for the leadership of a gang involved in drug dealing and prostitution. These activities are highly profitable for the leader of the gang. In an attempt to eliminate his rival, one of the contestants shoots from a moving car into a crowd where he has seen him. The bullet hits an innocent bystander, who is killed instantly. The intended victim escapes uninjured. What are the "benefits" of this crime? It is difficult to see that the idea of there being any benefits at all makes sense in a case like this. There might perhaps have been some benefits to the murderer, if he had been able to kill his rival. But there was no benefit to anybody, in any meaningful sense of the term, by killing an innocent bystander.

It is not difficult to see the analogy between this case and a case of speeding. Speeders sometimes hit innocent bystanders as well. They do not intend to kill them. In the huge majority of cases, however, there is not any identifiable victim of speeding and other violations of road traffic law. Perhaps that is why many of these violations are socially accepted, even to the extent that assigning a benefit to them, to be counted as a societal gain in a cost-benefit analysis, is regarded as entirely appropriate.

But, it may be objected, what about laws that impose huge costs on the public, for little or no benefit? A distinction must be made between two types of decisions:

1 Passing a new law, or changing an existing law, and
2 Allocating resources to enforcing an existing law.

When a new law is proposed, all impacts of that law should be considered before it is passed. Once the law has been passed, however, it is no longer obvious that society can assign moral legitimacy to illegal behaviour the same way legal behaviour is regarded as right or appropriate. By treating violator benefits from violations as a societal benefit in cost-benefit analyses, society is, in effect, approving of such behaviour and treating it as morally legitimate (although not legal).

5.5 CONCLUSIONS CONCERNING CHOICE OF FRAMEWORK

This chapter has discussed implications of the choice of framework for cost-benefit analysis to traffic police enforcement. The discussion focused on whether it is appropriate to include the benefits that violators get from violating road traffic law in cost-benefit analyses of enforcement, counting the loss of these benefits as a loss to society. The discussion can be summarised in the following points:

There are many ways of interpreting how best to apply the principles of cost-benefit analysis to traffic police enforcement. It is not obvious that the standard interpretation of welfare economics is the only one that is defensible.

Three alternative frameworks for cost-benefit analysis of traffic police enforcement, differing in terms of the treatment of (a) violator benefits from violations, and (b) outlays for traffic tickets, were formulated. The three frameworks were applied to four cost-benefit analyses of various types of traffic police enforcement in Norway. The analyses, particularly of speed enforcement, show that the choice of framework can have a major influence on the results of the analyses. In general, all types of enforcement become less cost-effective when the loss of benefits from violations of the law is included in cost-benefit analyses.

Most people would probably regard it as morally wrong to include the benefits of violations of the law in cost-benefit analyses of measures intended to increase compliance with the law. The moral objections to respecting the preferences of the violators are probably strongest for serious crimes, like homicide. To be consistent, however, one should treat all types of violations the same way. It would be inconsistent to include benefits to the offender of some types of crime, but not others, in cost-benefit analyses.

This means that the principle of basing the valuation of costs and benefits strictly on individual preferences cannot be applied indiscriminately in cost-benefit analysis. Some preferences, like those of criminal offenders, are by their nature “anti social” and should therefore not be respected in cost-benefit analyses. The analyses presented in the next chapter disregard violator benefits from violations. They are not included in the analyses. Income from traffic tickets has been omitted as well. This means that the analyses are based on the framework, which is most consistent with normative ethics, of the three alternative frameworks that have been discussed.

6 COST-BENEFIT ANALYSES OF INCREASED TRAFFIC POLICE ENFORCEMENT IN NORWAY

6.1 ASSUMPTIONS MADE IN THE ANALYSES

This chapter presents the results of cost-benefit analyses of traffic police enforcement that have been performed recently in Norway, as part of the preparation of the National Transport Plan (NTP) for the ten year period of 2002-2011 (Elvik 1999A). The assumptions made in the analyses are documented in greater detail in another report (Elvik 1999A, in Norwegian only). The most important assumptions made can be summarised as follows:

The analyses comprised the following types of enforcement:
1 Stationary speed enforcement
2 Random breath testing (drinking and driving)
3 Seat belt enforcement
4 Automatic speed enforcement (speed cameras)

For each of these types of enforcement, the following levels of increase compared to the current level of enforcement were considered:
1 Doubling the level of enforcement (factor of two)
2 Trebling the level of enforcement (factor of three)
3 Increasing enforcement by a factor of six
4 Increasing enforcement by a factor of ten

The effects of these increases in the amount of enforcement were estimated separately for each type of enforcement. How to estimate the combined effects of jointly increasing more than one type of enforcement will be discussed later. Violator benefits from violations and outlays for traffic tickets were not included in the analyses.

The marginal effects of successive increases in the amount of enforcement were assumed to be declining, as indicated by the dose-response functions surveyed in chapter four. Although these dose-response functions were derived from studies of stationary speed enforcement only, functions having a similar general shape were assumed to apply to the other types of enforcement as well. There is evidence to support making this assumption as far as speed cameras are concerned (Elvik 1997B). Indirectly, studies of the effects of laws making the wearing of seat belts mandatory (Elvik et al 1997) also support the existence of a dose-response function exhibiting declining marginal effects.

It was arbitrarily assumed that the maximum potential effects on accidents of increasing the amount of enforcement – obtained by a tenfold increase in the amount of enforcement – correspond to roughly 60% of the maximum theoretical potential effect on accidents of eliminating altogether a certain type of violation. It has been estimated, for example, that perfect compliance with current speed limits in Norway would reduce the number of road accident fatalities by 20% (Elvik 1999B). Based on this, it was assumed that a tenfold increase in stationary speed enforcement should reduce the number of fatalities by 12%. Although arbitrary, some arguments can be given for making such an assumption:

1 Even if enforcement is stepped up to ten times its current level, the risk of apprehension will still be quite low in absolute terms. It is therefore not realistic to assume that perfect compliance can be attained.

2 The assumptions made with respect to the effects of enforcement on accidents should, at least broadly speaking, be consistent with the results of the evaluation studies quoted in chapter three. In general, these results probably refer to quite substantial increases in the amount of enforcement, often by a factor of 5 to 10.

3 The assumption is a conservative one, meaning that the potential effects of enforcement on safety are not likely to be overestimated.

It was assumed that the effects on accidents of enforcement are concurrent with the enforcement activity. No effects persist after enforcement has ceased. Again, this is a rather conservative assumption. Some studies, e. g. Vaa (1995), have found halo effects of enforcement for several weeks after it was terminated. It is not known if the risk of apprehension for traffic violations in Norway differs greatly from other countries. No comparable statistics has been found that could shed light on this question. It is, however, known that the risk of apprehension for most violations is very low in absolute terms, in the order of 1 per 1,000 or 1 per 10,000 violators.

6.2 RESULTS OF THE COST-BENEFIT ANALYSES

Table 17 summarises the results of the cost-benefit analyses of increased traffic police enforcement in Norway.

It can be seen that increasing stationary speed enforcement by a factor of up to six times the current levels gives benefits that exceed the costs. The additional benefits of increasing speed enforcement from six times to ten times its current level are, however, smaller than the additional costs (compare marginal benefits and marginal costs in table 17).

More random breath testing gives benefits that are greater than costs up to a level of three times the current amount of random breath testing. Further increases beyond this point are not cost-effective.

Table 17: Summary of results of cost-benefit analyses of increased traffic police enforcement in Norway

		Amounts in million NOK (1 NOK = 0.125 US Dollars)			
Type of enforcement	**Increase (factor)**	**Total benefits**	**Total costs**	**Marginal benefits**	**Marginal costs**
Speed enforcement	2	990	108	990	108
	3	1393	216	403	108
	6	1955	540	562	324
	10	2227	972	272	432
Random breath testing	2	265	132	265	132
	3	399	265	134	133
	6	587	662	188	397
	10	790	1191	203	529
Seat belt enforcement	2	290	38	290	38
	3	477	76	187	38
	6	727	189	250	113
	10	874	340	147	151
Speed cameras	2	2326	337	2326	337
	3	4109	674	1783	337
	6	8600	1685	4491	1011
	10	13483	2841	4883	1156

Increasing seat belt enforcement is cost-effective, nearly up to ten times its current level. The marginal benefits of a tenfold increase are almost as large as the marginal costs (147 vs 151 million NOK). Increasing the use of speed cameras is cost-effective throughout the range considered. Even at a tenfold increase, marginal benefits clearly exceed marginal costs.

These analyses show that, in Norway, it would be cost-effective to increase all types of traffic police enforcement. The analyses indicate that it is cost-effective to substantially increase the use of speed cameras and seat belt enforcement. Stationary speed enforcement is cost-effective at six times the current level, whereas a more moderate increase would be cost-effective with respect to random breath testing.

Do these results apply to other countries as well? This question will be discussed in a subsequent chapter. Meanwhile, some other issues related to the interpretation of the results presented in Table 17 will be discussed.

6.3 SOURCES OF UNCERTAINTY IN COST-BENEFIT ANALYSES

There are several sources of uncertainty in the cost-benefit analyses presented in Table 17. In this chapter, the following sources of uncertainty will be discussed:

1. Uncertainty in the estimated effects of enforcement on accidents
2. Uncertainty in the economic valuation of impacts, particularly accident costs
3. Uncertainty with respect to the joint effects of simultaneously increasing more than one type of enforcement

As far as the first if these items is concerned, the 95% confidence intervals for the effects on accidents given in chapter three have been used to estimate lower and upper limits for the effects on accidents. Table 18 gives the results of these estimates, applying to a threefold increase in the amount of enforcement.

Table 18: Lower and upper 95% confidence limits for the estimated effects on the number of injured road users attributable to a threefold increase in the amount of police enforcement in Norway. (Source: Elvik 1999B)

	Estimated reduction in the annual number of injured road users in Norway if enforcement is increased by a factor of three – first order effects		
Type of enforcement	**Best estimate**	**Lower limit**	**Upper limit**
Speed enforcement	492	197	788
Random breath testing	144	134	155
Seat belt enforcement	178	107	241
Speed cameras	204	131	276

Table 18 gives the best estimate of the first order effects of a threefold increase in each type of enforcement, and the lower and upper 95% confidence limits of the best estimate. The first order effects are the estimated effects of each type of enforcement when applied alone, i. e. not assuming a corresponding increase in any of the other types of enforcement. It is apparent that the largest element of uncertainty concerns speed enforcement. For speed enforcement, the ratio of the upper to the lower confidence limit is 4 (788/197 = 4). For random breath testing, the corresponding ratio is only 1.15 (155/134). Seat belt enforcement and speed cameras occupy a middle position between these extremes in terms of the uncertainty of the estimated effect on safety.

Accident costs are uncertain. Table 19 shows the lower and upper 95% confidence limits applied to quantify the uncertainty of the accident costs (Elvik 1999A). It is beyond the scope of this report to explain in detail how these confidence limits were obtained. Lower and upper confidence limits for the discount rate have been given as well. The joint effects of several sources of uncertainty to the total uncertainty of an estimate, which is derived from a set of uncertain estimates, X, Y, ... Z, can be estimated according to the standard model for the propagation of errors, reduced form:

$$Var(R) = \left(\frac{\partial R}{\partial X}\right)^2 Var(X) + \left(\frac{\partial R}{\partial Y}\right)^2 Var(Y) + \ldots + \left(\frac{\partial R}{\partial W}\right)^2 Var(W)$$

The reduced form assumes that the uncertainties of each of the items are not correlated with each other (i. e. the variance of X does not depend on the variance of Y, etc).

Table 19: Lower and upper 95% confidence limits for road accident costs in Norway. (Source: Elvik 1999A)

Parameter	Best estimate	Lower limit	Upper limit
Cost of a fatality	18,600,000	13,100,000	24,400,000
Cost of a serious injury	5,400,000	5,400,000	7,100,000
Cost of a slight injury	560,000	560,000	730,000
Discount rate	7%	6%	8%

In order to estimate the joint effects of several measures that affect the same set of accidents, it is useful to define some concepts. The effects of a certain road safety measure on the number of accidents may depend on whether it is introduced as a stand-alone measure or as part of a package of measures. Hence, to obtain the total effects of a set of measures, it may be wrong to simply add their first order effects. To illustrate this, consider the case of road lighting and bypasses. Suppose cost-benefit analyses have been made of these two measures for a small village. Suppose that the results, provided only one of the measures is carried out, are as given below (arbitrary monetary values for illustration only):

	Bypass	Lighting
Benefits	102	35
Costs	100	20

Now suppose the bypass is built. Traffic volume in the village is then cut in half and the expected number of accidents in the village is then also cut in half. The benefits of introducing road lighting are then reduced from 35 to 17.5, and the measure no longer gives a benefit that exceeds the cost. Suppose, on the other hand, that road lighting is installed before a bypass has been built. Road lighting cuts the number of accident by about 10%, and thus reduces the benefits of the bypass from 102 to 98.5. It is no longer good value for money to build the bypass. Hence, both measures give benefits that are greater than costs if carried out alone, but none of the measures give benefits that are greater than costs if the other measure has already been introduced. But if both measures were introduced at the same time, then what would their joint benefits be?

The benefits of introducing both measures would essentially, be the sum of the benefits of measure A, given that measure B has been introduced and the benefits of measure B, given that measure A has been introduced. In the present example, that would be 98.5 + 17.5 = 116. The combined cost would be 120. Hence, a cost-benefit analysis would conclude that these two measures should not be introduced as a package.

Evidently, only one of the measures ought to be introduced in this case, although both of them pass the cost-benefit test when taken alone. In this case, road lighting should be introduced first, because it has both the best benefit/cost ratio and the highest net present value.

In general, denote by E_i the effect of measure i on the number of accidents, expressed as a percentage change (in most cases a percentage reduction). Then R_i is the residual number of accidents still expected to occur when measure i has been implemented:

$R_i = 1 – E_i$

If, for example, a measure affects 100 accidents and has a 20% effect on those accidents, the residual when the measure has been implemented is 0.8 (1 – 0.2). A simple model to estimate the combined effect of two measures on the number of accidents, when one of them reduces the number of accidents by 20% and the other by 30%, is:

Combined effect = 1 – (0.8 x 0.7) = 1 – 0.56 = 0.44

That is, the combined effect of the measures is an accident reduction of 44%, not 50%, as the sum of their individual effects would seem to imply. This simple model of estimating the combined effects of several safety measures that affect the same target accidents assumes that the percentage effects of the measures remains unaffected when the measures are combined in a package. The validity of this assumption is unknown. It is, however, the simplest model that can be used. Until a more complicated model can be supported by empirical research, using the simplest possible model is defensible by virtue of the principle of insufficient reason.

As far as increasing enforcement is concerned, the total effects of these sources of uncertainty can now be summarised. Table 20 shows the estimated effects of the various sources of uncertainty to the total effects of implementing a cost-effective combination of enforcement measures in Norway. The term cost-effective denotes any type of enforcement for which marginal benefits are greater than or equal to marginal costs.

It can be seen that the uncertainties that have been estimated do not decisively influence the results of the cost-benefit analyses. The best estimate of the overall benefit-cost ratio for cost-effective enforcement measures in Norway is 3.94. The lower limit for this estimate is 2.59, which means that benefits still exceed costs by a wide margin. The upper limit is 6.92.

Table 20: Uncertainty in the effects of a cost-effective combination of enforcement measures in Norway. Lower and upper 95% confidence limits for benefit-cost ratio

	Estimated benefit-cost ratio of combining cost-effective types of enforcement and sanctions in Norway		
Source of uncertainty accounted for	**Best estimate**	**Lower limit**	**Upper limit**
(0) Sum of first order effects only, deterministic estimate	4.32	4.32	4.32
(1) Uncertainty in estimates of effect on accidents	4.32	2.91	5.72
(2) Uncertainty in accident costs	4.32	3.66	5.86
(3) Joint effects of several measures, deterministic estimate	3.94	3.94	3.94
(1) + (2) + (3) All sources of uncertainty combined	3.94	2.59	6.92

6.4 CONCLUSIONS BASED ON COST-BENEFIT ANALYSES

The cost-benefit analyses that have been presented in this chapter are based on rather conservative assumptions. It is unlikely that these analyses overstate the likely benefits of increasing the amount of police enforcement. Cost-benefit analyses based on Norwegian data clearly indicate that it is cost-effective to increase all types of enforcement. Marginal benefits exceed marginal costs for substantial increases in speed enforcement, seat belt enforcement and the use of speed cameras. With respect to random breath testing, a more modest increase in the amount of enforcement is cost-effective. The term cost-effective denotes an action whose marginal benefits are greater than the marginal costs.

The results of these analyses are uncertain. However, the uncertainty does not appear to be so great as to cast doubt on the main findings of the cost-benefit analysis. It can be stated with a very high degree of confidence that increasing traffic police enforcement in Norway today is cost-effective. This fact alone, however, does not mean that the priority given to different types of traffic police enforcement can, or indeed should, be based on cost-benefit analyses exclusively. The next chapter will briefly discuss some issues in priority setting for police enforcement that may not be fully addressed within the framework of cost-benefit analysis.

7 ISSUES IN PRIORITY SETTING FOR POLICE ENFORCEMENT

For a number of reasons, cost-benefit analyses can only provide a general framework for priority setting in police enforcement. Cost-benefit analyses indicate, in general terms, whether it is worthwhile strictly from the point of view of economic efficiency to increase certain types of enforcement or not. However, as shown by the discussion of the treatment of violator benefits from violations and violator outlays for traffic tickets, a straightforward application of conventional principles of cost-benefit analysis to traffic police enforcement is difficult. There is little doubt that, according to a standard interpretation of welfare economics, road user preferences as revealed in road user behaviour, ought to be respected as the correct basis of cost-benefit analyses. But this means that benefits obtained by violating the law should enter cost-benefit analyses of police enforcement as a loss sustained by being forced to comply with the law. In this report, this point of view has been rejected as politically and morally indefensible once a certain law has been passed. Before the law is passed, on the other hand, it is of course entirely appropriate to assess the likelihood of violations and the amount of effort it is worthwhile to put into enforcing the law. There is little point in passing a law, which is expected to be widely disregarded, and ineffectively enforced.

There are some issues of priority setting for police enforcement that are not adequately addressed within the framework of cost-benefit analysis. A brief discussion of these issues is called for. The issues include:

1. Putting police enforcement into a larger context: Does it compete well with other road safety measures?

2. Funding of increased police enforcement: Where should the funds come from, that would be needed to increase the amount of enforcement?

3. Selecting violations to be targeted for enforcement: Can, or ought target violations to be chosen on the basis of cost-benefit analyses exclusively?

4. The deployment of enforcement manpower: What is the most effective way of deploying manpower for enforcement?

5. Selection of enforcement methods: Should stationary or mobile enforcement be applied, should units be uniformed or civilian?

7.1 TRAFFIC POLICE ENFORCEMENT VERSUS OTHER ROAD SAFETY MEASURES

The cost benefit analyses presented in chapter six indicate that increasing police enforcement in Norway is very cost-effective. Estimated benefits are, roughly speaking, four times greater than costs. But this does not rule out that other road safety measures – like black spot treatment or new vehicle safety regulations – could be even more cost-effective. In that case, cost-benefit analyses would recommend implementing these other measures before police enforcement was stepped up. In principle, implementing other effective road safety measures could make police enforcement less cost-effective, because the number of accidents or injuries would already have been reduced by the other measures.

A recent study in Norway (Elvik 1999A) has assessed costs and benefits of a broad range of road safety measures. As part of this study, five alternative road safety strategies were proposed for Norway. One of these strategies was the "cost-benefit strategy". This strategy consists only of cost-effective road safety measures, i. e. measures for which marginal benefits are greater than marginal costs. The estimated benefit-cost ratio of various categories of measures was:

Group of measure	Benefit cost ratio
Road safety audits	1.1
Improving road design and roadside equipment etc	1.9
Improving road maintenance, especially in winter	2.5
Traffic control, including new speed limits	2.2
New motor vehicle safety standards	1.3
Driver training, public information and education campaigns	3.0
Increasing traffic police enforcement	3.3
All road safety measures	1.8

Traffic police enforcement is on top of this list. It is the most cost-effective road safety measure. It would therefore seem that, at least for the case of Norway, one cannot argue against increasing traffic police enforcement by pointing out that some other road safety measure would be even more cost-effective.

7.2 FUNDING INCREASED POLICE ENFORCEMENT

Current funding for police enforcement in Norway amounts to, in round figures, 350 million NOK per year (Hagen 1992). The only source of funding for this activity is general public funds. It has been estimated that if traffic police enforcement in Norway were increased to an optimal level, annual expenditures would increase to about 1,400 million NOK per year, or four times the current level of expenditures. In what way could such an increase in activity be funded? There are at least four alternatives:

1. Increasing the police budget, while leaving other items of public expenditure unchanged

2. Transferring funds from another budget to the police, for example by cutting road investments

3. Earmarking the income from traffic tickets to enforcement activity

4. Trying to make enforcement more effective, thereby getting more out of the money spent on enforcement.

The first option may, in many ways, seem the easiest. However, police budgets have been increasing more than other sectors of public expenditure in Norway for quite a few years, and politicians are starting to get tired of listening to the pleas of police chiefs for more people and more funds. Crime rates are not going down, say politicians. You had better deliver the goods before we give you any more money. If you can show that increasing the police force leads to less crime, we may increase funding further. Otherwise we must look for other ways of crime prevention, many politicians say.

In principle, it is possible to finance an increase in police enforcement by cutting other expenditures, in particular by transferring funds from the road sector to the police. In Norway, highway authorities are already involved in traffic enforcement. Patrols employed by the state highway agency have been granted authority to enforce the seat belt law, the law requiring crash helmets to be worn by motorcycle riders, and all technical regulations for motor vehicles, including the mandatory use of headlights during daytime. These patrols are eager to extend their jurisdiction to all types of traffic offences, but the police are against this.

A fairly large proportion of road investments in Norway consists of upgrading rural highways with a very low traffic volume. Most of these investments clearly fail the cost-benefit test: benefits are usually much smaller than costs. In theory, by cutting these investments, funds could be made available for police enforcement. There is, however, strong resistance against such an idea. The situation is, in other words, a stalemate. The state highway agency wants its patrols to be granted the full authority of police patrols, in order to be able to conduct all types of enforcement. The police oppose this. At the same time, the state highway agency does not want to part with any of its funds in order to place them at the disposal of the police. This gridlock has lasted for many years.

A study made at the Institute of Transport Economics in 1992 indicated that, in principle, traffic enforcement could be funded by earmarking the income from traffic tickets (Hagen, 1992). The income from traffic tickets that year was 394 million NOK, the costs of police enforcement, including imprisonment, were 352 million NOK. However, the ratio of income to expenditures varied substantially between different types of enforcement. Speed enforcement was clearly the most "profitable", whereas the income from fines given for drinking and driving was too small to cover the costs of random breath testing and imprisoning drinking drivers.

Random breath testing is an expensive type of enforcement. The incidence of drinking and driving in Norway is so low, that patrols may have to breath test more than 1,000 sober drivers before a drunk one finally comes along. Speeding, on the other hand, is very common. On some roads, 8 out of 10 drivers are speeding. It is therefore very easy to catch speeders.

The police are very sceptical of a system of funding enforcement by means of traffic tickets. In theory, such a system would give incentives to increase enforcement up to the point where the marginal income from tickets equalled the marginal costs of enforcement. However, this would not necessarily results in an optimal deployment of enforcement from a societal point of view unless some additional conditions were fulfilled. These conditions include:

1. The system would give the police an incentive to go for the most "profitable" types of violations. To give an optimal outcome from a societal point of view, the size of traffic tickets given to violators would then have to reflect the contribution of the violations to accidents. It is for example not optimal that parking violations are heavily fined, since these violations probably constitute a minor road safety problem.

2. A system of funding enforcement by making violators pay for it, may appear to be uncomfortably close to bribery. The system would have to contain safeguards against degenerating into bribery, as that would destroy the fairness of the system (equal treatment of similar offences).

3. Some offences, in particular drinking and driving, have a very low incidence, but involve a very substantial increase in accident risk. It may be difficult to fund the enforcement of this type of violation by means of tickets issued to violators, as each violator would then have to pay a prohibitively high ticket. Most drinking drivers live on the fringes of society. Many of them are unlicensed and unemployed, and will be unable to pay the tickets that would cover the costs of detecting them.

4. The system would put the police in the position of a monopolist. According to economic theory, a monopolist will adapt his supply to the marginal revenue curve, not to the marginal cost curve. This means that less will be supplied of the good than in a perfectly competitive market.

The fourth possibility for increasing police enforcement is to shift resources between different types of enforcement within current budget limits. This possibility is not particularly attractive, as any increase in a certain type of enforcement always means that there will be a corresponding reduction in another type of enforcement. Although there may be some possibilities of enhancing the effectiveness of police enforcement within current budget limits, these possibilities are obviously much smaller than those of increasing the total amount of enforcement.

7.3 SELECTING TARGET VIOLATIONS FOR ENFORCEMENT

The emphasis given to the enforcement of various types of violations according to a cost-benefit analysis will depend on the relationship between the marginal benefits and the marginal costs of enforcing each type of violation. According to the analyses presented in this report, the main emphasis should be put on speed enforcement and seat belt enforcement, somewhat less emphasis on random breath testing.

But there is a host of other violations that also contribute to accidents, like right of way violations, failure to yield to pedestrians at pedestrian crossings, close following, and overtaking at locations with insufficient sight distance. It would not be acceptable to stop enforcing these violations altogether, simply because they did not come on top of a list of priorities based on a cost-benefit analysis. If such a policy were announced, road users would know that some of the regulations of road traffic law could be disregarded with impunity, because they are never enforced. This could lead to more violations and, in turn, to more accidents.

Based on an analysis made for Norway, the following ranking of the ten most important violations according to their contribution to road accident fatalities can be drawn up (Elvik 1997A):

Violation	Attributable fatality risk (first order effect)
Speeding	0.190
Not wearing seat belts	0.149
Drinking and driving	0.126
Right of way violations at junctions	0.038
Failure to yield to pedestrians at crossings	0.028
Driving against red traffic signals	0.019
Not using child restraints in cars	0.010
Technical defects on heavy vehicles	0.010
Not wearing crash helmets	0.007
Violations of health regulations for drivers	0.006

An attributable risk denotes the fraction of injuries that would be eliminated if the risk factor did not exist. Hence, an attributable fatality risk of 0.19 for speeding means that the number of fatalities could be reduced by 19% of speeding was eliminated. Although the three violations on top of this list contribute a lot more to road accident fatalities than each of the other seven violations listed, it could hardly defended to stop enforcing these violations altogether. In other words, every violation must be enforced, even if – taken in isolation – the benefits of doing so may be smaller than the costs. Priorities cannot be based slavishly on a cost-benefit analysis.

7.4 CHOOSING HOW BEST TO DEPLOY ENFORCEMENT MANPOWER

Traditionally, it has been assumed that the most effective deployment of enforcement resources is obtained by targeting enforcement to road sections that have a high rate of violations or a high accident rate. In Norway, this practice is institutionalised. The police get lists of road accident black spots from highway agencies, as well as results of speed measurements made by highway agencies. Enforcement is then targeted to the worst road sections, in terms of speeding and/or accident record.

Although this sounds eminently sensible, both theoretical and empirical research suggests that it may not be the most effective way of deploying enforcement resources, at least not in the long term. Bjørnskau and Elvik (1992) argue, on the basis of a game theoretic model of the interaction between road users and the police, that the most effective way of deploying enforcement is according to a chance mechanism that is not based on the incidence of violations on a certain road. If enforcement is targeted strictly according to the incidence of violations, road users will quickly adapt their behaviour to this. The incidence of violations will be reduced at the locations subject to enforcement, but is likely to increase at other locations.

Vaa (1993) refers to empirical research that confirms this hypothesis. He compares the size of the distance halo effect of a stationary enforcement unit obtained according to different patterns of deployment. The largest distance halo effect was obtained when a police car was moved in an apparently random fashion between a set of locations. The point is that, whenever there is a systematic pattern in the deployment of enforcement, some road users will discover this pattern and use their knowledge of it to escape detection.

Research therefore suggests that the best way of deploying enforcement is, by relying on a random selection of the locations and times of deployment, thus avoiding a pattern that road users may discover. Moreover, deploying enforcement in a random pattern is fair, in that it, ideally speaking, gives every road user the same probability of becoming a subject of enforcement.

7.5 SELECTION OF ENFORCEMENT METHODS

There is a choice between civilian and uniformed patrols, and between stationary and mobile patrols. Research suggests that the most effective method is uniformed, stationary patrols. Once again, however, exceptions must be made. Some civilian patrols should be used, in order to be able to apprehend unsuspecting violators. This may be important to ensure both general deterrence and specific deterrence of notorious violators.

Stationary patrols are generally observed by more road users than are mobile patrols. On some roads, however, notably motorways, there are no suitable locations for setting up stationary police patrols. On these roads, therefore, the only possibility is to use mobile patrols.

8 GENERALISING THE RESULTS OF COST-BENEFIT ANALYSES AT THE INTERNATIONAL LEVEL

All the cost-benefit analyses that have been presented in this report are based on Norwegian data. Ideally speaking, it would have been preferable to conduct similar cost-benefit analyses for all countries that take part in the ESCAPE project. Within the time available for this project, such an international comparative analysis has not been possible. It is, therefore, appropriate to discuss briefly the possibilities of generalising at an international level the results of cost-benefit analyses made in a specific country. The discussion is based in large part on a similar discussion carried out as part of the PROMISING project, performed for the EU Commission (Elvik 1999B).

8.1 FACTORS THAT INFLUENCE THE RESULTS OF COST-BENEFIT ANALYSES

The results of cost-benefit analyses can probably only rarely be generalised from one country to another. The basic approach to cost-benefit analysis is, of course, universal. But the numerical values for costs and benefits that are put into the analyses are likely to vary widely from one country to another. Add to this the variation in accident reporting level, possibly varying effects of safety measures and varying initial levels of safety, and you get a picture of very widely varying results of cost-benefit analysis.

It is perhaps instructive to try to distinguish between legitimate and irrelevant sources of variation in the results of cost-benefit analyses. Among the legitimate sources of variation in results are:

1. Varying *economic valuation of road safety* between countries, at least in so far as it can be traced to varying income levels and varying preferences for safety. Differences that are attributable to an incomplete estimation of costs are, on the other hand, irrelevant and should be disregarded (this argument assumes that the same basic cost components are relevant everywhere).

2. Varying *levels of cost of implementing* a certain safety measure. The costs of implementing a certain safety measure are likely to vary between countries. The most comparable cost estimates are those that have been converted to a common currency, like the Euro, on the basis of exchange rates adjusted to purchasing power parity.

3. Varying *adjustment factors for incomplete accident reporting* based on the level of reporting prevailing in each country.

4. Varying *economic valuation of effects other than safety* of measures taken primarily to improve road safety. It may be the case, for example, that the costs used for travel time vary between countries. Such variations ought to be accepted on the same basis as similar variations in accident costs.

5. Varying *discount rates* used to convert future costs and benefits to present value. Differences in discount rates that are related to the real level of interest rates in a country or to the average return on capital earned by investments in a country should be retained at an international level.

6. Varying *effects of safety measures*, attributable to either (a) systematic and known differences in traffic environment between countries or (b) whether the measures are carried out as part of a package of measures or not.

If these factors are treated as legitimate sources of differences in the results of cost-benefit analyses, it means that no attempt should be made to standardise the analyses at an international level with respect to these factors. Irrelevant sources of variation should on the other hand be removed, and analyses standardised with respect to these factors. They include:

1. Differences in road accident costs, attributable to *differences in estimation methods and cost components included*. Confer the report from COST-313 (Alfaro, Chapuis and Fabre 1994) for recommendations with respect to cost elements to be included and estimation techniques to be used.

2. Differences in the valuation of other effects, like travel time, changes in pollution, and so on, related to *differences in items included and estimation techniques* used.

3. Differences in the estimated effects on safety of a specific measure that *cannot be justified in terms of research findings* documenting that the true effects differ between countries (and preferably explaining why this is the case).

4. Differences with respect to the *items included in a cost-benefit analysis*, unless there is research to show, for example, that a measure affecting travel time in one country has no effect on travel time in another country.

As these lists indicate, a fairly detailed examination a cost-benefit analyses performed in different countries is needed in order to determine if differences in the results are due to legitimate or irrelevant factors.

8.2 CONVERSION FACTORS FOR THE VALUE OF BENEFITS AND COSTS

In an attempt to make the results of the cost-benefit analyses as widely applicable as possible, conversion factors have been developed to translate results that apply to one country to another country. These conversion factors are based on comparisons of accident costs in different countries (ETSC, 1997; Miller, 1998) and adjustment factors for price levels (ESA, 1997). Table 21 presents the conversion factors. Average costs for all EU-countries are available in a report from the European Transport Safety Council (ETSC 1997).

Table 21: Conversion factors for costs and benefits of road safety measures in the EU-countries and Norway. Sources: See text

	Relative levels. Average for EU = 100				
Country	**Value of a statistical life ETSC 1997**	**Value of a statistical life Miller 1998**	**Accident costs**	**Prices of public con-sumption**	**Net correction factor**
Austria	166	116	116	116	100
Belgium	109	132	132	98	135
Denmark	70	134	134	122	110
Finland	157	111	111	97	114
France	63	123	123	111	111
Germany	189	128	128	130	98
Great Britain	103	81	81	87	93
Greece	38	26	26	57	46
Ireland	58	NA	58	78	74
Italy	126	82	82	91	90
Luxembourg	97	NA	97	141	69
Netherlands	122	125	125	104	120
Norway	NA	153	153	114	134
Portugal	63	34	34	45	76
Spain	38	54	54	77	70
Sweden	106	135	135	115	117
Mean for EU	**100**	**100**	**100**	**100**	**100**

NA = not available

The first column gives the relative level of accident costs (the value of a statistical life) in the EU-countries in 1995, according the report published by the European Transport Safety Council (ETSC, 1997). In this report, an attempt has been made to eliminate differences between countries in estimation methods affecting the level of accident costs. The costs given by ETSC include a valuation of lost quality of life ("pain, grief and suffering") caused by road accidents. The average cost for all EU-countries has been set to 100 and the costs for each country are given relative to this value. The second column gives similar estimates prepared by Miller (1998). Miller has summarised studies made in twelve countries of the willingness-to-pay for reduced risk of fatal injury. A best estimate was derived for each country. The estimates were then regressed on mean income per capita. An income elasticity of about 1.5 in the demand for safety was found. Based on this income elasticity, Miller estimated predicted values of a statistical life for several countries.

As can be seen from Table 21, the estimates of ETSC and Miller are very similar. There are some differences as well. In developing the correction factors, the values presented by Miller have been used for all countries for which they are available. For countries that Miller did not include in his survey, the values provided by ETSC have been used. The results are presented in the third column.

The fourth column gives the relative price levels for final government consumption in the EU as of 1995, according to the European Statistical Agency (ESA, 1997). The net correction factor to be used in cost-benefit analyses is the ratio of the correction factor for accident costs to the correction factor for price level. For Austria, for example, this (116/116) x 100 = 100, when setting the EU-average equal to 100. An example will show the use of the correction factors. If the benefit-cost ratio of a measure has been estimated to 1.5 for Austria, the benefit-cost-ratio of the same measure in Norway would be 1.34 x 1.5 = 2.0. For Greece it would be 0.46 x 1.5 = 0.7.

The conversion factors are very crude. They are based on accident costs and prices of government consumption only, and disregard all other impacts of road safety measures. Besides, the factors assume that the effects of the measures are the same in all countries. These assumptions are unlikely to be correct. It is nevertheless hoped that the conversion factors at least indicate the direction of the corrections that have to be made in order to transfer the results of cost-benefit analyses from one country to another.

The implications of using the conversion factors will not be explored in this report. It should be pointed out, however, that these implications are likely to be regarded as problematic in some cases. A measure that gives good value for money in, for example, Norway, will not necessarily do so in Greece and Portugal. This means that policy recommendations based on cost-benefit analyses may recommend further improving safety in countries that have a good safety record, while not introducing the same safety measures in countries that have a poorer safety record.

In addition to varying economic valuations of a given effect, one might hypothesise that the effects of enforcement on accidents vary between countries. To account for such variations, one would need to apply the results of evaluation studies made in different countries. In general, currently available evaluation studies have not been made in a sufficient number of countries to confirm that effects vary systematically between countries.

8.3 SUMMARY OF RECOMMENDATIONS IN ETSC REPORT ON POLICE ENFORCEMENT

Last year, the European Transport Safety Council (ETSC) published a report on traffic police enforcement. The report was prepared by an international group of experts, and reflects the consensus of these experts with respect to the effects of police enforcement. Excerpts from the summary of the report (ETSC 1999) is quoted below, in order to put the conclusions of the present report into a wider context.

"In comparison with other types of road safety activity, relatively little is being done to prevent road users from committing offences. In view of the many other pressing problems facing police forces, road traffic regulation enforcement typically has low priority. While traffic levels continue to rise, several European countries appear to be devoting fewer resources to traffic policing than they were several years ago.

In some cases, the scarce resources allocated are not always used optimally. Much of the knowledge that has been gained through enforcement experiments and demonstration projects carried out over the years has yet not been translated generally into strategies that effectively change road user behaviour, reduce crash risk or reduce injury severity. On the other hand, there is evidence of demonstrably effective policing activity which, if pursued more widely across Europe, could contribute significantly to casualty reduction. A very substantial safety benefit would be achieved if road users were to be deterred from committing traffic law offences. Estimates vary, but it seems reasonable to assume that the magnitude of potential crash savings would be in the order of 50 per cent.

The review includes discussion of the key traffic offences which are important for road safety and which need to be targeted in enforcement strategies. This goes beyond the enforcement of speed, alcohol and seat belt offences. Enforcement is not a stand-alone activity. There is ample evidence that enforcement is much more effective if it forms part of a systematic approach to road safety and is backed up by information and engineering measures. There is a large body of information to confirm that traffic regulation enforcement can be highly cost-effective.

What is the purpose of traffic regulation enforcement?

The main objective of traffic regulation enforcement is road safety – achieved by deterring road users from committing offences which are related to road crashes and injuries. It is not to maximise the number of infringement notices issued. Many enforcement activities are still too often directed towards detecting and apprehending the offending driver. Police activities should primarily serve as deterrence for drivers inclined to commit traffic offences through increasing road users' perception of the risk of being caught. Consistent deterrence strategies, which typically comprise highly visible police or camera activity can bring about lasting changes in road user behaviour and, as a consequence, changes in road users' attitudes which reinforce these behavioural changes.

Excess speed

Excess speed is by far the most frequent road traffic offence. The problem of excess and inappropriate speed is the most common and the most severe road safety problem. Both crash frequency and crash severity increase as driving speed increases. The potential for reducing crash injury, and particularly fatal injury, is substantial. On average, a 4 per cent reduction in crashes is estimated to occur for every 1 km/h decrease in average speed. The benefits are particularly high where vulnerable road users are involved: the probability of a pedestrian fatality reduces from 85 per cent at 50 km/h to less than 10 percent at 30 km/h.

In a recent analysis of 16 studies in which stationary speed enforcement was used alone or in combination with other enforcement methods, the average overall effect was estimated to be a 6 per cent reduction in casualties and a 14 per cent reduction in fatal crashes. Several studies have estimated the benefit-to-cost ratio of stationary speed enforcement to be between 3 and 12. Speed enforcement needs to be prolonged and intensive to obtain optimal effects.

In recent years speed camera technology has been used very cost-effectively. A recent analysis of 11 studies evaluating the effects of speed cameras found an average reduction of 19 per cent in the number of casualties. Cost benefit analysis in one Member State found that the investment in speed camera technology generated a return of 5 times the amount after 1 year and more than 25 times the amount after 5 years.

Alcohol

While drink driving is relatively infrequent, compared to other traffic offences, it is highly dangerous. For the EU as a whole a rough average of about 3 per cent of journeys are associated with an illegal BAC, but about 30 per cent of injured drivers *are under the influence of alcohol. Alcohol is one of the major causes of crashes and can increase the severity of injury outcomes.*

The key to successful enforcement strategies to reduce alcohol-related casualties is to increase drivers' perception of the probability of detection through programmes that involve the following:

1. *A high number of persons tested (at least one in ten drivers every year, one in three drivers if possible, as in Finland). This can only be achieved through wide-scale application of random breath testing and evidential breath testing,*

2. *enforcement that is unpredictable in terms of time and place, deployed in a widespread manner to ensure broad coverage of the road network and difficult (for drivers) to avoid when encountered and*

3. *highly visible police operations. Targeted policing can be employed to maximise apprehension of persistent offenders. For apprehended drivers, remedial treatment can be offered as an alternative to traditional penalties to reduce recidivism.*

Enforcement needs to be accompanied by publicity in order to inform drivers and provide them with feedback. This serves to increase public acceptance of enforcement activity and reduce public acceptance of drinking driving. The development and consistent application of such enforcement and publicity activities has been carried out notably in Finland where the number of excess alcohol offenders has fallen during the past ten years from 33 to 14 per 1000 tested drivers.

Seat belt use

Seat belt wearing is mandatory (through EU Directive) in the front and rear seats of passenger cars in European countries. However, in spite of this legislation, usage levels vary widely from one country to the next. About 75-80 per cent of EU passenger car drivers reported using seat belt in the front seats in 1996. In most countries rear seat belt use was substantially less. If every car occupant had used existing seat belts that year about 10,000 of a total of 25,000 killed car occupants in EU would have survived. About 7,000 lives could have been saved had all wearing levels been up to the best achieved internationally.

Many studies show that enforcement increases seat belt use when combined with other activities such as information campaigns. The best way of achieving increases currently is through intensive, highly visible and well publicised enforcement. So-called 'blitz' approaches have been shown to be extremely effective in producing sharp increases in seat belt use. If such 'blitz' enforcement, usually lasting only one to four weeks, is repeated several times a year, high levels of wearing rates can be maintained. The

STEP enforcement and publicity campaigns carried out in Canada have also been shown to be most effective. Several studies have estimated that the benefit-to-cost ratio of such seat belt enforcement programmes is of the order of 3 or above.

Priority or "right of way" offences

Failure to observe red lights or pedestrian crossing lights is a major safety issue in urban areas. The same applies to offences which involve failure to observe the priority or right of way of other road users, which comprise about half of the road collisions in urban areas. However, little enforcement effort is devoted to these types of offences. The same observation applies to offences such as use of restricted lanes, making U-turns or turning left or right where prohibited or overtaking in chevron-indicated areas. All these types of behaviour emerge as disproportionately risky in crash analysis but are rarely the targets of systematic enforcement.

However, camera technology is being used increasingly and very cost-effectively to prevent red light running amongst car drivers. Cost benefit analysis of red light camera operation in one Member State indicates that the return was nearly twice the investment after one year and twelve times this by year five.

Proposals for effective traffic law enforcement in EU countries

While traffic regulation enforcement is a matter for Member States, the EU can play an important role in its road safety programme in encouraging information exchange on effective strategies, disseminating research-based information in EU programmes and carrying out new research. The following recommendations are made, in particular, for action by those responsible for defining, promoting and implementing enforcement strategy at local, national and EU levels.

On the basis of detailed crash data analysis, set specific targets nationally for compliance with key traffic offences which influence road safety levels – the arrangements for doing so will vary from country to another. These targets specify the offences to be enforced and the acceptable compliance level for each offence after enforcement in quantitative terms (for example, 95 per cent seat belt use). These offences include, as a minimum, the general target behaviours (speed, drinking-driving, and seat belt use) but also other safety-relevant offences relevant for the country.

For each offence, integrate police enforcement activities into the national traffic safety policy relevant to that offence, at least including publicity activities.

In each country formulate for each offence, effective and feasible police enforcement strategies. These strategies should take into account the results achieved in experimental or demonstration projects carried out elsewhere, specify the means and *methods of police enforcement and specify the allocation of resources. Increase effectiveness of detection by allowing random breath testing and camera evidence for offences such as speeding, red light violations and tailgating.*

In each country identify offences that could be dealt with under administrative or civil law rather than criminal law.

Develop information and training resources in order to increase awareness and competence of police enforcement staff.

Obtain explicit agreements between the various actors (legislators, police, prosecuting bodies) about the consequences that follow detection of offenders.

As part of the EU road safety information system, communicate the results of specific demonstration projects amongst policymakers and police.

Encourage and support the establishment of an effective network of traffic police in Europe. As part of the Fifth Framework Programme, set up an EU-wide monitoring project to allow objective comparison of the incidence of specific offences and the incidence of crashes related to these offences."

These conclusions appear to accord very well with those of the present report.

9 DISCUSSION AND CONCLUSIONS

There is little doubt that traffic law violations are a major road safety problem in many countries. Although precise estimates of the contribution of traffic law violations to road accident occurrence are not available for all EU countries, there is no doubt a large potential in all countries for improving road safety by making road users comply with road traffic law.

Police enforcement is an effective measure to ensure better compliance with road traffic law. The chief benefit of more effective enforcement will be a reduction in the number of road accident fatalities and injuries.

Cost-benefit analyses indicate that there is too little enforcement today, and that it would be highly cost-effective to increase enforcement substantially. It should be noted, however, that the conventional framework for cost-benefit analysis, as given by economic welfare theory, cannot be applied to cost-benefit analyses of traffic police enforcement. More specifically, it would be wrong to count the benefits that violators get from violations as a societal benefit in cost-benefit analyses of enforcement. Counting the benefits of violations as a societal benefit would confer a moral legitimacy to violations that cannot be defended as a general practice. It would, as an example, be absurd to count the "benefits" of a murder as a gain to society in cases of homicide. The fact that most traffic violations do not have an identifiable victim is irrelevant to this assessment. It is, at least for the case of Norway, highly likely that more people die every year as a direct result of traffic violations than those who are assassinated.

The results of cost-benefit analyses presented in this report are likely to apply to most motorised countries. Speeding, drinking and driving and not wearing seat belts are serious offences, committed by many road users in many countries. Speeding is likely to be the most common type of traffic violation in most countries. It is, moreover, a violation that contributes more to road accidents than perhaps any other type of violation.

While cost-benefit analyses indicate that the benefits to society of more traffic police enforcement would greatly exceed the costs, these analyses do not by themselves constitute an adequate basis for planning enforcement in detail. It may not be possible to set priorities for enforcement strictly on the basis of cost-benefit analyses. Setting priorities strictly according to such analyses might result in some types of violations never being enforced at all. It is, however, necessary to have a certain minimum level of enforcement of all types of violations in order to prevent them from becoming legalised by default.

Moreover, one should not forget the difficulties of generalising the results of cost-benefit analyses at the international level. The level of accident costs, as well as the current risk of apprehension, vary substantially between countries. One should therefore always base cost-benefit analyses on national data.

REFERENCES

Alfaro, J-L.; Chapuis, M.; Fabre, F. (Eds) (1994) COST 313. Socioeconomic cost of road accidents. Report EUR 15464 EN. Brussels, Commission of the European Communities.

Andersson, G. (1991) Effekter på hastigheter av intensifierad övervakning med radar. Transportforskningberedningen (TFB) og Statens väg- och trafikinstitut (VTI) forskning/research nr 6. Stockholm.

Bjørnskau, T.; Elvik, R. (1992) Can road traffic law enforcement permanently reduce the number of accidents? Accident Analysis and Prevention, 24, 507-520.

Blomquist, G. C. (1979) Value of life saving: implications of consumption activity. Journal of Political Economy, 87, 540-558.

Cerwenka, P.; Hauger, G.; Klamer, M. (1998) Postmoderne Kabbalistik zur volkswirtschaftlichen Rechtfertigung von Verkehrsüberwachung? Zeitschrift für Verkehrssicherheit, 44, 3, 98-103.

Cirillo, J. A. (1968) Interstate System Accident Research Study II, Interim Report II. Public Roads, 35, 71-75.

Elvik, R. (1993) Økonomisk verdsetting av velferdstap ved trafikkulykker. Dokumentasjonsrapport. TØI rapport 203. Oslo, Transportøkonomisk institutt.

Elvik, R. (1994) The external costs of traffic injury. Definition, estimation and possibilities for internalisation. Accident Analysis and Prevention, 26, 719-732.

Elvik, R. (1997A) Vegtrafikklovgivning, kontroll og sanksjoner. Potensialet for å bedre trafikksikkerheten og nytte-kostnadsvurdering av ulike tiltak. TØI notat 1073. Oslo, Transportøkonomisk institutt.

Elvik, R. (1997B) Effects on accidents of automatic speed enforcement in Norway. Transportation Research Record, 1595, 14-19.

Elvik, R. (1999A) Bedre trafikksikkerhet i Norge. TØI rapport 446. Oslo, Transportøkonomisk institutt.

Elvik, R. (1999B) Cost-benefit analysis of safety measures for vulnerable and inexperienced road users. TØI report 435. Oslo, Institute of Transport Economics.

Elvik, R.; Amundsen, A. H. (2000) Improving road safety in Sweden. Draft report in preparation. Oslo, Institute of Transport Economics.

Elvik, R.; Mysen, A. B.; Vaa, T. (1997) Trafikksikkerhetshåndbok. Tredje utgave. Oslo, Transportøkonomisk institutt.

Engdahl, S.; Nilsson, E. (1983). Trafiköververvakningens långsiktiga effekter på olyckor och beteenden. TFD rapport 1983:13. Stockholm, Transportforskningsdelegationen.

European Transport Safety Council. (1997) Transport accident costs and the value of safety. Brussels, European Transport Safety Council.

European Transport Safety Council. (1999) Police enforcement strategies to reduce traffic casualties in Europe. Brussels, European Transport Safety Council.

Eurostat. (1997) Comparison in real terms of the aggregates of ESA. Table 2 Price level indices. Provided by Statistics Norway, Oslo.

Evans, L. (1991) Traffic safety and the driver. New York, NY, VanNostrand Reinhold.

Glad, A. (1985) Research on drinking and driving in Norway. A survey of recent research on drinking and driving and on drinking drivers. State-of-the-art report 15, series "Transport and Communications". Oslo, Institute of Transport Economics.

Gottfredson, M. R.; Hirschi, T. (1990) A general theory of crime. Stanford, Ca, Stanford University Press.

Hagen, K-E. (1992) Kostnads- og inntektsanalyse av politiets trafikkontroller. TØI rapport 116. Oslo, Transportøkonomisk institutt.

Hanley, N.; Spash, C. L. (1993) Cost-benefit analysis and the environment. Edward Elgar, Aldershot.

Harsanyi, J. C. (1982) Morality and the theory of rational behavior. In Sen, A. K.; Williams, B. (Eds): Utilitarianism and Beyond, 39-62. Cambridge, Cambridge University Press.

Kidholm, K. (1995) Estimation af betalingsvilje for forebyggelse af personskader ved trafikulykker. Udgivelse 21 i serien: Afhandlinger fra det samfundsvidenskabelige fakultet på Odense Universitet. Odense.

Knoflacher, H. (1998) Eine Kosten-Nutzen-Analyse der Verkehrsüberwachung. Zeitschrift für Verkehrssicherheit, 44, 1, 12-18.

Leite, M. E. (1998) Bruk av bilbelter blant førere og passasjerer. Fra 1973 til 1997. Rapport TTS 2 1998. Oslo, Vegdirektoratet, Transport og trafikksikkerhetsavdelingen, Transportanalysekontoret, 1998.

Miller, T. R. (1998) Variations between countries in values of statistical life. Unpublished manuscript. Landover, MD, National Public Service Research Institute.

Mishan, E. J. (1972) Evaluation of life and limb: a theoretical approach. In Layard, R. (Ed): Cost-benefit analysis. Selected Readings, 219-242. Harmondsworth, Penguin Books. Originally published in the Journal of Political Economy, 79, 1971, 687-705.

Munden, J. M. (1966) An experiment in enforcing the 30 mile/h speed limit. RRL Report No 24. Harmondsworth, Road Research Laboratory.

Nilsson, G. (1984) Hastigheter, olycksrisker och personskadekonsekvenser i olika trafikmiljöer. VTI rapport 277. Linköping, Statens Väg- och Trafikinstitut.

Rawls, J. (1971) A theory of justice. Cambridge, Mass, Harvard University Press.

Sager, T. (1974) Økonomisk vurdering av bot eller fengsel som promilledom. TØI-notat 161. Oslo, Transportøkonomisk institutt.

Schwab-Christe, N. G.; Soguel, N. C. (Eds) (1995) Contingent Valuation, Transport Safety and the Value of Life. Boston, MASS, Kluwer Academic Publishers.

Shoup, D. C. (1973) Cost effectiveness of urban traffic law enforcement. Journal of Transport Economics and Policy, 12, 32-57.

Udvarhelyi, I. S.; Colditz, G. A.; Rai, A.; Epstein, A. M. (1992) Cost-effectiveness and cost-benefit analyses in the medical literature: are the methods being used correctly? Annals of Internal Medicine, 116, 238-244.

Vaa, T. (1993) Politiets trafikkontroller: Virkning på atferd og ulykker. En litteraturstudie. TØI rapport 204. Oslo, Transportøkonomisk institutt.

Vaa, T. (1995) Politiets fartskontroller: Virkning på fart og subjektiv oppdagelsesrisiko ved ulike overvåkingsnivåer. TØI rapport 301. Oslo, Transportøkonomisk institutt.

Vaa, T. (2000) Effects of police enforcement measures on accidents and levels of injury. Working paper SM/1104/2000. Oslo, Institute of Transport Economics.

Waard, D. De; Rooijers, T. (1994) An experimental study to evaluate the effectiveness of different methods and intensities of law enforcement on driving speed on motorways. Accident Analysis and Prevention, 26, 751-765.

Østvik, E.; Elvik, R. (1991) The effects of speed enforcement on individual road user behaviour and accidents. Chapter 12, 56-59, in Koornstra, M. J.; Christensen, J. (Eds): Enforcement and Rewarding: Strategies and Effects. Proceedings of the International Road Safety Symposium in Copenhagen, Denmark, September 19-21, 1990. Leidschendam, SWOV Institute for Road Safety Research.