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Can the use of road safety measures on national roads in Norway be interpreted as an informal application of the ALARP principle?

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ABSTRACT

The ALARP principle, stating that risks should be reduced to a level "As Low As Reasonably Practicable", is widely known and discussed in risk management. The principle is flexible, as the interpretation of the key concepts of reasonable and practicable can be adapted to different contexts. This paper discusses whether the use of road safety measures on national roads in Norway can be interpreted as an informal application of the ALARP-principle. According to official guidelines, priority setting for major road investments should be based on cost-benefit analysis. Most road safety measures are low-cost projects that have traditionally not been subject to cost-benefit analysis. A use of these measures regarded as reasonable in the ALARP sense may include considerations of cost, efficiency and fair distribution. Data on 328 road safety measures implemented around 2000 is used to evaluate factors influencing their use. It is argued that the use of these measures is consistent with an informal application of the ALARP-principle.

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Key words: Efficiency; fairness; ALARP; safety measures; roads; accidents

1 INTRODUCTION

In Norway, the Ministry of Transport and Communications has the overall responsibility for road safety policy-making. Together with several executive agencies, including particularly the Norwegian Public Roads Administration (NPRA), it develops and issues every fourth year a National Transport Plan (NTP), which is mainly a programme for major investments in infrastructure (see e.g. Ministry of Transport and Communications, 2017). To plan road safety measures, a supplementary plan, the National Action Plan for Road Safety, is developed. This plan lists road safety measures that will be implemented during the next four years.

According to formal guidelines, the priority given to major investments should be based on cost-benefit analyses. However, previous studies by Fridstrøm and Elvik (1997), Odeck (2010), Sager and Sørensen (2011), Eliasson et al. (2015), and Sager (2016), have found that actual priorities are hardly related to the results of the cost-benefit analyses. For minor projects, which includes most road safety measures, there is no requirement to perform cost-benefit analysis. Traditionally no such analyses have been made of road safety measures. Software to support cost-benefit analyses of road safety measures has only existed for a little more than ten years.

Despite the absence of cost-benefit analysis, the use of road safety measures seems to be quite efficient. The implementation of road safety measures was studied in detail for national roads for the year 1986 (Elvik 1987) and again for years surrounding the year 2000 (Elvik and Rydningen 2002). Both studies found that road safety measures tend to be implemented on roads with a high traffic volume and a high accident rate (accidents per million kilometres of travel), i.e. locations where the benefits are likely to be large. On the other hand, Elvik (2004) found that quite a few road safety measures were implemented at low-risk locations where no accidents or injuries had been recorded in the last four years. Efficiency, i.e. value for money, is thus not the only factor influencing the use of road safety measures.

2 THE ALARP-PRINCIPLE AS APPLIED TO ROAD SAFETY

Can the use of road safety measures on national roads in Norway be regarded as an informal application of the ALARP principle? ALARP refers to the level of accident risk and means "as low as reasonably practicable". It can be interpreted as a more flexible guideline for priority-setting than cost-benefit analysis (French et al. 2005, Jones-Lee and Aven 2011, Ale et al. 2015, Hurst et al. 2019). Official documents contain no explicit reference to this principle; hence, any use of it is implicit and informal. To judge whether implementing a safety measure is reasonable or not according to the ALARP-principle, one does not necessarily rely on a formal comparison of its costs and benefits. Rather, safety measures are implemented, except when they involve grossly disproportionate costs.

The studies quoted above take different points of view with respect to the relationship between ALARP-thinking and cost-benefit analysis. French, Bedford and Atherton (2005) assess the support cost-benefit analysis and multi-attribute utility theory can give to decision making based on the ALARP-principle. They conclude that cost-benefit analysis does not allow for disproportionate costs; benefits must be greater than costs, otherwise the measure is rejected. They argue that multi attribute utility theory is a more flexible tool, which explicitly recognises the subjectivity of the criteria decision makers base their decisions on. Jones-Lee and Aven (2011), on the other hand, regard the use of cost-benefit analysis as entirely consistent with the ALARP-principle, but discuss whether "gross disproportion" between costs and benefits, i.e. that costs exceed benefits, can be justified. They identify four cases in which cost-benefit analysis would approve of measures even if costs exceed benefits, i.e. in these cases it would be reasonable to implement the measures.

The first case is when accidents can have large external effects that are not included in monetary valuations of safety. As an example, major accidents in aviation and rail transport can affect travel demand, leading to losses to transport companies that are not included in willingness-to-pay estimates of the value of safety the way these are normally obtained. The second case is when there is large uncertainty about the risk involved in an activity. It can then be argued that decisions about permitting the activity should be guided by the precautionary principle, and err on the side of safety. The third case is when the level of risk is high. The monetary valuation of risk reductions is positively related to the level of risk and could be substantially higher for a high risk than for a low risk. Finally, it can be argued that a policy asking business firms to implement safety measures they regard as costly may create incentives to minimise costs, i.e. find the most cost-effective ways of improving safety.

Ale, Hartford and Slater (2015) state that ALARP and cost-benefit analysis both seek to guide decision-making and will not necessarily lead to different policy recommendations. In particular, they point out that estimates of the value of a risk reduction corresponding to the prevention of a fatality, often called the value of a statistical life, have been found to vary enormously and depend both on the method for eliciting the value and on characteristics of the societal context. Hence, there is not always a clear and convincing answer to the question of whether benefits exceed costs or vice versa.

Fairness in the distribution of risks, i.e. seeking to reduce disparities in risks is implied by the ALARP-principle. If, for example, there is a choice between measure A, which will reduce a comparatively low risk to an even lower level, and measure B, which will reduce a comparatively high risk to a level closer to the risk influenced by measure A, ALARP would favour measure B, even if it was (within limits) more expensive than measure A, as that would result in a lower overall level of risk than measure A. Taken together, the points raised in the papers discussed above suggest that use of the ALARP-principle to guide priority setting for road safety measures implies that:

1. Costs and benefits of safety measures will be considered, but only as a guideline and not as an absolute requirement. Some implemented road safety measures will have benefits greater than costs, others costs greater than benefits.
2. All else being equal, reducing a high risk will be regarded as more important than reducing a low risk. Marginal spending on reducing high risk will be greater than marginal spending on reducing a low risk.
3. Fairness in the distribution of risk will be favoured along two dimensions in addition to the level of risk: relative deprivation and variation between groups of road users.
4. Elements of ALARP-thinking are analogous to the precautionary principle, aiming to prevent latent risks before they become manifest in the form of accidents. Thus, it is consistent with ALARP to implement safety measures, even if accidents have not been recorded in the recent past.

These implications are not entirely consistent. In particular, a precautionary approach of implementing measures at comparatively safe locations is inconsistent with favouring the treatment of high-risk locations. However, trying both to keep a low risk low while at the same time aiming to reduce a high risk can be defended by reference to ALARP-thinking.

3 DATA ON THE USE OF SAFETY MEASURES ON NATIONAL ROADS

To assess whether the use of road safety measures on national roads in Norway can be interpreted as an informal application of ALARP-thinking, data on 328 road safety measures implemented around the year 2000 have been applied (Elvik and Rydningen 2002). The data covered road safety measures implemented during a period of about four years. For each measure, the following data were collected:

1. The type of measure; 17 different road safety measures were identified.
2. The county where the measure was implemented.

3. The annual average daily traffic (AADT) at the location.
4. The number of killed or injured road users in the last four years, by severity.
5. The cost of implementing the measure.

These data were later augmented by adding the following items:

1. The municipality where a measure was implemented.
2. A deprivation score for each municipality.
3. An empirical Bayes estimate of the expected number of injured road users at each location (Elvik 2004).
4. An estimate of any future maintenance or operation costs for measures, if relevant.
5. Cost-benefit analyses of the measures.

For each road safety measure, the road where it was implemented was stated by road number, section number and kilometre post. These data made it easy to identify the municipality where the measure was implemented. For each measure, the municipality was added. It is then possible to examine how widely spread among municipalities the road safety measures are.

A deprivation score was computed for each municipality. It was based on two items. The first was changes in population from 1995 to 2005. This was estimated as the ratio of population in 2005 to population in 1995. In most cases, this ratio had a value close to 1, but some municipalities experienced a decline in population, making the ratio less than 1. The second item was the ratio of mean income per household in the municipality to the mean income per household for Norway as a whole. Values above 1 indicate that households in a municipality on average have higher income than an average household in Norway. To obtain the deprivation score, the values for population and income were multiplied. The deprivation score ranged from 0.63 to 1.74.

A deprived municipality may have fewer resources for improving road safety than a wealthy municipality. Deprived municipalities may therefore, to a larger extent, be more favoured by road safety measures on national roads that the municipality does not pay for than wealthier municipalities.

Empirical Bayes estimates were developed in order to control for regression-to-the-mean. Regression-to-the-mean is observed in accident data that refer to a short time period, in this case four years. In such a short period, the recorded number of accidents or injured road users may be higher or lower than the long-term expected number of accidents or injured road users. Quite a few of the sites where road safety measures were implemented recorded 0 injured road users, but that does not mean that the long-term expected number of injured road users is zero. The expected number of injured road users is always a positive number.

The empirical Bayes method (Hauer 1997) applies accident prediction models to estimate a normal, expected number of accidents or injured road users for sites with a given combination of values for variables influencing the expected number of accidents or injured road users, e.g. a given AADT, number of lanes and speed limit. However, no such model can include all factors that influence the number of accidents. There will always be local factors that cannot be included in an accident prediction model. To capture the influence of such factors, the empirical Bayes method estimates the long-term expected number of injured road users as a weighted average of the model-predicted number and the recorded number:

Long-term expected number = (model-predicted number · weight) + (recorded number · (1 – weight))

The value of the weight depends on how well the accident prediction model explains systematic variation in the number of accidents or injured road users. The higher the explanatory performance of the model, the larger the weight. The weight takes on values between 0 and 1, and so does the complementary weight, which is applied to the recorded number of accidents or injured road users.

To give an example, consider three-leg junctions that were converted into roundabouts. There were 27 projects of this type. The recorded number of injured road users before conversion varied between 0 and 13. In total, 81 injured road users were recorded. The model-predicted (normal) number of injured road users was 34.8, showing that, as a group, the junctions had an abnormally high number of injured road users before conversion to roundabouts. The long-term expected number of injured road users was estimated to be 68. The long-term expected number is always between the recorded number and the model-predicted number. Figure 1 shows the recorded, model-predicted and long-term expected numbers of injured road users for all 27 junctions.

Figure 1 about here

After correction for regression-to-the-mean, all 328 sites had a positive expected number of injured road users.

The data collected stated the investment costs of each measure. Some measures can be expected to have future maintenance and operation costs, in addition to the investment cost. Thus, for road lighting, for example, there will be costs of electricity consumed. There will also be occasional costs for repair, both of burned-out lamps and lighting posts that may be struck by cars or get out of position due to frost action in the soil. Estimates of these costs were added to investment costs when relevant.

Finally, cost-benefit analyses, relying on conservative assumptions, were made of all 328 projects. These analyses relied on the monetary valuations recommended in 2002 for road safety, travel time and other impacts. These valuations are revised every few years. The valuations in 2002 of the main items were 22 million NOK per prevented fatality, 6.2 million NOK per prevented serious injury and 0.66 million NOK per prevented slight injury. One vehicle hour was valued at NOK 125. The time horizon was 25 years and an annual discount rate of 8 % was used. This is much higher than the currently recommended rate of 4 %. However, the future benefits of road safety measures may decline faster than the future benefits of many other investments, because there is a long-term trend for road safety to improve. This trend is partly attributable to road safety measures, partly to other, largely unknown factors (Høye, Bjørnskau and Elvik 2014). At any rate, it is reasonable to assume that, for example, a junction that had an expected number of injured road users around 2000 of, say, 0.6 per year, would have an annual expected number of injured road users closer to 0.3 today, even if no safety measure had been implemented at the junction between 2000 and now.

The age of the data may raise doubts about their relevance for current road safety policy. Unfortunately, more recent data at this level of detail are not available. However, similar data were collected on road safety measures implemented on national roads in 1986 (Elvik 1987). A comparison of key statistics from the two data sets indicates whether the selection of sites for the implementation of road safety measures is stable over time or not. Two important factors influencing the number of accidents is traffic volume (AADT = Annual Average Daily Traffic) and accident rate (accidents per million vehicles (junctions) or vehicle kilometres (road sections)). As mentioned in the introduction, road safety measures tend to be implemented at locations with a high traffic volume and above-average accident rate. Table 1 shows key statistics for the road safety measures that were included in both studies (Elvik 1987, Elvik and Rydningen 2002).

Table 1 about here

The statistics show very similar values. This indicates that there is great stability in the criteria used by road authorities when deciding where to implement road safety measures. Nothing suggests that there have been major changes after 2000 with respect to how sites are selected for the implementation of road safety measures.

4 A COST FUNCTION FOR ROAD SAFETY PROVISION

Based on the data collected about each project, it is possible to estimate a cost function for the provision of road safety. This was done as follows. For each project, the marginal annual cost of preventing an injury was estimated. To give an example, the cost of converting a specific junction into a roundabout was 2.1 million. The expected number of injured road users (for a four-year period) was estimated to be 0.33. Converting the junction to a roundabout was estimated to prevent 0.11 injured road users. Estimates of the effects of road safety measures were to a large extent taken from the Handbook of Road Safety Measures (Høye et al. 2019). Table 2 presents the estimates of safety effects that were applied for each road safety measure.

Table 2 about here

The estimate of 0.11 prevented injuries in the junction converted to a roundabout is the sum of three terms:

Number of prevented injuries = $[(0.33 \cdot 0.012) \cdot 0.58] + [(0.33 \cdot 0.180) \cdot 0.46] + [(0.33 \cdot 0.808) \cdot 0.30]$

The first bracket refers to fatal injuries (which make up 1.2 % of the total = 0.012), which are reduced by 58 %, the second bracket refers to serious injuries (0.180; reduced by 46 %), the third bracket refers to slight injuries (0.808; reduced by 30 %). This method was used to estimate the effects of all road safety measures.

Marginal cost was estimated as:

Marginal annual cost of preventing an injury per year = $(2{,}100{,}000/10.675)/(0.11/4) = 7{,}127{,}953$.

In the numerator, the investment cost is converted to an annuity by dividing it by the accumulated discount factor for 25 years at 8 % annual discount rate (10.675). In the denominator, the number of injuries prevented for a period of four years (0.11) is divided by 4 to get the annual number of prevented injuries. The cost per injury prevented is slightly more than 7 million NOK. In this case, the marginal cost of preventing an injury was higher than the investment cost. This need not be the case, as this example shows:

Marginal cost of preventing an injury per year = (16,200,000/10.675)/(3.66/4) = 1,656,669.

The marginal cost per injury prevented per year was defined for 269 of the 328 projects. For the remaining projects, the road safety measure was assumed to have had no effect on injuries or had been found to be associated with an increase in the number of injured road users (environmental streets; see Elvik 2012). In these cases, marginal cost per injury prevented is infinite.

Projects were ranked from lowest to highest marginal cost. The cost function shown in Figure 2 was then derived. The total cost of all 328 projects was 1,138,269,914 NOK or slightly more than 1.1 billion NOK (1 NOK = 0.118 US dollars in April 2019). The total estimated number of injured road users prevented annually was 47.6. This is a surprisingly small number, considering the fact that the total annual number of injured road users in police reported accidents around the year 2000 was about 12,150. The estimated annual reduction attributable to road safety measures implemented on national roads was just 0.4 % of the total annual number of injured road users.

Figure 2 about here

As can be seen from Figure 2, the cost of preventing an injury rises slowly for most of the range of the cost function. Of the total annual number of injured road users prevented, 80 % is accomplished for a cost of 188 million NOK or 16.5 % of the total cost of the measures. The vertical part of the cost function refers to measures with no known benefit in terms of injury prevention, for which marginal cost per injury prevented is infinite. The lowest cost per injury prevented was 13,725 NOK, the highest cost (except for the cases of infinite cost) was 169,299,174 NOK. The cost per injury prevented is closely related to the estimated benefit-cost ratio. The lowest cost per injured road user prevented for a measure with benefits smaller than costs was 408,917 NOK. The highest cost per injured road user prevented for a measure with benefits greater than costs was 8,523,581 NOK. The mean cost per injury prevented was 23,902,564 NOK.

4 REDUCING HIGH RISK

To assess whether more is spent on reducing high risks than low risks, as one would expect according to ALARP-thinking, sites for which marginal spending per injury prevented was finite were grouped according to the ratio of the EB-estimate of the expected number of injuries and the model-predicted number of injuries. Sites where this ratio was above 1 can be regarded as high-risk, sites where it was below 1 can be regarded as low-risk. Table 3 shows the results of the analysis.

Table 3 about here

The hypothesis that more is spent to prevent high risks than low risks, and that lower benefit-cost ratios are accepted when preventing high risks than low risk is not supported. On the contrary, marginal spending per injury prevented is higher at low-risk sites than at high risk sites. This finding is not consistent with the ALARP-principle.

5 FAVOURING DEPRIVED MUNICIPALITIES

The data collected on road safety measures were provided by all counties in Norway except for Østfold, Vestfold and Aust-Agder. The number of municipalities in Norway in 2001, excluding the three counties not providing data on road safety measures, was 387. One or more road safety measures were implemented in 160 municipalities. There were 328 road safety projects in total. Thus, the maximum possible dispersion of these would be one in each of 328 municipalities, leaving no projects in the remaining 59 municipalities. Spreading the projects among 160 municipalities means that, on average, 2.05 projects were implemented in each municipality

(328/160). In more than half of the municipalities where a road safety measure was implemented, only one measure was implemented. This applied to 88 of the 160 municipalities. The largest number of projects carried out in one municipality was 15 in Oslo.

Are deprived municipalities favoured by the implementation of a higher share of comparatively costly measures, with a low benefit-cost ratio, compared to wealthier municipalities? Table 4 explores this question. It includes data about all projects. Marginal cost in projects not reducing the number of injured road users was set to zero (rather than infinity). All these projects had other benefits than reducing traffic injury and may therefore have a favourable benefit-cost ratio despite not improving road safety. In Table 4, municipalities have been divided into four groups based on deprivation score. Benefit-cost ratio (BC-ratio) has been divided into greater than 1 and lower than 1.

Table 4 about here

Slightly less than half of the projects have an estimated benefit-cost ratio of less than 1. In municipalities that score above 1 on the deprivation scale (with population growth and/or income above average), the majority of projects had an estimated benefit-cost ratio above 1. In more deprived municipalities (deprivation score below 1), the majority of projects had a benefit-cost ratio below 1. It is seen that the majority of projects (215 out of 328) were implemented in municipalities with a deprivation score below 1. Marginal spending increased with declining deprivation score and was highest in the most deprived municipalities. These results show that deprived communities are favoured by higher spending on road safety measures than more wealthy communities. This pattern can be viewed as consistent with the ALARP-principle.

6 FAVOURING VULNERABLE ROAD USER GROUPS

Pedestrians and cyclists have a higher risk of injury per kilometre of travel than car occupants (Bjørnskau 2015). In Table 2, the road user groups that mainly benefit from the road safety measures were identified. Five road safety measures were listed as reducing injuries to pedestrians or cyclists. Do these measures have a lower benefit-cost ratio than the other measures and a higher share of project with benefits smaller than costs? If they do, that indicates that ALARP-thinking may be applied informally to go further in trying to reduce the risks faced by pedestrians and cyclists than the risks faced by motorists.

Table 5 shows the benefits, costs and benefit cost ratio for all road safety measures.

Table 5 about here

The five top rows of Table 5 contain the road safety measures specifically targeted at pedestrians or cyclists. The sum of benefits for these measures is NOK 628.3 million. The sum of costs is NOK 834.3 million. Benefit-cost ratio is 0.75. For the other road safety measures listed in Table 5, the summary benefit-cost ratio is 1.33. For road safety measures targeted at pedestrians or cyclists, the share of projects with benefits smaller than costs was 62 % (69 of 112). For the other road safety measures, the share of projects with benefits smaller than costs was 42 % (90 of 216). These statistics show that more is spent on road safety measures benefitting pedestrians or cyclists than on other road safety measures. This tendency is consistent with the ALARP-principle of targeting the reduction of high risks rather than low risk and seeking to reduce disparities in risks.

7 COMPENSATORY THINKING AS A FORM OF REASONABLENESS

Normative models of rational choice emphasise that compensatory thinking is an essential element of rationality. Compensatory thinking is embedded in the assumptions of complete and continuous preferences. Completeness means that everything can be compared and that you are always able to form a preference, rather than simply say: These things cannot be compared, and it makes no sense to choose between them. Continuity means that gains and losses are comparable in the same metric, so that you can say whether a certain loss can be compensated for by another gain. This is the essence of compensatory thinking as implemented within cost-benefit analysis. You add up different effects and determine whether benefits are greater than costs. What counts is total benefits. It is inconsistent with the principles of cost-benefit analysis to have a lexicographic preference for a certain type of benefit and to prefer projects giving that benefit, no matter what the other effects are.

The ALARP-principle can be interpreted as encouraging compensatory thinking with respect to the implementation of safety measures but of a different kind than the compensatory thinking within cost-benefit analysis. Within an ALARP framework, it may be regarded as reasonable to compensate for projects producing a large surplus of benefits over cost, by implementing additional projects where benefits are smaller than costs.

For all types of road safety measures, except for installing traffic signals in three-leg or four-leg junctions, the projects are a mixture of those with benefits greater than costs and those with costs greater than benefits. This can be seen from Table 6.

Table 6 about here

A small majority of the projects (51.5 %) had benefits greater than costs. One might therefore expect that about half of the measures gave benefits greater than costs and half, the opposite. In fact, most measures had benefits greater than costs; see Table 5. Benefits are greater than costs for 13 out of 17 measures. Even for some measures where nearly half of the projects have smaller benefits than costs (for example, horizontal curve treatments), benefit-cost ratios are very good (8.17 for curve treatments). However, when benefits and costs are summed for all measures, the benefits are just a trifle greater than the costs, consistent with the fact that only a little more than half of the projects had benefits greater than the costs. This pattern can be interpreted as the result of compensatory choices made by the road administration when implementing road safety measures.

To explain the compensatory mechanism, it is instructive to develop a numerical example. To simplify, divide projects into those that have benefits greater than costs and those that have benefits smaller than costs. As shown in Table 6, the share of projects in each group varies between road safety measures. There is also variety in how much greater the benefits are than the costs, for projects that have benefits greater than costs, and how much smaller the benefits are than the cost for projects that have benefits smaller than costs. The following compensatory thinking is proposed:

When benefits are much larger than costs, one can afford to implement a large number of additional projects for which benefits are smaller than costs, while the full set of projects, including both those with benefits > costs and those with benefits < costs, still has a surplus of benefits over costs. When, on the other hand, benefits are only slightly greater than costs, one cannot afford to implement very many or costly projects with benefits < costs without making the sum of benefits for all projects smaller than the sum of costs. It is not suggested that policy-makers consciously engage in this sort of compensatory thinking. They would probably not be able to do so, since decisions about the implementation of road safety measures are made at the local level and decision-makers typically do not know which road safety measures are being implemented in other parts of the country. Nevertheless, even without cost-benefit analysis, a decision-maker can have, and probably has, an intuitive idea about whether, and by how much, benefits are greater or smaller than costs. The costs are known, and so is the number of injuries that can be prevented. ALARP operates at an intuitive and informal level; a policy consistent with it does not necessarily rest on formal analyses. Policy-makers form an impression of what seems reasonable. It is therefore fruitful to assume that policy-makers behave as if they engage in compensatory thinking, even if they do not consciously do so.

The proposed compensatory behaviour is illustrated in Figure 3. Two measures are used as examples. The horizontal axis shows costs stated as a percent. The vertical axis shows benefits as multiple of the costs in percent.

Figure 3 about here

For the first measure, projects with benefits > costs have an average BC-ratio of 19.92. This implies that one can add a substantial number of projects with benefits < costs before the overall BC-ratio becomes less than one. For the measure shown uppermost in Figure 5, only 43.4 % of the overall cost was spent on projects with benefits > costs. The remaining 56.6 % of costs were spent on projects that had a mean BC-ratio of only 0.26. Nevertheless, when all projects are added, the BC-ratio is 8.79 (879 in Figure 3). The second measure did not have projects with such large benefits. Projects with benefits > costs made up 48.7 % of total costs and had a mean BC-ratio of 1.64. The remaining 51.3 % of total costs were spent on projects that had a mean BC-ratio of 0.63, which is considerably higher than the 0.26 for the first project.

The existence of the suggested compensatory behaviour is tested in Figure 4. It lists 15 road safety measures that contained both projects where benefits > costs and projects where benefits < costs. The hypothesis was that: (1) when the projects with benefits > costs have very high BC-ratios, a higher share of the total budget will be spent on projects with benefits < costs than when the BC-ratios are lower: (2) when the projects with benefits > costs have lower BC-ratios (closer to 1), the projects with BC-ratios < 1 will be closer to 1 than when BC-ratios are much higher than 1.

Figure 4 about here

The data do not support the hypothesis. When road safety measures are ranked according to: (1) the share of the budget spent on projects with benefits > costs (ranked from lowest to highest) and (2) BC-ratio (ranked from highest to lowest), a negative correlation is found between the ranks (-0.343). Thus, although there may be some form of compensatory thinking, it is clearly not as systematic as implied by the hypothesis.

8 THE RESEMBLANCE OF PRIORITY SETTING FOR ROAD SAFETY MEASURES TO PRIORITY SETTING FOR MAJOR INVESTMENT PROJECTS

When the National Transport Plan is developed, agencies are given three alternative budget limits:

1. A basic budget
2. The basic budget plus 20 percent
3. The basic budget plus 45 percent

The reason for providing alternative budgets is to assess whether there are enough projects with benefits > costs to justify a larger budget than the basic one. If priorities were set to maximise social benefits, the basic budget ought to contain a higher share of projects with benefits > costs than the augmented budgets. In practice, however, this is not the case. Eliasson (2015) compared the share of projects with net BC-ratio (net BC-ratio = benefits minus costs in the numerator, costs in the denominator) above and below zero within the alternative budgets. The results are shown in Figure 5.

Figure 5 about here

Each line represents an investment project. For lines above the horizontal line, benefits are greater than costs. Lines below the horizontal line indicate that benefits are smaller than costs. The block of projects labelled "Government" consists of those the Ministry of Transport submitted to the Storting (national assembly) for approval. The next block, labelled "Road administration" are projects the road administration proposed, but the Ministry of Transport rejected. The next two blocks, labelled "budget + 20 %" and "budget + 45 %" are projects that were proposed within these larger budgets. Finally, "Rejected" are all projects that were rejected and not entered into any of the budgets.

It is seen that the majority of projects had negative net benefits within all alternative budgets, and that the largest number of projects with high net benefits was found among those that were rejected, i.e. not included in the proposed investment plan. Comparable data for road safety measures are not available, but the 328 road safety projects can be sorted according to net benefit, analogously to the sorting in Figure 5. The results are shown in Figure 6.

Figure 6 about here

Projects with positive net benefits are more clearly visible in the figure than projects with negative net benefits. However, when costs are considered, only 36.3 % of the costs refer to projects with benefits larger than costs. In other words, nearly two thirds of expenditures are for projects whose benefits are smaller than the costs.

9 DISCUSSION

The National Transport Plan for the period 2018-2029 (Ministry of Transport and Communications, 2017, p.27) states that government policy-making related to road safety will be based on risk assessment. In addition, also following the NPRA guidelines (NPRA, 2018), measures should be prioritised according to cost-benefit analyses. It is, however, not entirely clear whether this guideline is intended to apply fully to road safety measures. Some road safety measures, or investments that have effects on road safety, will undergo cost-benefit analysis. It is, however, unlikely that most low-cost road safety measures undergo cost-benefit analysis or that a comprehensive list of such measures is developed to support a formal selection of measures to be implemented.

It seems natural that candidate road safety projects are concentrated in areas where the expected number of injured road users is high, but, as pointed out by Elvik (2009), this would most likely lead to concentration on roads with high traffic volume, typically around the major cities. It has been found that many road safety measures are implemented on low-volume roads where no accidents or injuries have been recorded in recent years (Elvik 2004). This can be interpreted as both a precautionary approach and a consideration of fairness, by aiming to improve road safety in all parts of the country.

The ALARP-principle states that risk should be reduced to a level that is "As Low As Reasonably Practicable", which means that a risk-reducing measure should be implemented, provided that it cannot be shown that the costs are grossly disproportionate to the benefits obtained; see e.g. HSE (2001), Vinnem et al. (2006) and Jones-Lee and Aven (2011). In the literature, there is no clarification of how to interpret the term 'grossly disproportionate', which means that the ALARP-principle can be interpreted in many different ways. A restrictive interpretation is to regard costs as grossly disproportionate to the benefits obtained, if the expected costs (EC) are higher than the expected benefits (EB) or higher than EB multiplied with a disproportionate factor d, i.e. $EC > d \cdot EB$. According to such an interpretation, the ALARP-principle becomes a traditional cost-benefit analysis. It is unlikely that proponents of the ALARP-principle will accept this interpretation. More specifically, as formulated ("reasonable and practicable"), it is reasonable to interpret the ALARP principle as embodying considerations of fairness, particularly by arguing that it is reasonable to spend more on reducing a high risk than a low risk, and spending more on reducing a risk that affects the less advantaged than a risk that affects the more well-off.

One may view ALARP as a dynamic decision-making principle, meaning that the grossly disproportionate criterion is interpreted differently for different decision-making contexts, such that the principle ranges from one extreme, where decisions are made with reference to expected values in some situations, to another, in which the precautionary principle is adopted without any reference to cost-benefit (cost-effectiveness) analyses in others. We refer to Abrahamsen et al. (2018).

When the ALARP-principle is used dynamically as described above, it provides full flexibility regarding the weight given to efficiency and fairness. Such a principle would be fully applicable to road safety policy-making. Adopting a dynamic ALARP approach is a way to achieve flexibility, but it remains unclear how much weight is to be given to efficiency versus fairness. To manage the ALARP-principle in a fruitful way, stronger guidance should be provided on when it is appropriate to prioritise the one over the other. Currently, there is no guidance available on such prioritisation. Hence, it is not certain that an appropriate balance between efficiency and fairness will be achieved consistently without improving the guidance (requirements).

Further, the guidance should move beyond efficiency and fairness as "static" decision-making criteria and, rather, give clear directions on how much weight should be placed on efficiency versus risk equity for different situations. Still there will be (at least theoretically) situations where it is appropriate to make decisions solely based on efficiency, as well as situations where there is minimal weight on cost. Nevertheless, in most situations, the appropriate balance will be somewhere in between the two extremes. The use of road safety measures appears to be guided by considerations of both efficiency and fairness.

8 CONCLUSIONS

Based on detailed data on 328 road safety measures implemented on national roads around 2000, it has been found that:

1. The government is willing to spend more on road safety measures than cost-benefit analysis would justify. The cost function for the provision of road safety indicates that about 80 % of the benefits are obtained for about 16 % of the total expenditure.

2. A small majority of the 328 road safety measures had benefits greater than costs. The mean benefit-cost ratio for all measures was 1.04.
3. More is spent per injured road user prevented in deprived municipalities than in wealthier municipalities.
4. More is spent to reduce injuries to pedestrians and cyclists than to reduce injuries to motorists.
5. Each road safety measure consists both of projects with benefits > costs and projects with costs > benefits.
6. Priority setting for road safety measures may involve a kind of compensatory thinking consistent with the ALARP-principle but not consistent with cost-benefit analysis.

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LIST OF FIGURES AND TABLES

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Benefit-cost ratio and marginal spending by level of risk before implementation of road safety measures

Table 4:

Benefit-cost ratio and marginal spending by municipal deprivation score before implementation of road safety measures

Table 5:

Benefits and costs of 17 road safety measures

Table 6:

Number of road safety projects with benefits>costs and costs>benefits by type of road safety measure

Figure 1:

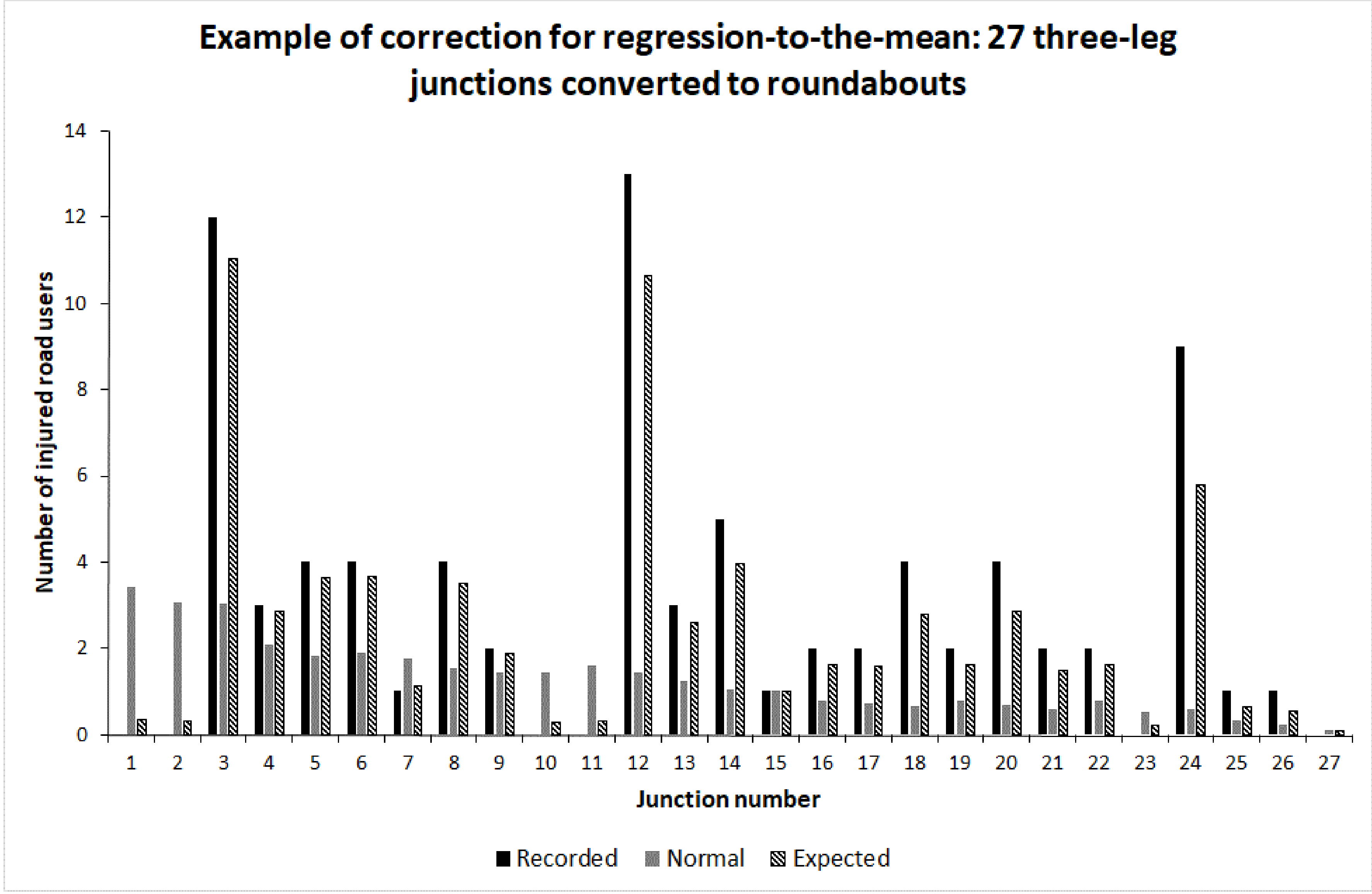

Example of correction for regression-to-the-mean: 27 three-leg junctions converted to roundabouts
Number of injured road users
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Junction number
Recorded
Normal
Expected

Figure 2:

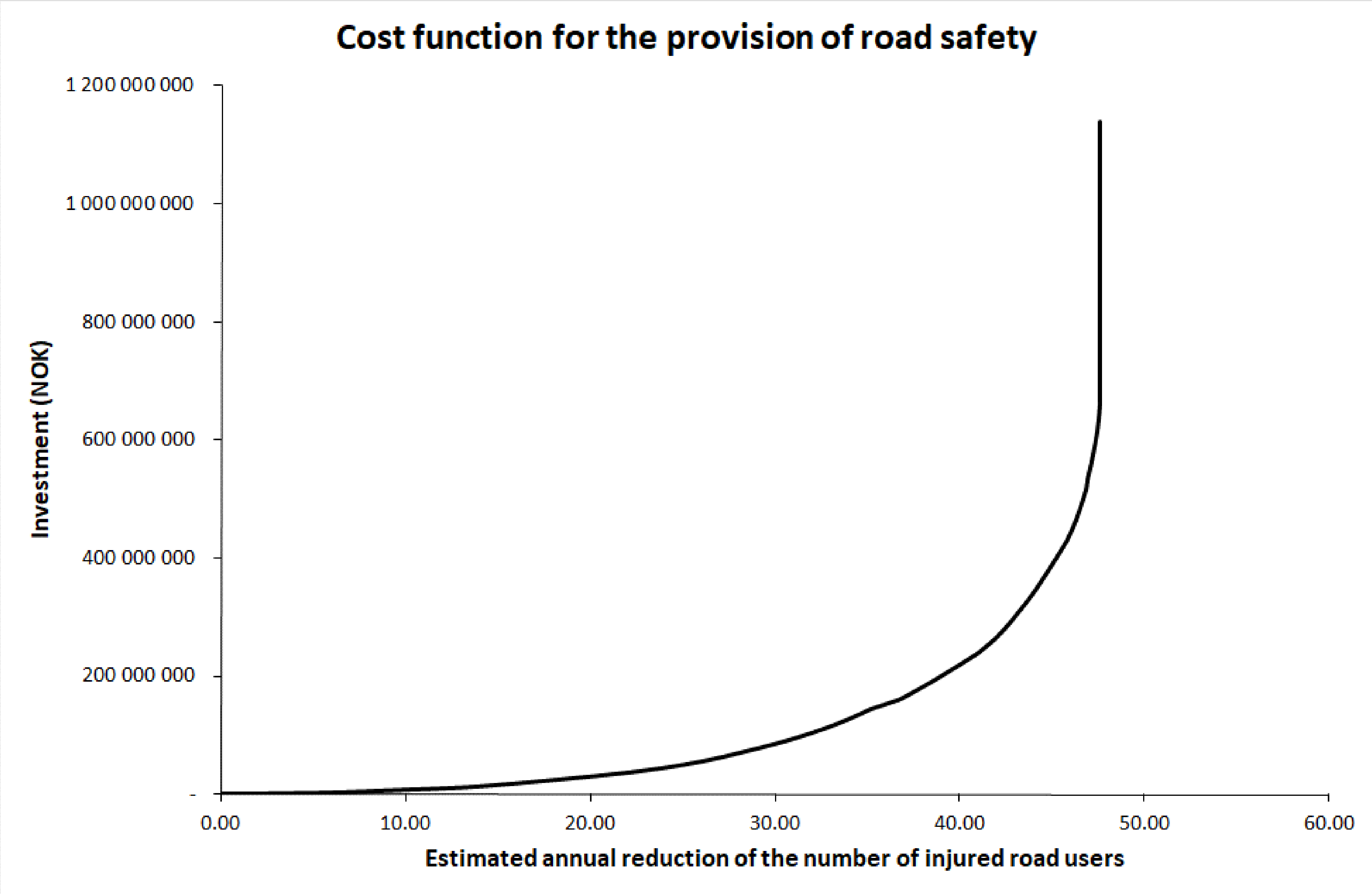
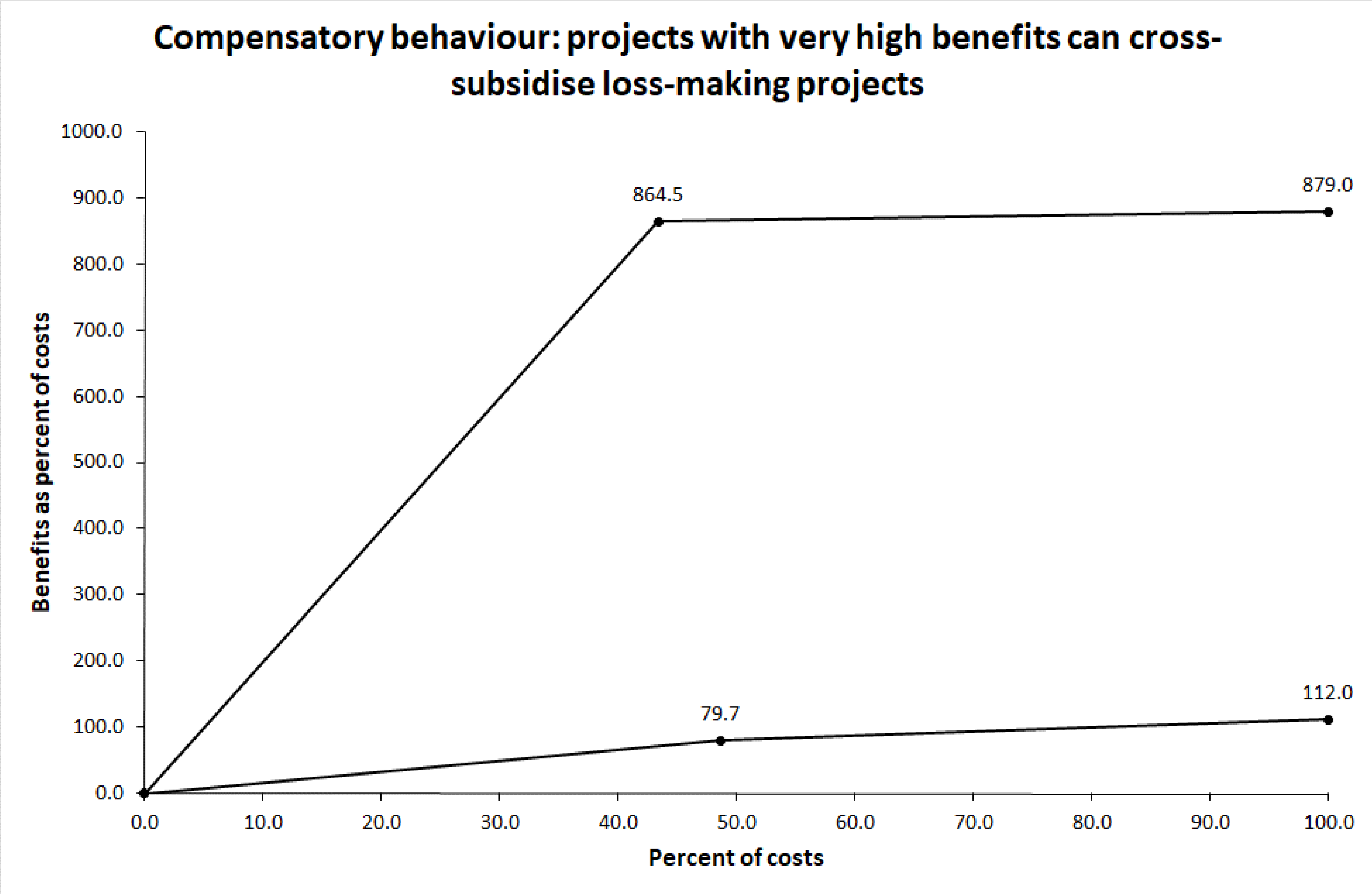
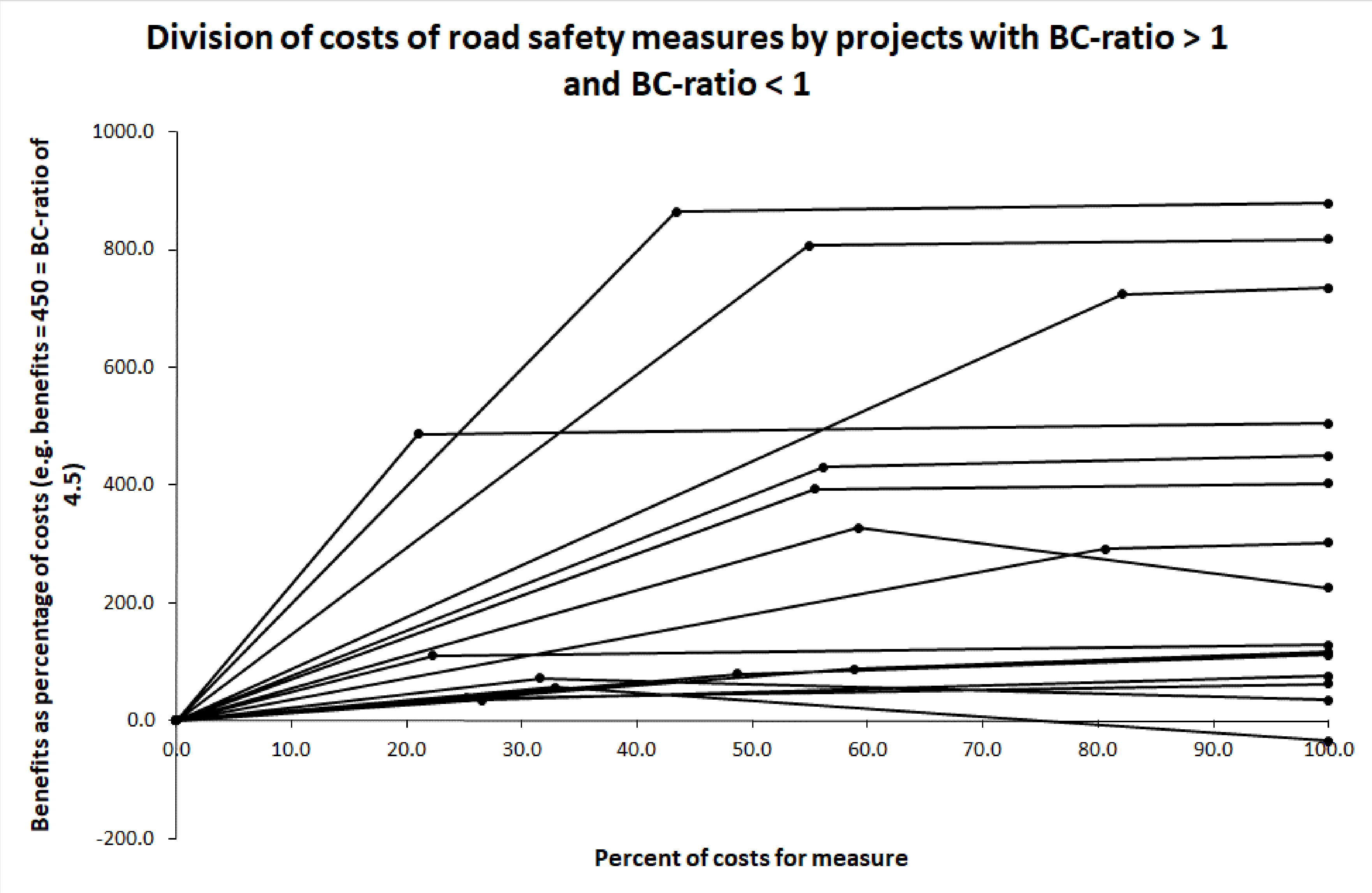

Cost function for the provision of road safety
1 200 000 000
1 000 000 000
800 000 000
600 000 000
400 000 000
200 000 000
-
Investment (NOK)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Estimated annual reduction of the number of injured road users

Figure 3:



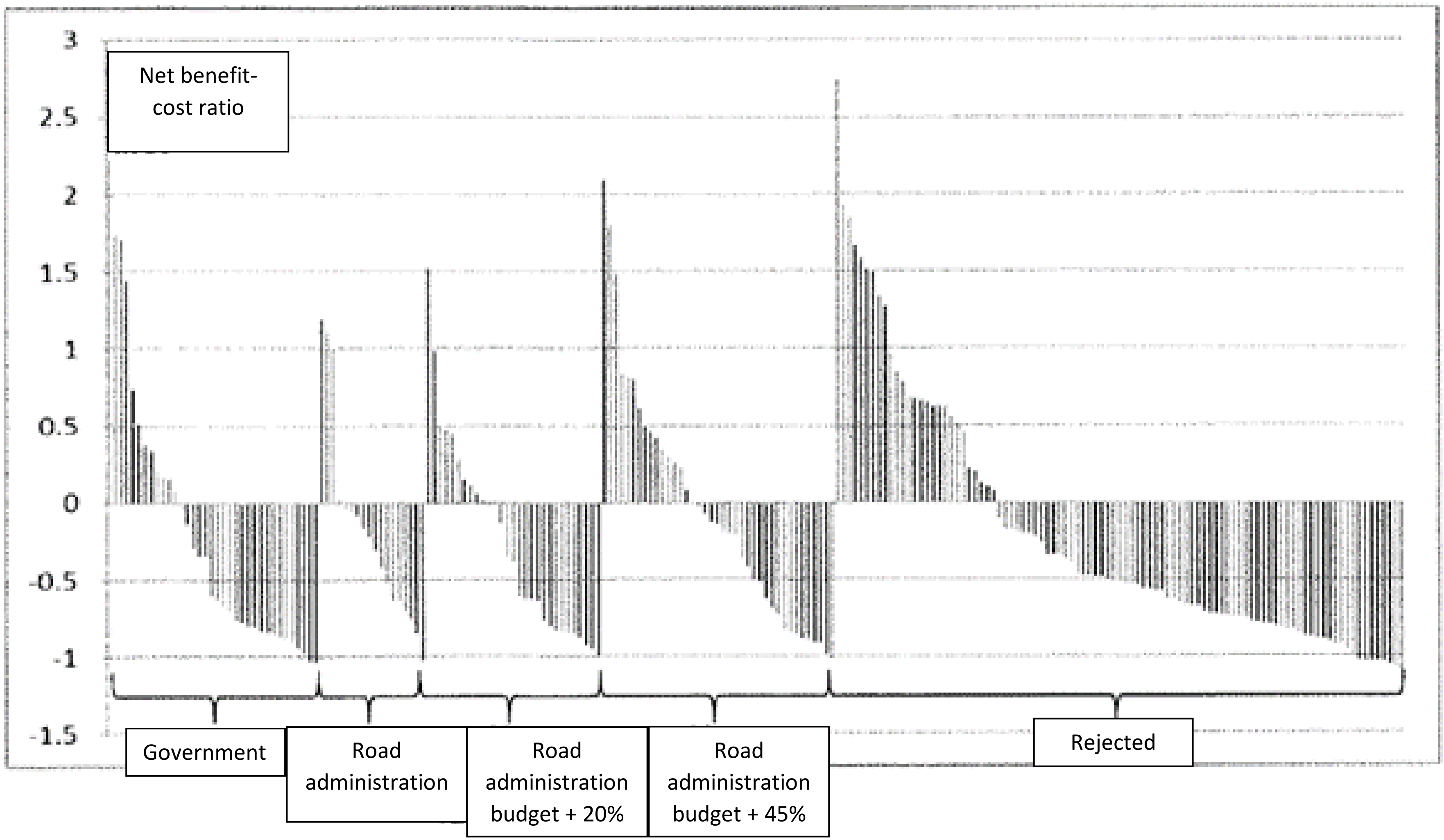
Compensatory behaviour: projects with very high benefits can cross-subsidise loss-making projects
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Benefits as percent of costs
864.5
879.0
79.7
112.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
Percent of costs

Figure 4:



Division of costs of road safety measures by projects with BC-ratio > 1 and BC-ratio < 1
Benefits as percentage of costs (e.g. benefits = 450 = BC-ratio of 4.5)
1000.0
800.0
600.0
400.0
200.0
0.0
-200.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
Percent of costs for measure

Figure 5:



3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
Net benefit-cost ratio
Government
Road administration
Road administration budget + 20%
Road administration budget + 45%
Rejected

Figure 9:

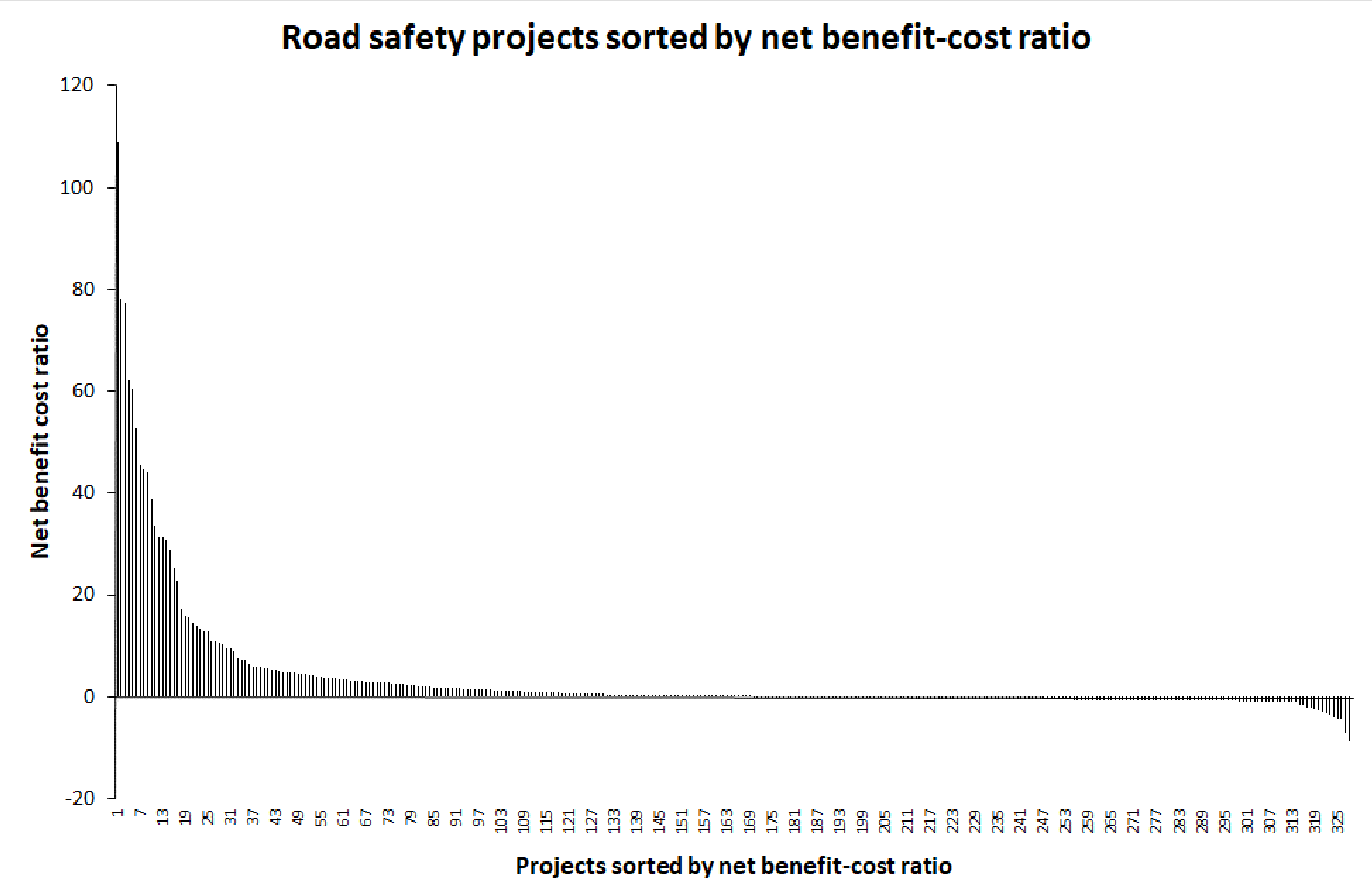

Road safety projects sorted by net benefit-cost ratio
Net benefit cost ratio
120
100
80
60
40
20
0
-20
Projects sorted by net benefit-cost ratio

Table 1:

	AADT and accident rate - 1986				AADT and injury rate – 2000 or after			
Measure	**Mean**	**Max**	**Min**	**Accident rate**	**Mean**	**Max**	**Min**	**Injury rate**
Track for walking or cycling	4520	25000	200	0.153	4436	30500	400	0.066
Bypass roads	5720	15500	1500	0.385	4526	12170	1100	0.419
Traffic signals in pedestrian crossing	20720	30000	5900	0.075	8718	15000	1200	0.079
Roundabouts	13520	25000	1800	0.188	9647	23500	900	0.193
Traffic signals in junctions	14280	24000	7850	0.253	14182	17400	6800	0.189
Environmental streets	6580	8000	6200	1.094	5990	17500	300	0.522
Guard rail along edge of road	1290	8500	150	0.503	10947	46900	150	0.118
Minor improvements	1560	7000	180	0.589	3269	74100	650	1.543
Road lighting	10750	47000	200	0.097	8179	46900	1000	0.123
Speed cameras	9283	55612	666	0.293	8740	60879	800	0.270

Table 2:

		Percentage change in number of injuries by severity		
Road safety measure	**Types of accident or injuries influenced**	**Fatal**	**Serious**	**Slight**
Tracks for walking or cycling	Pedestrians and cyclists	0	0	0
Bridge or tunnel for crossing road	Pedestrians and cyclists	-80	-80	-80
Establishing a bicycle lane	Cyclists	-53	-53	-53
Upgrading pedestrian crossing	Pedestrians	-37	-27	-16
Traffic signals in pedestrian crossing	Pedestrians	-27	-27	-27
Roundabout in three-leg junction	Accidents in junctions	-58	-46	-30
Roundabout in four-leg junction	Accidents in junctions	-86	-68	-45
Traffic signals in three-leg junction	Accidents in junctions	-29	-29	-29
Traffic signals in four-leg junction	Accidents in junctions	-29	-29	-29
Environmental street (1)	Accidents in small towns	+4	+4	+4
Median guard rail	Head-on collisions	-75	-45	0
Guard rail along edge of road	Single-vehicle off-road	-45	-40	-40
Roadside safety treatments	Single-vehicle off-road	-25	-25	-25
Horizontal curve treatments	Single-vehicle off-road	-22	-16	-11
Minor improvements	Motor vehicle crashes on sections	-20	-20	-20
Road lighting	Accidents in darkness	-50	-30	-25
Feedback signs for speed	All accidents	-22	-16	-11

(1) This is the mean effect for 16 projects; effects varied from project to project

Table 3:

Ratio of EB-estimate of expected number of injuries to model-predicted number	Sites with benefits > costs (N and percent)	Sites with benefits < costs (N and percent)	Total (N and percent)	Marginal spending per injury prevented (NOK)
Above 3.0	40 (83 %)	8 (17 %)	48 (100 %)	1 657 458
2.99 to 2.0	29 (78 %)	8 (22 %)	37 (100 %)	1 625 465
1.99 to 1.0	51 (74 %)	18 (26 %)	69 (100 %)	3 119 072
0.99 to 0.5	25 (31 %)	55 (69 %)	80 (100 %)	8 607 776
0.49 to 0.0	12 (34 %)	23 (66 %)	35 (100 %)	4 449 640
Total	157 (58 %)	112 (42 %)	269 (100 %)	4 458 274
Chi-square = 57.833; degrees of freedom = 4; p < 0.0000				

Table 4:

Deprivation score	Sites with benefits > costs (N and percent)	Sites with benefits < costs (N and percent)	Total (N and percent)	Marginal spending per injury prevented (NOK)
Above 1.2	30 (63 %)	18 (37 %)	48 (100 %)	2 940 876
1.19 to 1.0	40 (62 %)	25 (38 %)	65 (100 %)	2 783 759
0.99 to 0.8	73 (46 %)	86 (54 %)	159 (100 %)	3 319 786
Below 0.8	26 (46 %)	30 (54 %)	56 (100 %)	6 306 382
Total	169 (52 %)	159 (48 %)	328 (100 %)	3 656 328
Chi-square = 7.512; degrees of freedom = 2; p = 0.026				

Table 5:

Road safety measure	Benefits (million NOK)	Costs (million NOK)	Benefit-cost ratio
Tracks for walking or cycling	491.8	646.4	0.76
Bridge or tunnel for crossing road	108.1	172.1	0.63
Establishing a bicycle lane	9.4	1.9	5.05
Upgrading pedestrian crossing	16.6	7.4	2.25
Traffic signals in pedestrian crossing	2.3	6.6	0.35
Roundabout in three-leg junction	175.7	156.3	1.12
Roundabout in four-leg junction	91.8	78.0	1.16
Traffic signals in three-leg junction	55.9	13.8	4.07
Traffic signals in four-leg junction	26.9	6.9	3.88
Environmental street	-111.5	318.4	-0.35
Median guard rail	145.8	19.8	7.35
Guard rail along edge of road	131.0	32.5	4.03
Roadside safety treatments	54.5	6.7	8.17
Horizontal curve treatments	49.8	5.7	8.79
Minor improvements	80.1	62.1	1.29
Road lighting	366.9	121.4	3.02
Feedback signs for speed	35.7	7.9	4.50
All measures	1730.9	1664.8	1.04

Table 6:

Road safety measure	Benefits > costs	Costs > benefits	Total
Tracks for walking or cycling	13	39	52
Bridge or tunnel for crossing road	5	21	26
Establishing a bicycle lane	3	1	4
Upgrading pedestrian crossing	17	2	19
Traffic signals in pedestrian crossing	5	6	11
Roundabout in three-leg junction	15	12	27
Roundabout in four-leg junction	12	7	19
Traffic signals in three-leg junction	8	0	8
Traffic signals in four-leg junction	3	0	3
Environmental street	3	13	16
Median guard rail	6	1	7
Guard rail along edge of road	18	11	29
Roadside safety treatments	3	5	8
Horizontal curve treatments	11	10	21
Minor improvements	8	14	22
Road lighting	31	11	42
Feedback signs for speed	8	6	14
All measures	169	159	328