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Essays on Cost Estimations and their Uncertainties in Transportation Projects

Thesis for the degree of Philosophiae Doctor

Trondheim, June 2011

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Preface and acknowledgements

Transport economics and transport planning are academic fields which have generated large amounts of research throughout history. Any contribution through published articles and reports will hence inevitably be small steps towards increased knowledge and improved practices. It is thus with great humbleness that I submit this PhD thesis in the hope that the matters raised will be of interest to both academics and practitioners.

The thesis is submitted to the Norwegian University of Science and Technology (NTNU), Faculty of Engineering Science and Technology, Department of Civil and Transport Engineering for the degree of philosophiae doctor. It consists of six essays, five of which are published in international journals. The papers form the core of the thesis. An introductory essay discusses the issues of risk and uncertainty in transport appraisal in more detail.

I was formally accepted as a PhD candidate at NTNU in September 2007. Before that, there was a period of self study and self motivation, and more importantly, relentless encouragement and support from my friend, colleague and later supervisor – Professor James Odeck. I am forever grateful to you, James.

Throughout the course of this PhD work, I have been employed at the Norwegian Public Roads Administration (NPRA). When I first approached my superior, Even Myhre, asking if I could devote half my working hours to PhD work, I was immediately given a positive response and encouraged to go ahead. My sincere thanks go to Even for his support, to the NPRA for providing the data and resources necessary and to all my colleagues there whose guidance and encouragement have been of great importance for this work.

Two of the papers in the thesis were written with co authors other than my supervisor. Paper 3, *The effects of removing the Trondheim toll cordon*, was written with Solveig Meland and Terje Tretvik of SINTEF Technology and Society. Paper 4, *Operating costs in Norwegian toll companies: a panel data analysis*, was written with Erik Amdal of Statoil ASA, and Gunnar Bårdsen and Kåre Johansen of the Norwegian University of Science and Technology, Department of Economics. Cooperating with all of you has been very rewarding and I thank you for allowing me to include our papers in my thesis.

Finally, my thanks go to NTNU for accepting me as a PhD candidate and to the staff at the Department of Civil and Transport Engineering for their helpfulness and for providing the seclusion and office space needed to finish the thesis during the autumn of 2010.

Trondheim, June 2011

Morten Welde

Abstract

This thesis deals with risk and uncertainty in the planning of transport projects. The overall objective is to reveal potential risks and uncertainties in road projects and propose methods by which forecasts can be made with increased accuracy. The main focus is on the period after the project is implemented.

The first part of the thesis consists of an introduction containing a discussion of the role of cost-benefit analysis in the impact assessment of road projects and in the decision making process. The concepts of risk and uncertainty are introduced, and their sources and consequences are discussed from both an international and a Norwegian perspective.

The second part of the thesis consists of six individual papers. The main findings in the papers dealing with forecast inaccuracies in Norwegian transport planning are as follows. Traffic forecasts in Norwegian toll road projects are fairly accurate. Traffic is on average 2.5% higher than forecasts, but variations are large. Inaccuracies are common among all project types and sizes, and estimates do not become more accurate over time. On toll free roads, traffic is generally underestimated, with a sample average of 19%. An explanation for the observed discrepancy between estimated and actual traffic among toll free roads is that road planners have ignored the existence of induced traffic and that the standard national traffic growth rates used in the transport models has been too low. For tolled roads, an explanation for the higher degree of forecast accuracy is that planners over the years have been scrutinized to provide careful estimates. However, the observed large discrepancies between forecasts and real traffic suggest that this is an issue which merits further attention.

Operating costs is a project-specific variable that we expect planners to estimate with a high degree of certainty. The findings with respect to operating cost forecast accuracy suggest that Norwegian planners have been rather unsuccessful in the estimation of these costs. Operating costs are frequently underestimated, possibly due to a degree of optimism bias. On average, these costs are about 30% higher than estimated. Given that these costs make up from around 10% to up to 40% of toll project revenues, this should be a cause of concern.

The Norwegian experience suggests that modelling traffic when users pay tolls is complicated, even if average accuracy is better than reported elsewhere. Knowledge of users' reactions to tolls is therefore valuable. In Trondheim, it was found that traffic is generally sensitive to both the introduction and the removal of tolls and. When the Trondheim toll cordon was removed in 2005 there was a considerable increase in traffic. On average, there was an increase in traffic over the previous cordon of 15.5% for the hours between 14:00 and 18:00, whilst traffic levels decreased in the evenings and at night.

The thesis also presents studies from economic evaluation of Intelligent transport systems (ITS) which increasingly constitutes alternatives to traditional road expenditure. If ITS is not evaluated in economic terms as is common for traditional transport projects, there is a risk of inefficient recourse allocation as decision makers could be lead to forego profitable ITS investments as their merits are not demonstrated. The results presented herein suggest that ITS may form an attractive investment opportunity and that ITS proponents should start using economic evaluations to objectively assess the merits of their projects.

The main conclusion in this thesis is that there are risks inherent in Norwegian transport appraisal which have not been brought to the attention of decision makers. Forecasts of

crucial variables in cost benefit analyses are inaccurate to such a degree that it should warrant greater scrutiny. In particular, methods of quantitative risk assessment should be incorporated in the appraisal framework so that risks are brought to the attention of decision makers.

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1. Introduction

The planning of transport projects is a complex process involving legal, administrative, economic and technical issues. To provide decision makers with the best possible information for decision making, planners are required to assess and, if possible, quantify all effects of implementing a new facility or policy. The estimation of costs and benefits is thus crucial for rational transport planning. Through the process of forecasting, we seek to calculate the needed capacity of the planned infrastructure, estimate the financial and social viability of projects and calculate environmental impacts. If we fail to provide accurate forecasts of crucial variables, we risk misinforming decision makers and allocating resources inefficiently.

Project appraisal is an integral part of transport planning that is aimed at calculating a project's viability. Decision makers require objective methodologies of appraisal that can be used to rank or prioritise between competing projects; one such methodology is cost-benefit analysis (CBA). CBA requires cost control and a methodical framework that allows for the quantification and estimation of all relevant variables. This is followed by a presentation of results to those involved in decision making. Although CBA cannot claim to measure the entire range of potential benefits and costs, it is by far the most widespread method of appraisal for choosing between different project alternatives. However, and as discussed further below, not all projects in the road sector are subjected to the same method of appraisal as traditional road projects. The implementation of new technologies, although sometimes experimental, is often carried out without the proper quantification of all costs and benefits to affected groups.

Nonetheless, a decision to carry out a project must be taken within some level of uncertainty. It is obvious that forecasts, which are predictions of future events, will never be 100 % accurate with respect to all variables. This inaccuracy means that risk and uncertainty are inevitable aspects of the process of planning and appraisal. This thesis seeks to reveal potential inaccuracies in Norwegian project appraisal and demonstrate how these inaccuracies translate into risk that needs to be brought to the attention of decision makers.

2. Objectives

The main objective of this thesis is to reveal potential risks and uncertainties in road projects and propose methods by which forecasts can be made with increased accuracy. The main focus will be on the period after the project is implemented. This focus will be pursued by surveying historical plans and comparing forecasts to real values, and by thereby suggesting how the divergences can be appropriately accommodated in the planning tools. If the real values turn out to be inaccurate, the causes should be investigated further, and measures to improve the accuracy of forecasts used in the planning of new projects should be introduced. In general, there have been few *ex post* assessments of road schemes in Norway.

Toll road projects are of particular interest to study. Toll financing constitutes an increasingly important part of the total funds available for road investment in Norway and elsewhere, and the implications of inaccurate estimates can be severe for all parties involved. In cases of financial difficulties, motorists can face increased tolls or a prolonged payoff period, and lenders and bondholders risk losing their money. Operating cost is a project-specific variable that we expect planners to estimate with a high degree of certainty. It will, therefore, be interesting to derive confidence intervals for operating costs of tolls and to analyse the level of efficiency at which toll road companies operate. This information will aid planners in the planning of new toll projects.

In addition to the aforementioned studies of traffic and operating costs, the thesis includes an analysis of traffic effects after the Trondheim toll cordon was removed. The evaluation also covers the effects on the retail market and environmental effects. The results will be of interest to cities planning to introduce systems of urban road user charging or cities with tolls already in operation.

Not all transport projects are subjected to CBA. Intelligent transport systems (ITS) are of increasing importance to enable better utilisation of road capacity and to improve the quality of the transport system in general. Therefore, there is a growing demand that these projects should also be subjected to the same method of appraisal as traditional transport expenditure. When ITS projects are not evaluated according to the same methodologies as traditional transport investments, many potential ITS projects may seem unfavourable relative to alternative solutions. Systems for electronic toll and fare collection for toll roads and public transport are good examples of ITS applications that are used throughout the world and deliver substantial benefits to road users and the society at large. Norway has had great experience in using modern technology to provide cost-efficient and user-friendly solutions that allows free flow through toll stations and interoperability between projects. The experience gained could provide guidance as to how such systems could be evaluated in economic terms and whether they provide attractive investment alternatives compared to traditional expenditure. The last two papers of the thesis include evaluations of two recently implemented ITS based payment schemes. The analyses provide a basis for further research on how economic assessment can be tailored for ITS projects.

2.1 Structure of the thesis

The first part of the thesis consists of an introduction containing a discussion of the role of cost-benefit analysis in impact assessment and in the decision making process. The concepts of risk and uncertainty are introduced, and their sources and consequences are discussed from both an international and a Norwegian perspective. We then elaborate on forecast accuracy in Norwegian transport planning and examine similarities in findings and conclusions between international and Norwegian studies. There are different methods available for addressing risk in transport appraisal. The most common of these methods is described. At the end, we attempt to draw some conclusions and make some recommendations for future research. We also assess potential policy implications of the conclusions made. Throughout the introductory part of the thesis, we discuss the findings and conclusions of the individual papers and how they relate to each other.

The second part of the thesis consists of six individual papers, which will be referred to in the text by their numerals.

Paper 1: Welde, M. and Odeck, J., 2011. Do planners get it right? The accuracy of travel demand forecasting in Norway. *European Journal of Transport and Infrastructure Research*, 11 (1), pp. 80-95.

Paper 2: Welde, M, 2011. Accuracy of demand and operating cost forecasting for toll road projects. *Transport Policy*, 18 (5), pp. 765-771.

Paper 3: Meland, S., Tretvik, T. and Welde, M., 2010. The effects of removing the Trondheim toll cordon. *Transport Policy*, 17 (6), pp. 475-485.

Paper 4: Amdal, E., Bårdsen, G., Johansen, K. and Welde, M., 2007. Operating costs in Norwegian toll companies: a panel data analysis. *Transportation*, 34 (6), pp. 681-695.

Paper 5: Odeck, J. and Welde, M., 2010. Economic evaluation of ITS strategies: the case of the Oslo toll cordon. *IET Intelligent Transport Systems*, 4 (3), pp. 221-228.

Paper 6: Welde, M., 2011. Are Smart Card Ticketing Profitable? Evidence from the City of Trondheim. Manuscript submitted to *Journal of Public Transportation*.

3. The role of cost-benefit analysis in the impact assessment of transportation projects

Well-informed decision making relies on access to all relevant information regarding the consequences of a proposed scheme. Large road projects in Norway are required to undergo a full impact assessment aimed at assessing all impacts, negative or positive and measurable in monetary terms or not, which are predicted to occur if a road transport project is implemented. In other words, impact assessment is a systematic illustration of *all* impacts that will take place if a project is carried out. The impacts of a proposed road project could be: a) impacts that can be valued in monetary terms such as construction costs, time, and accidents; b) impacts that are not possible to value in monetary terms or c) distributional impacts of political interest.

The role of economic theory in promoting efficient resource allocation was recognised as early as the 1930s when the discipline of welfare economics was used to introduce the concept of cost-benefit analysis to prioritise between project alternatives in the United States Flood Control Act. However, it was not until the 1950s that the guidelines issued by the U.S. Federal Inter-Agency River Basin Committee formalised the use of CBA for project appraisal (Pearce and Nash, 1981). Harberger (1971; cited in Winston, 2006) later described the principles of applied welfare economics through CBA as follows: benefits and costs to consumers should be calculated using consumer surplus; benefits and costs to producers should be calculated using producer surplus; and benefits and costs to each group should be added without regard to the individual(s) to whom they accrue. It is thus the *change* in consumer and/or producer surplus that determines the change in social surplus in a CBA (for a comprehensive review of cost-benefit theory and methodology, see Boardman *et al.*, 2006). In other words, CBA is concerned with the welfare of society as a whole and not just a smaller part of it.

CBA is aimed at identifying projects that represent potential Pareto improvements, i.e., projects where some people are made better off without making anyone worse off. Of course, such projects are extremely rare. In reality, CBA is based on the Kaldor-Hicks criterion, which recommends projects where the benefits for one group are so large that they, in theory, could compensate those who do not benefit so as to obtain an overall welfare improvement.

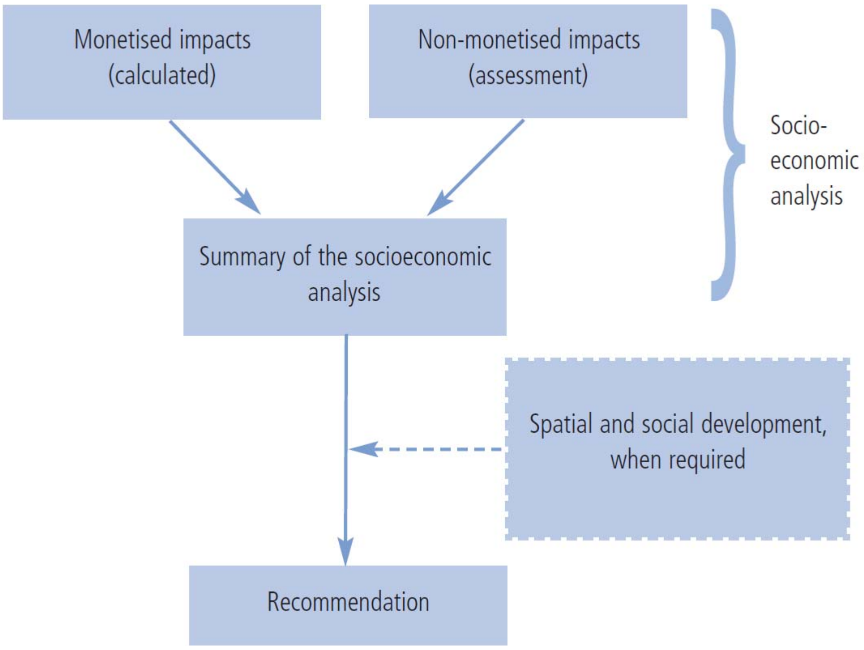


Figure 1: Relationship between impact assessment, socio-economic assessment and cost-benefit analysis.

As illustrated in Figure 1 (NPRA, 2006, p. 60), the impact analysis consists of a socio-economic analysis, which consists of both monetised and non-monetised impacts, and an assessment of local and regional development and distributional impacts. A common misconception is that only CBA results are presented to the decision makers. In reality, the CBA, represented by the upper left-hand square in Figure 1, is only one part of the overall impact assessment. Non-monetised impacts, such as the effects on landscape, effects on wildlife, and perceived economic development impacts, often matter more to decision makers than the results of the CBA alone. In several studies of the Norwegian decision making process, it was shown that projects with high estimated social benefits are not more likely to receive funding than others (Odeck, 1996; Fridstrøm and Elvik, 1996; Odeck, 2010b; Martinsen *et al.*, 2010). Decision makers appear to emphasise factors other than those included in the CBA, and much of the information provided to them was either ignored or misunderstood. Similar results were found in Sweden, with Nilsson (1991) concluding that the connection between CBA and decisions on the ranking of Swedish road projects was limited, and in the UK, with Nellthorp and Mackie (2000) finding little impact of benefit-cost ratios on investment decisions. Im Sweden, planners play an important part in the selection of projects, and there Eliasson and Lundberg (2010) showed that CBA results do play an important part in the selection of projects and that projects with a high BCR have higher probabilities for inclusion in the investment plan. However, for investments selected directly by politicians, no connection between high BCRs and the selection of investments was found.

The fact that results of a CBA may play a minor role in the decision making process does not necessarily mean that the information therein is ignored. The most recent study by Odeck (2010b) showed that decision makers used and appreciated the monetised impacts, even if others were ignored. In other words, the components of a CBA mattered while the end result did not. Even if the net present value was negative, the focus was on traffic safety or freight benefits. The reason for this behaviour could be a lack of understanding of the welfare maximising principles upon which CBA is based or a desire to use road investments to reward one's constituency in return for its political support. The patterns of political support for road investment and priorities of rural areas over urban areas have been illustrated by Helland and Sørensen (2009) and may further explain why CBA may play a less decisive role in Norway than in other countries.

The limited use and lack of understanding of CBA have sometimes raised debate on both its applicability and the principles upon which it is based. This debate is not new; since its introduction, CBA has been the subject of criticism and debate. One such critique is the so-called *management critique,* where the main strands of criticism have been the following: firstly, that CBA gives an incomplete picture when some impacts cannot be monetised, making it unsuitable for projects in which non-monetised impacts are important, and secondly, that CBA is too demanding and hence inflexible for screening many project alternatives. It is from this criticism that multi-criteria analysis, which involves a closer interaction with decision makers and relies more on their personal judgements, has been suggested as an alternative method of appraisal (Dodgson, 2009). The treatment of non-monetised impacts in CBA has always been a subject of much debate. The *political science critique* emphasises that if the monetary values are not robust, then the analysis itself will be flawed. Further, if vital impacts are not included, then the results will not give a complete picture, and finally, the treatment of distributional effects is insufficient (Parsons, 2002). The latter point is similar to *the planners' critique,* the key point of which is that presenting the results of the analysis as single net present value or benefit cost ratio estimates could potentially obscure rather than clarify who does and does not benefit from a project (Lichfield, 1971). A similar but more recent discussion of common flaws in transport modelling and CBA practice was raised by Mackie and Preston (1998), who suggested that appraisal optimism represents the greatest danger in transport investment analysis. Scheme promoters could be tempted to disclose the inherent uncertainty in the results presented or worse, to deliberately bias the appraisal. A final critique is the *microeconomists' critique*, as discussed by Pearce and Nash (1983), which includes the Scitovsky paradox in which, under certain conditions, it is possible for Project A to be preferred to Project B by the Kaldor-Hicks compensation criteria and Project B to be preferred to Project A by a set of moves by the same criteria. The Kaldor-Hicks criterion was also criticised in early work by the Oxford philosopher-turned-economist I.M.D. Little (1950) where he tore apart traditional welfare theories and paved the way for social choice theory. His main point was that because the compensation test only relies on theoretical compensation, a welfare improvement according to the Kaldor-Hicks criterion could easily have adverse distributional effects (Arrow, 1951).

All of these critical views have contributed to the debate and helped to improve the frameworks of CBA in use today. CBA has in any case never been intended as a substitute for political decisions; it is concerned with how resources *should* be allocated – it is in other words *normative*. Furthermore, there will always be costs and benefits that we did not anticipate, costs and benefits that could never be forecasted with absolute certainty and other grounds as to why a policy might be impossible, prohibited or undesirable to carry out. However, the decision support that impact assessment coupled with CBA provides is, in our view, far superior to alternative approaches by far. Many of the traditional critiques have been blunted by the improvements to CBA over time. Central assumptions regarding the value of travel time, which often account for the main proportion of monetised benefits (Grant-Muller *et al.*, 2001; Mackie *et al.*, 2001), are still under close and continuous scrutiny. However, in the Norwegian context, the argument is often that measured benefits fail to include the wider economic impacts that transport projects are likely to deliver rather than, say, that values of travel time are too high. There will, of course, always be impacts that cannot be monetised, but as long as the analysis captures the most important effects, there is less to gain from extensive valuation studies aimed at monetising impacts that are not traded in markets. As this monetisation is potentially more confusing than clarifying, non-monetised impacts are presented to decision makers on the impact assessment sheet for them to make their own personal judgements. Distributional impacts have always been high on the agenda in Norway, where politics sometimes take on an almost Rawlsian starting point from which benefits to society is measured according to the benefit to those least advantaged. As such, Lichfield's objections could have relevance, but again, CBA has undergone much refinement since he offered his points of criticism. Since then, CBA has gone down the road of disaggregation where impacts for all groups and regions are specifically discussed. However, and as we shall see further below, single-point estimates of NPV/BCR, even if disaggregated, could in worst-case scenarios misinform rather than inform decision makers of the socio-economic viabilities of projects by concealing the inherent risk of a multi-variable model such as CBA. In this sense, the planners' critique represents the main challenge to CBA today, which in our opinion is the treatment of risk and uncertainty.

3.1 Profitability measures in cost-benefit analysis

The aim of CBA is to quantify all benefits and costs associated with a project. The basic decision rule of CBA is that a policy is desirable if the following condition holds:

$$B - C > 0 \qquad (1)$$

i.e., accept the project if the benefits generated (B) are larger than the cost of implementation and operation (C). However, if some benefits or costs cannot be quantified in monetary terms, then the decision rule in (1) can be modified to the "implicit price rule", which may aid decisions. Suppose, for example, that it is impossible to put a monetary value on some environmental aspects arising from a policy. If we denote those environmental aspects as E, then the basic requirement in (1) could be re-written as the following:

$$B - C - E > 0 \qquad (1^*)$$

where E represents the environmental costs that are not measured in monetary terms. If B and C are measured in monetary terms, then $B - C$ can be expressed as a monetary total, for example $\$H$. The rule in (1*) can further be modified to the following:

$$\$H - E > 0; \text{ or simply } \$H > E \qquad (1^{**})$$

Approached in this way, we then know that the policy is worthwhile if and only if it is judged (by the planner/decision maker) that the net monetary benefits are worth more than the non-monetised environmental costs. CBA does not therefore require that all costs and benefits must be measured in monetary units, but benefit measurement is a necessary part of CBA. Incidentally, this approach is similar to the Norwegian method shown in Figure 1, even though that similarity may not be emphasised strongly enough. In reality, as costs and benefits will accrue over time, discounting is needed to summarise future streams of benefits and costs to a single value. The most common evaluation criteria used to discount costs and benefits over time are the following:

- Net present value (NPV)
- Benefit cost ratio (BCR)
- Internal rate of return (IRR)

The most common profitability measure in CBA is the net present value (NPV), which is defined as follows:

$$NPV = I_0 + \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \qquad (2)$$

where I_0 represents construction costs, B_t and C_t represent benefits and costs, *r* is the discount rate, and *t* is the appraisal period. The appraisal period should reflect the expected life of the asset. What is of interest is the economic life, i.e., the period during which the asset could produce a significant stream of benefits, after which the asset would have to be abandoned or replaced. In reality, the appraisal period is subject to practical constraints, as the uncertainty with regard to benefits and costs many years into the future would be significant. In appraisal, it is generally regarded as meaningless to discuss transport demand forecasts decades into the future. Norwegian appraisal is thus based on a 25-year period of analysis, whereas the total life span of infrastructure is assumed to be 40 years. To account for benefits in the remaining 15 years, a residual value of 15/40 of the investment cost is added at year 25 and discounted to the year of comparison.

The discount rate reflects the fact that resources today are worth more than at a future date. Future benefits and costs will hence have a lower value in an appraisal than benefits and costs that occur in the first years after opening. Therefore, uncertainties with regard to input variables in the post opening years should be given special attention. A high discount rate will thus mean that risk increases with time. At present, the prescribed discount rate in Norwegian CBA is 4.5%.

The NPV determines the absolute economic merit of a project. If its value is greater than zero, it means that the project generates benefits greater than its cost and is therefore profitable from an economic point view. A basic decision rule would thus be to adopt the project if its NPV is greater than zero.

We often find that projects are mutually exclusive or decisions have to be taken within a budget constraint. In such instances, we need a value for money measure such as the benefit-cost ratio (BCR). The BCR is defined as the ratio of the net benefits of a project to its costs and is written as follows:

$$BCR = \frac{NPV}{C} \qquad (3)$$

where the denominator C is often defined as costs financed through government budgets. If so, the returns of a project with a BCR of, for example, 0.4 can be interpreted as 40% per krone invested. The BCR is clearly a useful tool to rank projects, but Boardman *et al.* (2006) have criticised the use of the BCR because it can sometimes confuse the decision process when the costs of carrying out projects are different. For example, a low-NPV project financed through user fees can have a very low C and produce a substantially higher BCR than a high-NPV project financed through government budgets alone. But clearly, the aim of the decision making process should be to maximise social surplus. Therefore, by using the BCR rather than the NPV as a decision criterion, we can put that objective at risk.

The internal rate of return (IRR) is defined as the discount rate at which the NPV is zero. In other words, it is the solution for r in Equation (4).

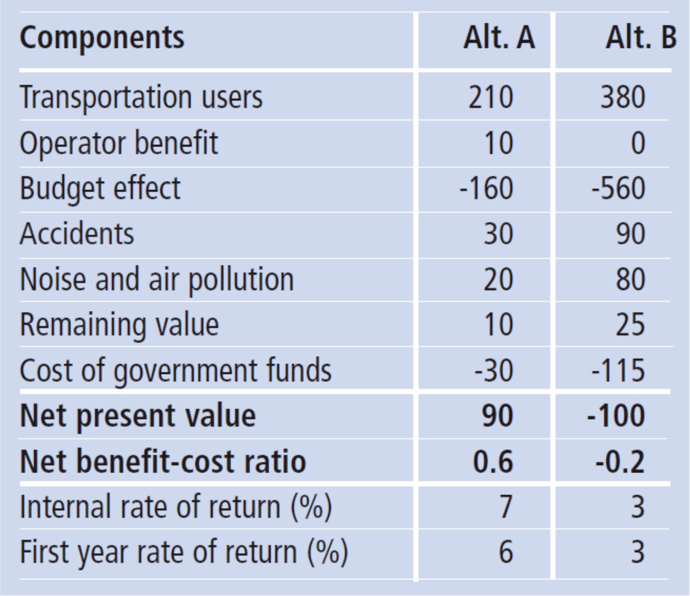
$$\sum_{t=0}^{n}(B_t - C_t)\times(1+r)^{-t} = 0 \tag{4}$$

The implication is that the IRR is the highest discount rate at which the project will have a positive NPV. If the IRR is equal to or greater that the discount rate applied, the project should be carried out. The IRR can help illustrate the return on the capital invested. In practice, the IRR method may lack intuitive appeal for decision makers, and as rankings established by the IRR may be inconsistent with those of the NPV and the BCR, it is not in common use (Salling, 2008).

Financing transport infrastructure over government budgets imposes costs to society greater than the costs of funds themselves because it is generally acknowledged that taxes lower welfare more than they collect in revenue. This distortion effect needs to be taken into account in a CBA. In Norway, this accounting is done by multiplying the net costs financed over government budgets by a factor of 1.2. Other countries use different factors, and some countries ignore this effect completely (Ødegaard *et al.*, 2005).

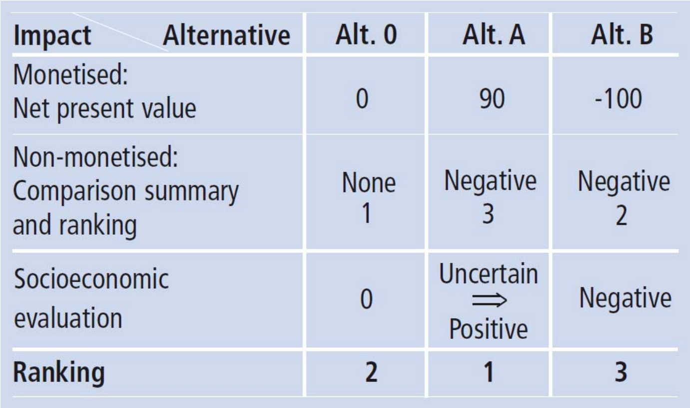
Along with information on non-monetised impacts, these profitability measures are used to inform decision makers on the effects of carrying out different project alternatives. Table 1 (NPRA, 2006, p. 240) presents the results of the CBA as presented to decision makers on the impact assessment sheet.

Table 1: Monetised impacts of two project alternatives.



Components	Alt. A	Alt. B
Transportation users	210	380
Operator benefit	10	0
Budget effect	-160	-560
Accidents	30	90
Noise and air pollution	20	80
Remaining value	10	25
Cost of government funds	-30	-115
Net present value	**90**	**-100**
Net benefit-cost ratio	**0.6**	**-0.2**
Internal rate of return (%)	7	3
First year rate of return (%)	6	3

Table 2: Ranking of projects.



Impact Alternative	Alt. 0	Alt. A	Alt. B
Monetised: Net present value	0	90	-100
Non-monetised: Comparison summary and ranking	None 1	Negative 3	Negative 2
Socioeconomic evaluation	0	Uncertain ⟹ Positive	Negative
Ranking	**2**	**1**	**3**

Overall, the ranking of projects is presented as in Table 2 (NPRA, 2006, p. 241). Here, Alternative A is the only one with positive monetised impacts. Non-monetised impacts are negative, but as overall pros are considered greater than cons in this example, it is recommended for implementation.

This information is supplemented with a discussion of non-monetised impacts, potential preferences of local authorities and an assessment of spatial and social development, i.e., impacts for groups of the population, local communities, municipalities or regions. Presenting alternatives with different monetised and non-monetised impacts will rely on a certain extent of professional judgement and will thus not yield precise answers. The explanation accompanying the table is therefore very important.

Finally, a short section on project uncertainty is included. This assessment is conducted via a partial sensitivity analysis where the effects of a change in investment costs by +/- 25% and changes in traffic growth by +/- 1% is illustrated.

4. Risk and uncertainty in transport appraisal

CBA requires us to predict the future, or more precisely, to predict future values of benefits and costs to arrive at an estimated net present value. This prediction is by no means a straightforward process, and Equation (2) may conceal the fact that benefits and costs consist of a wide range of impacts for several groups of stakeholders. Table 3 (adopted from NPRA, 2006, p. 62) illustrates the main monetised impacts that are estimated in CBA.

Table 3: Main monetised impacts in CBA.

Participant	Main theme	Sub-theme
Transport users	Benefit for transport users	- Travel time - Travel costs - Travel inconvenience - Positive health effects
Operators	Operator benefit	- Costs and revenues for public transport operators, toll companies, ferry companies, and parking companies , for example - Transfers/subsidies
The government	Budget effect	- Investment - Management - Maintenance - Subsidies to operators - Tax revenue
Third parties	Traffic accidents	- Accidents with personal injury and material damage
	Noise and air pollution	- Indoor noise - Local, regional and global air pollution
	Residual value	- Residual value (15/40) of investment
	Cost of government funds	- Loss of efficiency due to tax financing

Arriving at an estimated NPV for a given project requires careful estimation of a range of variables. All of these variables, such as construction cost, operating costs and traffic, will inevitably take on values that, over an appraisal period of up to 40 years, could be different from the expected values used in the appraisal. Even if factor prices are given by standard values in the appraisal framework, such as that provided by Handbook 206 (NPRA, 2006), we are still left with a long list of input variables that are likely to vary, either as a consequence of inaccuracy in estimation or as a consequence of the macroeconomic development. These potential variations will almost certainly impact the NPV and are the source of considerable risk and uncertainty in the decision making process.

4.1 The concepts of risk and uncertainty

Risk and uncertainty are key problems facing both the private and the public sector. Although often treated as a single concept, it is useful to distinguish between the two. Pearce and Nash (1981) defined a risky context as one where the outcome could vary but the probabilities of the different outcomes are known. Uncertainty relates to a context where the outcome could vary, and the probability of different outcomes is unknown. In other words, risk is measurable, while uncertainty is immeasurable. The difference between risk and uncertainty is illustrated in Figure 2, which shows that in addition to known probabilities, risk differs from uncertainty in that the probability distribution for risk is known.

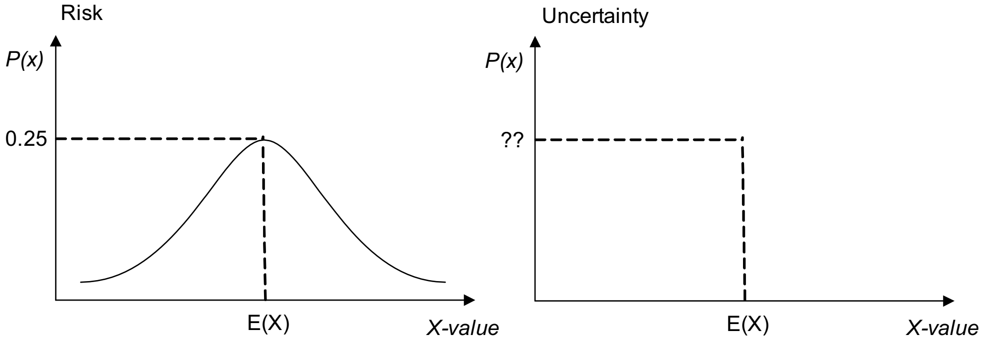


Figure 2: Probability distributions associated with risk and uncertainty.

Austeng *et al.* (2005) used a slightly different definition and pointed out that uncertainty could be separated into two categories: *risk*, which represents the potential downside of a project, and *opportunity*, which represents an upside. Hence, uncertainty is related to the lack of knowledge about the future, and the final outcome could be both positive and negative.

In transport appraisals, the concepts of risk and uncertainty are often used interchangeably. The aim in the planning process should be to produce accurate forecasts and to reveal potential risks before a decision is made.

In examining risk, we often categorise it into two concepts: *unsystematic risk* and *systematic risk*. Unsystematic risk, or project-specific risk, is the random variation around the mean, specific to one project, and reflects that the future is uncertain and that there will always be deviations from expected values that are uncorrelated to market movements. Because unsystematic risk is project-specific and most likely uncorrelated with the risk in other projects, it can potentially be cancelled out by diversifying investments in a large number of projects. Systematic risk, on the other hand, is risk that is correlated with general economic activity and is often managed by adding a risk premium to the discount rate. For transport projects, systematic risk is typically reflected in the variations in traffic levels that can be expected under periods of economic growth and recessions.

4.2 The sources of, and consequences of risk and uncertainty

An increasing number of studies have demonstrated that the interval within which forecasts of benefits and costs fall is so wide that it should be a serious cause of concern for planners and decision makers alike. Transport projects are by nature risky because of their complex nature and the long planning horizons, but failure to inform decision makers of risks inherent in forecasts represents a major source of error in project appraisal.

For construction costs, studies have revealed that there is a systematic tendency to underestimate costs in transportation projects. In the UK, Mott MacDonald (2002) found that construction cost escalations in 50 UK projects varied from 24% to 36% and that the main cause of this variation was usually (in 6 out of 10 cases) an inadequate business case or poor planning. In a series of large sample studies, Flyvbjerg *et al.* (2003b) demonstrated that estimates of construction costs in transport infrastructure projects were inaccurate and that a substantial cost escalation was the rule rather than the exception for all categories of projects. Cost escalation appeared to be a global phenomenon, and the average cost overrun ranged from 20% to 45%. The authors concluded, rather depressingly, that cost estimates and cost escalation have not improved over the last few decades and that cost estimates provided to decision makers are highly misleading. Odeck (2004) provided a slightly more encouraging picture from Norway. In a study of 620 road projects, he showed that the mean cost overrun was 7.9% and, perhaps surprisingly, that cost overruns were more common among small rather than large projects. His study did, however, show that discrepancies between estimated and actual costs were large (from -59% to a formidable +183%) and that this uncertainty was not properly brought to the attention of decision makers. Earlier work by Odeck and Skjeseth (1995) showed that from a sample of 12 toll projects, the average cost overrun was only 5%, but the interval was large (from -10% to +170%).

The same inaccuracies could be found in the estimation of traffic. The literature discussed in detail in Paper 1 and Paper 2 suggests that planners generally do a poor job in estimating traffic in all transport projects. For toll-free road projects, the clear tendency is that of underestimation (Goodwin, 1996; Flyvbjerg, 2005; Flyvbjerg *et al.*, 2005, 2006; Næss *et al.*, 2006). Traffic generally tends to be higher than forecasted. The implications could either be that benefits are underestimated, as suggested by Kjerkreit and Odeck (2009), or that the initial period of relief from congestion will be shorter and that benefits will therefore be overestimated, as suggested by the international literature. In other words, findings with respect to forecast accuracy are similar, but interpretations vary.

In toll road projects, the situation appears strikingly different. Traffic, with few exceptions, is overestimated. Studies with examples from throughout the world have shown that real traffic in toll projects is lower than forecasted (Odeck and Skjeseth, 1995; JP Morgan, 1997; Joosten, 1999; Bain and Wilkins, 2002; Bain and Plantagie, 2003a; George *et al.*, 2003; Bain and Plantagie, 2004; Bain and Polakovic, 2005; Næss *et al.*, 2006; TRB, 2006; Vasallo, 2007; BBC, 2008; Bain, 2009a, 2009b; Li and Hensher, 2010). Considering that the consequences of overestimated traffic in toll projects are not just a potentially distorted NPV but also financial default, this overestimation should be a serious cause of concern for planners and decision makers as well as for investors who expect some return on their invested capital.

Other transport projects that partly or wholly rely on a revenue stream include rail and transit projects. For these projects, the situation has been reported to be even worse. Urban transit projects, and light rail and tram projects in particular, are often projects of political prestige, making them susceptible to optimism bias. Pickrell (1989) demonstrated this bias by showing serious demand shortfalls in US urban transit projects during the 1970s and 1980s. More recent examples from the UK have shown that passenger levels in tram projects in urban areas in the opening year were well below what was projected (Bain and Plantagie, 2003b). Later, Flyvbjerg (2007a) used larger samples than typical previous studies to show that urban rail projects suffer from both large cost overruns and demand shortfalls, making them economically risky on two fronts. A tempting conclusion is that forecasts for urban rail projects are highly certain. Costs will almost certainly be higher than forecasts, and ridership will almost certainly be lower.

The consequences of not taking risk into account can be severe. With over- or underestimation of costs or benefits, results that are presented to decision makers could be of little value. If best-case alternatives are used throughout the appraisal, the NPV will typically be inflated and potentially misleading. This point was illustrated by Anguera (2006), who demonstrated that the British economy would have been better off if the Channel Tunnel rail link had never been constructed as systematically overestimated benefits in the original cost-benefit analysis concealed the fact that the tunnel has never been a viable project in cost-benefit terms. If they had known this fact, decision makers would probably have resolved to choose alternatives such as the following: a) not implementing the project at all, b) implementing the project in another form, or c) implementing other projects (Odeck, 2004). Ignoring risk can thus imply that methodologies such as CBA are of little value, that nonviable projects are implemented or that resources are allocated inefficiently because risks have not been considered properly in the planning process.

A potentially more severe consequence is that presenting misleading estimates to decision makers could represent a democratic problem. This consequence is especially the case if project promoters knowingly misinform parliaments, the public and the media to get a specific project built. Extremely risky projects are presented as “safe bets” by concealing the inherent risk to politicians, taxpayers and investors. If such practices spread to other projects, the consequence might be destabilised project development throughout the economy (Flyvbjerg *et al.*, 2003a).

Apart from CBA and the results thereof, input variables used in CBA are regularly used to dimension the capacity of transport infrastructure. Inaccurate traffic forecasts could therefore result in inefficient over- or under-dimensioning of the road. For toll road projects, or other projects that involve payment at the point of use, the implications of inaccurate forecasts are even more serious. Whether a road project can (completely or partly) be financed using tolls will largely depend on the traffic level (i.e., the number of paying vehicles), toll collection costs (operating costs) and financing costs. If the forecasts for any of these turn out to be overly optimistic, the result could be financial default for the agency responsible for collecting the tolls.

4.3 Causes of, and explanations for the miscalculation of costs and benefits

The substantial risks, in the form of the overestimation of costs and benefits, revealed for all transport projects form barriers to the effective allocation of resources and have been the source of much discussion in the academic literature. Cantarelli *et al.* (2010) proposed four categories of causes of and explanations for cost overruns: technical, economical, psychological and political.

Technical explanations are caused by unforeseen events in the planning and/or construction phase, such as changes in input prices, lack of quality data, lack of skills and change of project scope and design. Technical explanations are considered to be variables that influence cost overruns rather than explain them. These explanations are circumstances that planners should ideally be able to manage and provide contingencies for in their estimates. Failing to do so could clearly influence cost overruns without necessarily being the main cause. However, as technical explanations relate to a lack of knowledge about the future, they are considered to be more “honest” than errors deriving from other explanations.

Economic explanations are related to a lack of incentives and, in part, strategic behaviour among project promoters and planners. Projects that promise to deliver high benefits at low costs appear more attractive to decision makers, and project promoters can hence be tempted to deliberately underestimate costs or overestimate benefits to get their projects selected for implementation. From an economic perspective, it makes sense to underestimate costs and overestimate benefits as this increases the chance of reward for project stakeholders.

Psychological explanations are based on the concepts of planning fallacy and optimism bias, i.e., the tendency to ignore risk, even when faced with projects that may involve high risk. Humans are often urged to have a positive outlook on the future. Although hardly a recommendable strategy for planners involved in the appraisal of large-scale transportation projects, this tendency could lead to the selection of the most optimistic rather than the most realistic forecasts. In addition, as a higher (personal) utility is obtained when a project is selected for implementation, a tendency to choose the most optimistic cost estimate could result in underestimation.

Political explanations are related to the economic explanations and are often regarded as one of the main explanations for forecast error. Costs are deliberately underestimated, and benefits are overestimated to increase the chance of project acceptance. This strategic misrepresentation, as it is often referred to as, is caused by a combination of a lack of coordination, lack of commitment, lack of discipline, organisational and political pressure and an asymmetry of information. Forecasts are adjusted to derive the most politically or organisationally attractive outcomes. Even if the allegations that planners and project stakeholders deceive and manipulate for personal gain are quite serious, there is a range of studies (see, e.g., Wachs, 1987, 1989; Mackie and Preston, 1998; Flyvbjerg, 2007a, 2007b) supporting the claims of widespread dishonesty in the transport community. The result, as claimed by maybe the most vocal proponent of this theory, Danish professor Bent Flyvbjerg, is that it is not the best projects that are being built, but the most misrepresented ones. Flyvbjerg (2007a) has argued that error caused by technical explanations, such as inadequate transport models and lack of data, would lead to forecast accuracy being equally distributed around the expected value, i.e., general error. However, the fact that construction cost estimates are often skewed to the right is a sign of bias. Flyvbjerg has found little support for the technical and psychological explanations in interviews with planners and has hence concluded that it is the political-economic explanations that hold merit. Economic and political explanations are similar as they both use utility as a basis for understanding behaviour, leading to inaccurate forecasts and cost overruns in particular. However, the starting point differs in that economic explanations are based on a lack of incentives and resources, whereas political explanations analyse cost overruns in the context of interest and power (Flyvbjerg, 1998; cited in Cantarelli *et al.*, 2010).

The political-economical approach to the explanation of cost overrun and benefit overestimation has been strongly contested by Norwegian academics Osland and Strand (2010), who found several shortcomings in the theory, both in theoretical and methodological terms. Even if there are examples of misrepresentation, and even if this is admitted by actors involved in the projects, it does not mean that strategic misrepresentation, bordering on fraud, would be the *only* explanation of why forecasts are often wrong. In other words, Flyvbjerg's methodological design is not sufficient to support the conclusion of the "survival of the unfittest". Osland and Strand claimed that Flyvbjerg's approach is too one-dimensional and does not offer the necessary variation in the motives of planners to fully explain the variation observed in the data at hand. The Norwegian research in this area, they claimed, has not supported the theory that project approval is the result of strategic behaviour. Overruns and other forecast inaccuracies are rather the result of a politicisation of the planning process, where the analysis and recommendations of planners have been neglected.

5. Forecast accuracy in Norwegian transport planning

In the previous section, we showed that the underestimation of costs and overestimation of benefits is widespread in transportation projects throughout the world. The causes may vary, but the consequences are that large and unaccounted risks may not have been brought to the attention of decision makers at the time of the decision to build. These consequences may have led to waste, such as the implementation of the wrong projects due to distorted NPVs, project misspecification or financial distress for projects with various degrees of user payment. CBA based on unreliable or misleading estimates may also explain the apparent widespread scepticism among politicians towards CBA as an instrument for decision making. In this section, we seek to investigate whether forecast accuracy in the Norwegian road sector follows the same patterns as those revealed by international studies.

The starting point of the analysis is to define the concepts of under- or overestimation. If X_{ai} are the actual costs in project *i*, traffic or another input variable in an implemented project, and X_{fi} is the forecast, then the forecast error can be defined as follows:

$$e_i = X_{fi} - X_{ai} \qquad (5)$$

A positive e_i indicates underestimation, while a negative e_i indicates overestimation. Equation (5) gives an indication of the error but does not facilitate adequate comparison, as the size of e_i will depend on the scale of the data (Odeck, 2010a). In Paper 1 and Paper 2, we hence use the percentage error, which is defined as follows:

$$pe_i = ((X_{ai} - X_{fi}) \times 100) / X_{fi} \qquad (6)$$

Equation (6) gives the percentage error of project *i*, which is independent of the scale of the data. To aggregate errors and express the overall error in a sample of projects, the mean percentage error (MPE) is defined as follows:

$$MPE = \frac{1}{n} \sum_{i=n}^{1} pe_i \qquad (7)$$

The mean error has one major weakness. As negative and positive values tend to offset each other, the mean tends to be small and will hence be better suited to show if there is systematic under- or overestimation. As such, the mean error can sometimes obscure rather than clarify the real forecast error. Odeck (2010a) hence suggested another measure of forecast error, namely the mean absolute percentage error (MAPE), which was also recommended by Makridakis *et al.* (1998):

$$MAPE = \frac{1}{n} \sum_{i=n}^{1} |pe_i| \qquad (8)$$

The MAPE reveals the absolute size of the forecast error, irrespective of direction. However, it does not reveal any potential skew or bias as its value will always be positive. In the following, we will cite the MPE and MAPE of all studies that we refer to, if available.

5.1 Construction costs

Construction cost overruns are internationally prevalent. As discussed in Section 4.2, Odeck (2004) showed that although the same pattern seems to be present in Norway, the magnitude was less, and interestingly, overruns was worse for small than for large projects. As a result, the last decade has seen an introduction of a system of mandatory quality assurance for Norwegian public investment projects over the size of NOK 500 million. Magnussen and Olsson (2006) studied the effect of this system and concluded that cost overruns have since been reduced based on a sample of 31 transport, building, defence and IT projects. In a more recent study, Odeck (2010a) investigated whether cost overruns of road projects have improved as a result of measures taken by the Norwegian governments, namely the reorganisation of departments responsible for the planning and construction of road projects. Using a sample of 1045 projects worth almost NOK 47.000 million and completed between 1993 and 2007, he revealed that there was a considerable improvement in construction cost accuracy over the period. Since 2003, when the Norwegian Public Roads Administration became a procurer and all road building was privatised, construction cost overruns have been significantly reduced; today, larger projects experience cost underruns more often than overruns. However, the reorganisation has not reduced delays in construction, which have been found to increase cost overruns. On average, Odeck found the MPE to be 11%, which is lower than what has been reported internationally. The MAPE, which gives the absolute size of the forecast error, was found to be 15% over the period as a whole and decreased by 3 percentage points from 1993-1996 to 2004-2007. The decrease in error constitutes an improvement, but as international studies lack this measure of forecast error, it is difficult to make comparisons with results derived from other studies.

5.2 Traffic

As discussed in Section 4, international studies show a strong tendency for traffic forecasts in toll road projects to be overestimated, and the consequences thereof are similar to those of construction cost overruns. However, whereas construction cost in many ways is an issue that could and should be dealt with internally, market risk is at the forefront of traffic forecasting, i.e., there is a range of variables outside the planners' control that may influence the level of traffic in a given project. This lack of control naturally increases the complexity of traffic forecasting and will almost inevitably lead to a higher level of uncertainty. What has often been found, however, is a striking skew in forecasts. Instead of being distributed around the mean, as would be the case if forecasts suffered from general error, toll road forecasts are regularly overestimated, while traffic forecasts in toll-free road projects are generally underestimated. It has been suggested that this skew is a pattern of bias or a deliberate attempt to mislead decision makers in both tolled and toll-free roads (see, e.g., Flyvbjerg *et al.*, 2006 and Bain, 2009a).

Road tolling is on the increase throughout the world, both for the purposes of finance and for demand management. The latter usually involves various urban charging schemes, which have been advocated as one of the most efficient policy measures for reducing congestion and emissions and for encouraging modal switch in urban areas. Despite these benefits, urban road user charging is still considered to be a radical policy, and the examples of real life implementation are limited. In Paper 3, the impacts of road user charging were explored, and the effects of removing the Trondheim toll cordon were presented. It was found that traffic is generally sensitive to both the introduction and the removal of tolls. In Trondheim, there was a considerable increase in traffic when the toll cordon was removed. On average, there was an increase in traffic over the previous cordon of 15.5% for the hours between 14:00 and 18:00, whilst traffic levels decreased in the evenings and at night. The example of Trondheim illustrated that a significant proportion of the motorists has some flexibility in their trip scheduling and responds to changes in tolls by changing their travel timing, choice of destination, route or mode. The removal of the Trondheim toll cordon also showed that low charges have little impact on total traffic levels. These observations provide valuable knowledge to those planning toll road projects or congestion charging schemes.

In Paper 1 and Paper 2, the accuracy of travel demand forecasting in Norway was investigated using traffic data from tolled and toll-free roads. The distinction was made because the consequences of traffic forecast inaccuracy were considered to be more severe for tolled roads. Similar to international findings, we found traffic forecasts in Norwegian toll projects to be higher than real traffic. However, with real traffic being, on average, 0.7% higher than forecasted traffic, the error is much less than what was revealed in studies from other parts of the world. A mean forecast inaccuracy of 0.7% is well within an acceptable range, but the range within which forecasts fall is alarmingly high and should give rise to some concern. Figure 3 illustrates the accuracy of toll road forecasts and demonstrates that traffic forecasts in several projects in the sample are highly inaccurate.

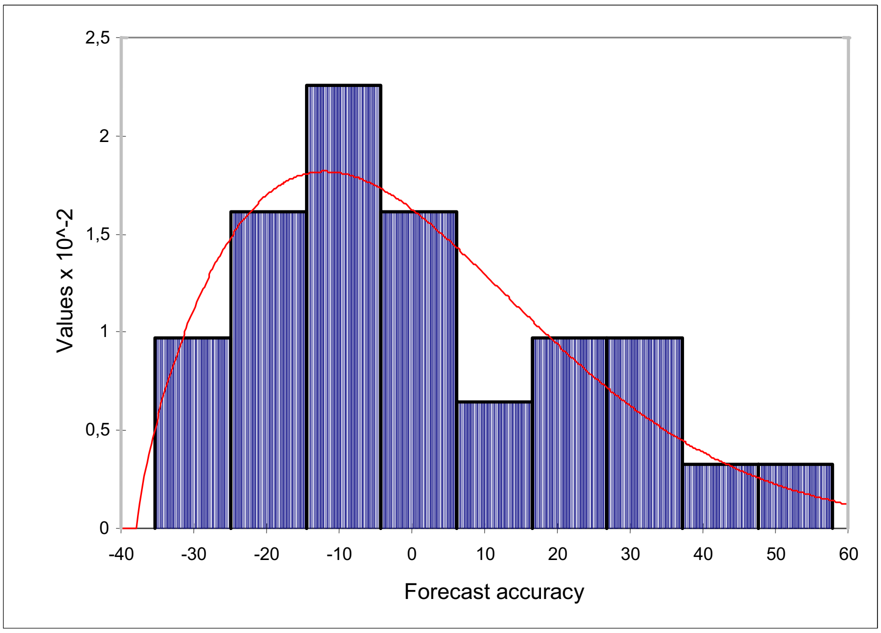


Figure 3: Inaccuracy of toll road traffic forecasts.

If traffic in one of four projects is overestimated by a margin of over 20%, this overestimation could have severe implications for projects' financial viability. Luckily, and as demonstrated in the papers, an increase in traffic that was larger than anticipated appeared to take place in the Norwegian toll road industry, with traffic levels increasing over time and exceeding original forecasts by Year 5.

There is clearly a need to further investigate the causes of traffic forecast inaccuracy in Norwegian toll projects, as the margin of error in forecasts provided is alarmingly high. However, even if traffic in a majority of the projects in the sample set is overestimated, we find no reason to accuse planners of deliberate misinformation. In other words, the results provided in Paper 1 and Paper 2 do not support the claim of over-optimism or bias in toll road forecasting.

Turning to forecast accuracy in toll-free roads, a pattern more similar to that of international studies was revealed. Traffic is, on average, higher than forecasted. The mean underestimation was 19.0%, while the range was large (from -14.6% to +76.1%). Only 6 projects had traffic levels below forecasted levels, and 13 projects exhibited traffic overestimation above the sample mean. In 7 projects, outturn traffic was over 30% higher than predicted. This inaccuracy is clearly unacceptable. We would expect forecast accuracy to be higher for toll-free roads, but this was not the case for Norwegian roads. The picture that emerges, as illustrated in Figure 4, is that traffic forecasts for toll-free Norwegian roads are skewed to the right.

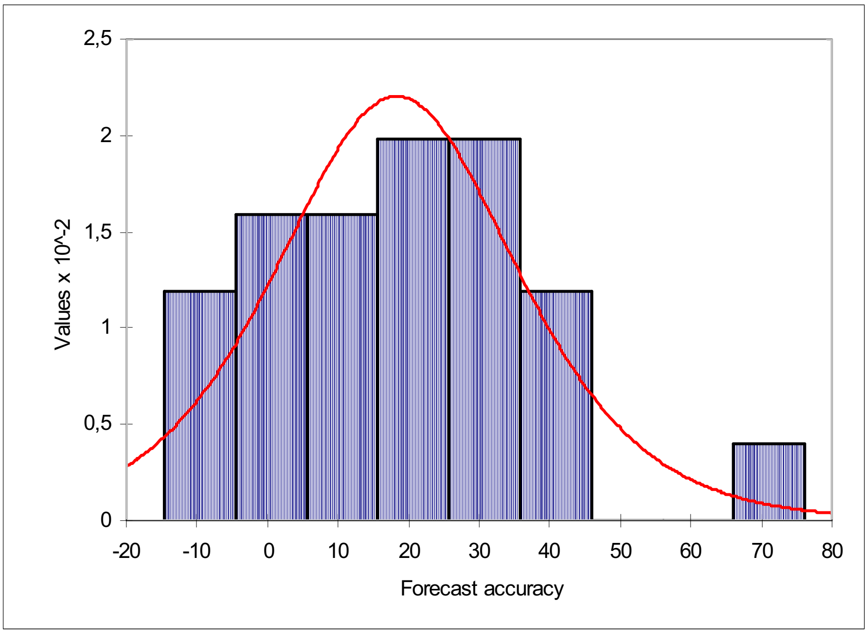


Figure 4: Forecast accuracy in toll-free roads.

This pattern is highly consistent with what has been found internationally. Traffic levels tend to be significantly higher than forecasted. This issue is evidently one that needs to be addressed. However, Paper 1 suggested that the causes for the observed underestimation could be found in model input error and failure to take induced traffic into account rather than deliberate human bias.

5.3 Operating costs

In Paper 2, we expanded the analysis by including toll road operating costs and forecasts of these as a measure of potential cost estimation uncertainty. Operating costs are real costs that will affect both financial and social viabilities of toll road projects. Also, as emphasised in Paper 4, "(…) any road user charging scheme should at least pass a social cost-benefit analysis, generate substantial net revenues and should be acceptable to a major proportion of the public. Minimising the operating costs is critical for meeting all these three basic criteria (p. 682)." Despite receiving some attention over the last few years (Prud'homme and Bocajero, 2005; Mackie, 2005; Raux, 2005; Odeck, 2008; Welde and Odeck, 2009; Eliasson, 2009; Hamilton, 2010), the number of studies focusing on this issue is extremely limited. Data on operating costs in toll companies are rare and often regarded as competition-sensitive information that is not readily available for research. In this context, Norwegian toll financing provides an interesting case. Here, detailed cost data from over 40 toll companies operating in different geographical regions and employing different tolling technologies are available to the authorities annually. This data allows for a more in-depth analysis of toll company performance and cost structures in the industry.

Decision makers are often faced with the choice between public and private finance, both of which have a cost to society. The cost of public funds is represented by the shadow price of taxation, which is commonly applied in cost-benefit analyses. The costs of toll financing are constituted by the efficiency loss generated by tolls deterring drivers from using the new road and the costs of collecting the tolls, i.e., the operating costs. The importance of operating costs in toll projects is discussed in detail in Paper 4. In the paper, the social costs of toll financing are defined as follows:

$$\mu = \frac{\alpha + T}{R - \alpha} \tag{9}$$

In equation (9), μ denotes the social costs of toll financing per unit of net revenue, α denotes the operating costs, T is the cost of traffic deterrence due to tolls, and R is the gross toll revenue.

If we assume a shadow price of public funds of 20%, the project should be financed using tolls rather than traditional public finance if μ in equation (9) can be kept below 0.2. This fact is often ignored in the public debate. Bråthen and Odeck (2009) discussed this issue further and estimated that toll financing could outperform public financing in urban areas and on trunk roads. Odeck (unpublished) investigated the issue in more detail and found that cost-benefit analyses of toll road projects presented to decision makers do *not* include the costs of toll financing. As such, these analyses are potentially highly misleading, as operating costs sometimes can constitute over 40% of the revenues. Further, tests of finance are left out, and decision makers may thus never learn whether tolling is the appropriate form of financing or not. Finally, 9 out of the 25 projects considered were more financially profitable to finance with tolls rather than with public funds. Hence, the use of tolls can constitute a welfare improvement if the right projects are selected for this method of finance and if the operating costs can be kept to a minimum. This information is new knowledge, and if the results of Papers 1-4 are used to assess the costs of toll financing, the total costs of road financing could be reduced. As argued in Paper 4, cost-efficient toll financing could represent the difference between a negative and a positive cost-benefit ratio.

Operating costs are thus important from both a financial and a social perspective. When planning new projects and considering different sources of finance, estimations of these costs should be carefully considered. In a cost-benefit analysis of the Stockholm congestion charging scheme, Eliasson (2009) identified that operating costs represented the highest loss to society and was the variable with the largest potential for efficiency improvements. Hamilton (2010) examined the costs of the scheme in more detail and found that even if estimates were fairly accurate, several of the original features of the system turned out to be either unnecessary or over-dimensioned.

In this context and given the long tradition of toll financing in Norway, we would expect planners in Norwegian toll projects to produce careful estimates of these costs. Surprisingly, the results provided in Paper 2 do not suggest that this experience has translated into accurate estimates of operating costs. On average, operating costs turned out to be 31.7% higher than planned. Furthermore, real costs ranged from -34.3% to +162.8% of forecasts. Norway has one of the world's most successful electronic toll collection schemes in operation (the AutoPASS system) but, for some reason, is unable to accurately estimate the costs of toll collection. Figure 5 demonstrates that an overwhelming majority of the projects in our sample had operating costs that were higher than what was originally forecasted.

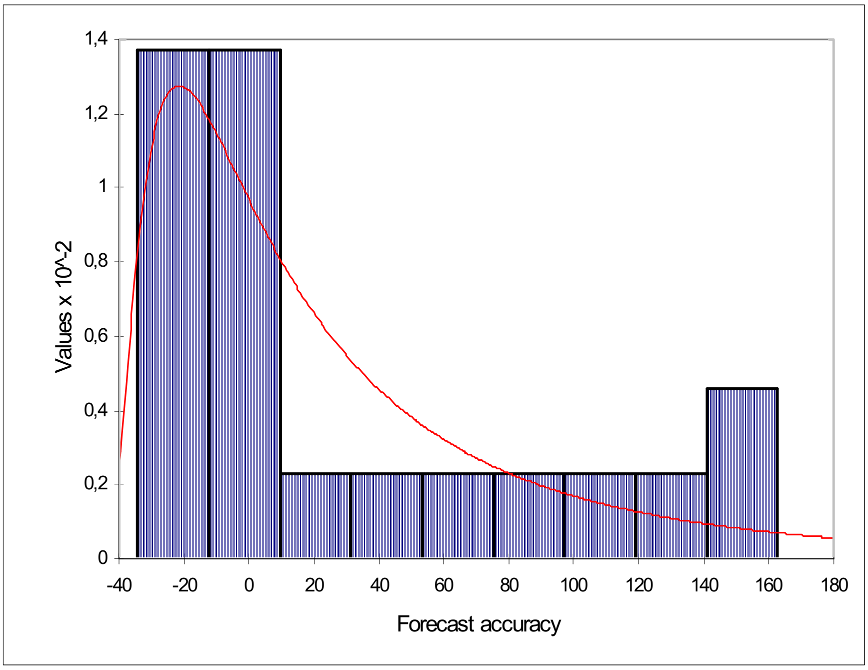


Figure 5: Inaccuracy of operating cost forecasts.

While traffic forecasts in toll projects were normally distributed around the mean (see Paper 1 and Paper 2), operating costs were noticeably skewed to the right. With a sample of only 20 projects, the results should be interpreted with care. Nevertheless, a distribution that is clearly to the right indicates that we cannot rule out that optimism bias has played a role in the estimation of operating costs in Norwegian toll projects.

5.4 Concluding comments: Norwegian forecast accuracy

Forecast accuracy in Norwegian road projects is similar to those that have been presented in international studies. Construction costs have been underestimated, traffic on toll-free roads has been underestimated, traffic on tolled roads has been overestimated and operating costs in toll projects have been underestimated. However, the discrepancies between estimates and actual costs/traffic seem to be smaller than experienced elsewhere. For constriction costs, there is even a tendency towards cost underrun for large projects. Table 4 summarises the results from the available studies of forecast accuracy in Norwegian road projects. Where data were available, we also included the mean absolute error as an illustration of the general error in the forecasts produced.

The causes for inaccurate forecasts are discussed in detail in Paper 1 and Paper 2, but a conclusion worth repeating is that the allegations of bias, with the possible exception of operating cost forecasts, find little support in the Norwegian data.

Internationally, the explanations of forecast inaccuracy based on suggestions that transport planners are involved in a worldwide conspiracy aimed at lying and deceiving decision makers to get projects approved have gained large support. However, if deliberate bias could be used as a universal explanation, applicable to different countries on different continents over several decades, planning and appraisal frameworks would have to be almost identical, but they are not. As shown by Grant-Muller *et al.* (2001) and Ødegård *et al.* (2005), there is great variation in the appraisal practice throughout Europe (not to mention other continents). CBA is the most commonly applied method of appraisal, but there is great variation regarding the standardisation of principles and the use of its results. If the results of CBA would be decisive for project approval, it could indeed give project promoters an incentive to lie. However, as suggested by Næss *et al.* (2006), if planners have no incentive to lie, the tendency to exaggerate benefits is reduced. And as discussed in Section 3, in the Norwegian case, projects with high estimated social benefits are not necessarily more likely to receive funding than others, which could be an explanation as to why bias seems less prevalent here than suggested elsewhere. We do not have data to assess if this is also the case in other countries, but in our view, the model proposed by Flybjerg (2007b) and outlined in equation (10) is too simplistic.

Underestimation of costs
\+ Overestimated benefits (10)
= Project approval

Osland and Strand (2010) also opposed Flyvbjerg's conclusions and argued that he lacks the data to verify his conclusions. To conclude that it is the most misrepresented projects that are selected for implementation, data on both selected and rejected projects are needed. That data has not been included in Flyvbjerg's research. Furthermore, in a sample of several hundred projects, there might be other explanations overlooked by Flyvbjerg that could help explain the observed inaccuracies.

Table 4: Forecast accuracy in Norwegian road projects.

Category	Mean percentage error	Mean absolute percentage error	Range	Study
Construction costs	+ 5.0%	n.a.	- 10% to + 170%	Odeck and Skjeseth (1995)
	+ 7.9%	n.a.	- 59% to + 183%	Odeck (2004)
	+ 11.0%	15%	- 67% to + 183%	Odeck (2010a)
Traffic, toll-free roads	+ 19.0%	22%	- 15% to + 76%	Welde and Odeck (Paper1)
Traffic, tolled roads	- 8.9%	17%	- 42% to + 23%	Odeck and Skjeseth (1995)
	+ 0.7%	19%	- 35% to + 45%	Welde and Odeck (Paper 1) and Welde (Paper 2)
Operating costs	+ 31.7%	47%	- 34% to + 163%	Welde (Paper 2)

However, this lack of data does not mean that forecast inaccuracy is not a problem. Inaccuracies are real, and their consequences are potentially serious, biased estimates or not. If CBA is to be used as a ranking tool, NPV estimates need to be accurate. If not, the wrong projects could be selected, and decision makers could be led to forego projects that could have provided a higher rate of return. This subject has been the focus of an on-going study initiated by the NPRA to estimate NPV in implemented projects *ex post*. The purpose is to reveal the extent to which forecasts made are correct and, if needed, correct future assumptions to increase accuracy and encourage the best practices. Preliminary results based on 11 projects show that NPVs was greater than forecasted for 8 of the projects studied. The main explanation for this result was found to be the underestimation of traffic, which is consistent with the findings in Paper 1. Further divergences between forecasted and actual results are explained by under-/overestimation of construction costs, differences in accident costs and changes in project designs (Kjerkreit and Odeck, 2009). As also argued by Osland and Strand (2010), this finding is contrary to the theory of strategic misrepresentation. Benefits are underestimated rather than overestimated, and even if there are inaccuracies, no sign of bias could be proven. Real NPVs will, on average, be at least as high as estimated. Earlier work by Bråthen and Hervik (1997) pointed in the same direction. By appraising five straight crossing projects *ex post* and including user inconvenience costs, they found that even if there were substantial differences in benefits *ex post* compared to *ex ante*, results indicated that the real NPVs of the five projects were higher than estimated.

This observation is encouraging. Even if CBAs contain inaccuracies, which of course should be a cause of concern, results are still reliable in the sense that conservative estimates are used in the analysis, and contrary to what has been suggested in international studies, the Norwegian road sector shows little sign of bias. Overestimation of benefits does not “pay off”, and there are other factors that may help to better explain why some projects are selected and others are not.

CBA results are vital inputs in the decision making process, but there are still transport projects that are not subjected to this method of appraisal. Intelligent transport systems (ITS) often offer effective solutions for many transportation problems. ITS have been around for decades, and there is increasing focus on how modern technology could help provide better services to motorists and travellers and better utilise the existing transport capacity. Today, transport services that involve user payment such as toll roads, ferry services and public transport rely completely on electronic payment systems, which offer user convenience and economic efficiency. Unfortunately, the benefits of ITS projects are not well understood compared to traditional transportation projects. Whereas ITS professionals understand the significant impacts that ITS can have on transportation networks, others, e.g., policy makers, may find it difficult to understand how and why ITS projects provide significant benefits. One method of enhancing the understanding of ITS benefits is to conduct an economic assessment, i.e., CBA, as is common for traditional transportation projects. However, ITS projects are often not evaluated in economic terms either because methodologies are not available or because data may be a limitation. Because there are tools for the economic assessment of traditional projects and decision makers rely on their results as a basis for making decisions, there are reasons to believe that many beneficial ITS projects may have been neglected. In other words, ITS projects could lose terrain to other solutions.

This point was illustrated in Paper 5 and Paper 6 where the modification of the Oslo toll cordon into a fully automatic toll collection system and the implementation of smart cards on public transport in Trondheim were used as case examples. Despite affecting a large number of users daily and despite being vital to large annual cash flows, neither of these systems were subjected to CBAs before implementation. The *ex post* analysis presented in the papers provided very positive results. The main conclusions were that the evaluation of ITS projects using the principles of traditional CBA is desirable and possible. The modification of the Oslo toll cordon was proven to be highly profitable in socio-economic terms and provided benefits in massive excess of what usually is delivered through traditional transport expenditure. Smart cards in Trondheim delivered many of the same benefits as the Oslo toll cordon and also delivered a positive net present value. Even if all effects were not monetised and included in the analyses, the main costs and benefits were. As non-included non-monetised effects would have mostly increased the net benefits of the schemes, we consider the analyses to be robust and, if anything, to have erred on the pessimistic side.

Commercial non-viability often represents constraints to the implementation of ITS used by commercial operators. The conclusions in Paper 5 and Paper 6 thus provide valuable input to those currently working on ITS strategies. Commercial appraisal from the perspective of the operator alone will often reveal costs to be greater than benefits; however, by applying the principles of social CBA and including effects to all parties involved, we may find that ITS could deliver substantial benefits to society. Since being made aware of these results, the NPRA has initiated cost-benefit analyses of other ITS schemes, and work is currently in motion to assess if the current CBA framework is sufficient or if it needs to be adjusted to include ITS-specific effects.

Not subjecting ITS to CBA is not a traditional risk, but the consequences are similar. As an example, when congestion in a network is a problem, road construction is often introduced as the most efficient cure. However, decision makers are in reality faced with an ITS alternative that is either unknown or, more often, known but not evaluated in economic terms. If information on the ITS alternative had been known and if it could even provide a higher NPV than the road construction alternative, decision makers could very likely have chosen to implement the ITS-based solution instead. A lack of information on potential ITS benefits could thus represent a risk of forgoing potential benefits and misallocation of resources.

ITS could also be a more sustainable solution when the future is uncertain. As argued by Samstad and Markussen (2000), ITS projects can, in spite of their technological complexity, represent lower risk than traditional projects. The reasons for this benefit are a shorter time horizon for analysis (sometimes down to 10 years), a high share of variable costs and finally, and maybe most importantly, that ITS investments are reversible to a greater extent than traditional road investments. ITS can thus provide a flexible solution when faced with complex problems for which there is no obvious solution. ITS can also be a temporary solution when investment in a new infrastructure is not possible because of financial or institutional constraints.

The studies referred to above suggest that the situation with respect to forecast accuracy in the Norwegian road sector may seem less discouraging than elsewhere because bias seems to be less of a problem than in other countries. However, the studies reveal that there is a large variation with respect to forecast accuracy. This variation is information that is not presented to decision makers. Presenting forecasts as certainties when they are in fact highly uncertain can be strongly misleading. There is thus a need to develop methodologies that could produce better forecasts and help illustrate the interval within which central parameters in the CBA are likely to fall. In this respect, of the explanations proposed by Cantarelli *et al.* (2010), technical and possibly psychological explanations are better suited than political-economic explanations for explaining forecast error in Norwegian road projects. As such, the balance of argument in the debate lies with Osland and Strand rather than with Cantarelli *et al.* and earlier work by Bent Flyvbjerg.

6. Addressing risk in transport appraisal

As the consequences of risks in transport projects can be serious, there are several methods available for risk management purposes, the most common of which are expected value analysis, sensitivity analysis and probability analysis. The aims of risk management are the following: (i) to improve the grounds for decision making by helping to determine if the project should be carried out or not and shed light on potential aspects of the project that may require advanced measures to be avoided; (ii) to support the steering regime of the project, especially with relation to dimensioning contingencies; and (iii) to increase the project actors' awareness of risks and probabilities by making clear where it is most important to concentrate attention (Austeng *et al.*, 2005).

In Section 4, we discussed the concepts of systematic and unsystematic risk. The former is the risk associated with aggregate market returns, and the latter is associated with project risk or random variation around the mean. This unsystematic risk could be diversified away in a large project portfolio. However, for individual projects, these variations will inevitably be a source of uncertainty concealed from decision makers in single-point NPV estimates. Regardless of definitions, a CBA needs to take into account that no variable can be estimated with perfect certainty, and information to decision makers should reflect this. Questions that we need to ask ourselves are "What can go wrong?", "How can it happen?", "How likely is it?", and "How bad can it be?" (NOAA, 2010). The methods outlined in the following sections could help us answer these vital questions.

6.1 Sensitivity analysis

Sensitivity analysis is the simplest method of risk analysis, and its purpose is to acknowledge underlying uncertainty and illustrate how sensitive net benefits are to changes in central assumptions.

Partial sensitivity analysis is based on changing one variable at a time to determine each variable's impact on the NPV. If the sign of the NPV does not change when assumptions regarding benefits and costs are changed, the results are robust, and we can have greater confidence in them. It is, however, a very crude method of risk analysis and is usually applied to the most important variables in the analysis. As the number of variables increases, the number of possible combinations of variables increases exponentially, and the probability of each possible outcome becomes unclear. Partial sensitivity analysis should be combined with expected value analysis. If we have estimated the probabilities of two outcomes p_1 and p_2, we can vary the probabilities of one and hold the other variables constant. This procedure could allow us to determine the variable that has the potentially biggest impact on the NPV and to find the breakeven value, i.e., the values of different parameters where the NPV is zero (Boardman *et al.*, 2006). However, for large projects and complex situations, this approach does not reflect that there are normally several variables that affect the outcome. Relying completely on one value at a time implicitly assumes that the other variables (held constant) are certain. Therefore, although methodically easy to carry out, partial sensitivity analysis is generally regarded as too simplistic for proper risk analysis in CBA.

Worst- and best-case analysis can be applied using the values derived from expected value analysis. However, instead of using a weighted average of the different probabilities, we employ the least favourable and the most favourable values of the different variables. We are thus able to calculate a pessimistic and an optimistic prediction of net benefits.

Worst-case analysis is generally preferred to best-case analysis because society is often risk-averse, meaning that decision makers would rather avoid negative returns than gamble and possibly obtain excess returns on an investment. Worst-case analysis also provides a useful check against optimism bias by illustrating the potential downside of an investment. If the NPV is negative under the base-case assumption, the method could also illustrate whether there are potential net benefits under more optimistic assumptions. If, however, the best-case assumption is also negative, the investment should not be carried out, at least not from a socio-economic perspective (Boardman *et al.*, 2006).

Worst- and best-case analysis can give the decision makers a vague idea of the risk profile of the investment. This information is particularly valuable to risk-averse decision makers, but assuming a normally distributed risk profile of the input variables, the chance of realising the worst- or best-case assumptions would presumably be small. However, the method forces us to determine a range of possible values and could (or should) be combined with expected value analysis. It is probably best suited for simple problems, and its applicability to multi-variable large transport projects should be limited. As pointed out by Park (1997; cited in Coates and Kuhl, 2003), worst- and best-case analyses are not easy to interpret and do not provide probabilities of occurrence.

Sensitivity analysis is best applied when faced with *uncertainty*, i.e., a situation when we do not know the probability of a certain outcome. It can be applied in all situations where forecasted costs and benefits are quantified. It does not require great computational power or analytic skills, but it can serve to illustrate potential risks in a project and the point at which a favourable project becomes unfavourable if central assumptions are changed.

6.2 Expected value analysis

Expected value analysis consists of modelling uncertainty as contingencies with specific probabilities of occurrence. The starting point is the specification of a set of contingencies that are exhaustive and mutually exclusive. Once representative contingencies are identified, probabilities are assigned to each of them. The probabilities must be non-negative and sum to one. The probabilities can be based on historically observed frequencies, subjective assessments, or expert opinion (based on information, theory, or both). Expected value analysis thus reflects that the future is uncertain and that benefits and costs can take on a range of values (Boardman *et al.*, 2006).

To calculate the expected net benefit in a situation where *n* contingencies could be defined, we assign probabilities for the occurrence of each contingency. The formula for the expected net benefit $E[NB]$ is thus given by the following expression:

$$E[NB] = p_i(B_i - C_i) + \ldots + p_n(B_n - C_n) \qquad (11)$$

In practice, expected value analysis involves assigning different probabilities to each benefit and cost. However, in a CBA, we often present central assumptions on benefits and costs as if they were certain amounts, even though the actual results rarely equal the expected value. This presentation will inevitably distort the NPV. Figure 6 illustrates the potential pitfalls of treating benefits and costs as certainties.

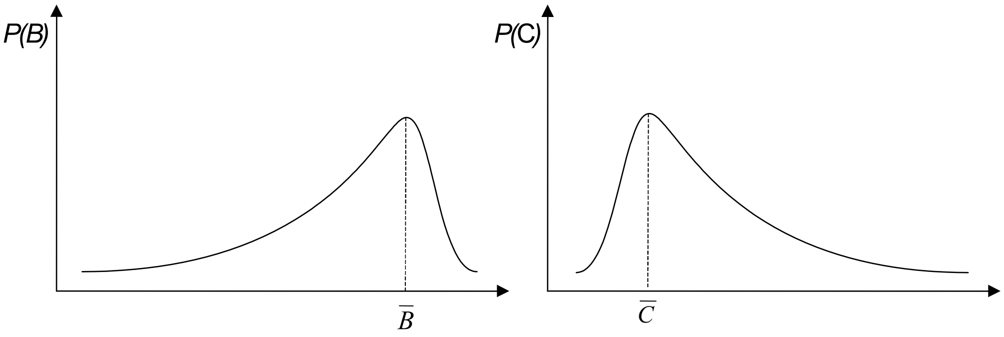


Figure 6: Probability distributions of benefits and costs.

Here, the true but unknown probability distribution of benefits reveals a large potential downside that is not accounted for if benefits are treated as certainties. Likewise, the probability distribution for costs shows a large potential for cost overruns. By assuming that benefits and costs will take on values $\overline{B}$ and $\overline{C}$, respectively, and ignoring probabilities for benefit shortfalls or cost overruns, we risk biasing the estimation and misinforming decision makers. Expected value analysis is hence a simple way to incorporate this risk into the decision making process.

In addition, and maybe most importantly, expected value analysis allows us to calculate the standard deviation or the intervals within which the expected value of the NPV is expected to fall. The expected value of the NPV is given by the following expression:

$$E(NPV) = \sum_{t=0}^{n} \frac{E(x_t)}{(1+r)^t} \qquad (12)$$

where $E(x_t)$ is the expected cash flow in a time period *t*. As $E(x_t)$ is the annual cash flow with multiple contingencies with variance $Var(x_t)$, the variation and standard deviation of the NPV can easily be calculated using equations (13-14):

$$\sigma^2{}_{NPV} = \sum_{t=0}^{n} \frac{Var(x_t)}{(1+r)^{2t}} \qquad (13)$$

$$\sigma_{NPV} = \sqrt{\sigma^2 NPV} \qquad (14)$$

The 95% confidence interval of the NPV can then be expressed as follows:

$$\mu_{NPV} = E(NPV) \pm 1.96 \frac{\sigma}{\sqrt{n}} \qquad (15)$$

where n is the number of contingencies by which $E(NPV)$ is calculated. Thus, in a model with 26 years of cash flow data, including the year of investment, and three contingencies for each cash flow, n would be 78.

The confidence interval is a tool of probability that is used to express the certainty or uncertainty of an estimated number. The width of the confidence interval is determined by the degree of confidence. A 95% confidence interval is narrower than a 99% confidence interval, indicating that there is a greater probability that the true mean lies within a wider confidence interval (Simley, 2011).

Expressing the confidence interval of the NPV, or indeed that of any variable, has several advantages. A small confidence interval expresses a higher degree of certainty in the end result, whereas a wide interval illustrates that the project is risky and that further analysis may be needed to reduce the uncertainty with regard to input parameters. A project that yields a confidence interval that includes negative values might be unattractive to the risk-averse decision maker, whereas decision makers should be indifferent to overlapping confidence intervals, even if the point estimates differ.

Expected value analysis is an improvement from traditional deterministic appraisal and helps us acknowledge the stochastic nature of input parameters. Information on the confidence interval of a proposed project could thus improve the quality of decision making under risky conditions.

6.3 Probability analysis

All the methods discussed above give us some idea of the inherent risk of a project, what the most risky variables are and what could potentially be gained or lost under extreme scenarios. However, for more complex and capital-intensive projects, risk analysis is increasingly being based on probability analysis. Probabilistic modelling is most commonly applied through Monte Carlo simulation. Until the 1990s, the method was not widely applied because of software and hardware limitations, but as the range of tailor-made computer software packages increased, so has the use of this method.

Monte Carlo simulation overcome the problem of only a few scenarios being analysed by allowing us to develop a total risk profile of the project based on hundreds or thousands of “what if” scenarios. In general, the main steps in conducting Monte Carlo simulation are as follows (Palisade, 2004):

1) *Develop a model: identify output and input variables.*
2) *Identify uncertainty: specify possible values with probability distributions of the input variables.*
3) *Analyse the model with simulations: values are selected randomly within the specified ranges of values.*
4) *Make a decision.*

In the context of transport project appraisals, CBA is the model in which we seek to expose potential risks. The output in CBA is the NPV or other decision criteria, and the relevant input variables include, for example, construction costs, operating costs, traffic, number of accidents, and value of travel time. In theory, all variables in a CBA could be included in the analysis. However, as argued by Savvides (1994), the greater the number of variables and hence, the greater the number of probability distributions used in a random simulation, the greater is the risk of inconsistency or bias in the final result because of correlation among the variables. Moreover, the cost (in terms of time and money) needed to define accurate value ranges and probability distributions of a large number of variables may exceed the additional gains from broadening the scope of the analysis. Therefore, although practices vary, Monte Carlo simulation is usually based on the most important variables. Partial sensitivity analysis could be a useful starting point to identify the variables with the biggest impact on the NPV.

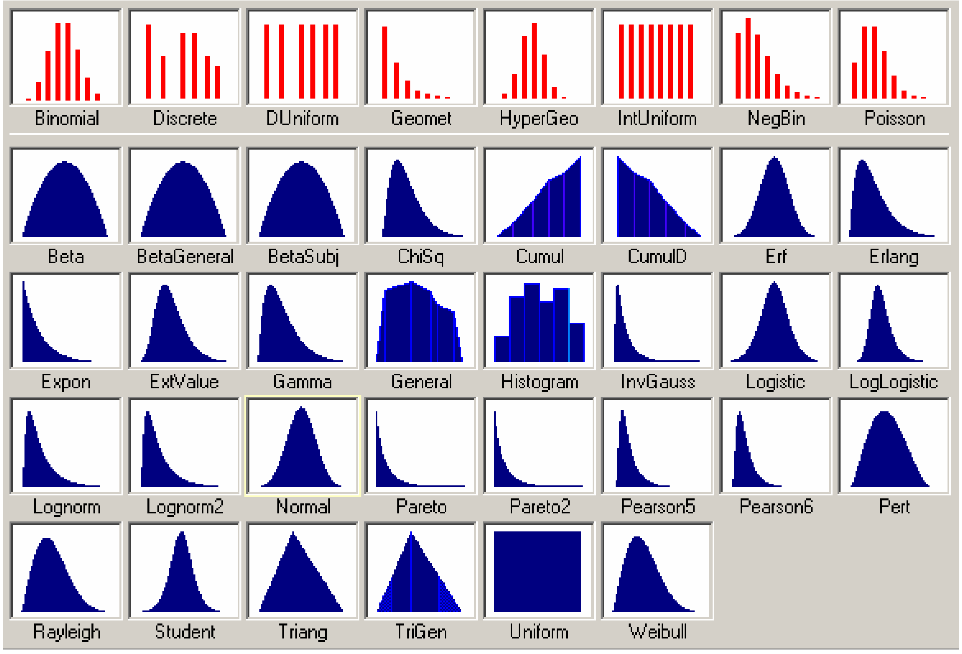


Figure 7: Probability distributions in a Monte Carlo simulation.

Defining the uncertainty or the possible ranges of the input variables is the most demanding and time consuming aspect of Monte Carlo simulation. Figure 7 illustrates some common probability distributions that are available in the @Risk Monte Carlo simulation software. A distinction is made between non-parametric and parametric distributions. Parametric distributions are based on mathematical functions, whereas non-parametric distributions are not. Generally, non-parametric distributions have a more intuitive appeal, and their function is merely a description of their mathematical shape: uniform, general, triangular, cumulative or discrete.

Applying the right probability distribution is essential in risk analysis. There is an increasing range of studies that focus on common probability distributions in risk analysis, their statistical properties and recommended distributions for different parameters (see, for example, Back *et al.*, 2000; Vose, 2005; Drevland *et al.*, 2005; Salling and Leleur, 2006; and Salling, 2008). In reality, the true distribution is unknown, and we often have to rely on expert opinion to define a range of values that are capable of capturing the actual value. Vose (2005) thus recommends non-parametric distributions to be used in all except a very few cases, as non-parametric distributions are generally far more reliable and flexible for modelling expert opinion about a model parameter than parametric distributions.

The increasing range of *ex post* studies of central input parameters, such as those presented in Paper 1 and Paper 2, can provide useful starting points for choosing the appropriate probability distribution. If historic data suggest that traffic forecasts are underestimated and that the ratio of actual traffic to forecasts is often skewed to the right, a distribution that reflects these tendencies should be applied. Modern simulation software also allows probability distributions to be fitted to available data.

Running the simulation is the part of the risk analysis where the computer takes over. Values are selected randomly within the set of probability distributions and defined correlation conditions. A sample size of 500 simulations is usually sufficient for the model to converge, but today's software allows us, if necessary, to run thousands of iterations in seconds. For each run, the NPV is computed and stored. Each run represents a probability of occurrence equal to the following:

$$p = \frac{1}{n} \tag{16}$$

where p represents the probability weight for a single run, and n is the sample size. The probability of a project being below a certain value is thus the number of results having a lower value multiplied with the probability weight of one run (Savvides, 1994). Figure 8 illustrates the results of a simulation process using the accumulated descending graph. In this case, the probability of project n costing less than 310 million is some 72%.

Most software packages for Monte Carlo simulation offer a range of results and statistics, which gives both the analyst and the decision makers the means with which to widen their assessment of proposed projects. In addition to the accumulated descending graph, other useful graphs illustrating simulation results includes the regression sensitivity graph (Figure 9), which shows the variables that influence the NPV (or cost) the most, and the histogram (Figure 10) which shows the frequency of estimated project values (figures adapted from Kvisvik, 2011).

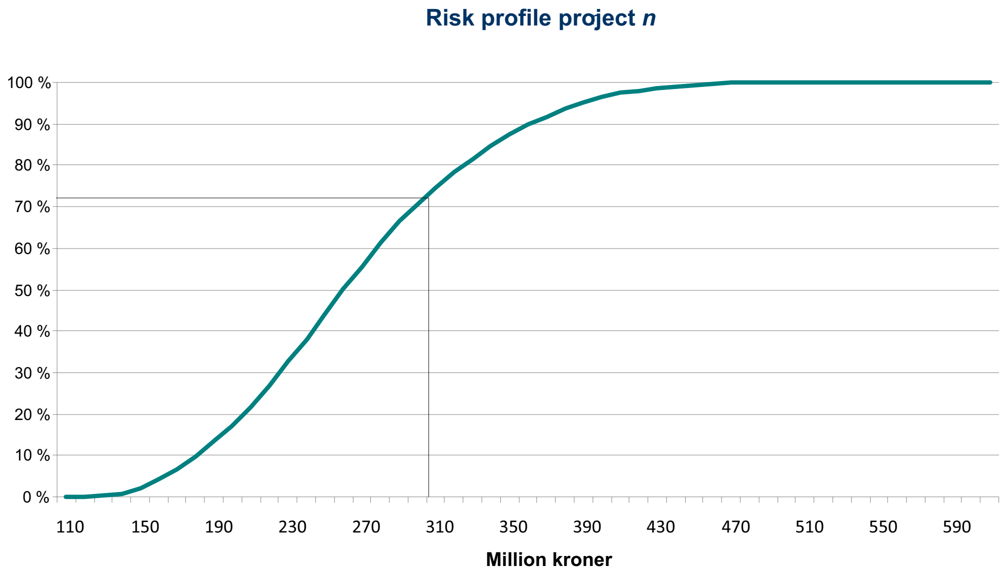


Figure 8: Distribution of results: net present value.

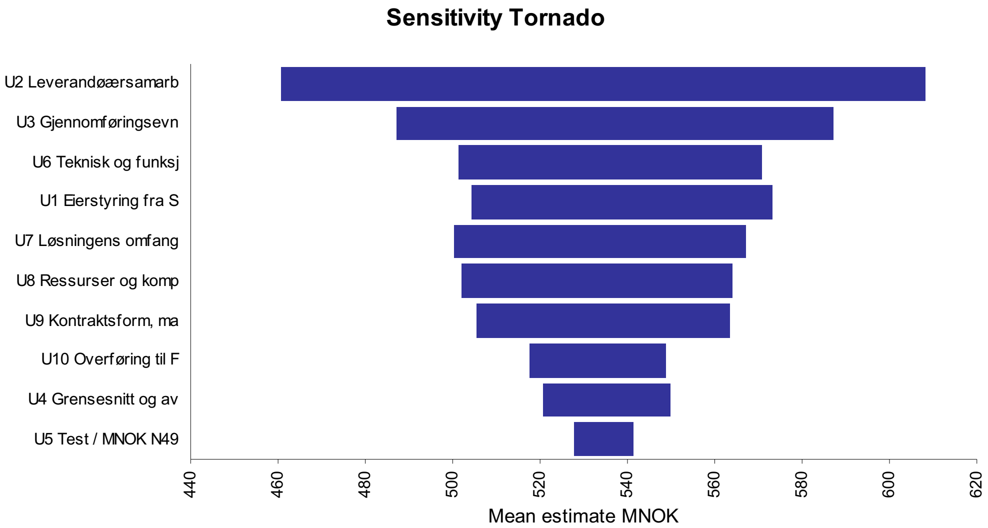


Figure 9: Sensitivity tornado.

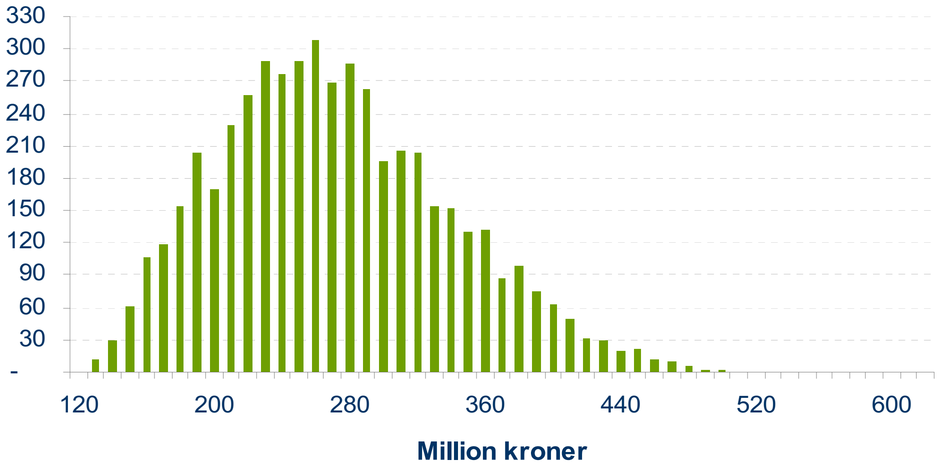


Figure 10: Histogram of the NPV distribution.

The results of Monte Carlo simulation are useful for illustrating the potential risk in a proposed project and for providing decision makers with interval results rather than single-point estimates of NPV/BCR. Rather than presenting estimated CBA results as certainties, decision makers would benefit more from confidence intervals. In Monte Carlo simulation, the 95% confidence interval for the NPV, or the risk-adjusted NPV, is similar to equation (15) and given by the following:

$$CI = NPV_s \pm 1.96 \times \frac{\sigma_s}{\sqrt{n}} \qquad (17)$$

where NPV_s is the sample mean of the NPV, σ_s is the sample standard deviation, and n is the number of iterations. If the confidence interval is too wide, it is an indication that forecasts for input variables are too uncertain and that the project itself is very risky.

Another useful summary measure of project risk is the coefficient of variation, which is defined as the ratio of the standard deviation of project returns to the expected value:

$$c_v = \frac{\sigma}{\mu} \qquad (18)$$

It is usually defined as a percentage, so that the value is multiplied by 100. The lower the coefficient of variation, the smaller the project risk.

Despite its many attractive features Monte Carlo simulation is not a widely applied method of risk analysis in CBA. Most European countries manage risks either by adding a risk premium to the discount rate or by means of sensitivity analysis (Ødegård *et al.*, 2005). Denmark provides an exception. There, the CBA-DK modelling framework has been developed to incorporate Monte Carlo simulation into the CBA of transport infrastructure projects (for an example of its use, see Salling and Banister, 2009) to assess risks and produce interval results.

The CBA-DK framework allows Danish infrastructure projects to be appraised along both the traditional deterministic lines of standard CBA methodology and a more elaborate stochastic risk assessment methodology based on Monte Carlo simulation and the @Risk software (Salling and Leleur, 2011).

If Monte Carlo simulation is carried out properly, risks should be incorporated into the appraisal and a risk-adjusted NPV could be presented to decision makers. However, to account for systematic risk, i.e., risk correlated with general economic activity, a risk premium is often added to the discount rate. Performing quantitative risk analysis *and* adding a risk premium to the discount rate could thus involve a double counting of risk. Brealy and Myers (1991;cited in Savvides, 1994) argued that the most appropriate discount rate to use in project appraisal in which quantitative risk analysis is carried out is the risk-free discount rate. Others maintain that the discount rate should include a premium for systematic risk, but not for project risk. Savvides (1994) recommended the use of the discount rate used in deterministic appraisal, i.e., the risk-free discount rate plus a risk premium. Vose (2000) took a similar view and argued that using the risk-adjusted discount rate is the most practical approach because it automatically incorporates correlations between distributions and enables decision makers to directly compare with past CBAs. In BTRE (2005), another concern of using the risk-free discount rate was raised, namely that using the risk-free discount rate for public sector investments could raise concerns about government investment crowding out private sector investments.

Risk is a natural part of project appraisal. Transport projects are always faced with uncertainty, ambiguity and variability. Even with access to exhaustive information, we cannot accurately predict the future. Probability analysis through Monte Carlo simulation allows us to see all the possible outcomes of a decision and to assess the impacts of underlying risk, allowing us to make better decisions under uncertainty. However, Monte Carlo simulation are not a substitute for appraisal methodology, but rather a tool to improve its results. Therefore, the results obtained can only be as good as the model employed.

6.4 Risk management in Norwegian cost-benefit analysis

With the increased focus on cost overruns, forecast error and the general tools available for decision making, Norwegian public sector investment and the methodologies for appraisal, including the treatment of risk and uncertainty, have come under scrutiny. Traditionally, the treatment of risk in Norwegian cost-benefit analyses has been restricted to a partial sensitivity analysis in which central assumptions such as construction costs and the discount rate have been changed to illustrate the sensitivity of the NPV to changes in central assumptions. More recently, the Ministry of Finance has issued guidelines that include recommendations on how to incorporate risk in CBA (Finansdepartementet, 2006).

In the guidelines, it is recommended that unsystematic risk is reflected in the project cash flows through expected values (see Section 6.1). Systematic risk should be managed either by replacing uncertain benefits with security-equivalent benefits or by adjusting the discount rate for risk. The latter is the most common method for accounting for systematic risk in Norwegian appraisals. Security-equivalent benefits are expressed as follows:

$$\frac{K}{(1+k)^t} = \frac{S}{(1+r)^t} \tag{19}$$

where *K* is the expected benefit and *S* is the security-equivalent benefit when *k* is the risk-adjusted discount rate and *r* is the risk-free rate. Rearranging the equation gives the following expression:

$$S = K\frac{(1+k)^t}{(1+r)^t} \tag{20}$$

This expression means that if the risk-free discount rate is 2%, the risk premium is 2.5% and the time frame is 25 years, the equivalence factor will be 0.55. Given this approach, a net annual benefit of 100 will need to be adjusted to 55 and then discounted to today's values using the risk-free discount rate to account for risk.

Finally, the Ministry of Finance has, since 1997, required all public investment projects larger than NOK 500 mil to undergo a system of mandatory third-party quality assurance. This involves a thorough scrutiny of cost estimates, traffic forecasts, uncertainties and choice of alternatives by external consultants. As discussed in Section 5.1, Magnussen and Olsson (2006) indicated that this system has contributed to reduced cost overruns since its implementation in the Norwegian planning and appraisal frameworks.

7. Concluding remarks and recommendations for the future

This thesis has focused on risk and uncertainty in Norwegian transport planning. We have demonstrated inaccuracies in the estimation of critical variables in the appraisal process and discussed the role of cost-benefit analysis in the appraisal of transportation projects. CBA is by far the most widespread method of appraisal of large infrastructure projects and, in our opinion, far superior to any other appraisal methodology available. The framework for appraisal as a whole is robust and defensible, but the often-observed limited use and understanding of its results suggests that a closer interaction between analysts and decision makers could improve the decision making process. Unless this issue is addressed and resolved, there is a risk that the appraisal process will fail to prioritise solutions that match the policy aspirations and priorities that are set.

The planning and appraisal of road projects involve multiple variables that all exhibit various degrees of uncertainty. In practice, projects where all inputs are certain are special cases. Inaccurate estimations of benefits and costs therefore represent a major source of risk in the planning of infrastructure projects. International experience suggests that bias, or deliberately skewed forecasts may have played a role in the planning of road-infrastructure projects and that risks have often been downplayed. An increasing number of international studies have shown that there is a clear tendency for construction costs to be underestimated. Traffic in toll projects is generally overestimated, and traffic in toll-free projects is often underestimated. Potential consequences of this practice include inefficient resource allocation, destabilised project development and a potential democratic problem in the long run.

The results presented in this thesis suggest that the forecast accuracy in the Norwegian road sector exhibits some of the same patterns as presented in international studies, but that the discrepancies between estimates and actual costs and traffic seem to be smaller than those experienced elsewhere. The observed inaccuracies should nevertheless be a cause of concern and should continue to be scrutinised by planners to provide carefully founded estimates. A perhaps unintended consequence of the limited use of CBA results is that planners have little to gain from downplaying costs and overestimating benefits. There is little sign of bias in the planning of Norwegian road projects.

A possible exception is operating costs in toll projects. An overwhelming majority of the toll projects studied had operating costs higher than forecasted. This tendency could be a result of deliberate underestimation or over-optimism. However, an equally plausible conclusion is that the apparent success of toll-financed road projects has concealed the fact that the estimation of central parameters of the business case of new projects has, at times, been sloppy. The results provided in the papers included in this thesis should be disseminated to planners and decision makers and, perhaps more importantly, the large amounts of high quality data from the Norwegian toll road industry should form the basis of an annual monitoring report in which data could also be made available for research.

Norway is considered by many to be a best-case country in terms of efficient planning and implementation of new toll projects as well as a stable regulatory framework that has allowed for the development of interoperable, user-friendly and cost-efficient new technologies. However, despite this vast experience and competence, relatively little emphasis has been placed on the evaluation of implemented schemes. Papers 1-5 in this thesis hence provide some exceptions. During the last decade, the much-acclaimed charging schemes of London and Stockholm have received extensive attention in the academic literature. Based on evaluations financed through user charges and government funds, British and Swedish research communities are now at the forefront internationally in the field of road user charging. There are no reasons as to why Norwegian consultancies and research institutions should not play similar roles, but this presupposes a domestic research market in which skills could be developed and results generated and disseminated. With annual toll revenues of about NOK 6 billion, toll companies should be required to contribute to an annual budget for research and development. The end result would most likely be improved service quality and cost efficiency to the benefit of users, operators and governments alike.

The most common decision criterion in CBA is the net present value. The NPV is normally presented as a certainty, with no possible variance or margin of error. This presentation conceals the fact that the underlying variation or inaccuracy in input parameters will inevitably increase the range in which the true NPV is likely to fall. Even if we use the most likely value of every project variable, it does not mean that the derived result will also be the most likely result. Therefore, a method of risk management is needed.

There are several methods available for risk management purposes, the most common of which are sensitivity analysis, expected value analysis and probability analysis, with the latter being regarded as the most comprehensive. Monte Carlo simulation allow us to see all possible outcomes of an estimated model and how likely they are to occur. This information can help us to judge the risks to accept and the ones to avoid, allowing for the best possible decision making under uncertainty. Quantitative risk analysis through Monte Carlo simulation provides valuable information throughout the appraisal process, increases the understanding of the nature of risk, helps identify the major threats to project profitability, reduces forecasting error and improves decision quality (Ho and Pike, 1998). The credit rating industry has long embraced Monte Carlo simulation for handling risk and uncertainty in complex decision making processes. Ironically, the method is still in limited use for risk analysis in public infrastructure projects. Risk in Norwegian cost-benefit analyses is currently managed by partial sensitivity analysis, risk adjustment of the discount rate and/or the use of security-equivalent benefits, none of which are easily communicated to decision makers who are expected to make decisions based on the results of these analyses. As such, we recommend looking to Denmark, where the CBA-DK framework has been developed to incorporate Monte Carlo simulation in the CBA of transport infrastructure projects to assess risks and produce interval results. The CBA-DK framework allows Danish infrastructure projects to be appraised along both the traditional deterministic lines of standard CBA methodology and a more elaborate stochastic risk assessment methodology based on Monte Carlo simulation. A starting point should nevertheless be to subject already implemented projects to Monte Carlo simulation to assess whether single-point NPV estimates have concealed large inherent project risks unknown to decision makers at the time of the decision to build. We suggest that this initiative be incorporated in the NPRA’s on-going programme of post opening studies of implemented projects.

Finally, as a word of caution, monetised impacts are often assumed to be the only source of risk in transport appraisals. However, as discussed in Section 3, non-monetised impacts, such as impacts on landscape, cultural heritage and distributional impacts, are part of the overall impact assessment and provide supplementary grounds for decision-making. As discussed by Odeck (2010b) and others, because monetised impacts sometimes matter less in the decision making process than is perhaps desirable from a rational point of view, there must be other factors, revealed or un-revealed, in the impact assessment process that determine decision makers’ preferences for road investments. The grounds for decision making could hence be regarded as insufficient for providing the desired level of information. A final area for further research should thus be an investigation into what level of information decision makers need and what the appraisal framework should contain to provide the necessary transparency in the decision making process.

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Paper I

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Do Planners Get it Right? The Accuracy of Travel Demand Forecasting in Norway

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This paper deals with the accuracy of travel demand forecasts among Norwegian road projects. We use data collected from tolled roads and toll free roads. The results reveal that while traffic forecasts of tolled schemes are fairly accurate, traffic forecasts among toll free roads have a higher degree of inaccuracy and are generally underestimated. An explanation for the observed discrepancy between estimated and actual traffic among toll free roads is that road planners may have ignored the existence of induced traffic and that the standard national traffic growth rates used in the transport models has been too low. For tolled roads, an explanation for the higher degree of forecast accuracy is that planners over the years have been scrutinized to provide careful estimates. Our recommendation is that traffic forecasts provided by planners should constantly be subjected to scrutiny by independent consultants before being presented to the decision makers. Aspects that need to be specifically examined include: (1) the extent to which a road project may lead to induced traffic, (2) the extent to which transport models accommodate appropriate factors and, (3) the extent to which forecasts made address uncertainties by providing confidence intervals of estimates.

Keywords: Traffic-forecast accuracy, toll roads, toll free roads

1. Introduction

Risk and uncertainty are issues of increasing concern in transport planning, and it is generally acknowledged that inaccurate travel-demand forecasts represent a major source of risk in the planning of infrastructure projects. International experience suggests that bias, or deliberately skewed forecasts, may play a role in the planning of road-infrastructure projects and that risks are often downplayed.

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The over- or underestimation of traffic levels can have severe implications. Traffic forecasts are used to determine the capacity of transport infrastructure, and inaccurate traffic forecasts can therefore result in inefficient and inaccurate sizing of the road. Accurate forecasts are also important from a socioeconomic point of view. All road projects in Norway and most other countries of Western Europe are subjected to traditional cost-benefit analyses, which rely heavily on the accuracy of the forecasts being used. If traffic levels turn out to be significantly lower than estimated, this can affect total benefits derived from time savings, reduced accidents or lower vehicle-operating costs. In the case of traffic underestimation, the capacity relief on the congested links could turn out to be lower than planned. This may distort the social viability of such projects and result in non viable projects being implemented. The end result may be inefficient resource allocation.

For toll projects, the implications of inaccurate forecasts are even more serious. Whether a road project can (completely or partly) be financed using tolls or not depends largely on the traffic level (i.e., the number of paying vehicles). Thus, in addition to the consequences for toll free roads, toll roads on which traffic levels fail to meet expectations also risk financial default. Furthermore, toll roads are often financed through non-recourse loans that are secured against future toll revenue only and with no other collateral. Bondholders and lenders should therefore require proposed toll roads to be subjected to a thorough risk assessment before investing in projects where the repayment of loans relies on precise traffic estimates.

Over the years, several toll projects have experienced financial difficulties due to traffic shortfalls, cost overruns and/or increased interest rates. The Ålesund Tunnels project in Norway experienced payment difficulties soon after opening in 1987, and the main creditor, Sunnmørsbanken, eventually collapsed. Despite a restructuring of the loans, the project was, in effect, bankrupt. The debt continued to increase, and when the project finally was terminated in October 2009, the remaining debt was still some € 165 million, which had to be covered by the government. To date, however, it is the only Norwegian toll project that has gone into default. With over 100 projects financed by tolls, the success rate of Norwegian tolling must hence be considered high. Internationally, the Hungarian M1/M15 represents a well-known example of overestimation. The project opened on time and within budget, but the traffic soon turned out to be only about half of what was projected. As the concessionaire relied solely on the traffic revenue, guarantees from both the shareholders and the state had to be drawn, and eventually, the concession was nationalised and toll rates halved. The shareholders suffered substantial losses and received no compensation (Joosten, 1999). More recently, the M6 toll road outside Birmingham, UK, is now being used by less than half the number of vehicles for which it was intended, and haulers have called for the road to be subsidised to ease congestion on the main M6, which has no tolls (BBC, 2008).

The aim of this study is to provide new evidence on the magnitudes of traffic forecast inaccuracies using Norway as a case study. We provide explanations for the accuracies and inaccuracies and, based on these explanations, give recommendations for improving road-forecast practices. The differences in the forecast accuracies between toll and toll free road projects are specifically examined.

The paper is organised into the following sections. Section 2 discusses the forecast uncertainties on toll roads versus toll free roads. Section 3 presents the data and methodology used in the analysis. In Section 4, the results are presented, and in Section 5, some conclusions are drawn.

2. Forecast inaccuracies for toll roads vs. toll free roads

The practice of financing new infrastructure through user fees is increasing worldwide. For roads, cost recovery through tolls is becoming ever more common as total tax revenues are often insufficient to cover the requisite infrastructure investments. Traffic forecasting is a complex issue, and adding tolls to the calculation normally increases the uncertainty of the forecasts. Road users respond to tolls in various ways, not all of which are rational, and the models used to forecast traffic are not necessarily designed to incorporate these reactions.

The financial viability of a toll project relies heavily on the number of paying vehicles passing through the toll stations, and overestimation of traffic can potentially have severe financial implications. Thus, it is expected that planners treat toll projects with a higher degree of caution and, even if uncertainties in the estimates cannot be eliminated, use conservative traffic estimates to avoid overly optimistic forecasts.

Forecast inaccuracy is not necessarily a problem. If the errors for various projects are randomly distributed around the true mean, there is a possibility that they would cancel each other out for a given project portfolio. When the forecasts are systematically biased, however, with averages significantly different from zero, perhaps due to over optimism or downright dishonesty on the part of the planners, the problem should be taken more seriously. Whereas transport models can be improved through increased computing power, improved data quality and other factors, deliberate human error is much harder to completely avoid.

The concept of optimism bias or risk denial has been the focus of several studies by Flyvbjerg (2005) and Flyvbjerg et al. (2005, 2006). Based on the data from transport projects around the world, the authors concluded that planners in the transport industry do a poor job of estimating demand. For roads, the actual traffic was found to be, on average, 9.5% higher than forecasted. The actual and forecasted traffic differed by more than ± 20% in over half of the road projects in the sample. Based on these rather disappointing results, Flyvbjerg suggested that planners and decision makers should take traffic forecasts, especially rail forecasts, which do not properly deal with uncertainty with "a pinch of salt" (Forster, 2006, p. 9). Furthermore, Flyvbjerg used these results to make allegations regarding the professional honesty (or dishonesty) of the planners and argued that the end result was often that the most misrepresented projects were built rather than the best ones (Flyvbjerg, 2007). This was opposed by Osland and Strand (2010), who found no general support for the theory of strategic misrepresentation and argued that there are other mechanisms at work that could better help to explain the variations in the forecast accuracies that were often observed.

It is often assumed that planners have become better at predicting traffic levels due to improvements in transport models and computing power. Flyvbjerg et al. (2006) did not support this proposition. In fact, the opposite seems to be the case for Danish road projects, as forecasts there seem to have become more inaccurate over time. Odeck et al. (2009), however, reached different conclusions. By investigating the accuracies of the national and regional traffic forecasts, they found that the forecasts have become more accurate since 2001, when the regional and national transport models were improved. Although their findings relate to forecasts at the macro- and regional levels rather than project-specific forecasts, it is still of interest to compare their results with ours.

Traditionally, the studies of forecast accuracy have been based on toll free roads. With the use of toll financing increasing, however, toll projects have come under increasing scrutiny, especially from credit-rating agencies that routinely gauge the financial viability of such projects on behalf of potential investors. Perhaps the first comprehensive study of toll road traffic-estimation performance was conducted by the investment bank JP Morgan (1997), revealing that 13 of the 14 newly implemented US toll roads displayed traffic levels below forecasts. In four of the projects, the opening-year traffic was 30% below what was expected. The bank concluded that traffic-forecasting inaccuracy represents one of the major sources of risk in toll road projects. The credit-rating agency Standard & Poor's (S&P) have performed risk studies of the traffic forecasts in toll projects since 2002 (Bain and Wilkins 2002; Bain and Plantagie 2003; Bain and Plantagie 2004; Bain and Polakovic 2005) and reported consistent findings. Their conclusions were that toll projects throughout the world suffer from extensive optimism bias and error. The performance of the projects studied ranged from actual traffic being only 15% of the forecasts to actual traffic exceeding forecasts by more than 50%. From the perspective of potential investors, these results are alarming. Even worse, it is likely that Standard and Poor's sample, like the other samples of misleading forecasts, was biased because the toll facilities with a higher credit quality were over-represented. The worst cases of traffic underestimation were probably not included in the sample. As stated by Bain and Polakovic (2005, p. 68): '(…) very poorly performing assets will remain under-represented in the sample and the results derived from our case studies are likely to be flattered in comparison with average, global toll road forecasting performance'. Forecasts for complex road schemes with intricate traffic patterns are hence likely to be vague or non existent, making follow-up studies more difficult.

The concept of demand ramp-up is often considered to be an argument against using the first whole year of operation as the basis for measuring the inaccuracy in forecasts because the demand for travel often depends on variables that might take years to spread through the system. It may thus take a few years before a new road reaches its full traffic potential. In the S&P 2005 study, however, Bain and Polakovic (2005) investigated the concept of demand ramp-up and found no such effect, as there was no systematic improvement in the traffic forecasting accuracy after Year 1. The underestimation of the traffic in Year 1 was likely to persist during Years 2-5, meaning that the forecasts did not become more accurate over time. Similar conclusions were reached by Fitch Ratings (George et al., 2003), who found the actual performance in US toll projects to be heavily skewed downward. However, unlike the other studies mentioned above, George et al. found clear evidence of ramp-up and that traffic tended to gravitate back towards and even exceed the original forecasts over time.

Given these rather disappointing results, one might ask why the toll-financing share of total road financing annually increases if traffic revenues regularly fail to meet expectations in the first critical years of operation. A probable reason is that a high proportion of user-financed projects actually do meet expectations. Mauchan and Bates (2007), of the transport-planning consultants Steer Davies Gleave (SDG), studied 15 privately funded toll projects and found that the forecasts showed a distribution around the expected value, with no evidence of optimism bias. In fact, for the majority of the projects, the traffic was within 5% of forecasts, which in many ways is extraordinarily accurate. Their sample was small, however, and even included seven shadow-toll projects, making them, in effect, toll free projects, so the transferability of the results may be limited. Users do not pay at the point of use in shadow-toll projects, and including such projects in a toll road sample could be considered dubious. However, Bain (2009b) argued that shadow-toll projects share the same error characteristics as traditional toll projects because of the private financing mechanism. The SDG study showed, however, that no general conclusions can be drawn regarding the accuracy of traffic forecasts for toll roads and that research in the industry would benefit from a more case-specific approach, focusing on one country or region at a time. However, the general impression of toll-project forecasting accuracy is of overestimation. Further examples from the US, Spain and Australia (TRB, 2006; Vasallo, 2007; Li and Hensher, 2009 – cited in Bain, 2009b) have all suggested consistent over optimism and/or optimism bias of toll road traffic forecasts.

Studies of forecast accuracies in toll roads versus toll free roads have been rare to date. However, Bain (2009a) provided a comparison of toll and toll free roads based on the data from the S&P studies referred to above and the sample presented in Flyvbjerg et al. (2005). The comparison showed that the toll roads and toll free roads suffered from the same uncertainties. The forecast distributions for the two categories of roads were similar (the same error) but centred around different means; this is a sign of potential bias. The traffic on toll roads was found to be generally lower than the forecast, whereas the traffic on toll free roads was found to be higher than the forecast. The consequence of a similar distribution is that the observed bias can be corrected for, and the potential for error and economic losses can be reduced. Thus, there is no evidence to support the theory that forecast error is reduced when drivers are not required to pay tolls. Næss et al. (2006) reached the same conclusions with similar forecasting accuracy in terms of the absolute error between the two classes of roads.

The studies cited above show that while traffic on ordinary road projects often turns out to be higher than the forecast, toll road traffic is generally overestimated. What these studies have in common though, is that the data often have been collected from secondary sources and from different countries on different continents. Some observations even date back decades. Given that different countries inevitably have different planning traditions and tools and place different emphasis on forecasting accuracy, we argue that the conclusions reached should be interpreted with care. A data set from one country and one data source only would, in our opinion, yield much more reliable results due to the greater opportunity for quality control of the data. Accordingly, the focus of this study is the accuracy of travel-demand forecasts for Norwegian road projects.

3. Data and methodology

3.1 Data

The data for this study consisted of observations from 25 toll projects and 25 toll free road projects in Norway. The data from toll projects are often more available and generally of better quality than for other road projects because all toll projects require a specific approval from the Norwegian parliament. The parliamentary bill in which the project is presented includes all financial assumptions, including the forecasts for the average annual daily traffic through the toll stations. The critical test for traffic forecast accuracy is thus how the actual traffic relates to what was presented to decision makers at the time of the decision to build. The Norwegian Public Roads Administration (NPRA) collects data annually on the traffic levels, costs and revenues in all toll projects throughout the country. The data set includes 12 fixed-link crossings (bridges and tunnels), 11 ordinary highway projects and 2 toll cordons. The tolling in the projects started in the years 1990 to 2007. In projects where the traffic patterns were difficult to forecast, the data are often unavailable. This is consistent with the sampling bias that was observed in the studies mentioned above.

Although our sample consisted of relatively few observations, we still consider it to be representative of the population. During the years 1990 to 2007, 33 toll projects were implemented. Thus, our sample comprised 76% of the total projects in the analysed period. The criteria on which the sampling was based were data availability and quality. We acknowledge that using the projects where data was not available or of a sufficiently high quality for inclusion in the data set would increase the precision in the various property estimates of the population. However, due to the high sample/population ratio and the fact that the quality of the observations was considered to be very high, we still expected to be able to draw some valid conclusions regarding the accuracy of the forecasts in the Norwegian toll road industry.

An important distinction between toll projects and toll free projects is that paying traffic will always differ from (and be lower than) ordinary traffic because of various discounts and exceptions. However, given that the information on the fare and discount system was known before the start of the project, we still expected planners to be able to estimate their effects with a reasonable degree of accuracy.

For the toll free projects, the data situation was somewhat more complicated. Although these projects are approved by parliament in the same way as the toll projects, less data are presented to the decision makers, and the quality of post opening data are generally less reliable. However, the parliamentary bill includes the net present value (NPV) estimated in the cost-benefit analysis (CBA) that relies heavily on the forecasted traffic levels. To find the original estimates, we thus had to consult the original CBAs in which the NPV estimates presented to the decision makers were found. The previous CBAs were not stored in a single database, and even when the estimates were present, they were often on an overall level, so access to the original detailed calculations was necessary. In the Norwegian case, impact assessment, including CBA, is carried out by use of the EFFEKT software. This was a rather demanding process and required collecting data from several sources. The next step was determining the actual traffic. The NPRA collects traffic data from 9,000 sites on all roads based on permanent and temporary monitoring. Among these, 600 sites are so-called Level 1 sites where the traffic is counted continuously. Unfortunately, no system is in place that requires traffic data to be automatically collected on new roads. This means that traffic data were not available for several new roads and could not be included in our data set. We were nevertheless able to find 25 toll free roads where both reliable estimates and actual traffic levels were available. The data were from the years 2001 to 2007 and consisted primarily of projects outside the major urban areas. We often found that less emphasis was placed on traffic forecasts for small road projects such as the straightening of curves. The sample thus consisted mainly of larger projects.

3.2 Methodology

To estimate the accuracy of the traffic forecasts, we compared the actual traffic with forecasted values:

$$U = ((X_a - X_f) \times 100) / X_f$$

where U is percent inaccuracy, X_a is the actual traffic and X_f is the forecasted traffic. With this estimation, perfect accuracy is indicated by zero, and for example, -20% would imply that the actual traffic was 20% lower than expected. For forecast values, we used the estimated traffic in the first calendar year of operation. This is normally presented in the parliamentary bill where the decision to approve the project is made. This means that if a project opens for traffic in August, the basis for comparison would be January to December the next year. In addition, we examined Years 3 and 5 to test whether any improvement in the forecast accuracy occurred over time. One might argue that focusing merely on the first year of operation does not allow for the long-run nature of many forecasting models. However, the principles of discounting suggest that the first years of operation are crucial for both financial and social viability. If a toll project with a pay-off period of 15 years fails to meet revenue expectations in the first five years, the risks of default increase considerably, even if the forecasts become more accurate in, for example, 8–10 years.

It is probably unreasonable to expect planners to be able to predict values with perfect accuracy, especially for projects with complex traffic patterns. However, no acceptable level of forecasting accuracy is defined, and it must thus be regarded as an empirical matter. For construction costs, the

Ministry of Transport and Communications requires cost estimates to be in the range of ±10%; with no specific requirement for demand-forecast accuracy, we used this as a benchmark and regarded the demand estimates that were within ±10% of the actual traffic to be within an acceptable range.

4. Results

The purpose of this study was to assess divergences between the forecasted and actual traffic for toll and toll free projects and to investigate whether there were differences in the forecast accuracies for the two types of projects. In this section, we present the results of our findings.

4.1 Forecast accuracy: Toll roads

As with the international studies referred to above, we found the forecasted traffic on Norwegian toll projects to be higher than the actual traffic. However, with the actual traffic being 2.5% less than forecasted on average, the scale of overestimation was much less than that revealed in the studies in other parts of the world. Summary statistics for the forecast inaccuracies with the Norwegian toll projects are presented in Table 1.

Table 1. Summary statistics for forecast inaccuracies for toll roads.

	Statistic
Number of cases	25
Mean	-2.5
Std. error of mean	4.4
Standard deviation	22.0
Minimum	-35.2
Maximum	45.0

These results appear to be encouraging. A mean of -2.5% was well within what we defined as an acceptable range. However, a closer look at the data revealed that a majority of the projects experience traffic overestimation, as in the international studies reported above. Additionally, 24% of the projects had over 20% less traffic than expected. Clearly, a traffic overestimation of up to 35% in the first whole year of operation can potentially have severe financial implications for the viability of a project. There is a significant risk that projects with traffic shortfalls of this magnitude could experience financial difficulties that necessitate loan refinancing, a prolonged payment period, increased tolls or a combination of alternatives. Luckily, the Norwegian economy has been blessed with the rare combination of high economic growth and low interest rates for some time. If this were to turn into a recession with increasing interest rates and demand shortfalls, as seen in the late 1980s and early 1990s, the risk of default would increase considerably. The standard deviation was 22%, indicating a rather large variation between the projects. Table 2 provides the distribution of projects by percentage inaccuracy.

Table 2. Distribution of projects by percentage inaccuracy.

	Number of projects	Percentage
Projects with overestimation larger than -20%	6	24.0
Projects with overestimation 0 to -20%	10	40.0
Projects with underestimation 0 to +20%	5	20.0
Projects with underestimation larger than +20%	4	16.0
Total	25	100.0

A histogram showing the distribution of these observations is provided in Figure 1.

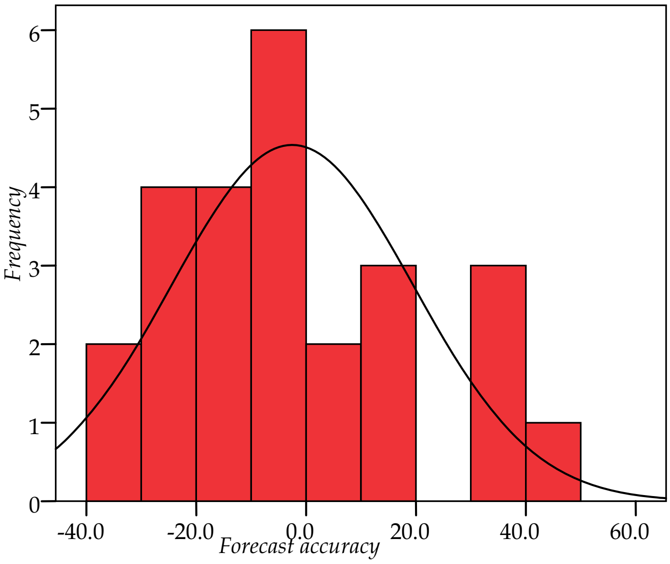

Figure 1. Inaccuracies of the toll road traffic forecasts.

Figure 1 reveals a curve that is close to a normal distribution. A Kolmogorov-Smirnov test of normality ($D(25) = 0.159$, $p > 0.15$) confirmed that the forecasts for the traffic levels in the Norwegian toll projects were normally distributed around the mean or that the assumption of a normal distribution was not rejected. A t-test for deviation from zero revealed a test statistic of -0.57 and a significance value of 0.58, which meant that the mean forecast inaccuracy was not significantly different from zero and that we could not conclude that the underestimation was more common than overestimation for the Norwegian toll roads.

From a credit perspective, it is worrying that the majority of the forecast errors for Norwegian toll projects were overestimations. However, a toll project can sometimes struggle to reach its full traffic potential in the first whole year after opening. This could potentially mean that the overestimation is more severe in Year 1 than in subsequent years and that the traffic better fits the forecasts as time progresses. The international evidence of ramp-up has been inconclusive, as different studies have shown different results. However, as shown in Table 3, even though the number of observations decreased over time (N = 22 in Year 3 and N = 19 in Year 5), there were signs of ramp-up in the Norwegian toll projects.

Table 3. Demand ramp-up.

Year since opening	*Mean inaccuracy*	*Std. dev.*
Year 1	-2.5%	22.0%
Year 3	-2.1%	20.0%
Year 5	2.3%	23.2%

Although the traffic in Year 1 was overestimated, it increased over time, and after five years, the average traffic exceeded the original forecasts. Although the financial implications of forecast error in Year 1 might be severe, there is less need to worry if the traffic soon increases to or even exceeds the necessary levels. This is contrary to Bain's (2009b, p. 37) claim that "…projects that under perform in their early years may never catch up with their original forecasts in later years". In our sample, among the 13 projects with an overestimation greater than the sample mean, four exceeded their original forecasts, five exhibited traffic growth that may well soon put them in the above-forecast figures and four continued to under perform at Year 5. From a financial perspective, the failure to meet revenue predictions in the first five years of operation is, of course, potentially alarming, but our results nevertheless provide a more nuanced picture than that painted by Bain.

4.2 Forecast accuracy: Toll free roads

For the toll free roads, for which we had 25 reliable observations from the last nine years, we noted that the traffic was, on average, *higher* than forecasted. The mean underestimation was 19.0%, but the range was large, from -14.6% to +76.1%. This was consistent with the pattern observed by Flyvbjerg et al. (2005) and Næss et al. (2006). Only six projects had traffic levels below the forecasts, and 13 projects exhibited traffic overestimation above the sample mean. In seven projects, the actual traffic was over 30% higher than predicted. This is clearly unacceptable. We would expect the forecast accuracy to be higher for toll free roads, but this was not the case for the Norwegian roads. The picture that emerged was that the traffic forecasts for the toll free Norwegian roads were skewed to the right. The summary statistics for the toll free roads are presented in Table 4.

Table 4. Summary statistics for the forecast inaccuracies for toll free roads.

	Statistic
Number of cases	25
Mean	19.0
Std. error of mean	4.1
Standard deviation	20.5
Minimum	-14.6
Maximum	76.1

Despite a high standard deviation, we found that the mean was significantly different from zero at the 99% level ($t(24) = 4.64$, $p < 0.05$). Thus, we concluded with a high level of certainty that the traffic on toll free Norwegian roads has been underestimated. The spread in the distribution was alarmingly high, which indicated a high level of general error. The shape of the distribution, as illustrated in Figure 2, indicated that the observations were normally distributed around the mean but with a slight positive skew (Kolmogorov-Smirnov: $D(25) = 0.098$, $p > 0.20$).

As illustrated by the standard deviations for both classes of roads, the internal variations with both the toll and the toll free projects were huge. However, the difference in the means between the two categories of roads was -21.5, and a *t*-test of the difference revealed that the difference in the mean forecast accuracy between the two categories was highly significant and not a result of coincidence ($t(48) = -3.58$, $p < 0.01$).

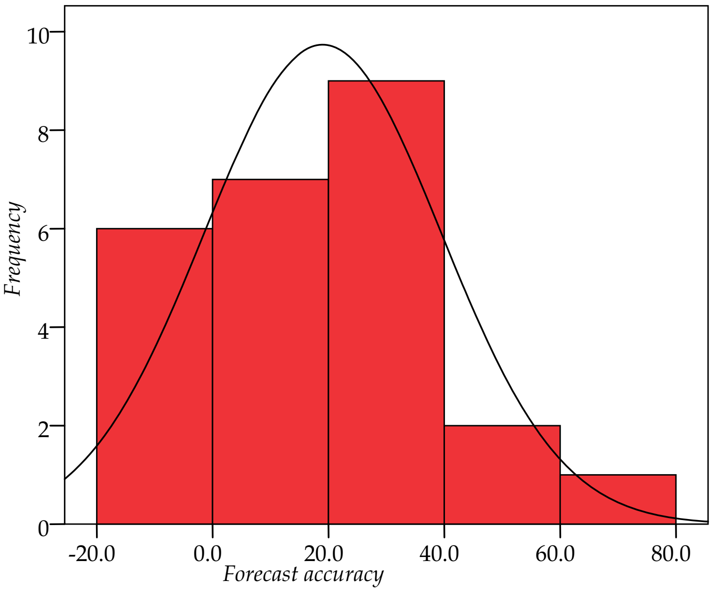

Figure 2. Forecast inaccuracies for the toll free roads.

4.3 Do planners get it right?

Our results suggest that the Norwegian transport planners should not be satisfied with the accuracies of their forecasts. On average, the planners do *not* get it right even if the toll road forecasts were, on average, within an acceptable range. Here, the results presented by Flyvbjerg (2005) and Bain (2009a) were confirmed because the toll road forecasts were more accurate than the forecasts for the toll free roads and because the countries with more toll road experience produced more accurate forecasts. However, the ranges that both the toll roads and toll free roads forecasts fell within were alarmingly high and should be a cause for concern.

The traffic on toll free roads was significantly higher than forecasted. This is worrying and would be doubly disturbing in a situation where the road capacity was limited and where the motivation for new road construction was to relieve congestion. But this is usually not the case in countries where the congestion is still limited to the peak-period traffic in the large cities. The higher traffic levels will often, as argued by Kjerkreit and Odeck (2009), lead to a higher NPV than originally estimated. However, this is obviously not a satisfactory situation in the long term. If the traffic is generally underestimated, then this could lead to inefficient resource allocation or the implementation of the wrong projects and a shorter relief period from congestion for the roads in urban and congested areas.

Transport models for the Norwegian roads sector have improved since 2001, when regional transport models replaced a wide range of locally developed models, and Odeck et al. (2009) claimed that the forecasts have since improved. Today, the traffic on ordinary toll free roads is estimated through the use of national transport models for trips longer than 100 km and regional transport models for trips shorter than 100 km. Both models are traditional four-step models based on the fixed-trip matrix approach. Induced traffic is thus not taken into account. The traffic on toll roads, however, is estimated using elasticity models where the effects of tolls are calculated specifically. Hence, there are two different models used, one for toll roads and one for toll free roads.

The use of the regional transport models has made it possible to identify the factors that lead to inaccurate forecasts. If the distributions of the forecasts between regions are similar, it is easier to isolate the cause of the error if the forecasts have been based on the same models than if different models have been used. Thus, it was interesting to test whether the assumption of increased accuracy after the introduction of regional transport models holds true using the data to which we had access. The toll road sample included 13 projects implemented in the years 1990 up to and including 2000 and 12 projects implemented in the years 2001–2007. For the toll free roads, we had 13 projects from 2001 to 2004 and 12 projects that opened for traffic in the years 2005–2007. Table 5 shows the differences in the mean accuracy for the two time periods for the two road categories. The number of observations is so low that caution should be taken when interpreting the results, but there appears to have been little or no improvement in the forecast accuracy over time either for the toll roads or for the toll free roads. However, the weaknesses in the Norwegian transport-demand models were first identified in the work leading up to the National Transport Plan for the years from 2002 to 2011, and because the planning process for roads often takes years, it has not been until very recently that we can expect to see real improvements caused by the improvements in the transport models.

Table 5. Traffic-forecasting inaccuracies over time.

Road category/opened for traffic	*Mean inaccuracy*
Toll roads 1990–2000	-2.7%
Toll roads 2001–2007	-2.2%
Toll free roads 2001–2004	18.6%
Toll free roads 2005–2007	19.4%

The concept of induced traffic is often used to explain traffic levels in excess of what was originally predicted. A study by Goodwin (1996) found the traffic in 151 UK highway schemes to be 10% higher on average than the forecasts in the short term and 20% higher in the long term. Thus, the forecasts for these projects were not able to fully include the extra traffic created by the network improvements leading to retiming, redistribution, mode shifting or change of frequency. Goodwin also suggested that the addition of the capacity itself, regardless of the changes in the travel time, could help explain the increases in traffic flow. However, the changes in traffic brought by the improvements in the pleasantness of travel, such as a smoother ride from better surfaces, remains an under-researched area (Goodwin and Noland, 2003).

Traditionally, transport planning has been based on the traffic levels and independent of the supply conditions and the quality of the road network. The growth demand has been largely attributed to economic factors such as income, population growth, the prices of petrol and other input factors. This is normally referred to as the fixed-trip matrix approach and is still in use in Norwegian road planning (except for the straight-crossing projects). Because the traffic on toll free roads is generally higher than forecasted, there are indications that this approach should be abandoned and that the induced traffic should be dealt with explicitly.

Another potential explanation for higher traffic levels than estimated is the long period of economic growth that Norway has experienced over the last decade. Because transport is a derived demand, forecasting traffic relies on the forecasts of a range of other parameters (Boyce and Bright, 2003). Thus, if the income estimates in the transport models are underestimated, traffic may also be underestimated. The same pattern was observed during the 1990s, when the average national traffic growth over the years 1992–2002 was higher than all the forecasts that had been produced (Larsen et al., 2004). The recession early in the decade was followed by an economic boom that was accompanied by strong traffic growth. De Jong et al. (2003) distinguished between input uncertainty, or difficulties in producing good forecasts for transport model input variables, and model uncertainty. Because Norway has experienced unprecedented, strong economic growth over the last decade, there are clear indications that while more emphasis has been put on improving the transport models, the main causes of the observed error are input error rather than model error. This fits well with the observations of Larsen et al., who found the standard national traffic growth rate, which has been a mandatory input in the transport models, to be too low.

Strategic behaviour and bias are often cited when no other explanations for forecast inaccuracy can be found. Wachs (1987, 1989) argued that because planners are concerned with having their projects financed and built, they deliberately produce overly optimistic forecasts for both capital costs and traffic. Because governments operate under budget constraints, the projects compete with each other for funding. Planners could thus be tempted to underestimate costs and overestimate benefits to meet a specific benefit-cost ratio (BCR) cut off. Although intuitively appealing, we do not necessarily agree that this serious allegation can be used as a general explanation for traffic-forecast inaccuracy. First, our results showed no evidence of such behaviour, which in itself was an indication that these forces are not occurring in Norway. Second, as the traffic on ordinary roads was underestimated, the benefits were also underestimated and not overestimated, all other things being equal (Kjerkreit and Odeck, 2009). In uncongested conditions, traffic in excess of what was forecasted will increase the overall benefits, and planners will thus have little to gain from underestimating the traffic, as this would mean presenting projects with a lower NPV than what they later turn out to produce. In fact, the funding for Norwegian road projects does not always rely on a positive BCR at all. Odeck (1996, 2010) studied whether Norwegian decision makers' ranking of road projects was explained and/or positively influenced by a positive BCR. Contrary to expectations, he found that the BCR was not a significant explanatory variable for the selection of projects and that more emphasis was placed on non monetised impacts. The projects with a positive BCR were sometimes not put on the priority list at all, whereas the projects with a negative BCR were sometimes given a very high ranking. Nilsson (1991) found similar results in Sweden. Although clearly unsatisfactory from a socioeconomic point of view, placing less emphasis on socioeconomic profitability and monetised impacts could reduce the risk of optimism bias in producing the traffic forecasts.

We do acknowledge, however, that the bidding process by which the toll road contracts are awarded may play a role in explaining the optimism bias. As argued by Flyvbjerg (2005), Vasallo (2007) and Bain (2009b), awarding toll road contracts based on a bidding process where the bidder with the highest revenue projections or the lowest capital cost projections wins could reward over optimism rather than accuracy. Here, the Norwegian framework for toll financing provides an alternative framework that might reduce the risk of overoptimistic forecasts. Norwegian toll projects are initiated locally, usually because much-needed road investments cannot be realised in the near future within the government budget. The proposal is then evaluated by the NPRA, who closely scrutinises all major assumptions before it is forwarded to the Ministry of Transport, which prepares a bill to be tabled in Parliament. The project might have a positive or a negative NPV, but all toll projects are stress-tested for financial robustness to ensure that the risk of financial default is low, even in worst-case scenarios. Once passed by Parliament, the operation of the toll road is managed by a non profit toll company operating as a financial vehicle on behalf of the NPRA, which remains the ultimately responsible party for the project (for a detailed presentation of the organisational framework of Norwegian tolling, see Welde and Odeck, 2009). Although the system is not without its flaws, there is less incentive for appraisal optimism than in alternative frameworks, and the system of quality control and the emphasis on conservative estimates has so far prevented any major financial scandals in the Norwegian toll road industry.

The absence of any major scandals due to inaccurate traffic forecasts should not, however, lead us to conclude that this is not an area that warrants continuous attention. The huge variation in forecasting accuracies continues to be a major source of risk in the planning of Norwegian road projects. However, merely pointing out the problem will not make it disappear. The increasing range of international studies focusing on this issue has apparently not contributed to any major improvements in terms of forecasting accuracy. However, the knowledge generated from studies such as this will hopefully facilitate learning and lead to improvements in the forecasting methodologies. Furthermore, we strongly suggest that that the fixed-trip matrix approach (i.e., assuming a zero elasticity of demand) be abandoned for all road projects, as this is very likely a cause of the poor estimation of traffic levels and, ultimately, total economic benefits. In addition, because the process of project bidding or requiring projects to pass a certain BCR threshold to receive financing clearly increases the risk of deliberate over optimism, a system where NPV/BCR is only one input variable in the decision-making process should be considered. It would be interesting to see if countries that apply alternative appraisal frameworks, such as Multi-Criteria Analysis suffer from the same inaccuracies as countries where the decision makers' preferences are more determined by the outcome of the traditional cost-benefit analysis. Finally, the signs of good practices should act as encouragement and as an incentive for further research into why some projects are more successful than others.

5. Conclusions

In this study, we examined the accuracy of traffic forecasts made in the Norwegian road sector. Two types of road projects were studied and compared: (1) toll roads and (2) toll free roads. This distinction was made because the consequences of inaccuracy with toll projects are considered to be more serious because they may lead to financial difficulties and the bankruptcy of toll companies.

We found that the traffic forecasts in the Norwegian toll projects have been fairly accurate. A likely explanation is that the planners over the years have been scrutinised and pressed to provide careful estimates for these projects. The results prove that the planners have been careful, but the number of projects where the actual traffic was significantly below what was forecasted suggest that the toll-project traffic forecasts should continue to be closely scrutinised. However, the variation in the forecast accuracies was high, and we suggest that the results from this study be used to identify the causes of why some projects have performed better than others. For the toll free roads, the results showed a clear underestimation of the traffic. Some of the projects studied had underestimations so great that there is reason to suspect that the projects may have experienced induced traffic for which the planners failed to account. This underestimation may have lead to inefficient resource allocation. Thus, the decision makers may have been misled into foregoing projects that were beneficial in favour of less beneficial ones.

The results from the Norwegian road sector are slightly better than some of those presented in studies from other countries, especially for the toll roads, where the actual traffic was, on average, very close to the forecasted traffic. Even though the number of projects with traffic levels significantly different from the forecasts was high, the mean forecast accuracy and the relatively high share of projects with traffic levels close to perfect accuracy is a source of some encouragement.

Our findings should be of interest to planners and policy makers in Norway and elsewhere. First, the planners need to reconsider their traffic-forecasting models, at least for the toll free projects, to ensure that all relevant factors are captured and forecast inaccuracy thus reduced. Second, the issue of induced traffic in particular must be considered. The Norwegian models for traffic forecasts do not consider induced traffic explicitly, and this may well be a reason why underestimation is prevalent. Third, with the high uncertainty revealed in such a crucial variable as the traffic level, presenting decision makers with single-point estimates for the NPV might potentially be misleading. This suggests that the presentation of social surplus through the NPV should be done through a confidence interval illustrating the inherent uncertainty in a project evaluation. Finally, the care taken when estimating traffic in toll projects demonstrates good practice but, even here, there is a potential for improvement.

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Paper II

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Paper III

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The effects of removing the Trondheim toll cordon ☆

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A R T I C L E I N F O

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A B S T R A C T

This article presents the effects of removing the Trondheim toll cordon, which was closed after nearly 15 years of operation on December 31, 2005. The traffic levels, measured as vehicles per hour, in 2006 are compared to traffic levels in 2005. The evaluation also covers the effect on the retail market and possible environmental effects. We also seek to investigate what the traffic levels would have been today if the cordon had still been in operation. We find that the closing of the Trondheim toll cordon has lead to increased traffic levels in the peak hours, with an average increase of 11.3% in the former charging hours of 06:00–18:00. On an average, the hours between 14:00 and 18:00 experienced an increase in traffic of 15.5%, whilst traffic in the evenings and nights decreased. Model results suggest that the removal of the toll cordon has caused the private car to increase its modal share at the expense of passengers per car, public transport and cycling/walking. The increase in the total number of trips would have been more uniformly distributed among the alternatives if the toll cordon had still been in operation.

1. Introduction

Congestion and emissions represent some of the most serious challenges that European cities face today. This affects the quality of life for the people living and working in the cities, and represent substantial costs to society. Road user charging is thus increasingly suggested as a possible solution to these problems, either as traditional tolls to finance new infrastructure or as more sophisticated demand management schemes designed to relieve congestion and to improve the environment.

Norway was among the first countries to implement cordon based charges, and Trondheim was the third Norwegian city to implement this method of finance. The Trondheim toll cordon, comprising 12 unattended toll stations, was opened in October 1991 and was later upgraded into a more sophisticated zonal based system and where 60% of motorists in the city paid tolls regularly. Even if the purpose of the cordon was mainly financial, there was an element of price differentiation, with traffic only being charged on weekdays during the hours 06:00–17:00, and tag holders having smaller discounts during morning peak hours (06:00–10:00) than during the rest of the day. The revenues were earmarked for road investment within the city with a smaller share being allocated to infrastructure for public transport (mainly bus lanes) and facilities for walkers and cyclists. In total, some 70% of the revenues in the Trondheim investment package, in which tolls contributed to 47% of the funds, was spent on planning and building roads, while some 20% was invested in public transport and various “soft measures”. The remaining 10% was spent on establishing and operating the toll stations.

The Trondheim scheme was unique in three aspects when it was introduced in 1991: (i) it was fully electronic with non-stop toll lanes from the start, (ii) it had time-differentiated charges supporting traffic management objectives, and (iii) every single crossing had to be paid for, but subject to a maximum limit of one chargeable crossing within an hour and 75 chargeable crossings per month. The one-hour-rule always applied, but the monthly limit was later changed to 60. The toll level was initially set at NOK 10 for ordinary vehicles (<3.5 tonnes) equalling approximately 10% of an average hourly rate for Norwegian industrial workers at the time. For tag holders, discounts of up to 60% were offered. Over the years, various aspects of the scheme were revised, such as the number and location of charging points, operating hours (extended to 18:00 h in 1998), contract options and toll levels. In 2005, the toll was NOK 15.[1] As more than 90% of the vehicles were equipped with tags, the average toll was only some NOK 8 after discounts. Fig. 1 shows the layout of the scheme

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[1] NOK=0.125 EUR as of 31.12.2005 when the cordon was removed.

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at its last year of operation, then comprising 24 stations and 59 payment lanes. The main characteristics of the 2005 scheme are summarised in Table 1.

The cordon was considered a success as it contributed to finance much needed infrastructure that would otherwise not be available. Although never popular among the motorists, negative attitudes soon decreased after the cordon opened and the advantages of it became clear. In fact, the most favourable measurement of public attitudes was from the summer of 1992, the first full year of operation when 37% of the respondents were positive to the cordon and 35% negative. An opinion poll from the autumn of 2005, the last year of operation, showed 19% positive attitudes and 47% negative. This poll was in line with a trend of decreasing public support since 1992, following two major expansions of the scheme (Tretvik, 2006). The diminishing support seems in part to be an effect of lack of continued information about the purpose of charging. When respondents in 2005 were reminded about what projects the income from charging had financed, the positive share increased to 30% and the negative share decreased to 38%. Interestingly enough,

Table 1
Main characteristics of the Trondheim toll cordon.

Characteristic	Trondheim toll cordon
Population of Trondheim	160,000
Average annual daily traffic across the cordon	82,000
Number of toll stations	24
Period of operation	Mon–Fri, 06:00–18:00
Mode of operation	Automatic lanes for tag holders, coin machines and two stations with attended toll booths
Percentage tag holders	94%
Standard toll rates (NOK light/heavy vehicles)	15/30
Discount for tag holders 06:00–10:00	20–40%
Discount for tag holders 10:00–18:00	40–60%
Gross revenues per year (NOK)	235,000,000
Operating costs per year (NOK)	25,000,000

Fig. 1. The 2005 Trondheim charging scheme.
Source: eMap, Trondheimskartboka. Statens kartverk/Trondheim kommune. SKST-16/2001.

responses were 48% positive and 27% negative to a similar question in 2006 about attitudes to having had urban charging in Trondheim (Tretvik, 2007a).

It might seem difficult to understand why such a successful measure for financial and for potential traffic management purposes was removed, but the reasons can mainly be found in the organisational framework of Norwegian toll financing. All toll projects, whether cordon based or as single link projects, are approved by local authorities and by the Parliament for a limited period of usually up to 15 years. It is as such a contract between the politicians and the voters, a contract that the former is normally reluctant to break. The politicians in Trondheim had therefore made a strong commitment that after 15 years of operation, the cordon should be removed.

This article deals with traffic effects after the cordon was removed in 2005 and proceeds as follows: Section 2 provides an overview of what effects tolls have had elsewhere. Section 3 examines the data and methods used in the study, while Section 4 presents the results. Section 5 presents elasticity estimates and in Section 6 some conclusions and policy implications are offered.

2. The impacts of road user charging

2.1. Traffic impacts

When planning transport projects, and projects which involve charges at the point of use in particular, accurate travel demand forecasts are of vital importance. Experience suggests that inaccurate travel demand forecasts represent a major source of risk in the planning of infrastructure projects. Knowledge of how motorists react to the introduction of tolls is thus crucial for a variety of reasons. Tolls are generally used to finance new infrastructure and/or to manage demand. Precise estimates of traffic levels are thus clearly important for both of these purposes. Failing to understand how road users will react when generalised costs are changed due to tolls can thus have severe implications for the dimensioning of transport infrastructure and for the financial and social viability of projects.

Whereas traditional toll charging to finance new infrastructure has been around for decades, urban charging schemes are still few and far between. Despite the efforts of the European Union, the OECD and transport economists throughout the world, urban road user charging is still considered to be a radical and controversial policy (Niskanen and Nash, 2008). Therefore, knowledge of user reactions to charges in an urban environment is limited.

After the Area Licensing Scheme in Singapore was introduced in 1975, it was not until 1986 that a cordon based charging scheme was implemented in the Norwegian city of Bergen. This was soon followed by cordons in Oslo in 1990 and Trondheim in 1991. The Norwegian toll cordons were all introduced mainly to raise revenue to finance new roads, and tolls were set so as to maximise revenues without acting as a major traffic deterrent. However, a moderate effect on traffic was expected. In Bergen and Oslo, the number of car trips decreased by some 6–8%, following the introduction of the cordons (Larsen, 1995), while Trondheim experienced a decrease of around 10% (Meland, 1994). In recent years, the London congestion charging scheme and the Stockholm congestion tax have received considerable attention and provided valuable new empirical results. The London scheme, introduced in 2003, was probably the first urban charging scheme since Singapore and was introduced solely to manage traffic demand. As traffic was reduced by almost 30%, this confirmed that users do respond to tolls and that congestion charging probably is one of the most potent measures for reducing traffic congestion and emissions. Similar results were found in the Stockholm congestion charging trial in 2006, which saw traffic reductions in the order of 20–25%. Although a traffic reduction in line with model estimates, the most groundbreaking feature of the Stockholm scheme was the later land-slide change in the public opinion towards tolls and the subsequent permanent implementation in August 2007 (Eliasson et al., 2009). Today, minor and limited schemes are in operation in cities such as Durham, Milan, Rome and Bologna, while the list of cities considering or planning to introduce charging schemes is on the increase (for a comprehensive state of the art review of urban road user charging, see May et al., 2009).

There is an increasing range of studies covering user responses to changes in prices or income. Amongst these are Graham and Glaister (2004) and Goodwin et al. (2004), both of which find transport demand to be fairly inelastic to changes in prices and income. The results presented in these reviews confirm previous findings presented by, amongst others, Oum et al. (1992) and Goodwin (1992).

Although the literature on transport elasticities is extensive, there is a limited number of studies available covering toll elasticities specifically. Odeck and Bråthen (2008) have thus recently provided an overview of toll elasticity studies from toll facilities throughout the world. They find that most of the studies reveal elasticity values around -0.5, implying that an increase in generalised costs of 10% (holding other variables constant), due to an increase in tolls will lead to a 5% reduction in traffic. All studies show that the elasticities are larger in projects with high tolls and where an untolled alternative exists. Furthermore, long-run elasticities are generally found to be higher, and sometimes even up to 2–3 times higher, than short-run elasticities. The reason for this is that travellers are more able to adjust to price signals through relocation, job-change, car ownership, etc. in the long-run than in the short-run.

The majority of these studies do, however, deal with situations where tolls have been introduced. The effects when tolls are removed have rarely been documented. The study by Odeck and Bråthen (2008), referred to above, includes 13 Norwegian toll projects where elasticities have been calculated after the tolls were removed. They find the average short-run elasticity where tolls have been removed to be -0.70, ranging from -0.03 to -2.26. The motorways in their sample have stable elasticities around -0.45, while rural roads have the largest spread. It is worth noting that the latter group includes the projects with the highest tolls. The authors hence find that tolls and elasticities are correlated and statistically significant at the 5% level. Elasticities are higher in schemes with high tolls. With regard to the difference between short- and long-run results, the long-run elasticity is found to be on an average 1.6 times the short-run elasticity and that the adjustment period was relatively short with most of the demand adjustment taking place within a year.

Even if the number of road user charging schemes is on the increase, toll cordons are still few and traffic effects, due to the introduction or removal or cordon tolls has rarely been documented. Urban road user charging is still relatively uncommon, but the U.S. provide some examples. Bridges and tunnels in the New York area have been subjected to tolls for decades and here Hirshman et al. (1995) have found the median toll elasticities to average -0.1. This is similar to findings from the San Francisco area (Harvey, 1994). In Singapore, Luk (1999) and Menon (2000) have found car travel to be inelastic to tolls reporting values of -0.19 to -0.58 and -0.12 to -0.35, respectively. A more recent example is represented by the London congestion charging scheme, where Santos and Shaffer (2004) report elasticities between -1.32 and -2.10. Transport for London's own calculations has given an elasticity value of around -1.6 (Evans, 2007), while Peirson and Vickerman (2008) estimates the elasticity to be −0.82. The generally high elasticities found in London are probably due to high charges and a wide availability of public transport. The well documented effects of the Stockholm congestion charging trial of 2006 also includes estimates of elasticity at around −0.8 for private car trips across the cordon (Eliasson et al., 2009).

2.2. *Effects on the local economy*

Urban road user charging remains a controversial issue. Of particular concern are potential adverse effects on the local economy, and especially the effects on retail trade located within the charging zone. Although the literature on the impacts of urban road user charging on the retail trade sector is scarce, research from London and Stockholm has provided us with some knowledge.

The London congestion charging scheme is notable for its high charges, where ordinary vehicles pay some EUR 9 to enter the charging zone. This has lead to a considerable decrease in the total number of car trips, and it is not unreasonable to expect some negative impacts on the local retail market. Despite this, Quddus et al. (2007) find no significant impact on the retail sector as a whole. However, negative impacts for the John Lewis store in Oxford Street were found to be statistically significant. This is consistent with the reporting of Transport for London (TfL), which concludes that there is no general evidence of any measurable impact from the central London congestion charging scheme on business and economic activity (TfL, 2008).

The Stockholm congestion tax system is more sophisticated with greater time differentiation of charges and no charge on evenings, nights, Saturdays and Sundays, public holidays and the day before such holidays. Today, even the whole month of July is exempt from payment. This means that the effects on an average disposable income is small, around one-tenth of a percent, (Eliasson et al., 2009) and evaluations indicate that the system has not affected retail revenue, neither in shopping malls nor in a sample of retail stores (Daunfeld et al., 2009).

The evidence provided in this section show that tolls do affect traffic levels. The impact on the local economy, on the other hand, is likely to be limited. Whether or not a charging scheme is introduced to manage demand or to finance new infrastructure, tolls will reduce traffic. The magnitude of the impacts depends on the size of the toll and the availability of alternatives in terms of other routes, destinations, modes of transport and/or time of day/week to carry out the desired travel activities. The literature provides elasticity estimates following introductions of tolls in urban areas and removal of tolls in rural or semi-urban areas. Moreover recent evidence from London and Stockholm indicates that effects on business and the local economy are likely to be limited. There are, however, no comprehensive studies of effects following the removal of an urban road user charging scheme. The time-differentiated charging scheme in Trondheim was introduced primarily to raise revenue, but also to achieve better utilisation of capacity in the transport network. This paper presents findings from the evaluation of the effects, following the removal of the cordon. Of special interest is to study if motorists have changed their trip timing back towards the pre charging hours, and whether the removal of the cordon has had an effect on overall traffic levels or not. Tolls in Trondheim were low, but made considerable contributions to transport investment. Evaluating the effects of removing the Trondheim toll cordon could thus help to determine if low and relatively uncontroversial tolls could also be an efficient traffic management tool.

3. Data and methodology

3.1. *Traffic impacts*

The data from this study is based on available traffic counts from 2006 for all the former toll stations sites. When charging was discontinued at the end of 2005, the vehicle counting equipment at all toll stations was maintained in operation for at least three months. Automatic counting was kept running for six months at five stations, and for the whole of 2006 at only two charging points. This enabled traffic changes between 2005, the last year with tolling, and 2006, the first year without tolling, to be compared hour by hour and day by day (Tretvik, 2007b). In order to control for seasonal variations, an average daily traffic for each month in 2005 and 2006 was calculated. Because of the time differentiation of the charges, an average daily traffic was split into the following subsets: Monday–Friday 06:00–18:00, Monday–Friday outside 06:00–18:00, Saturdays and Sundays. In total, traffic was registered in all the former charging points and the Ranheim toll station, which is still in operation—in total 61 lanes in 25 toll stations. The revenues from the Ranheim toll station are financing the E6 East motorway project.

3.2. *City centre trade*

The basic source of data for being able to study changes in city centre trade is the VAT register managed by the Norwegian Central Bureau of Statistics. Sale figures are distributed by an area in the city, according to location of shops and businesses. This makes it possible to study development in trade by year and geographical location. The local Chamber of Commerce has collected these data annually since 1987, and provides a source for comparing market shares in different parts of the city—some affected by the toll cordon and others are not.

3.3. *Transport model*

Although traffic counts in 25 toll stations provide good insight into changes in traffic levels after the cordon was removed, it does not provide us with information on changes in the overall traffic levels, mode use and geographical traffic patterns in the Trondheim area. To get indications of the magnitude of such effects, the strategic transport model for Trondheim (TASS5) has been used to simulate the transport situation in the area with and without the charging scheme in operation. The TASS model, which is implemented in the CUBE system, has been developed to support local transport policy decision-making, and has been used to analyse effects of various road user charging schemes over the two decades with RUC in Trondheim. TASS is a network equilibrium model for passenger transport, based on the traditional four-step principles, but includes hierarchical choice models for simultaneous choice of mode and destination for the “dynamic” trip purposes (mainly trips not related to work and/or school). The model is based on local data describing transport supply and demand in the Trondheim area, and all parameters in the choice models are derived from data from local travel surveys.

de Palma et al. (2006) discuss challenges in modelling urban road pricing. Their paper is mainly based on the MC-ICAM research project of the European Commission, and present findings from five case studies involving five different modelling tools for five different road pricing schemes in five different European cities. Although none of the combinations of RUC schemes and modelling tools in these case studies are directly comparable to that of Trondheim, it is likely that the conclusion they draw from their study, is valid for the Trondheim case too:

"there is clearly a considerable gap between an idealised approach, and what is feasible in applied modelling work using large-scale empirical network models (p. 100)". This gap is probably smaller for the car driver option than for the alternative modes included in the model. Data describing factors affecting the demand for these modes and good quality data to calibrate the models is much harder to come by than similar data for the car alternative. This may, among other things, affect the ability of the model to represent the competition between the alternative modes, and thus the magnitude of changes for each of these modes as a consequence of the measures studied. Albeit these shortcomings, the network model for Trondheim has been used and developed for RUC-related analyses for over more than two decades, and during this process the model has proved its relevance for these topics.

3.4. Energy consumption

The total energy consumption for passenger transport in Trondheim has been calculated for each of the modelled alternatives, using rough figures for an average energy consumption per person-km with motorised road transport alternatives (car and bus). The following key figures have been used as basis for the calculations (Andersen, 2001):

- Car with one person/vehicle: 0.55 per kWh/person-km.
- Bus with 25% occupancy rate: 0.30 per kWh/person-km.
- Bus with 50% occupancy rate (normal occupancy): 0.15 per kWh/person-km.

In TASS5, the weekday is divided into four periods:

1. Evening and night, 18:00–06:00.
2. Morning, 06:00–09:00.
3. Mid day, 09:00–15:00.
4. Afternoon, 15:00–18:00.

The energy consumption for private cars is estimated based on the key figure for energy consumption per person-km for a vehicle with one person per vehicle, and the calculated number of vehicle kilometres from the model. For public transport, there is no information available about the true occupancy rate for the peak and off-peak periods. As a proxy, it is assumed that there is a 50% occupancy rate during the peak (time periods 2 and 4), and a 25% occupancy rate outside the peak (time periods 1 and 3). These bus occupancy rates are assumed to include empty running related to the operation of the bus service. Thus, the energy consumption for public transport is estimated based on key figures for energy consumption per person-km for bus in and outside the rush hours, and the calculated number of public transport person-km within each or the four time periods in the model.

4. Results

4.1. Traffic changes 2005–2006

A result for typical local traffic is shown in Fig. 2 for three stations located along the main bypass road (Moholt, Nardo and Nidarvoll, see Fig. 1 for their locations). These stations were chosen for further analyses because they were fairly typical for local inbound traffic within the city, and they were among the few stations for which it was possible to retrieve data for a continuous six month after-period. Whilst traffic in these stations increased by 12% during the formerly charged periods of Monday–Friday 06:00–18:00, traffic for the whole week increased by only 4%, and traffic at working day evenings and at weekends decreased. This shows that motorists that were priced out during the charged periods have returned back to the more preferred periods for making trips. Looking at percentage of traffic within charged hours for working days, this increased from 73.9% in 2005 to 76.5% in 2006. This indicates that a considerable shift has occurred, in relative terms, back to hours of the day that were formerly charged.

Fig. 3 provides evidence that some drivers in 2005 started early to avoid being charged. Traffic in 2006 between 05:00 and 06:00 decreased by 11%, whilst traffic between 06:00 and 07:00 increased by 11%. It seems that drivers were no longer deterred by the tolls that had started at 06:00. In the afternoon, shifts in departure times to avoid being charged are even more evident. The last of the charged hours, between 17:00 and 18:00, had a 20% increase in 2006, compared to an 8% decrease in the following hour.

Finally, Fig. 4 shows that the increase in volumes for working days was largest in the afternoon, smaller during the middle of the day and smallest in the morning. This may at first glance seem surprising, considering that charges were higher in the morning hours 06:00–10:00 than later in the day (see Table 1). However, the reaction from the motorists is associated with a large share of rather inelastic work, school and business trips during 06:00–10:00 (69%), compared to only 17% during 10:00–14:00 and 9% during 14:00–18:00. Thus, the progressively larger increases during the day can be explained by a corresponding larger share of private trip purposes, having a larger elasticity of demand with respect to the choice of departure time.

Traffic entering the city from the east, is clearly affected by the fact that the Ranheim toll plaza (see Fig. 1) is still in an operation. When the charging stations in the toll cordon were removed, motorists were able to make detours using routes that were now free of charge, to avoid passing through Ranheim. The result had considerable increases between 2005 and 2006 at places like Skovgård (48% for charged periods and 25% for average daily traffic) and Tunga (20% for charged periods and 16% for an average daily traffic), and corresponding decreases at Ranheim (− 17% for charged periods and—11% for an average daily traffic). It should be noted that charging at Ranheim was at a flat rate 24 h a day, 7 days a week. It is unlikely that this rerouting would have affected traffic in any other stations than Skovgård and Tunga.

Some of the stations that came into operation close to the city centre during the last expansion of the charging system were also affected by route change adjustments. Considerable increases in traffic levels at these stations in 2006 indicate that motorists returned back to preferred routes which they had been priced out from using.

On the whole for the Trondheim charging system, traffic in the formerly charged periods Monday–Friday 06:00–18:00 increased much more than traffic during other periods of the week between 2005 and 2006 (see Fig. 5). For all the former toll stations, traffic increased 11.3% between 06:00 and 18:00, while the other parts of the day experienced no traffic increase at all. The traffic increase for the week as a whole was just 2 percentage points above the general traffic growth in the county in 2006. The removal of the Trondheim toll cordon thus did not lead to a dramatic increase in total traffic. Only for stations located at the southern part of the municipality did the termination of charging lead to traffic increases that were higher than the general growth of traffic in the county.

These results are interesting compared to what happened during the first year of operation of the original Trondheim toll cordon. The evaluation from that time (Meland, 1994) showed that during 1992 inbound car traffic through the cordon decreased by 10% during both the high and low charged periods.

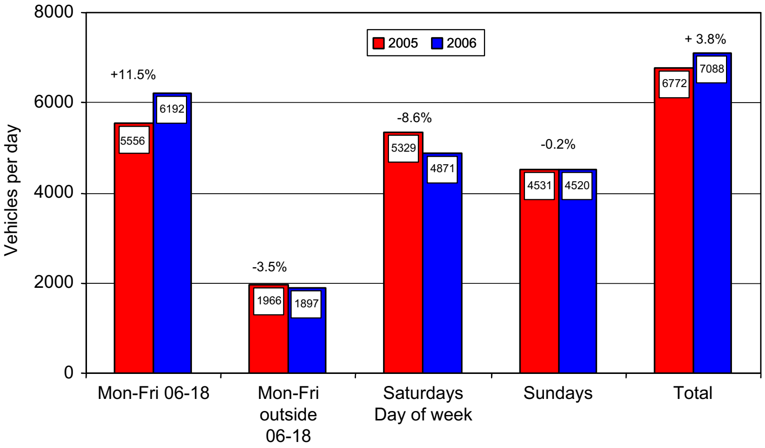

Fig. 2. Average daily volumes January–June 2005 and 2006 for three charging points located on the outside of the bypass road.

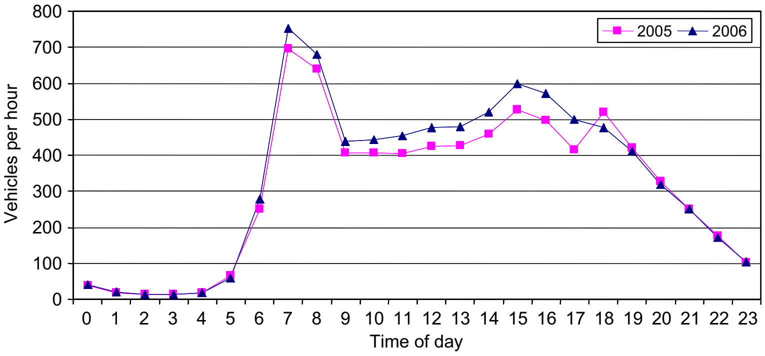

Fig. 3. Average hourly volumes for working days January–June for three charging points located on the outside of the bypass road.

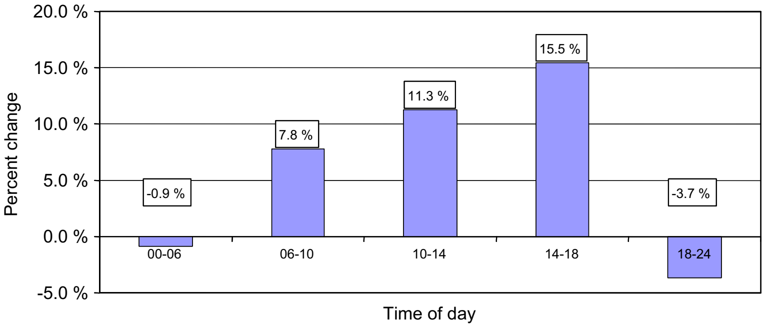

Fig. 4. Average changes in volumes for time intervals during working days January–June for three charging points located on the outside of the bypass road.

The toll cordon caused a general shift in timing of car trips away from the charged hours, but the percentage reduction was not affected by the differentiation between peak and off-peak charges. This decrease in traffic was offset by increases in an inbound car traffic in evenings and at weekends. Thus, over the week as a whole, total traffic volumes across the toll cordon were virtually unaffected by the charging. For some trip purposes like an inbound work-home and home-shopping, there were substantial shifts away from the charged afternoon period to the uncharged evening period.

When charging was terminated at the end of 2005, traffic impacts were in many ways mirror images of the impacts, when charging was introduced in 1991. Changes in departure times and route choices were the most visible responses to the termination

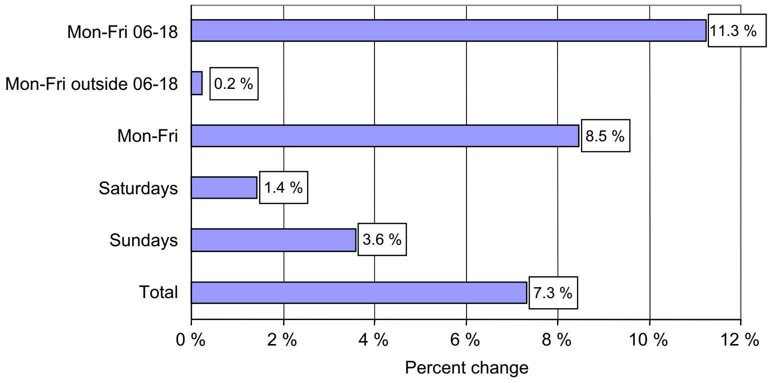

Fig. 5. Changes in total traffic volumes for all former toll stations.

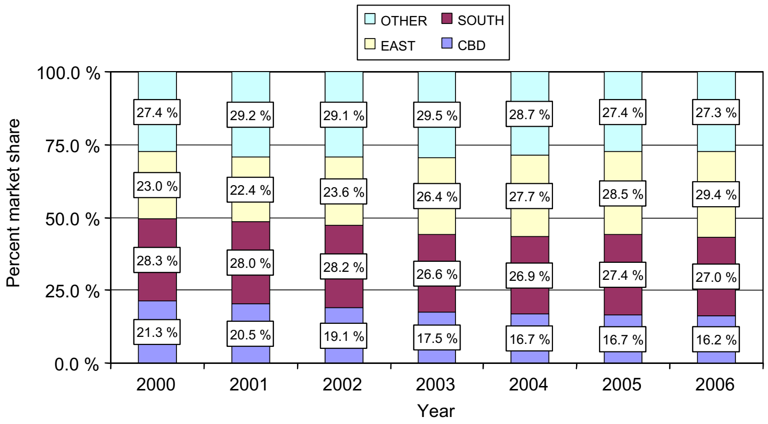

Fig. 6. Retail market share and volumes by city sector 2000–2006.

of charging by car drivers. In general, the Trondheim charge levels were modest, but traffic still displayed sensitivity to tolls.

4.2. Effects on the city centre trade

Prior to implementation of the 1991 charging scheme, there were concerns about negative effects on the attractiveness of the CBD for business activity, and great uncertainty prevailed about the possible effects on shopping trips. During the first months of 1992, there was evidence of some businesses located inside the toll cordon losing trade. However, from the summer of 1992, no distortion of competition due to the toll cordon could be read out of the statistics. Businesses located in the CBD had prior to the toll cordon predicted major negative swings in trade once the cordon came into operation. The Chamber of Commerce in its own study concluded that there was hardly any effect of the cordon on the CBD trade at all. Fig. 6 shows what happened to CBD retail trade in relation to other areas in the municipality since the turn of the century. A long term trend of decreasing market shares has continued, even though the net sales volumes have grown modestly. However, the market share did not drop during 2005, and the drop during 2006 was smaller than in previous years. Still, the removal of the cordon did not lead to an upswing in city centre trade during 2006. Thus, it can be concluded that the often expressed concern that city centre trade will suffer from urban tolling, cannot be supported by the evidence from Trondheim.

4.3. Overall changes in transport patterns, 2005–2006

In this section, results from the modelling of three alternatives are presented: the situation in 2005 with the tolling system in operation (2005), a scenario for 2006 with tolling (2006WT) and the situation in 2006 with no tolling (2006NT).

Factors causing changes in transport demand in these analyses are changes in the transport system – namely removing the toll charging – and growth in population and labour-market from 2005 to 2006. The comparison of 2005 and 2006WT thus gives the effects of the demographic and work-related changes, while the comparison of 2006WT and 2006NT isolates the effect of removing the charging. Finally, comparison of results from 2005 and 2006NT gives the total calculated effects, caused by changes in population, labour-market and the charging being ended. If nothing else is stated, the latter results are the ones commented in the following.

As shown in Table 2, the car driver alternative represented almost half of the trips in 2005, and with the charging being brought to an end, the share is estimated to have increased further by 3.1 percentage points in 2006NT, mainly at the expense of the car passenger and slow mode alternatives.

Table 2
Mode distribution Trondheim municipality; 2005, 2006 with tolling (2006WT) and 2006 with no tolling (2006NT).

Mode	Alternative			Change		
	2005 (%)	2006WT (%)	2006NT (%)	2005– > 2006WT	2006WT – > 2006NT	2005 – > 2006NT
Car driver	49.6	49.9	52.7	+0.2%-points	+2.9%-points	+3.1%-points
Car passenger	8.6	8.7	7.0	+0.1%-points	−1.7%-points	−1.6%-points
Public transport	10.4	10.4	10.0	+0.1%-points	−0.4%-points	−0.4%-points
Pedestrian/bicycle	31.4	31.0	30.2	−0.3%-points	−0.8%-points	−1.1%-points
Total	100.0	100.0	100.0			

Table 3
Transport indicators for working days Trondheim municipality; 2005, 2006 with tolling (2006WT) and 2006 with no tolling (2006WNT).

Mode				Change					
	Alternative			2005– > 2006WT		2006WT- > 2006NT		2005- > 2006NT	
Unit	2005	2006WT	2006NT	Absolute	Relative (%)	Absolute	Relative (%)	Absolute	Relative (%)
Car driver									
Trips	297,751	305,137	323,040	+7386	+2	+17,903	+6	+25,289	+8
km	3,155,730	3,251,480	3,414,216	+95,750	+3	+162,736	+5	+258,486	+8
min	4,626,557	4,818,557	5,317,183	+192,000	+4	+498,626	+10	+690,626	+15
Car passenger									
Trips	51,685	53,203	42,857	+1518	+3	−10,346	−19	−8828	−17
km	510,530	532,742	417,609	+22,212	+4	−115,133	−22	−92,921	−18
min	682,942	719,059	565,575	+36,117	+5	−153,484	−21	−117,367	−*17*
SUM car driver+passenger									
Trips	349,436	358,340	365,897	+8904	+3	+7557	+2	+16,461	+5
km	3,666,260	3,784,222	3,831,825	+117,962	+3	+47,603	+1	+165,565	+5
min	5,309,499	5,537,616	5,882,758	+228,117	+4	+345,142	+6	+573,259	+11
Public transport									
Trips	62,320	63,916	61,498	+1596	+3	−2418	−4	−822	−1
km	570,411	592,276	570,582	+21,865	+4	−21,694	−4	+171	+0
min	832,316	862,879	831,999	+30,563	+4	−30,880	−4	−317	−0
Pedestrian/bicycle									
Trips	188,048	189,753	185,144	+1705	+1	−4609	−2	−2904	−2
km	521,271	530,018	513,186	+8747	+2	−16,832	−3	−8085	−2
min	6,255,252	6,360,216	6,158,232	+104,964	+2	−201,984	−3	−97,020	−2
Total									
Trips	599,804	612,009	612,539	+12,205	+2	+530	+0	+12,735	+2
km	4,757,942	4,906,516	4,915,593	+148,574	+3	+9077	+0	+157,651	+3
min	12,397,067	12,760,711	12,872,989	+363,644	+3	+112,278	+1	+475,922	+4

Due to the increase in population, a 2% increase in total number of trips is expected (Table 3). Due to the removal of the toll cordon, shares of other modes than car are estimated to have decreased. The number of trips by car increased by 8%, mainly at the expense of car passenger trips, but also trips by public transport and pedestrian/bicycle are estimated to have decreased slightly. Due to the increase in traffic levels, especially during the peak periods, the overall average speeds by car decreased somewhat in the alternative 2006NT. Coupled with the increase in the number of trips, this lead to a 15% increase in vehicle time. The modelling results indicate that if the cordon had still been in operation (comparison of 2005–2006WT), the 2% increase in total number of trips would have been more uniformly distributed among the alternative modes.

4.4. *Resulting changes in energy consumption*

The main purpose of the road user charging scheme in Trondheim was to raise revenue to finance new infrastructure. However, for many new urban RUC schemes, concerns about environmental issues are an important part of the motivation. The Trondheim evaluation therefore includes a rough estimate of changes in energy consumption as a consequence of the termination of the charging scheme.

The total energy consumption for passenger transport in Trondheim has been calculated for each of the three alternatives modelled, as described in Section 3.4.

For 2005, the total energy consumption for passenger transport in Trondheim is calculated to nearly 1900 MWh per day. For the 2006NT alternative, there is an increase of 7–8% to 2000 MWh (Table 4). The energy consumption levels per hour are highest during the afternoon peak period. For this time of day, the increase in total energy consumption is estimated to 10%, with 172 MWh per hour in 2005 and 189 MWh per hour in 2006NT.

The increase in an energy consumption by passenger cars is 8%, and for buses, almost no change. While public transport is used for some 13–14% of the person-km by motorised transport, it represents only 7–8% of the total energy consumption for local person transport in the Trondheim area. The removal of the Trondheim toll cordon has thus led to a 4% increase in energy consumption per person-km in the area.

Table 4
Estimated energy consumption (kWh) Trondheim municipality local transport: 2005, 2006 with tolling (2006WT) and 2006 with no tolling (2006NT).

Time of day	**Alternative**			**Change**		
Mode	**2005**	**2006WT**	**2006NT**	**2005 – > 2006WT (%)**	**2006WT – > 2006NT (%)**	**2005 – > 2006NT (%)**
1 Evening–night (18–06)						
Passenger car	369,503	382,358	386,394			
Bus	35,959	37,281	36,983			
SUM	405,462	419,638	423,377	+3.5	+0.9	+4.4
kWh/h	33,789	34,970	35,281			
2 Morning (06–09)						
Passenger car	223,128	232,555	246,420			
Bus	20,947	21,633	21,139			
SUM	244,075	254,189	267,559	+4.1	+5.3	+9.6
kWh/h	81,358	84,730	89,186			
3 Mid day (09–15)						
Passenger car	654,943	669,763	704,083			
Bus	55,331	57 212	55,407			
SUM	710,274	726,975	759,490	+2.4	+4.5	+6.9
kWh/h	118,379	121,162	126,582			
4 Afternoon (15–18)						
Passenger car	488,078	503,638	540,922			
Bus	28,098	29,411	27,493			
SUM	516,176	533,049	568,415	+3.3	+6.6	+10.1
kWh/h	172,059	177,683	189,472			
Total						
Passenger car	1,735,652	1,788,314	1,877,819	+3.0	+5.0	+8.2
Bus	140,336	145,537	141,021	+3.7	−3.1	+0.5
SUM	1,875,987	1,933,851	2,018,840	+3.1	+4.4	+7.6
kWh/h	78,166	80,577	84,118			

5. Elasticity estimates

The responsiveness of demand to changes in factors affecting the level of demand is normally measured through the concept of elasticities. Elasticities measure the change in one variable due to a change in an another variable. The level of demand for car travel is affected by the generalised costs, which could be assumed to consist of variables such as travel time, vehicle operating costs and tolls. Other costs could also be included, such as the value of accident risks and insurance costs, but these are considered to be of negligible magnitude for car trips in Trondheim, which on an average are just above 10 km long. The extent to which travellers take time costs into account or if small time savings/increases affect travel choices are debatable. The increase in an average travel time in Trondheim from 2005 to 2006 was just 55 s or 6%. To account for this uncertainty, elasticities based on generalised costs, both with and without time costs are calculated.

Several measures could be used to calculate elasticities, with the most common ones being the *point elasticity* and the *arc elasticity* (for a full discussion of elasticity measures, see TRL, 2004). The point elasticity is used to express the effect on demand from marginal changes in price, while the arc elasticity is used for larger price changes as it assumes a convex demand curve which is generally regarded as a more appropriate approximation to the true demand curve.

For estimating the elasticity of demand due to the removal of the Trondheim toll cordon, the average generalised costs for car travel in Trondheim is needed. As the charging system covered most of the municipality of Trondheim, the calculation is based on all car trips in Trondheim and not just those crossing the cordon. From the modelled results presented in Section 4, we are provided with data on an average travel time and an average length in kilometres per trip. These are used to calculate the generalised costs. Estimates for vehicle operating costs and value of travel time is provided by the national framework for cost–benefit analysis set out in the Norwegian Public Roads Administration's "Handbook 140—Impact assessments" (NPRA, 2006). As Tables 5 and 6 show the value of travel time varies from NOK 53 to NOK 198 for ordinary vehicles, depending on trip purpose, while buses and HGVs are assumed to have value of travel time of NOK 321 and NOK 464 NOK, respectively. For vehicle operating costs, values of NOK 1.54 per kilometre for ordinary vehicles and NOK 4.42 for heavy vehicles are used. Using this information, the average generalised costs for car trips in the municipality of Trondheim in 2005 and in 2006 is calculated. The calculations indicate that the average generalised cost per car trip in Trondheim were some NOK 53 in 2005 and NOK 47, one year after when the tolls were removed.

The removal of the toll cordon thus resulted in a 12.4% reduction in generalised costs when time costs are included, while car kilometres are estimated to have increased by 7.6%. If we assume that the increase in time costs has had no effect on travel demand, generalised costs decreased some 30%. Table 7 presents elasticity estimates for the Trondheim toll cordon in the order of −0.22– −0.59 depending on whether we assume motorists take time costs into account or not. This is fairly equal to the elasticities reported in Section 2. The relatively low elasticity values in Trondheim confirm that total demand for car travel is inelastic and that low tolls have a relatively limited impact on total traffic levels, even if tolls can make traffic levels over the day vary considerably.

The experiences from Trondheim indicate that even relatively small price changes and low tolls can affect travel decisions. However, it is not possible to determine with absolute certainty if the increase in the demand for car trips is the result of the removal of the toll cordon alone or the result of other factors. The elasticities in Trondheim are short-run estimates. In the long-run, travellers are able to fully adjust to new levels of generalised costs, and higher elasticities could be expected.

Table 5
Generalised costs per car trip. Trondheim municipality 2005.

Cost component	Unit	Share of total traffic	Value	Share	Average travel time 2005	Average kilometres 2005	Generalised costs (excluding tolls)	Average tolls	Share of tolls	Generalised costs (including tolls)
Time costs business trips	Hours	0.923	198	0.17	15.54	10.60	8.05	8.18	7.55014	26.34
Time costs to/from work			57	0.24			3.27			
Time costs leisure trips			53	0.59			7.48			
Time costs heavy vehicles		0.077	464	0.50			4.63		0.62986	8.46
Time costs buses			321	0.50			3.20			
Vehicle operating costs ordinary vehicles	Kilometres		1.54	0.92			15.08			15.08
Vehicle operating costs heavy vehicles	“		4.42	0.08			3.56			3.56
SUM	–	–	–	–	–	–	45.26	–		53.44

Table 6
Generalised costs per car trip. Trondheim municipality 2006.

Cost component	Unit	Share of total traffic	Value	Share	Average travel time 2006	Average kilometres 2006	Generalised costs (excluding tolls)	Average tolls	Share of tolls	Generalised costs (including tolls)
Time costs business trips	Hours	0.923	198	0.17	16.46	10.57	8.52	0.00		19.90
Time costs to/from work			57	0.24			3.46			
Time costs leisure trips			53	0.59			7.92			
Time costs heavy vehicles		0.077	464	0.50			4.90			8.29
Time costs buses			321	0.50			3.39			
Vehicle operating costs ordinary vehicles	Kilometres		1.54	0.92			15.04			15.04
Vehicle operating costs heavy vehicles	“		4.42	0.08			3.55			3.55
SUM	–		–	–	–	–	46.79	–		46.79

Table 7
Estimated elasticities for the Trondheim toll cordon.

	Arc elasticity
Including time costs	−0.59
Excluding time costs	−0.22

6. Conclusions

This article has provided empirical results from the effects of the removing of the Trondheim toll cordon. Traffic is sensitive to changes in tolls, and even though the average toll in Trondheim was relatively low, there has been a considerable increase in traffic in the former charging periods. On an average, there was an increase in traffic over the previous cordon of 15.5% for the hours between 14:00 and 18:00, whilst traffic levels decreased in the evenings and at night time. Trondheim is thus experiencing traffic growth at times when capacity constraints are already present. The long term effects of this are likely to be more congestion and increased environmental problems. No effects on the city centre trade are found. This is in line with the experiences when the cordon was introduced.

The experiences from Trondheim show that road user charging works. Even small charges can contribute to a more efficient utilisation of the road network, as traffic levels can be reduced in the peak hours and increased in the off-peak, when time-differentiated tolls are introduced. From the evaluation activities related to the Trondheim RUC scheme, there is clear evidence that a significant proportion of the motorists has some flexibility in their trip scheduling and responds to changes in tolls through changing their travel timing, choice of destination, route or mode. The removal of the Trondheim toll cordon also shows that low charges have little impact on total traffic levels. There is little evidence of motorists being ‘priced off’. As such, the Trondheim toll cordon met objectives concerning efficiency, equity and finance.

The strategic transport model for Trondheim has been used to estimate the effects on the total transport demand in the municipality of Trondheim. The model results suggest that the removal of the toll cordon has caused the private car to increase its modal share at the expense of passengers per car, public transport and cycling/walking. According to the model, the increase in the total number of trips would have been more uniformly distributed among the alternatives if the toll cordon had still been in operation.

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Paper IV

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Paper V

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Paper VI

Are Smart Card Ticketing Profitable? Evidence from the City of Trondheim

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Are Smart Card Ticketing Profitable? Evidence from the City of Trondheim

Abstract

Electronic ticketing in public transportation based on smart cards is gaining momentum worldwide. It is widely recognized that smart cards can deliver benefits to both passengers and operators, but due to its complexity, implementation can come at a considerable cost. Therefore, it is likely that a commercial appraisal from the perspective of the public transportation operator would reveal that costs are higher than benefits and hence economic non-viability. This paper presents the experiences of the Norwegian city of Trondheim, which has recently implemented a fully interoperable electronic smart card system. A social cost-benefit analysis of the scheme is presented, focusing on net overall benefits for the passengers, the bus company, the local transportation authority and the rest of society. The main conclusion of the paper is that the smart card ticketing system in Trondheim delivers a positive net present value. The paper demonstrates that an economic evaluation of smart card ticketing schemes using the principles of social cost-benefit analysis is desirable and possible. Because commercial non-viability may represent constraints for the implementation of such schemes, the findings presented in this paper provide valuable information to those currently working on smart card ticketing strategies.

Background

Electronic ticketing in public transportation based on smart cards is gaining momentum worldwide. It is widely recognized that smart cards can deliver benefits to passengers and public transportation operators through time savings, increased travel convenience, more flexible ticketing, lower administrative costs and better marketing information. The implementation of smart card systems is, however, a complex process that includes legal, economic and technological issues. Implementation can thus come at a considerable cost. Therefore, it is likely that a commercial appraisal from the perspective of the public transportation operator alone would reveal costs higher than benefits and hence economic non-viability. Authorities and public transportation operators are thus often reluctant to sanction large investments in such systems.

A striking example of transportation investments that may not generate sufficient revenues to justify private investment alone is public transportation investments. Public transportation is often subsidized to ensure that important services are provided even if they do not generate sufficient ticket revenues to justify their operations. Even in countries where the public transportation industry is completely deregulated, there is usually some kind of operator reimbursement for services such as certain rural routes, school travel or free travel for the elderly. Other arguments for subsidizing public transportation include the positive externalities generated by the service, the potential for user-scale economics (often referred to as the Mohring effect) and the alleged public or merit good characteristics. This implies that, in reality, very few, if any, investments in public transportation are profitable from a purely commercial perspective. When deciding whether to implement smart card ticketing systems, we should hence evaluate the investment from a social perspective, following the principles of social cost-benefit analysis. That is the purpose of this paper.

This paper presents the experiences of the Norwegian city of Trondheim, which has recently implemented a fully interoperable electronic smart card system. A social cost-benefit analysis of the scheme is presented, focusing on net overall benefits for the passengers, the bus company, the local transportation authority and the rest of society.

Smart Card Ticketing in Trondheim

The city of Trondheim (pop. 175,000), which is the third largest city in Norway, implemented electronic smart cards (the *t:card*) for its public transportation system in June 2008. It is a region-wide scheme in which customers can use one smart card based on one contract for buses, trams and regional coaches operated by ten public transportation operators in Trondheim and the two counties surrounding the city. The total population in the two counties, including Trondheim, is approximately 425,000. Prior to the implementation, payment was based on a wide array of paper-based ticketing schemes. Customers can still pay with cash, but soon after implementation, smart card usage accounted for approximately 70% of all payments; after nearly three years of operation, approximately 90% of all trips are currently paid for using the t:card. This means that accommodating those customers who still pay their fares by cash is becoming more expensive, which raises the issue of transferring to full-scale electronic ticketing with no option to pay by cash. Customers using the t:card are offered discounts from 5% to 25%, depending on prepaid amounts and other contract arrangements. In addition, monthly passes are offered, which gives frequent travelers significantly lowers fares than they would pay if purchasing single tickets. The single ticket cash fare in Trondheim is $5.30, while the price of a monthly pass for the greater Trondheim area is $100.

In 2009, ⅔ of the costs of public transportation operations in Trondheim were paid for by ticket revenues (approximately $35 m). The remaining ⅓ was covered by local authority subsidies. Ten years ago, the share of subsidies to costs was close to zero, but that share has increased due to a freeze on fares, increased operating costs and increased bus frequencies.

The public transportation system in Trondheim is based on 42 bus routes and one tram line. Trains, which are not currently part of the smart card system, carry passengers to and from neighboring towns. Currently, the total number of bus trips per year is 18 million.

Until recently, bus services in Trondheim were provided by a direct contract with a publicly owned local bus company, but they are now based on gross subsidy tendering, where services are planned and managed by the transit authority AtB, a subsidiary of Sør-Trøndelag County, where Trondheim is located. With services now tendered, the quality of buses and bus services is expected to increase. Beginning in the autumn of 2011, all services will be provided by low-floor buses, which as a minimum fulfill the Euro 5 guidelines for emissions. New buses will also have a rear access option for t:card holders. Although this option increases the risk of fraud, it is expected that this will also contribute to a reduced dwell time.

Literature Review

Smart cards are utilized for a number of different transportation applications, among which ticketing is the most widespread. However, despite being invented more than 30 years ago, the history of smart cards is littered with a number of spectacular and costly failures. Regardless, the last 15 years have seen a growing number of smart card schemes being launched, many of which are a result of the success of large-scale electronic ticketing schemes in Asia (Blythe 2004). This has lead to an increased interest in investigations into the benefits and costs of smart card ticketing for public transportation.

In a report by the UK Department for Transport (DfT) and Detica (2009), the net present value (NPV) of a national smart ticketing infrastructure over a ten-year period was estimated at £22.2 bn with full take-up. Even with a minimal rollout of smart cards, the NPV was estimated at £1.7 bn, equivalent to a Benefit-Cost Ratio (BCR) of 1.8, which is close to the level considered as a high value for money (2.0). The DfT concluded that the installation of smart card infrastructure in UK public transportation has large one-off costs, but relatively low operating costs. The benefits are large and come from factors such as modal shifts, cost savings, increased revenue, fraud reduction, better service and improved access and integration with other services. It is worth noting that the DfT report identified real scale economies in the implementation of smart card technology. Although some benefits could be gained from partial implementation, real payback is expected once a full national interoperable scheme is in place.

The view of large potential benefits was not, however, supported by the Confederation of Passenger Transport. In a *Local Transport Today* article published on November 19, 2009, they argued that the lack of smart card schemes in operation was not a result of market failure, but due to an unviable business case for public transportation operators and uncertain benefits for all parties involved. Fearnley and Johansen (2009) reached the same conclusion in a commercial appraisal of the *Flexus* system for public transportation in Oslo, which is struggling to implement an interoperable smart card system for buses, trams and metro lines in Oslo and the neighboring county. The new system provided a negative NPV for the operator, and initial assumptions have so far turned out to be overly optimistic.

This is similar to the views of Iseki et al. (2008), who claimed that the benefits of smart card systems are often vague and that it is still unclear whether the benefits of smart cards outweigh the costs. More importantly, Iseki et al. identified one of the serious shortcomings of intelligent transport systems (ITS) and perhaps of smart card systems in particular: namely, the consistent lack of comprehensive economic evaluations to properly appraise the costs and benefits of such schemes. As argued by Odeck and Welde (2010), when ITS projects are not evaluated according to the same methodologies as traditional transportation investments, many potential ITS projects may lose terrain relative to alternative solutions. In addition, ITS often represent new applications that are still in their early stages in many countries. Ascertaining their expected effects is therefore often difficult. This might make traditional evaluation methods such as cost-benefit analysis (CBA) inappropriate. Although frameworks for CBA exist in most countries, these are not necessarily suitable for ITS evaluation. In particular, the limitations of traditional CBA for ITS evaluation are related to data issues, the time horizon and the valuation of user benefits. Odeck and Welde nevertheless concluded that evaluating ITS projects using the principles of cost-benefit analysis is desirable and possible. Although there are costs and benefits associated with ITS that are difficult to monetize, most of the benefits and costs of ITS schemes, such as electronic payment systems, are measurable in monetary terms and are therefore suitable for CBA.

One of the very few economic appraisals of smart card technologies was presented by Cheung (2006), who analyzed the effects of the Dutch national smart card system. Although not necessarily providing benefits to each of the individual operators involved, the analysis indicated that the project has resulted in large cumulative benefits, with a BCR on the order of 0.2-0.5. The most important direct benefit for passengers was the amount of time spent purchasing tickets, while operators have benefited from reduced fraud and increased opportunities for more sophisticated price differentiation.

Framework for Evaluation

In this article, the evaluation of the smart card system in Trondheim is based on social cost-benefit analysis. Social CBA differs from commercial appraisal in that all costs and benefits associated with a particular scheme are included regardless of to whom they accrue. This means that a scheme that involves direct revenues and turns out to be non-viable from a commercial perspective may still be desirable from a social perspective when all external benefits and costs are included.

The implementation of an interoperable smart card system in Trondheim was motivated by potential benefits for all parties involved and affected by public transportation in Trondheim: passengers, operators, local authorities and the wider community. Table 1 outlines the expected impacts for all of the affected groups.

Table 1: Benefits and costs – affected groups.

Passengers	*PT operators*	*Local authorities*	*Wider community*
Time savings	Time savings	Improved statistics	Cost of taxation
Reduced delays	Increased reliability	Project costs	Reduced emissions
Less need to carry cash	Project and investment costs		
	Operating costs		
+	+/-	-/+	-/+

The introduction of smart cards in public transportation reduces the time spent boarding and paying, provided that payment is done when boarding. This constitutes a time saving for each passenger. Although this may be a small and potentially negligible time saving for the individual, normally not more than a few seconds, it is important to note that the individual passenger will save time at *every* stop and for *every* foregoing passenger who would have previously paid by cash. Over the course of an average bus or tram journey, this could constitute a significant time saving for both the passengers and the operator(s). This is similar to the user-scale economies identified by Mohring (1972), where the presence of an additional user increases the likelihood of additional services being provided due to time savings and the resulting increased demand. This is also similar to benefits arising from measures to improve accessibility to passengers with special needs, often referred to as ‘universal design’ (UD). The conventional thinking is that UD is for the few, i.e., the impaired, and given that they are few in numbers, UD projects will generally be unprofitable from a socioeconomic point of view because benefits will be low while investment costs will be high. However, a recent study has shown that UD projects benefit all users of the facility, whether impaired or not, and the additional costs of implementation are generally low; hence, their NPVs are high and positive (Odeck et al. 2010).

Smart cards often also increase bus route reliability and reduce delays for passengers. Payment by cash can be a complex process, where the average time per passenger varies from a few seconds to over a minute. This makes scheduling difficult. The introduction of smart cards normally reduces this pay time variability and hence contributes to both reduced delays and increased reliability.

Another benefit for passengers and operators is a reduced need for cash. Today, people are increasingly carrying no cash at all, and the percentage of transactions made by credit and debit cards is increasing annually. In 2009, there were 1.2 bn card transactions in Norway (up 10% from 2008). This is equivalent to 246 transactions per person (Norges Bank 2010). Norges Bank, Norway's central bank, has estimated that cash only settles about 23% of transactions at the point of sale, representing 14 to 38% of the value of all sales. The ratio of the cash stock to GDP in Norway has fallen over the past decades and has fallen considerably faster in Norway than in the other Nordic countries (Gresvik and Haare 2008).

It is expected that smart cards, at least initially, increase operating costs for the operators involved. These, along with project and investment costs, which are shared with local authorities, represent the direct costs of implementing the smart card system. In addition, costs financed by the public sector through taxation should be multiplied by 1.20, which is the standard marginal cost of public funds in Norway, reflecting the fact that distortive taxes lower welfare by more than they collect in revenue.

Finally, smart card systems normally provide local authorities with better public transportation statistics and ease the planning and scheduling of services. In addition, operators may benefit from additional information on customers' trips, paving the way for loyalty schemes and a better understanding of customers' needs and journey patterns (Davis 2002, in Blythe 2004). It is also not unreasonable to believe that, as smart cards reduce dwell time, local emissions could be reduced. This will benefit the wider community.

From the above, we notice that most of the envisaged effects can be measured in monetary terms, and an economic assessment can be done. In CBA, the relevant investment criteria are the NPV and the BCR. The NPV can be expressed as follows:

$$NPV = I_0 + \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \tag{1}$$

Here, *B* and *C* represent benefits and costs, *r* represents the discount rate, and *t* represents the time period. The NPV determines the absolute economic merit of a project. If its value is greater than zero, it means that the project generates benefits that are greater than its cost and is therefore profitable from an economic point view.

The BCR is a value for money measurement and is different from the NPV. It is defined as the ratio of the net benefits of a project to its costs. Formally, the BCR is written as:

$$BCR = \frac{NPV}{C} \tag{2}$$

The BCR has a simple interpretation, making it useful for policy makers to judge the worthiness of projects in terms of returns per euro invested. If the ratio is, for example, 0.2, it means that the returns are 20%, or a 20-cent profit for every dollar invested in the project.

In practice, we use the NPV to determine whether a project is profitable from an economic point of view. If the aim is to rank ITS projects among themselves or against other projects, then the BCR should be used, because it shows which projects give the greatest returns per dollar invested.

Data and Methodology

Data

The data for the analysis were collected in cooperation with AtB, the body responsible for Trondheim’s public transportation system. Stensrud and Kuipers (2008) provided a comprehensive overview of all costs associated with the smart card system. Although it was implemented in 2008, the process leading up to implementation was an arduous and prolonged affair. The planning started in the early 1990s, but because implementation turned out to be more complex than was first assumed, it was postponed several times. The process even resulted in a court case with the equipment supplier, which ended in a settlement in 2007. After the settlement, the project was restarted and reorganized. Therefore, as the project contents and organization have been so different, the project can be split into two phases: before and after the court settlement in 2007. In this paper, we use the costs after 2007 as the basis for the analysis. The analysis only covers the city of Trondheim and not those neighboring regions where the t:card can also be used.

Time savings usually constitute the largest share of estimated benefits of transportation projects, and the estimation of time saved per passenger therefore requires careful calculation. The estimated time saving of 6.8 seconds, as shown in Table 2, for each boarding passenger using a smart card is based on registrations performed by students at the Norwegian University of Science and Technology during the spring of 2009. The means are based on a sample of 900 observations. Unfortunately, this was done almost a year after implementation, and we cannot rule out the possibility that those still opting for cash payment at this stage represent the slower payers. The time savings may thus be underestimated. As Table 2 shows, even smart card transactions take time, but cash is more time-consuming and, above all, involves more variability in time spent per passenger, which makes scheduling more difficult.

Table 2: Time in seconds spent on cash payment vs. smart card payment.

	Cash transactions	*Smart card transactions*
No. of cases	436	466
Mean	8.3	1.5
St.dev.	6.5	1.8
Minimum	2	1
Maximum	47	18

The analysis is based on measured data after 12-24 months of operation. In addition to time savings, the data are composed of investment and operating costs, reinvestment costs, project costs, bus trips, t:card shares, load factors and standard national values for the value of time and discount rates. The appraisal period is 10 years. This is considerably shorter than what is used for traditional transportation expenditures, which are appraised over a 25-year period. A 10-year appraisal period reflects the uncertainty associated with technology investment and ensures a conservative approach to the analysis. The main parameters used in the estimation are listed in Table 3. The values are listed in Norwegian Kroner (1 NOK ≈ $0.18).

Table 3: Overall assumptions for estimation.

Parameter	Value
Investment costs	13.000.000
Operating costs per year	4.900.000
Annual service and maintenance costs	1.100.000
Reinvestment costs (every three years)	7.500.000
Project costs	7.800.000
Total number of bus trips per year	17.300.000
Share of trips performed with the t:card	70% in 2008, 80% in 2009, 90% thereafter
Annual increase in the number of bus trips	2.5%
Average time saving per t:card transaction	6.8 seconds
Average load factor	20
Time value for bus passengers	68 NOK/hour
Time value for bus company	356 NOK/hour
Discount rate	4.5%
Appraisal period	10 years
Marginal cost of public funds	20%

Methodology

The average time saving per passenger is estimated to be 6.8 seconds for each time a boarding passenger uses a smart card instead of paying by cash. Notice that this does not mean that each smart card transaction represents a time saving. The previous paper-based ticketing arrangements also included monthly passes, which holders would simply display to the bus driver. This proportion of users would not generate time savings when switching to the t:card.

This means that the total gross time savings *t* per year, measured in hours for passengers using smart cards, can be expressed as follows:

$$T_{t:card_t} = \frac{P_{t:card} \times tk_{\sec}}{3600} \tag{3}$$

where $P_{t:card}$ is the total number of passengers using smart cards per year, and $tk_{\sec}$ denotes the average time savings per smart card transaction.

The net annual time savings for all passengers is hence expressed as:

$$T_{tot_t} = (T_{t:card_t} + (T_{t:card_t} \times BP) \times (1 - m) \tag{4}$$

Here, the time saving for smart card users is adjusted for *m*, the proportion of users with monthly passes in the last year before smart card implementation. In addition, the equation includes time savings for passengers already on the bus, *BP*. These passengers will also save time at each bus stop whenever a boarding passenger uses a smart card.

The annual value of time savings can then easily expressed as:

$$B_t = (T_{tot\,t} \times w_p) + (T_{t:card_t} \times w_b) \tag{5}$$

Here, w_p and w_b express the value of travel time savings for bus passengers and the bus company, respectively.

By including investment costs and operating costs and inserting B_t into Equation (1), we are able to calculate the NPV of the smart card ticketing system in Trondheim.

Results

Based on the data and methodology presented above, a cost-benefit analysis was performed. The results are presented in Table 3.

Table 3: Cost-benefit analysis of the smart card system in Trondheim.

	NPV costs	**NPV benefits**	**NPV**
Investment costs	(13.000.000)		
Project costs	(7.800.000)		
Operating and reinvestment costs	(64.700.000)		
Marginal cost of public funds	(4.200.000)		
Time savings of bus passengers		177.400.000	
Time savings of bus company		88.100.000	
NPV	**(89.700.000)**	**265.500.000**	**175.800.000**
BCR			**1.96**

The smart card ticketing system in Trondheim is profitable from a socioeconomic point of view, with an NPV of 175.8 m NOK or approximately $30.8 m. This equals a BCR of 1.96, meaning that $1 spent on the t:card system generates benefits of $2.96. This is also substantially more than what is usually provided through traditional transportation expenditure, which, in the Norwegian case, may struggle to deliver a positive NPV at all.

The implementation of smart card ticketing is a complex process, involving a number of actors and requiring readjustments for both operators and passengers. It often takes time before all challenges are overcome and before all benefits can be realized. The long-term objective should, in our opinion, be to abolish cash payment completely. This will increase the social surplus further. In time, it should also be a realistic objective to reduce the costs of operating the system. The first years of a new ticketing system often have a high number of customer inquiries, but as users become familiar with the system and take advantage of more efficient ways to manage their contracts, savings could be realized. It is also worth noting that conservative estimates were used throughout the analysis. It is likely that the NPV of Trondheim's smart card system is higher than that estimated above.

There are also a number of benefits that are not monetized and included in the analysis. One such benefit is the reduced need for cash. For bus drivers, large amounts of cash pose a security risk. During the last five years, there have been several robberies and attempted robberies on buses in Trondheim, and the union representing the drivers has suggested a complete removal of all cash on board the buses. In Sweden, work to remove cash from buses is in progress in several cities (Rathe 2008), and the t:card could therefore be a step in the direction of cashless public transportation in Trondheim.

Another non-monetized benefit is the improved quality of public transportation statistics. Accurate travel information is important for transportation research, policy analysis and planning. Previous paper-based systems have failed to provide planners with necessary information. Statistics are incomplete and consist of a limited set of information needed for analysis and planning. Previously, the bus company in Trondheim, which was responsible for collecting the data, even failed to provide information on the development in the number of bus passengers from one year to the next. The introduction of smart cards has improved this situation, and now detailed statistics on the number of trips per bus service, including time of day and day of week, is available. It is expected that this information could be used to improve the quality of public transportation in Trondheim.

Trondheim's smart card system generates substantial time savings for both passengers and operators. Let us take a five-kilometer bus service with 10 stops as an example. At an average speed of 15 kilometers per hour, the trip will take 19 minutes and 48 seconds. If, at each stop, two of the passengers boarding are previous cash payers, this will generate a total time savings of two minutes. Depending on where passengers board along the route, this could constitute a time savings of up to 10%. It is not unreasonable to expect that this time savings could increase the demand for public transportation. Rødseth and Bang (2006) used a travel time elasticity of −0.26, whereas Balcombe et al. (2004) reported long-run travel time elasticities between −0.38 and −0.69. This means that a 10% reduction in travel time along a bus route could generate passenger growth on the order of 3 to 7%. Introducing smart cards and increasing the efficiency of ticketing could hence be efficient tools in increasing the demand for public transportation and promoting a modal shift away from private cars.

Conclusions

In this paper, we have demonstrated that the smart card ticketing system in Trondheim delivers a positive net present value. For bus passengers, the main benefit lies in time savings during boarding and a reduced dwell time. Although these represent only a small time savings for the individual, all passengers already on the bus will save time at every stop when passengers pay using smart cards, so the total time savings due to the t:card could be considerable over the course of a bus trip. This is an example of user-scale economics. Further passenger benefits include increased timetable reliability and a reduced need for cash. The bus company benefits from reduced delays and increased reliability because of the shorter time spent at bus stops. This could allow the bus company to reduce the number of buses needed or increase the service level to passengers.

This paper has demonstrated that an economic evaluation of smart card ticketing schemes using the principles of social cost-benefit analysis is desirable and possible. Even if all effects are not monetized and included in the analysis, the main costs and benefits are, and because the non-included non-monetized effects mostly would have increased the net benefits of the scheme, we consider the analysis to be robust and, if anything, to err on the pessimistic side. Because commercial non-viability often constrains the implementation of smart card schemes, these findings provide valuable information to those currently working on smart card ticketing strategies.

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