Is CBA ranking of transport investments robust?

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Abstract
Cost-benefit analysis (CBA) is often used when many transport investments need to be ranked against each other, for example in national investment planning. However, results are often questioned on claims that the ranking depends crucially on uncertain assumptions about the future, and on methodologically or ethically contestable trade-offs of different types of benefits relative to each other. This paper explores the robustness of CBA rankings of transport investments with respect to two types of uncertainties: relative benefit valuations and scenario assumptions related to car ownership, characteristics and costs. The study is based on CBAs of 479 suggested road and rail investments in Sweden that have been shortlisted for possible inclusion in the national transport investment plan. The CBA ranking turns out to be robust to variations in the studied scenario assumptions. The CBA ranking also turns out to be robust to changes in the relative valuations of different types of benefits – person travel time savings, traffic safety, emissions and freight benefits. We also compare two sets of travel time valuations against each other, one of which differentiated with respect to mode and travel purpose and one which is not, again concluding that the investment ranking is robust.

Keywords: Cost benefit analysis, appraisal, robustness, decision support.

JEL Codes: R41, R48.

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1 INTRODUCTION

Cost-benefit analysis (CBA) is used for evaluating transport investments in many countries. In particular, CBA often plays an important role when many investments need to be ranked against each other, for example in national investment planning ((Bristow & Nellthorp, 2000); (Grant-Muller, Mackie, Nellthorp, & Pearman, 2001); (Eliasson & Lundberg, 2012). However, results are often questioned on claims that this ranking may depend crucially on uncertain assumptions about the future, and on contestable or methodologically uncertain valuations of different types of benefits relative to each other. There seems to be a widespread concern among planners and decision-makers that CBA rankings are so sensitive that even small changes in uncertain or controversial input parameters may give completely different policy recommendations. These concerns have led to long and animated debates about scenario assumptions and valuations, both among decision-makers and planning professionals, in some cases leading to complete rejection of CBA's usefulness as decision support. Moreover, it is common that scenario assumptions or benefit valuations are blamed when CBA results differ from what is expected or desired by decision-makers.

The purpose of this paper is to shed light on these concerns by examining the sensitivity of CBA rankings, first with respect to relative valuations of different benefit types, and second with respect to a number of scenario assumptions such as future oil price, fuel tax and car ownership. Our analyses are based on CBAs of 479 Swedish road and rail investments shortlisted for possible inclusion in the national transport investment plan.

There are obviously several other sources of CBA uncertainty, such as traffic forecasts and investment cost calculations. This paper concentrates on relative benefit valuations and certain scenario assumptions for a number of reasons. First, valuation of benefits is associated with both methodological and ethical difficulties. Since valuations of different benefit types are usually obtained using different methodologies, there may be concerns about the comparability of valuations. Further, there may be ethical or philosophical concerns regarding the possibility to trade accessibility or money for, for example, reduced carbon emissions or saved lives. Hence, we study the impact of variations in the relative valuations of person travel time savings, emissions, traffic safety and freight transport costs. Motivated by the long debate about to what extent values of travel time should be differentiated (whether to use "behavioural" or "equity" values of time(Mackie, Jara-Díaz, & Fowkes, 2001), (Sugden, 1999)), we also study how rankings are affected when valuations of travel time are differentiated with respect to mode and travel purpose instead of averaged over these dimensions. Second, future scenario assumptions are often at the centre of heated political debates. Some of the most contested assumptions are those associated with future climate policy. Hence, we study the impact of future oil price, future technological development of cars, future car ownership, and a package of climate policy measures including kilometre charges for trucks and substantially increased fuel taxes.

In spite of the often heated public debate, the scientific literature on CBA uncertainty and robustness is limited. The only paper on the robustness of CBA ranking that we are aware of is (Holz-Rau & Scheiner, 2011). They vary relative valuations of travel time savings and traffic fatalities, finding that the ranking of around 400 road investments is robust against such variations. (Almström, Berglund, Börjesson, & Jonsson, 2012) study the impact of land use assumptions (with given total population) and find the CBA evaluation and ranking of six large transport investments to be robust. (Eliasson & Lundberg, 2009) study the effects of road pricing on CBA results, concluding that the effect may be substantial but difficult to generalize. (Eliasson & Börjesson, 2012) show that timetable assumptions have a crucial impact on CBA for railway investments. (Boyce & Bright, 2003), (Rodier & Johnston, 2002), (de Jong et al., 2007) study the robustness of CBA outcomes for specific transport investments. (Matstoms & Björketun, 2003) study CBA sensitivity with respect to future scenario assumptions using Monte Carlo simulation. There is a related literature on the accuracy of transport forecasts: (Bain, 2009), (Flyvbjerg, Holm, & Buhl, 2005), (Li & Hensher, 2010), and (Parthasarathi & Levinson, 2010) provide comparisons of forecasts and outcomes for large numbers of investment. The first two studies deal with large or very large investments, and find substantial forecasting errors which they ascribe primarily to structural reasons such as incentives to exaggerate benefits, optimism bias and winner's curse (rather than to model deficiencies). The latter two studies also find substantial forecasting errors, but it is not clear what have caused them. (Widlert, 2002), (de Jong et al., 2007) argue that future scenario assumptions are usually a more important source of forecast errors and uncertainty than deficiencies of transport models. (Zhao & Kockelman, 2002), (Beser Hugosson, 2005) and (Brundell-Freij, 2000) study forecast uncertainty due to limited size of estimation samples.

We concentrate on uncertainties in the relative ranking of investments, rather than CBA results in absolute numbers, for two reasons. First, only the relative ranking matter for which investments are chosen from a shortlist of suggested investments if the total available budget is given, and CBA results are seldom used to decide the total national investment budget (with the possible exception of certain mega-projects). Second, absolute CBA results are greatly affected by a number of inherently uncertain global parameters that shift the net present value of all investments up or down almost equally: future GDP growth, the social discount rate, the marginal cost of public funds, the marginal benefit (opportunity cost) of public funds etc. The inherent uncertainty of such parameters means that the relative ranking of investments or policy measures is often more interesting than CBA results in absolute numbers.

The paper is organized as follows. Section 2 describes the data, section 3 analyses robustness with respect to relative benefit valuations, and section 4 deals with robustness with respect to scenario assumptions. Section 5 concludes.

2 DATA

This study uses CBA results for 417 road and 62 rail investments that were shortlisted for possible inclusion in the National Transport Investment Plan for Sweden 2011-2021. CBA has been used as a tool for Swedish transport planning in general and investment planning in particular for decades. In the most recent investment plan, the Government declared that CBA results should carry even more weight, and would also affect the allocation of funds between road and rail investments (earlier each mode had had pre-specified budgets). This made the Road and Rail Administrations, responsible for delivering the investment plan proposal to the Government, devote considerable effort to ensuring that the CBA process and methodology were comparable between modes. A first selection process shortlisted nearly 700 road and rail investments for the plan, of which a total of 479 made it to the second stage, where standardized, comparable CBAs were produced for all investments. These 479 investments were the ones anticipated to yield the highest net benefit, according to planners' judgment. However, there is a substantial variation in net benefit even for this shortlisted selection, with nearly half of the investments yielding negative net benefits (Figure 1).

(Net benefits)/(investment cost)	<-0.5	-0.5 – 0	0 – 1	1 – 2	>2
Share of shortlisted investments	18%	25%	38%	11%	9%

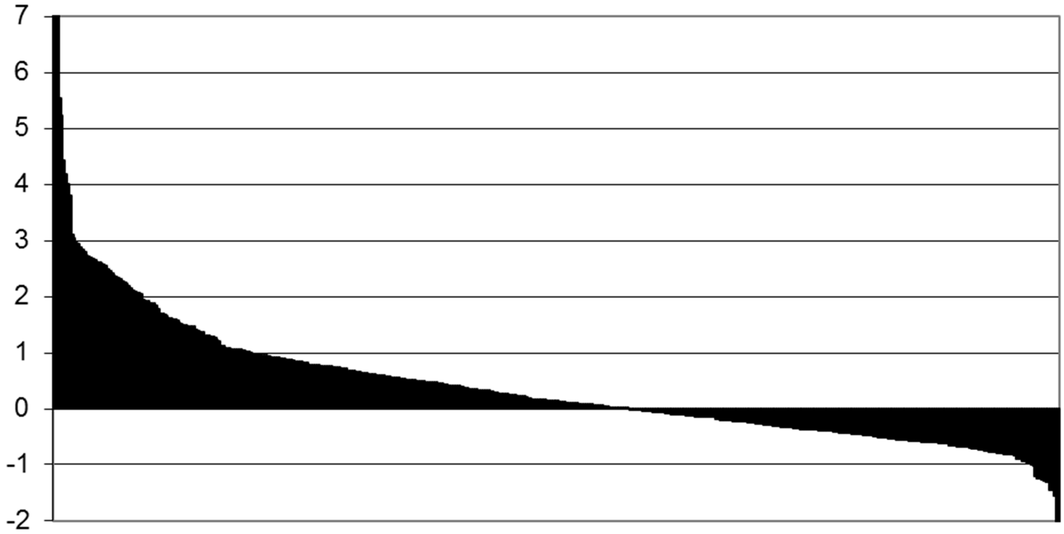

Figure 1. Distribution of net benefits/investment cost ratios (NBIR). Each bar represents one investment. NBIR>0 means that total benefits exceed the investment cost.

The share of total benefits by benefit type is shown in Table 1. Accessibility consists of both benefits for freight and personal travel. It is the dominant effect, accounting for about 90 per cent of total benefits. For road investments, traffic safety is the second most important benefit. For railway investments, emissions reduction is the second most important benefit. The negative figure under budget effects for rail investments is due to reduced tax revenues when lorry transport and car journeys switch to rail. Roughly, it is equivalent to the corresponding benefits in terms of road safety, noise and emissions, the reason being that these effects are to a high degree internalized by taxes (fuel and distance taxes).

Table 1: Share, for different groups of effects, of the total benefits of the national investments in the latest Swedish investment plan.

	All suggestions		**Selected for investment plan**	
	Road	**Rail**	**Road**	**Rail**
Accessibility	85%	95%	87%	104%
Traffic Safety	20%	5%	15%	5%
Emissions	-1%	11%	-1%	14%
Producer surplus and budget effects	3%	-13%	3%	-28%
Noise	0%	3%	0%	5%
Maintenance	-6%	-1%	-6%	0%

All forecasts were produced with the national transport models SAMPERS (for person trips) and SAMGODS (for freight transport). SAMPERS consists of five regional sub-models for short-distance trips and one national sub-model for long-distance trip. The demand models are nested logit models, while the assignment to the road and transit networks is carried out with EMME/2. The composition of the car fleet is forecasted by a separate model, where the core parts are a choice model for new vehicle sales and an exogenous vehicle choice set. SAMGODS calculates national and international freight flows. A prior O-D matrix is adjusted using changes per economic sector from a multiregional input-output model. Freight volumes per O-D pair are hence not sensitive to changes in transport costs. O-D volumes are then assigned to transport chains (combinations of modes and routes) with a deterministic assignment model (STAN).

CBA parameters such as benefit valuations and discount rate are decided by representatives from a number of public authorities. Most values and practices are harmonized with the recommendations of (HEATCO, 2006). Table 2 presents the most important parameters.

Table 2: Some of the parameters used in Swedish transport-related CBAs. Source: SIKA (2008). 1 SEK is roughly € 0.1.

Value of time	Private trips <10 km Private trips >10 km Business trips	51 SEK/h 102 SEK/h 275 SEK/h
Value of lives and injuries	Life Severe injury Light injury	22.3 MSEK 4.15 MSEK 0.2 MSEK
Emissions[1]	Carbon dioxide Particles VOC SO2 NOx	1.50 SEK/kg 11 494 SEK/kg 68 SEK/kg 333 SEK/kg 36 SEK/kg
General parameters	Discount rate Producer/consumer price conversion factor Appraisal period (default project lifetime)	4% 1.21 40 years

3 IMPACT OF VARIATIONS IN RELATIVE VALUATIONS

Considerable research efforts are spent on measuring monetary valuations of time, safety, emissions etc. Nevertheless, the relative weight of these benefits will always be a controversial issue. The assumption in the CBA methodology that there is an explicit and fixed trade-off between for example saved lives, travel time savings and carbon emissions is admittedly somewhat baffling, and is often mentioned as one of the main criticisms of the CBA approach as such. Still, such trade-offs have to be made, implicitly or explicitly, whenever decisions are made. Many have argued that one of the virtues of CBAs is that the trade-offs are made explicit and hence can be challenged. One source of uncertainty in relative valuations is that valuations of different types of benefits are measured with different methods. Freight benefits are derived using estimates of average transport costs, while travel time savings are usually derived from stated choice studies. The value of a statistical life is usually derived from stated choice studies as well, but with a completely different choice setting. Several emission valuations are derived from the value of statistical life, despite that this typically varies between contexts. Finally, the value of carbon emission is derived from political goals.

[1] Values depend on geographical area (except for carbon dioxide), among other things on exposure rates. The table shows values for Stockholm city.

Since it is known that valuations are influenced by the choice context, this is a source of concern regarding the consistency of valuations for different types of benefits.

Hence, there may be several reasons for concerns about whether different types of benefits can be reliably converted to a common currency, which is a fundament of the CBA framework. These concerns are increased by the fact that officially recommended valuations vary considerably between countries (HEATCO 2006). The methodological and ethical debate is not the issue of this paper. Instead, we explore how the CBA ranking is affected by the relative weight of different types of benefits. We focus on relative valuations of the dominant posts in the CBAs: freight benefits (savings of transport time, costs and delays), traffic safety benefits (reduced fatalities and injuries), emissions (carbon dioxide, NO_x, SO_2, particles) and travel time savings for person trips (all trip purposes).

Using the 479 investment appraisals described above, each type of benefit was increased with 50 and 100 per cent, respectively, while all other valuations were held constant. Then, differences in the investment ranking were studied by checking how many of the top-ranked 50, 150 and 250 investments differ from the base case. To simultaneously compare the entire rankings, Spearman's rho was used. Results are found in Table 3.

An alternative method to explore robustness would have been to use Monte Carlo-simulation, randomly changing all relative valuations simultaneously. The method to increase one valuation at a time was chosen because the issue is usually brought up by arguing that some specific benefit is undervalued (rather than through the argument that valuations are uncertain in general). Moreover, changing one valuation at a time will affect the ranking more than randomly changing all valuations simultaneously, and as will be shown, the ranking turns out to be robust in spite of this.

Table 3: Changes in CBA ranking of 479 investments when various valuations are increased.

	Original list	Freight benefits +50%	Freight benefits +100%	Traffic safety benefits +50%	Traffic safety benefits +100%	Emission benefits +50%	Emission benefits +100%	Person travel time benefits +50%	Person travel time benefits +100%
Changes in Top 50		7	10	5	11	3	4	7	9
Changes in Top 150		8	14	15	22	1	5	7	11
Changes in Top 250		8	13	15	27	3	5	12	21
Changes in bottom 150		4	9	12	18	2	4	7	15
Spearman's rho		0.99	0.98	0.98	0.95	1.00	1.00	0.99	0.97
Median ratio of net benefits to investment costs	0.14	0.20	0.29	0.30	0.50	0.13	0.12	0.45	0.76
Rail investments among top 100	21		24		17		23		17

The table indicates that the CBA ranking is more stable than what might have been expected. A very large majority stays in the top-ranked segment even if any of the valuations is doubled. Even if the valuations in a CBA are uncertain by nature, a doubling is a very large change – well beyond the typical difference between different valuation studies. The impact of changing relative valuations is different for different benefits, though: varying the value of traffic safety affects the ranking the most, while varying the value of emissions affect it the least. The reason that changing the emission valuation affects the ranking so little is the effects of transport investments on emissions are small compared to the effects on travel times and traffic safety.

Although the relative ranking of investments is usually the most important policy outcome, it is also relevant to explore how absolute benefit-cost ratios are affected. One reason is that CBA results sometimes seem to play a particularly important role as a screening tool, helping planners to avoid investments with negative net benefits (Eliasson & Lundberg, 2012). The median NBIR for all investments in the original list was 0.14. Doubling the value of various benefit types, this increases up to 0.76. Hence, CBA outcomes in absolute levels are much less robust than the ranking, as was expected. The largest change is when the value of travel time savings is doubled, which is natural since travel time benefits is the largest benefit for most investments. Increased emission valuations, however, decreases median NBIR because a majority of the projects lead to (slightly) increased emissions.

The balance between investments in different transport modes often attracts political interest. The last row of Table 3 shows the number of rail investments among the top 100 investments. The balance between road and rail investments is fairly robust even for large changes in valuations. The original list included 21 rail investments in the top 100. When traffic safety or person travel time is doubled, the number of railway investments decreases to 17. Doubling freight valuations results in 24 rail investments among the top 100, while doubling emission valuations results in 23 rail investments among the top 100. The last result is particularly interesting since emission reductions are often used as an argument for railway investments. It should also be pointed out that emission benefits from railway freight capacity expansions tend to be overestimated by the methods used here: the analysis method assumes that all additional rail freight volumes induced by capacity expansions would otherwise have been transported by truck.

So far only the relative valuation of different types of benefits has been varied. There are varying practices in different countries regarding the differentiation of the value of travel time, which is usually the main source of benefits. Although the underlying economic theory of CBA would prescribe a detailed differentiation of values of time with respect to journey purpose, income, distance, mode etc., several countries recommend the same average value of time for all travel modes and sometimes for all private purposes and distances, motivated by equity concerns put forward by Mackie et al (2001). Most countries with official recommendations for CBA parameters face similar debates regarding the extent of value of time differentiation. Sweden has up to very recently only differentiated between business/private and long/short trips (<100 km). However, the new Swedish value of time study (Börjesson & Eliasson, 2012), which will be applied in forthcoming investment plans, also differentiates between modes and commute/other private trips. The currently used values and the suggested, more disaggregated values are shown in Table 4.

Table 4: Currently recommended values of time for private trips in Sweden (in SEK/hour), and new values of time. "Long distance" means >100 km.

	Currently recommended values of time	New value of time study
Long distance, road	102	109
Long distance, rail	102	75
Short distance, road, commute	51	97
Short distance, rail, commute	51	65
Short distance, road, other	51	67
Short distance, rail, other	51	53

The first five columns of Table 5 show what happens if the valuation of one specific trip type is increased[2]. The last column shows what happens when the values of time from the new value-of-time study are used. Apparently, differentiating the value of time hardly affects the ranking at all. Since values of time for road trips increase more than those for rail trips (the value for long distance rail even decreases) in the new value of time study, one might expect that the share of rail investments among the top ranked 100 would decrease considerably. The share is virtually unchanged, however; only one rail and two road investments are replaced by other investments in the same modes.

[2] Trip shares for business/private and long/short distance were taken from default recommendations for road trips. Rail trip shares were gathered from the national travel forecast for the rail lines closest to the investment in question. Commute/other private trip shares were taken from the Swedish national travel survey.

Table 5: Changes in CBA ranking of 479 investments when the value of travel time is differentiated.

	Long distance +50%	Short distance +50%	Commuting trips +50%	Other private trips +50%	Business trips +50%	New VoT study
Changes in Top 50	1	2	1	3	1	1
Changes in Top 150	3	3	2	4	3	5
Changes in Top 250	7	7	4	9	5	5
Changes in bottom 150	5	3	3	4	2	4
Spearman's rho	1.00	1.00	1.00	1.00	1.00	1.00
Median NBIR	0.27	0.24	0.19	0.32	0.22	0.23

4 THE IMPACT OF SCENARIO ASSUMPTIONS

Forecasts about future benefits of a transport investment rests on assumptions about the future, so-called scenario assumptions. These are of course uncertain and often intensively debated. Partly because of controversies about future climate policy, one particularly contested area is assumptions related to car use: future car ownership, fuel price, vehicle characteristics etc. To test the sensitivity of the CBA ranking with respect to these scenario assumptions, we will compare the ranking of the baseline scenario with four scenarios with, respectively, higher oil price, slower technical development of cars, higher car ownership and a package of policy measures aiming at reducing carbon emissions.

In the baseline scenario, the crude oil price was assumed to remain constant at $62 (2006 price level) between 2006 and 2020. This followed the then-current forecast from the International Energy Agency (November 2007). In the *Higher oil price* scenario, the oil price is assumed to roughly double, to $120 in 2020 and to $150 in 2040 (2006 prices).

The second scenario assumes different technical characteristics of vehicles, specifically the market availability of alternative-fuel vehicles. In the baseline scenario, the technological development of cars was assumed to be rather fast. The assumed future vehicle characteristics fed into the car fleet model led to a forecast for 2020 where plug-in hybrids made up 10 per cent of the total car fleet, and ethanol-driven cars made up 23 per cent. In the *Slower technological development* scenario, plug-in hybrids were assumed to be unavailable, and a much higher price ethanol (+38 % relative to the baseline scenario) led to a very small share of ethanol-driven cars.

In the baseline scenario, the increase in car ownership was assumed to be held back by some unspecified policy measures, so that car ownership increased only slightly compared to the current level. In the *Higher car ownership* scenario, car ownership was instead assumed to increase as the historical trend, giving a 7 percentage points higher car ownership level than in the baseline scenario 2020.

In the baseline scenario, a package of ambitious climate policy measures was assumed to be implemented. These policies included a distance-based tax on trucks (approx. 1

SEK/km), increased fuel taxes on gasoline and diesel, and increased vehicle taxes, differentiated with respect to fuel consumption. The increased taxes resulted in an increase in the real petrol price of 38 per cent from 2006 to 2020 and a corresponding rise of the real diesel price of 64 per cent. In the *No greenhouse gas policy measures*, these measures were assumed not to be implemented.

Table 6: Average changes in person and freight benefits for road and rail investments in four alternative scenarios.

	Road, person benefits	Road, freight benefits	Rail, Person benefits	Rail, freight benefits
I) Higher oil price	-5%	-5%	+2%	+4%
II) Slower technological development	-3%	-	+1%	-
III) Higher car ownership	+5%	-	-1%	-
IV) No GHG policy measures	+7%	2%	-2%	-4%

Table 6 summarizes the effects of the alternative scenarios on person and freight benefits for average road and rail investments.

In the *higher oil price* scenario, average road investment benefits decrease with around 5 per cent, while average railway investment benefits increase with around 4 per cent. The main reason why the effect is not larger is that the underlying oil price only constitutes about 20 per cent of vehicle running costs. Another reason is a rebound effect: when gasoline and diesel prices increase, people tend to buy more fuel-efficient vehicles, or switch to alternative-fuel vehicles.

In the *slower technological development* scenario, road investment benefits decrease with a little less than 3 per cent on average, while railway investment benefits increase with 1 per cent on average. The small effect is largely due to the slow turnover of the car fleet (the average scrapping age is 17 years), so that the composition of the entire car fleet changes slowly.

In the *higher car ownership* scenario, average benefits for road investments increase with around 5 per cent, while average benefits of rail investments decrease with less than 1 per cent. The effect of road benefits is comparatively large, considering that the change in car ownership is moderate.

In the *no GHG policy measures* scenario, average road investment benefits increase around 7 per cent (2 per cent for freight benefits), while average rail investment benefits decrease around 2 per cent (4 per cent for freight benefits).

Table 7 shows how rankings change in the different scenarios. Since most the changes in benefits are limited, the rankings stay virtually unchanged in all scenarios.

Table 7: Changes in rankings and Spearman's rho for four alternative scenarios.

	Higher oil price	Slower technological development	Higher car ownership	No GHG policy measures
Changes in Top 50	1	0	0	0
Changes in Top 150	2	1	2	3
Changes in Top 250	2	1	1	2
Changes in bottom 150	1	0	2	3
Spearman's rho	1,00	1,00	1,00	1,00

The conclusion from all of these tests is that CBA outcomes are fairly robust with respect to these scenario assumptions. Even rather drastic assumptions, such as a doubled oil price, change the benefits with only a few per cent. The exception seems to be car ownership, where benefits changed appreciably with a moderate change in the scenario assumption.

5 CONCLUSIONS

This paper is motivated by what seems to be a widespread concern: that CBA rankings are very sensitive to various potentially controversial assumptions. If it is the case that even small changes in uncertain input parameters give completely different policy recommendations, then CBA's usefulness as a decision tool would be limited at best. This has led to heated debates about scenario assumptions and valuations, and also about CBAs usefulness on the whole, in some cases leading to complete rejection of CBA. The purpose of this paper is to shed light on these concerns by examining the sensitivity of CBA rankings with respect to two specific sets of assumptions: the relative valuations of different types of benefits, and scenario assumptions related to costs and availability of cars.

Our results suggest that CBA rankings are robust to the variations studied here. It is largely the same investments that are ranked highest even when benefit valuations are changed rather drastically – increasing the weight of one benefit type 50% or 100%. In particular, differentiating the value of time with respect to purpose and mode or increasing the value of emissions – two of the most controversial valuation issues – have very little impact on the ranking. The largest impact in the ranking occurs when the valuation of traffic safety is increased, but even this change is moderate. Second, the ranking turns out to be robust also with respect to the studied variations in scenario assumptions, even though these included fairly ambitious policies such as 50 per cent higher fuel taxes.

In conclusion, we find no evidence suggesting that CBA rankings are overly sensitive, neither to the relative benefit weights, nor to the tested scenario assumptions. Our results indicate that the ranking changes only moderately or very little even with drastic changes in input parameters. This conclusion coincides with that of a companion paper (Almström et al., 2012), in which effects of land use assumptions are tested (three different land use developments with a given total population: sprawl, central or transit station-oriented). These results become even more striking considering that the 479 investments analysed here had already been filtered: these were the ones put on the shortlist by experienced planners. Despite this, there is a substantial variation in value-for-money among the investments on the list.

This is not to say that the CBA framework is perfect: it is well known that standard CBA omit certain effects, only represents a partial analysis, and neglects equity and spatial fairness considerations. But in terms of singling out investments that yield the most value for money, especially when a large number of investments need to be compared against each other, CBA is an extremely useful tool; and the conclusion from our analyses indicate that it is also robust to uncertainties in input parameters.

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